UNIVERSITY "UNION - NIKOLA TESLA"

Nikola Tesla

THE FOURTH INTERNATIONAL CONFERENCE ON SUSTAINABLE ENVIRONMENT AND TECHNOLOGIES

PROCEEDINGS

"Creating sustainable commUNITy"

INTERNATIONAL CONFERENCE ON SUSTAINABLE ENVIRONMENT AND TECHNOLOGIES

27-28 SEPTEMBER 2024

CARA DUŠANA 62-64, BELGRADE, SERBIA

UNIVERSITY "UNION - NIKOLA TESLA"

THE FOURTH INTERNATIONAL CONFERENCE ON SUSTAINABLE ENVIRONMENT AND TECHNOLOGIES

PROCEEDINGS

27-28 SEPTEMBER 2024

CARA DUŠANA 62-64, BELGRADE, SERBIA

The Fourth International Conference on Sustainable Environment and Technologies

„Creating sustainable commUNiTy“

Organizer of the Conference: University „Union Nikola Tesla", Belgrad, Serbia

Editors:

Ph.D Ljiljana Nikoluć Bujanović

Ph.D Sanja Mrazovac Kurilić

Publisher: University „Union Nikola Tesla", Belgrad, Serbia, 2024.

For publisher:

Ph.D Nebojša Zakić

Design:

MSc. Arh. Dunja Bujanović

Mateja Đurić, student

Printed in: Dobrotoljublje, Belgrade

Printing 60

ISBN 978-86-89529-46-3

Conference is financially supported by
The Ministry of Education, Science and Technological
Development of the Republic of Serbia

ORGANIZING COMMITTEE

PHD LJILJANA NIKOLIĆ BUJANOVIĆ
PHD SANJA MRAZOVAC KURILIĆ
PHD SLOBODAN ANĐELKOVIĆ
PHD ANA ANUFRIJEV
PHD MARINA BUGARČIĆ
PHD VIOLETA NIKOLIĆ
PHD OLJA KRČADINAC

SCIENTIFIC COMMITTEE („UNION-NIKOLA TESLA“)

PHD NEBOJŠA ZAKIĆ
PHD LJILJANA NIKOLIĆ BUJANOVIĆ
PHD SANJA MRAZOVAC KURILIĆ
PHD MARINA MILOVANOVIĆ
PHD DEJAN BELJAKOVIĆ
PHD ALEKSANDAR MILAJIĆ
PHD TATJANA KOSIĆ
PHD DARINKA GOLUBOVIĆ –MATIĆ
PHD DRAGANA VASILSKI
PHD MIŠA STOJADINOVIĆ
PHD IVAN PETROVIĆ
PHD JUGOSLAV ANIČIĆ
PHD MARIJANA MILUNOVIĆ
PHD TATJANA ILIĆ KOSANOVIĆ
PHD JASMINA PERIŠIĆ
PHD VESNA MIŠKOVIĆ–STANKOVIĆ
PHD DRAGANA DUDIĆ
PHD ZORAN CEKIĆ
PHD NEVENKA RAJIĆ

INTERNATIONAL SCIENTIFIC COMMITTEE

PHD PIETRO ELISEI - ITALY
PHD AMELA JERIČEVIĆ- CROATIA
PHD GORAN GAŠPARAC- CROATIA
PHD SANJA KAPELJ - CROATIA
PHD PREDRAG ILIĆ - BOSNIA AND HERZEGOVINA
PHD SUZANA GOTOVAC ATLAGIĆ - BOSNIA AND HERZEGOVINA
PHD HEIDI HUNTREISER - GERMANY
PHD ANKE ROIGER - GERMANY
PHD MILOŠ SIMIČIĆ - LIBYA
PHD ANJA JOKIĆ- SERBIA
PHD GORDANA GOJGIĆ CVIJOVIĆ - SERBIA
PHD ZORAN NIKIĆ- SERBIA
PHD BENIAMINO MURGANTE - ITALY
PHD SONJA RADOVIĆ JELOVAC - MONTENEGRO
PHD ALEKSANDAR PAVIĆ - UNITED KINGDOM
PHD FERID SKOPLJAK - BOSNIA AND HERZEGOVINA
PHD MAJA ROSO POPOVAC - BOSNIA AND HERZEGOVINA
PHD SINIŠA TRKULJA - SERBIA
PHD SRĐAN REDŽEPAGIĆ - FRANCE
PHD LIDIJA STEFANOVSKA - NORTH MACEDONIA
PHD SONJA LEPITKOVA - NORTH MACEDONIA
PHD JAKA VADNJAL- SLOVENIA
PHD JASMINA STARC - SLOVENIA
PHD FRANC VIDIC - SLOVENIA
PHD JEAN VASILE ANDREI - ROMANIA
PHD JONEL SUBIĆ- SERBIA
PHD BRANKO LATINOVIĆ- BOSNIA AND HERZEGOVINA
PHD LJILJANA RADOVANOVIĆ - SERBIA
PHD MARKO RISTIĆ - SERBIA
PHD SUZANA BROWN - SOUTH KOREA
PHD DARKO MATOVIĆ - CANADA

CONTENTS

THE ROLE OF CORROSION PROTECTION OF METALS IN SUSTAINABLE DEVELOPMENT

Ingrid Milošev

Jožef Stefan Institute, Department of Physical and Organic Chemistry, Jamova cesta 39, SI-1000 Ljubljana, Slovenia

e-mail address: ingrid.milosev@ijs.si

Corrosion protection is integral to sustainable development as it enhances the durability and efficiency of infrastructure, conserves resources, and prolongs the lifetime of objects. Corrosion of metals is a huge issue due to the consequences of corrosion damage to the economy. It was estimated that the global cost of corrosion is over 2.5 trillion USD, equivalent to 3.4% of the global domestic product. Corrosion of metals can be defined in many different ways, but in principle, it is the deterioration of a metal caused by its reaction with the environment, for example, aqueous solutions, marine environments, soils, gases, elevated temperatures, coolants, etc. There are five primary methods of corrosion control: material selection, coatings, inhibitors, cathodic protection and design. Each one of these methods can contribute to the sustainable development.

Keywords: corrosion, corrosion protection, metals, alloys, sustainable protection

INTRODUCTION

Corrosion of metals can be, in principle, defined as the deterioration of a metal caused by its reaction with the environment, for example, aqueous solutions, marine environments, soils, gases, elevated temperatures, coolants, etc. (Davis, 2000). Corrosion causes the destruction of the metal object and the release of metal ions into the environment, thus becoming an environmental issue. Further, corroded objects endanger the safety of humans, vehicles, process components and operating devices. Corrosion of metals is a huge issue due to the consequences of corrosion damage to the economy. It was estimated that the global cost of corrosion is over 2.5 trillion USD, equivalent to 3.4% of the global domestic product (Koch et al, 2016). When taking into consideration direct costs in five major anti-corrosion measures, the largest share accounts for coatings (ca. 66%), corrosion-resistant materials (ca. 19%), surface treatments (ca. 13%), electrochemical protection (ca. 0.6%), corrosion inhibitors (ca. 0.5%) and rust preventing oils and greases (ca. 0.2%) (Hou et al, 2017; NACE Impact Report, 2016). Corrosion protection is one of the important methodologies to reduce the need for steeply increasing production and thus preserve resources.

Due to the enormous costs, protecting metals and alloys is essential. Corrosion protection, aiming to prolong the lifetime of metallic materials, is one of the essential ways to reduce the need for steeply increasing production and thus preserve resources for the following centuries. Traditional ways of corrosion protection, such as conversion chromate coatings, can no longer be used due to ecological restrictions. The needs of industry, in particular transportation, construction, machine, and electronics, postulate the requirements for developing efficient, sustainable, and environmentally friendly coatings, which at the same time exhibit additional functional characteristics.

THE CONSUMPTION OF METALS

The growing population with a need for modern and high-tech technologies is boosting the consumption of major and rare earth metals (Watari et al, 2021; Vidal et al, 2013; Schipper et al, 2018). Among major metals, the most important are iron and steel, copper, aluminium, zinc and nickel. Future metal supply is limited by physical, economic, societal or environmental factors, including the depletion of natural ores, which are estimated to deplete (i.e. when cumulative primary production exceeds reserves) during the 21st century (Watari et al, 2021). At the same time, the demands for major metals are projected to increase strongly: depending on the models used (top-down or bottom-up), the largest median growth rate in 2050 compared to 2010 can be seen in Al (215%), Cu (140%), Ni (140%), Fe (86%) and Zn (81%) (Watari et al, 2021). These results imply that demand for the major metals will likely increase by 2-6 fold over this century. With these facts in mind, strategies for promoting sustainable metal cycles have to become increasingly operative, namely circular economy, efficiency and 3R concept (reuse-recycle-remanufacture) (Vidal et al, 2013). However, even in ideal scenarios with a high recycling rate of 70 or 90%, the expected increase in demand would still result in reaching the exhaustion of e.g. copper by the end of the 21st century (Schipper et al, 2018). Therefore, new strategies from the perspective of the metal life cycle are required to narrow the gap between the growth of high demand and the assurance of resources.

THE ROLE OF CORROSION PROTECTION IN THE SUSTAINABILITY DEVELOPMENT

According to the Brundtland Report, „sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundlandt Commission). Society today is well aware that the classical linear economy approach, „mine-make-use-dispose," is not sustainable and is moving toward the circular economy approach that was postulated to meet the need for sustainable development, including „3Rs" (reduce-reuse-recycle). We are currently in the reuse economy phase, a mixture of the two models. A broader concept of materials stewardship was recently introduced as a concept of improved materials conservation through a 4D strategy: dematerialisation, durability, design for multiple life cycles, and diversion of waste streams through industrial symbiosis (Taylor et al, 2016).

Recently, Milošev and Scully published a perspective paper on the challenges for the corrosion science, engineering and technology community due to the growing demand and consumption of materials (Milošev and Scully, 2023). Two classical models of a materials economy are linear economy, with a „mine-make-use-dispose" approach focusing mainly on profit without concern for ecological footprint, and circular economy, with a „make-use-recycle" approach comprising renewable resources and targeting sustainability. The next step is the advanced approach of a circular, sustainable economy, where each process step can be further improved by materials science and engineering and corrosion science. Some examples are presented in Figure 1 and include recycling, lifetime extension, light-weightening, fabrication improvement, reuse and manufacture and more intensive use. Each step of the cycle is foreseen as a part of the final solution toward more sustainable development.

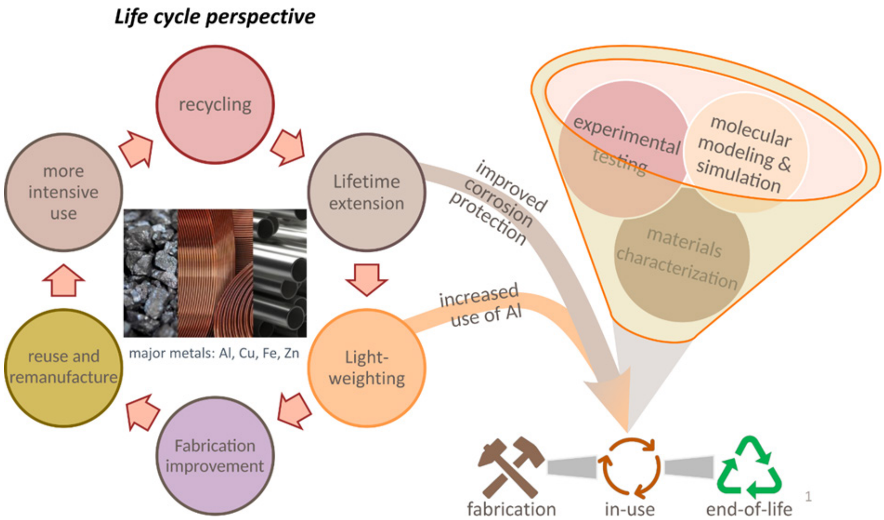


Figure 1 Prolongation of life cycle perspective of metals using contemporary corrosion protection strategies.

An important part of controlling the costs and safety of corrosion is a corrosion management system, which helps improve an organisation's ability to manage and mitigate corrosion threats for current and future assets. Corrosion protection plays a crucial role in sustainable development by contributing to resource conservation, reducing waste, and minimising the environmental impact associated with the production and disposal of materials (Milošev and Scully, 2023; Bender et al, 2022). Societies benefit from economic, environmental, and social sustainability by investing in advanced corrosion protection technologies and practices. Scientific and technological innovations in developing novel sustainable materials with enhanced functional abilities are crucial in that framework (Milošev and Scully, 2023).

CORROSION PROTECTION METHODS

Corrosion occurs on the metal surface where heterogeneous sites exist (anodic and cathodic sites). These sites are present in the same metal specimen due to the heterogeneity of the surface, which is related to metal impurities, microstructure, grain orientation, local composition, etc. A reaction of metal dissolution occurs at anodic sites, while at cathodic sites, the reduction of oxygen or protons in electrolytes occurs. Two basic modes of corrosion processes can be distinguished (Figure 2): uniform corrosion, which proceeds uniformly at the whole surface, and localised corrosion, which is limited to certain sites at the surfaces; these are usually sites insufficiently protected by the protective layer.

Localised corrosion processes are for example, pitting, crevice and intergranular corrosion and dealloying.

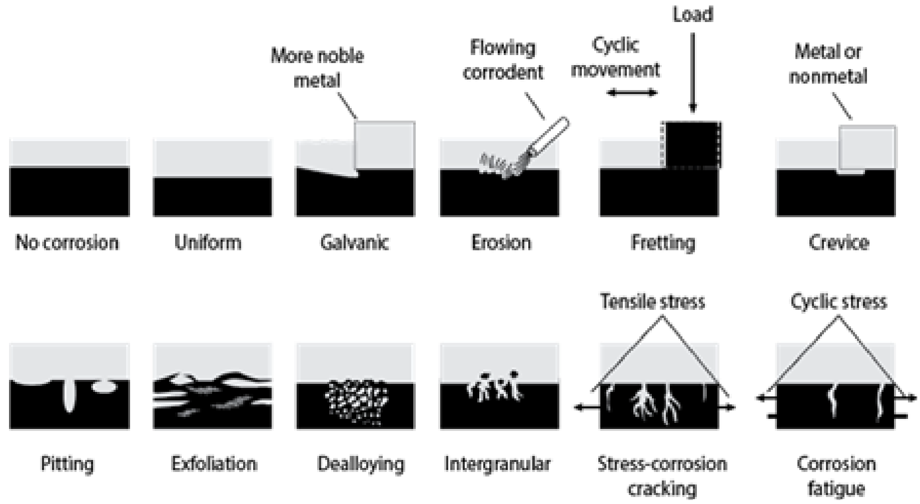


Figure 2 Different modes of corrosion processes (Milošev, 2019).

Major metals and alloys groups are indispensable in today's era as major lightweight (aluminium), energy efficient (copper), infrastructure (iron and zinc) and transportation and medicine (titanium) materials (Figure 3). The lightweight aluminium alloys and contemporary high-strength steels are used in various applications, especially in the transportation industry, where there is a great need to reduce the weight of vehicles and consequently reduce emissions into the environment. Steels and alloys based on copper are indispensable materials in infrastructure, construction, and other industries. Titanium alloys are major materials for high-demanding environments and biomedical applications, especially permanent orthopaedic implants. These materials are exposed to various harsh environments (marine, atmospheric, transportation and electronic industries, engine components, biomedicine, etc.), and their protection requires various methodological approaches (Figure 3).

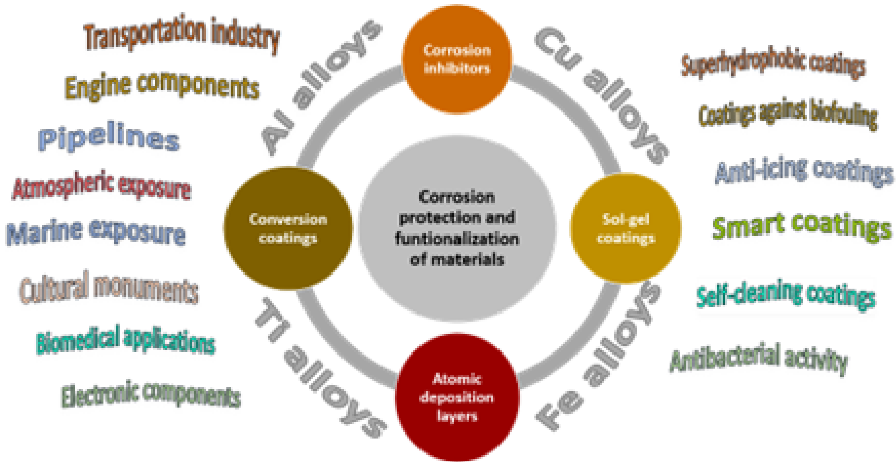


Figure 3 Types of corrosion protection and functionalisation of materials.

There are five primary methods of corrosion control: material selection, coatings, inhibitors, cathodic protection and design. Our research in corrosion protection in the last decade was devoted to all major surface treatments - corrosion inhibitors, conversion coatings, organic and inorganic coatings (Figure 4) (Milošev, 2019).

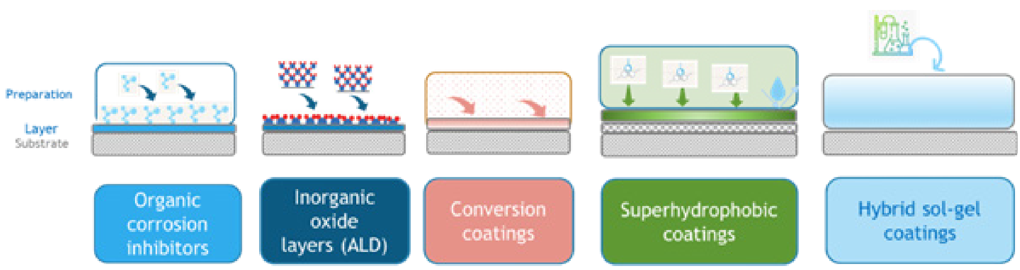


Figure 4 Types of corrosion protection and functionalisation of materials.

Inhibitors are inorganic or organic compounds that, when added in small concentrations, form a surface layer that protects the underlying metal surface from dissolution and decreases the corrosion rate. We have achieved a major breakthrough in the understanding of the mechanism of corrosion inhibition by organic molecules by introducing an integrative experimental-modelling approach (Figure 1) with the combination of experimental electrochemical and surface analysis techniques and modelling and simulation based on first principles using density functional theory (DFT) methods (Milošev and Kokalj 2021). Atomic layer deposition (ALD) is the method which produces thin, dense layers of inorganic oxides grown on a substrate by exposing its surface to alternate gaseous species. These oxide films represent the barrier to metal dissolution.

Conversion coatings can be defined as coatings formed by conversion from soluble salt to a slightly soluble or insoluble oxide and/or hydroxide, which precipitates either throughout the metal surface or at intermetallic particles which are electrochemically more noble in respect to the surrounding matrix and where oxygen reduction takes place (Milošev and Frankel, 2018). Today, two main types of conversion coatings are being explored for aluminium alloys: rare earth coatings or zirconium, chromium, and titanium coatings.

Sol-gel coatings are important in designing different corrosion protection strategies today, including barrier protection, superhydrophobic, self-cleaning, and anti-icing coating. Usually, hybrid sol-gels, consisting of inorganic and organic precursors, are explored. Inorganic precursors are metal alkoxides $M(OR)_{4,}$ and organic precursors are organic alkoxides $(R–O)_{4-n}MR_n$' (Rodič et al, 2022)

The coatings and films developed by these methodologies differ in composition, structure, and thickness. They are all important when mitigating the corrosion of metals in various environments. Furthermore, their combinations and synergy play a crucial role in metal sustainability by prolonging the lifetime of materials with the existing resources.

ACKNOWLEDGEMENTS

The financial support of the Slovenian Agency for Research and Innovation is acknowledged for programme core funding P2-0393, and bilateral projects between Slovenia and the US (grant No. BI-US/22-24-140) and between Slovenia and Serbia (grant No. BI-RS/23-25-013).

REFERENCES

Bender, R. et al. (2022). "Corrosion challenges towards a sustainable society." Mater. Corros. 73: 1730-–751. https://doi.org/10.1002/maco.202213140

"Brundtland Commission," Wikipedia, https://en.wikipedia.org/wiki/Brundtland_ Commission (Aug. 7, 2023).

Davis, J.R. (2002). Editor, "Corrosion: Understanding the Basics", chapter 1: The Effects and Economic Impact of Corrosion, ASM International (2000).

Hou, B., Li, X., Ma, X., Du, C., Zhang, D., Zheng, M., Xu, W., Lu, D. and Ma,

F. (2017). ”The cost of corrosion in China.” npj Materials Degradation 1: 4. https://doi.org/10.1038/s41529-017-0005-2

Koch, G., Varney, J. Thompson, N, Moghissi, O., Gould, M., and Payer J. (2016). "International Measures of Prevention, Application, and Economics of Corrosion Technologies Study." NACE International Impact. /Nace-International-Report.pdf

Milošev, I. and Frenkel, G.S. (2018). "Review—Conversion coatings based on zirconium and/or titanium." J. Electrochem. Soc. 165 (3): C127–C144. https://iopscience.iop.org/article/10.1149/2.0371803jes

Milošev, I. (2019). "Contemporary modes of corrosion protection and functionalization of materials.", Acta Chim. Slov. 66: 511–533. https://doi.org/10.17344/acsi.2019.5162

Milošev, I., Kokalj, A. et al (2021). "The effects of perfluoroalkyl and alkyl backbone chains, spacers, and anchor groups on the performance of organic compounds as corrosion inhibitors for aluminum investigated using an integrative experimental-modeling approach." J. Electrochem. Soc. 168: 071506. https://iopscience.iop.org/article/10.1149/1945-7111/ac0d3d

Milošev, I. and Scully, J.R. (2023). "Challenges for the Corrosion Science, Engineering, and Technology Community as a Consequence of Growing Demand and Consumption of Materials: A Sustainability Issue." CORROSION Journal 79 (9): 988–996. https://doi.org/10.5006/4428

NACE IMPACT "International Measures of Prevention, Application, and Economics of Corrosion Technologies Studies." NACE, Houston, TX, 2016. http://impact.nace.org/economic-impact.aspx

Rodič, P., Kapun, B. and Milošev, I. (2022). "Superhydrophobic aluminium surface to enhance corrosion resistance and obtain self-cleaning and anti-icing ability". Molecules 27: 1099. https://doi.org/10.3390/molecules27031099

Schipper, B.W., Hsiu-Chuan, L., Meloni, M.A., Wansleeben, K., Heijungs, R., and van der Voet, E. (2018). "Estimating global copper demand until 2100 with regression and stock dynamics." Resources, Conservation & Recycling 132: 28-36. https://doi.org/10.1016/j.resconrec.2018.01.004

Taylor, C.D., Gully, B., Sánchez, A.N., Rode, E., and Agarwal, A.S. (2016). "Towards materials sustainability through materials stewardship." Sustainability 8 (10) 1001. https://doi.org/10.3390/su8101001

Vidal, O., Goffé, B. and Arndt, N. (2013). "Metals for a low-carbon society." Nature Geosci. 6: 894–896. https://doi.org/10.1038/ngeo1993

Watari, T., Nansai, K., and Nakajima, K (2021). "Major metal demands, supply, and environment impacts to 2100: A critical review." Resources, Conservation & Recycling 164: 105107. https://doi.org/10.1016/j.resconrec.2020.105107

FROM "MIND OVER MATTER" TO A SUSTAINABLE "KNOWLEDGE SOCIETY"

Judith Ryser

judith@urbanthinker.com

Judith Ryser, CityScope Europe, London
www.urbanthinker.com

Abstract

This paper traces the evolution of environmental consciousness and sustainable development through a seasoned urban planner's five-decade career. It chronicles the shift from post-war materialism to growing environmental awareness, exploring the transformation of environmental thinking in urban planning and design.

The narrative examines the changing human-nature relationship, the emergence of ecological design principles, and the development of sustainability practices. It reflects on sustainable development's multifaceted nature, emphasising interdisciplinary approaches and institutional reform.

The paper concludes by advocating a holistic, integrated approach to planning that incorporates diverse knowledge forms, challenging academic and professional communities to embrace comprehensive strategies for addressing urgent environmental predicaments.

Keywords: Sustainable development, Urban planning, Environmental consciousness, Climate change mitigation, Ecological design, Interdisciplinary approaches, Institutional reform, Collaborative planning, Environmental history

INTRODUCTION

Some Personal - Professional Highlights of Environmental Action in a Changing Context

Wartime solidarity and postwar sharing of scarce resources prevented waste from childhood. However, post-rationing recovery generated unsustainable consumption and rising materialism experienced during my study years of architecture and urbanism. Designers dominated modernism, but population explosion led to rapid urbanisation and quantity over quality was spawning system building technology. The cold war sharpened competition between individualistic capitalism and collectivist communism, epitomised in the West Berlin enclave (recycling, a must) where I was working on the Free University structure competition with Jean Prouvé (1965).

Disillusioned by the modernist ideology I became editor of a magazine sponsored by developers and contractors and later learnt a lot about the benefits and drawbacks of industrialised building as analysed by urban sociologists. Seminal were Henry Lefebvre's lectures on "the production of space" during the '68 student rebellion. Archigram, Cedric Price, Rayner Banham, Paul Oliver, Sam Stevens, Colin Rowe and many others debated the future of the built environment and the role of designers at the London Architectural Association where I worked with Otto Koenigsberger (late 1960s) on what was then called "tropical design" but was in effect a sea-change of relations between the ex-colonial north and the global south to improve environment-human interaction. I was always sharing my activities between academia and practice, with emphasis on participatory processes and bottom-up perspectives. Our local environmental movement in London was challenging the urban renewal policies of the public local sector and achieved landmark changes (e.g. early 1970s the preservation and regeneration of the Covent Garden market neighbourhood, now one of the most popular tourist destinations in London).

My research approach was always multi-disciplinary and cross-departmental. It aimed to create results for practice, despite resistance by the institutional silo structure. During my Master degree (systems analysis, operations research, urban sociology, economic geography, ergonomics) at UCL (University College London) I was project leader of Duccio Turin's cross-disciplinary research on building economics at regional level (UCERG,1972) where I discovered the power of networks between people with leading roles in different institutions - central and local government, academia, research institutes, industry, business and the private sector; likewise the importance of "the right people, in the right position, at the right time, in the right place on the right topic", still valid today.

The first global energy shock was my luck to work at the Greater London Council (GLC) on strategic issues of power generation in Greater London with the CEGB (Central Electricity Generation Board), the de facto electricity production monopoly. This was on instruction of Tony Benn, the first ever UK energy minister, following his inclusive conference on the energy crisis to which he invited the key protagonists with diverse vested interests, including environmentalists and user associations. As a result, energy supply, cost and efficiency of use, together with environmental impact analysis, became new factors of spatial planning (Greater London Council, 1974).

Disillusioned when the GLC did not seize the grant I brought from the EU to carry out a large heat pump pilot project in London Dockland I became responsible for urban and regional research cooperation in the Environment Division of the United Nations Economic Commission for Europe (UNECE). Inter alia, I gathered and analysed Europe-wide data on environmental pollution towards the East-West Europe Convention on Transboundary Air Pollution, achieved by the UNECE Executive Director Janez Stanovnik in response to the acid rain crisis (late 1970s).

Due to a sea-change of UN management when the war-time generation retired I left to work on energy and environment policies with the Swedish research council. Sweden was among the most progressive and politically daring countries on energy efficiency policies and combating environmental pollution. In the 1980s my work with K-Konsult [RISE] included a nuclear free national energy policy, together with applied experimentation with energy efficiency measures and storage over 24 hours, across the seasons, as well as developing alternative renewable and sustainable energy solutions (geothermal, hydro, ecological insulation, environmental urban design, behaviour change, etc). I also contributed a monograph on Swedish energy policy towards comparative European research commissioned by the French Agency for the Mastery of Energy (Ryser, 1982).

In 1981 I set up IRC (International Researchers Cooperation) with my contacts from my UN work. The objective of IRC was to create and share knowledge across the iron curtain. For this work I obtained grants from several European governments while UCL was hosting the IRC working paper publications. A major action-research commissioned from IRC was assisting the Pohja municipality in Finland in its transition from post-industrial, early heavy industry into a sustainable local service and 'maker' economy (Ryser & Rautsi, 1986). At the fall of the Berlin wall in 1989 IRC became redundant but benefited especially researchers from Eastern Europe in their pan-European careers. One of them, Pavel Gantar became Minister for the Environment in Slovenia.

Learning that it was equally constraining to work with heavy bureaucracy than without any formal institutional umbrella made me focus on political and institutional issues in planning and development. During French decentralisation I undertook research for the French Ministry MELATT (Ministère de l'Équipement, du Logement, de l'Aménagement du territoire et des Transports, 1989) on the institutional and environmental impact of the abolition of the Greater

London Council with focus on waste disposal (Transformations dans la gestion urbaine et mutations institutionnelles: le cas de l'abolition du conseil du Grand Londres, 1987). I returned to UCL and worked, inter alia, on the Bartlett Master programme on European Planning and Development and gained a large EU research grant to broaden the cooperation between academia and practice. I also carried out European comparative research on understanding and managing the urban microclimate at UCL with the then Building Research Establishment (Keeble & et.al.1990/1991).

I decided to focus on research communication and dissemination. I was very active in ISOCARP (International Society of Urban and Regional Planners) as vice-president and general rapporteur (2015) (Ryser, 2016), writing and editing books, among them the 50th anniversary book on ISOCARP (Ryser, 2015) and IMPP (International Manuel of Planning Practice) with co-editor Teresa Franchini (Ryser & Franchini, 2008, 2015). I became senior adviser to Fundacion Metropoli in Madrid, responsible for writing and editing books and carrying out research on "urban ecosystems of innovation". One project was "Building the European Diagonal" (2008), an innovative cooperation between the mayors of Lisbon, Madrid, Barcelona, Marseille, Milan and later Casablanca to work on common environmental issues (desertification, heat wave and scarce water management, etc.) by adopting a sustainable approach to economic growth (Ryser, 2008). Another global comparative study critically analysed the sustainability initiatives of nine "innovation-hubs" conceived as eco-cities: Dublin, Helsinki, Linz, Marseille, Singapore, Melbourne, San Jose and Dongtan. Alfonso Vegara and I elaborated the concept of Landscape Intelligence (Vegara & Ryser, 2013 I wrote a retrospective of the achievements of the Fundacion Metropoli (2010) (Ryser, 2010) and a book to celebrate their 25th anniversary (2024) (Ryser, 2024). For FutureArc I produced a critical analysis of Asian eco-cites (FutureArc, 2013) and contributed to the EU-Asia dialogue on eco-cities (Konrad-Adenauer-Stiftung , 2014). I produced an essay towards how scientists approached cities undergoing climate change (ECF, 2009).

I was many years and still am on the editorial team of CORP (International Conference on Urban Planning and Regional Development in the Information Society), as well as of Silk-Cities [Silk Cities] where I peer-review and mentor authors and co-edit books on post-disaster planning and intangible heritage (Arefian&et.al., 2021; Ryser& Arefian, 2022) As part of my professional dissemination activities I published many articles, book chapters, conference papers, keynote addresses and several books.

All these activities were influenced by the changing understanding of the natural and the built environment which led me to reflect on their context. Most difficult for planners - whose business it is to shape the future - is unpredictable context beyond their control. The covid pandemic is just one example. However, context is more common as driver of change. Technological innovations (e.g. GIS, ICT and now Artificial Intelligence) can be great potential planning tools but they have also adverse effects. Eco-activism (e.g. Greenpeace, Friends of the Earth, Extinction Rebellion, Just Stop Oil) is another contextual driver of change with influence on planning. Most significantly, the intrinsic context of planning – its political-institutional setting – is bound to hamper planning's extrinsic context of promoting sustainability. The importance of context and the world of politics led me to my present activity, working with global co-authors on a book: "Drivers of Urban Change, People's Perspectives" which proposes an alternative holistic planning paradigm and examines its applicability to existing urban conditions in different parts of the world.

My personal-professional trajectory is very much embedded in the wider context of change from the Enlightenment "domination of nature by man" to the current climate crisis in a globally interdependent world. What follows aims to elucidate the key contextual changes of relevance to planners and planning during this period.

Evolution of "Environment–Human Interaction", Past History

The Enlightenment introduced a fundamental change to the relation between humans and nature, which may have been at its most ecological during the hunter-gatherer era. Agriculture and sedentary way of life rested on human intervention in nature, cultivating land and producing built environment. Arguably though, the Enlightenment brought a fundamental change to the nature-human relation based on the philosophy of human domination, exploitation and control of nature. The objective truth attributed to science at that time engendered reductionist and atomistic thinking. This heritage still lives to this day. Slow to start but still active now, the environmental movement, emerged in the 1940s to react against the excesses of human wants over nature.

For planning this meant protection and preservation of the natural environment, regeneration instead of demolition and reconstruction of the built environment, later also restoration of material and intangible heritage. Planning adopted a series of tools to deal with ecological issues. It created ecosystems of innovation to secure a sustainable balance between nature and the human-made environment. Greening was a further design technique with nature based solutions, but the acceleration of adverse climate change now requires more drastic measures of adaptation and mitigation.

Evolution of "Environment–Human Interaction": The Present

The current focus of environmental issues is guided by the notion of 'sustainability' which rests on a series of definitions. The Oxford Dictionary states: *"Sustainability is a social goal for people to co-exist on Earth over a long time. Sustainability usually has three dimensions: environmental, economic, and social"*. However, many definitions of sustainability emphasise the environmental dimension. Sustainable economic growth thus implies avoidance of the depletion of natural resources to maintain an ecological balance.

The first "political" definition of sustainability was proposed in the Brundtland World Commission on Environment and Development 1987 "Our Common Future". There sustainability means: *"...development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (UN Brundtland Commission). The World Health Organisation (WHO) also focuses on sustainability which it defines as: *"Sustainable development is a broad term to describe policies, projects and investments that provide benefits today without sacrificing environmental, social and personal health in the future"*(WHO). This line of thought is taken up in the UN Sustainable Development Goals (SDG). SDGs are designed to be a *"blueprint to achieve a better and more sustainable future for all"*. The 17 global goals were adopted by all United Nations Member States (UN Sustainable Development Goals).

Climate change accelerated faster than the scientists had anticipated and was more recently coined by David Whyte as "ecocide" (Whyte, 2020). None of this is preventing the eco-sceptics from denying scientific predictions of irreversible global warming due to excessive human consumption of environmental resources, despite mounting greenhouse gas emissions which lead to more flooding, drought, weather extremes, storms, hurricanes, cyclones, tsunami, ocean warming, increased rainfall, water scarcity, heat island effects, rising sea and river levels and coastal inundation. Antarctic ice continues to melt, tundra acting as CO_2 sink becomes precarious, and planetary climatic interdependence is manifesting itself more forcefully, making global climate negotiations on limiting emissions vital. In 1992 countries joined the UN Framework Convention on Climate Change treaty (UNFCCC) (UN Climate Change) to combat climate change, and signed the legally binding emission reduction targets adopted in the Kyoto Protocol in 1995 (UN Climate Change, Kyoto Protocol). In 2015 The Paris Agreement COP21 (Conference of the Parties) (UN Climate Change, Paris Agreement) aimed to keep global temperature rise below 2 degrees Celsius and limit it to 1.5 degree Celsius. The following annual COPs refined methods, requirements, actions and finance to achieve this goal signed by 198 countries by 2023 (UN COP 27). This pressing issue concerns also planners and designers who have to help strengthen resilience and reduce vulnerability of precarious human-made and natural habitats.

Evolution of the Concept of "Environment" in Planning and Design

"Environmental design" was a response to the "Environmental Movement" and designers developed a series of measures over time. Initially, designing the built environment required considering the natural environment. R W Caves (Caves, 2004) defined *"Environmental design as the process of addressing surrounding environmental parameters when devising plans, programs, policies, buildings, or products. It seeks to create spaces that will enhance the natural, social, cultural and physical environment of particular areas"*. The environment was included as an important component in land use planning which evolved into multifaceted integrated spatial planning with the environment as an integral part.

Environmental Design evolved further into measures of "environmental protection" and the creation of measurement techniques such as "Environmental Impact Assessment", still in use. Due to the various "energy shocks" in the 1970s energy became a design issue and especially its adverse pollution which affects the built environment and the wellbeing of its users. BREEAM (The Building Research Establishment Environmental Assessment Method, 1990) and LEED (Leadership in Energy and Environmental Design, 1998) were the main updated environmental assessment methods among others. "Greening", supported by the Greening Campaign (The Greening Campaign, 2008) was a step into community involvement in behaviour change, while sustainable design methods, including nature based solutions and sponge cities are supported by Green Building Councils (World Green Building Council, While Life Carbon Vision, UKGBC) and LETI (London Energy Transformation Initiative).

"Ecology" was introduced as a systemic concept of "environment-human interaction" seeking an equitable balance between the needs of the planet and that of humans which was taken up by WHO. It included awareness of entropy, limits to growth promoted by Donald Meadows with his MIT scientists in their seminal work (Meadows, 1972) and increasing recognition of the interdependence between the environment and energy (Heshmati & et al. 2015), which acid rain manifested intensely in the 1970s. Periodic energy supply crises encouraged opposition to more fossil fuel exploitation, as well as recycling, reusing, repairing, refurbishing, materials recovery, later biodiversity preservation and restoration, and more recently the notions of circular economy and regenerative economy, while designers coined the concept of eco-cities.

"Sustainable development" claimed to increase resilience and reduce vulnerability of precarious habitats, but that requires more fundamental behavioural change towards finite natural resources, as elaborated in a special issue on Psychology of Climate Change (Whitmarsh & et al. 2021) and, most importantly, the break-down of institutional sectoral silos and their replacement by more inclusive comprehensive action and social responsibility of all the development protagonists. Interestingly, understanding of "breaking down silos" are intra- not inter-institutional. Stina Ellevseth Oseland recognises three important factors to overcome institutional barriers at local level: broad processes, political will and institutional entrepreneurs (Oseland, 2019). For designers and planners it means moving from token public consultation to genuine public participation and community engagement, indeed to closer interaction between "planners and the planned" by engaging in co-design and co-planning which require cooperation, collaboration, coordination, co-creation, co-production and, most of all, shared benefits.

In summary, over time the notion of environment has evolved from an exploitable asset under the Enlightenment and an "as-of-right" resource under liberal capitalism, to a fundamental building block of the planet - the provider of human survival - as reflected in the United Nations sustainable development goals (Klinke, 2025).

Application of Sustainability Principles in Planning, Politics and Practice

Planning

The UN Habitat publication of 2014 "Planning for climate change, a strategic value based approach for urban planners" (UN Habitat, 2014) is meant as global guidance for the planning community in contributing to a sustainable built environment. Focusing on city planning action it claims that there exists a close relation between disaster risk reduction and planning for climate change, and that good planning practice equates to climate-smart planning practice.

However, planning approaches require diverse measures depending on their scale of action (global, nation state, region, city, community, family, individual). Ideally these measures could take place at all levels simultaneously and transactionally. Time and space also have a direct impact on planning actions aimed to influence sustainable development as they are place-specific, embedded in context, historic period, geography and culture. Advanced design tools can assist with the complex requirements of sustainable development. Planning resorts a lot to information technology (GIS sensors, central remote control, surveillance, all applied in smart cities) and increasingly to Artificial Intelligence.

Planning education could assist in shaping new models of thinking for planning - collective and individual - in the context of climate change and uncertainty (Klinke, 2025). However, planning professionals are only one of many actors intervening in sustainable development.

The built environment actors

Many different actors are involved in climate change mitigation and adaptation. Central governments are taking national strategic (political) decisions. They participate in intergovernmental bodies in devising global sustainability policies. Cities and local authorities are expected to implement top-down decisions, but they can also take initiatives within their political competences and resources (albeit often subject to national frameworks). The planning system is a means to legitimising interventions in cities through local plans and development control. However, the development industry is the main actor of realising the built environment and its changes. Developers protect their own interests through land ownership, implementation decisions, technological command, labour management and construction capacity, while trade unions are custodians of the construction trades and their interests. Planners are acting for the public as well as the private sector, less often for the social sector, while their professional institutions are providing support, guidance and professional protection. Communities and individuals also play a part in the sustainable development process, yet with less powers and material resources.

Achieving sustainability requires to go beyond the conventional sustainability criteria: environmental, economic, social. Strategic decisions of climate change interventions (remedies as well as prevention) and the provision of finance and other resources are essentially political, shaped by the existing administrative institutions, as well as by sectoral lobbies.

Environmental action: opportunities and social responsibility

Motivations for interventions in climate change are driven by collective and/or personal motivations. They depend on context and models of thinking which in turn are influenced by the socio-cultural environment as well as personal experience, with all the contradictions inherent in such complexity. Bottom-up actions (community participation and engagement) are often temporal and reactive rather than pro-active, due to socio-economic fragmentation and personal life conditions. Nonetheless environmental activism is playing its part in the approach to climate change.

It is important to stress that action is necessary at all levels to achieve the UN sustainability development goals. It means avoiding the discourse of no influence on the global situation of individual actors or nation states in comparison with larger and more polluting ones. Behavioural change of institutional actors, communities, as well as individuals is essential to achieve climate mitigation and adaptation, by accepting social responsibility as well as grasping opportunities.

CONCLUSION

Thoughts for the future

For Humankind

The decision on the "planet-humankind survival" rests with humans: they have the choice between treating their relation with the environment as contradiction, confrontation and conflict, or as communication conciliation, coordination, cooperation, collaboration and harmonious cohabitation.

For Planners: Action Now

Human Interventions in the environment are often sectoral and lack awareness of their adverse impacts and consequences. Planners are not well prepared to respond to contextual change beyond their control. A humanistic vision of a sustainable future is to change the evolution of the environment-human interaction towards a more holistic, integrated, inclusive, multidisciplinary, interactive, horizontal approach. Political and institutional reform may well be necessary to improve the environmental, economic and socio-cultural conditions of sustainable development. Our current book project is addressing this issue (Ryser et.al, publication forthcoming).

For Academia: Knowledge or Wisdom?

Knowledge is assumed to be generated by science in academia, transmitted in papers, citations and teaching by these custodians of knowledge (or of conventional wisdom?).

My question to the conference is: is it wise to ignore other types and forms of knowledge, or would it be proficient to harness also professional experience and especially tacit knowledge, a rich resource embedded in all humans?

References

Andreas Klinke A Theory of Uncertainty, perspectives in philosophy, social sciences and rusk research, , 2025 Routledge

Alfonso Vegara & Judith Ryser, Landscape Intelligence, In: A Centenary of Spatial Planning in Europe, Joao Teixeira (ed), 2013 ECTP-CEU

Almas Heshmati, Shahouz Abolhosseini & Joern Atmann, The Energy and Environment Relationship, In: Almas Heshmati, Shahouz Abolhosseini & Joern Atmann, The Development of Renewable Energy Sources and its Significance for the Environment, 2015 Springer

BREEAM (The Building Research Establishment Environmental Assessment Method) was introduced in the UK as a new environmental assessment method by the BRE in 1990, leading to a 'certificate.

Climate Change and the Cities of the Future, art, technology and economics in the face of climate change, ECF 2009

David Whyte, Ecocide, kill the corporation before it kills us. 2020, Manchester University Press

Donald Meadows, Limits to Growth, Club of Rome 1972

Drivers of Urban Change: People's Perspective, current research, Judith Ryser et.al., publication forthcoming

EJ Keeble, M Collins & J Ryser (eds), The Potential of Land Use Planning and Development Control to Help Achieve Favourable Microclimates Around Buildings, A European Review, In: Energy and Buildings, 15-16 (1990/91) 823-936

Fatemeh Farnaz Arefian, Judith Ryser, Andrew Hopkins, Jamie Mackee (eds), Historic Cities in the Face of Disasters, Springer 2021;

FutureArc: special issue on are Asian eco-cities ecological, 2013

Greater London Council (1974): Power Generation in Greater London, strategic issues

https://greening-campaign.org/our-story/

https://ukgbc.org/wp-content/uploads/2023/03/Sustainable-Design.pdf

https://unfccc.int/

https://unfccc.int/kyoto_protocol

https://unfccc.int/process-and-meetings/the-paris-agreement

https://worldgbc.org/advancing-net-zero/whole-life-carbon-vision/

https://www.concern.org.uk/news/explained-sustainable-development-goals?

https://www.google.co.uk/search?q=sustainable+development+according+to+brundtland+commission&sca_esv

https://www.un.org/en/climatechange/cop27

https://www.uncclearn.org/wp-content/uploads/library/planning_for_climate_change.pdf

https://www.who.int/health-topics/sustainable-development#tab=tab_1

Judith Ryser & Jussi Rautsi (eds). The Pohja Case; A Finnish Municipality in Transiton. IRC for Finnish Ministry of the Environment 1986

Judith Ryser & Teresa Franchini (eds). International Manual of Planning Practice, 2008 edition, 101 countries; 2015 edition 145 countries), ISOCARP

Judith Ryser (ed), Building the European Diagonal, Fundacion Metropoli 2008

Judith Ryser (ed), Fundacion Metropoli Landscape Intelligence, Visions and Projects of the Fundacion Metropoli, 2010, Fundacion Metrooli

Judith Ryser (ed), Metropoli, Designing Future Cities, 2024 Metropoli group

Judith Ryser (general rapporteur and editor), Cities Save the World, Let's Reinvent Planning, Groningen, Antwerp, Schiphol, Maastricht, Dortmund, Brussels, Rotterdam, Deventer. Delft,-The Hague. Amsterdam. Wageningen, Eindhoven, Porceedings and Synthesis, 2016 ISOCARP

Judith Ryser (writer and editor), ISOCARP Fifty Years of Knowledge Creation and Sharing, 2015 ISOCARP

Judith Ryser and Fatemeh Farnaz Arefian, Prerequisites for Post-Disaster Regeneration of Historic Cities, Silk-Cities org. 2022

Judith Ryser, Economies d'Energie en Suede, pour l'Agence Francaise de la Maitrise de l'Energie, 1982

Konrad-Adenauer-Stiftung (2014): Eco-cities, sharing European and Asian Best Practices and Experiences

LEED (Leadership in Energy and Environmental Design) was launched in 1998 by the US Green Building Council, leading to 'AP" (accredited professional).

LETI (Low Energy Transformation Initiative C.I.C.) https://www.leti.uk/cedg

LETI Climate Emergency Design Guide https://www.leti.uk/cedg

Lorraine Whitmarsh, Wouter Poortingo, Stuart Capstick, Behaviour change to address climate change, In: Current Opinion in Psychology, Special Issue Psychology of Climate Change, Vol 42, December 2021, 76-81, Elsevier

Ministere de l'equipement, du logement, de l'amenagement du territoire et des transports, 1989

R W Caves, Encyclopaedia of the City, Routledge 2004

RISE - Swedish local authorities owned technical research and support institution; retrieved August 2024: https://living-in.eu/smartcommunities/rise-research-institute-sweden

Stina Ellevseth Oseland, Breaking silos, can cities break down institutional barriers in climate planning? In: Journal of Environmental Policy and Planning. Vol 21, 2019- Issue 4, Taylor & Francis

The Greening Campaign, launched in 2008, aims to engage the community in CO2 emission reduction and sustainable development.

Transformations dans la gestion urbaine et mutations institutionnelles: le cas de l'abolition du conseil du Grand Londres, 1987

UCERG (1972): The Mechanism of Response to Effective Demand, University College London,

UKGBC (UK Green Building Council_ Sustainable design, practical guide

World Green Building Council, While Life Carbon Vision, supported by industry

www.silk-cities,org Hub promoting sustainable urban development

HIGH RADON CONCENTRATION IN THE HOUSE: A CASE STUDY OF THE "TREPČA" MINING DISTRICT

Ljiljana Gulan*, Dušica Spasić, Biljana Vučković

University of Priština in Kosovska Mitrovica, Faculty of Sciences and Mathematics, Lole Ribara 29, 38220 Kosovska Mitrovica, Serbia

* Corresponding author: ljiljana.gulan@pr.ac.rs

Abstract:

This study deals with results of continuous indoor radon measurements in the house in the area of „Trepča" mine, near the town of Kosovska Mitrovica. Annual measurements were performed using detector Airthings Corentium Home in the bedroom of old residential building. Daily radon concentrations ranged from 91-3017 Bq/m^3. Monthly averaged radon concentrations ranged from 1186 Bq/m^3 (August) to 1938 Bq/m^3 (October). Obtained high radon levels in this house pose a significant indication which concerned the health hazard.

Keywords: indoor radon, high concentration, mine

INTRODUCTION

The noble radioactive gas radon (^{222}Rn) with a relatively long half-life (3.8 days) is created by the disintegration of radium (^{226}Ra) in uranium decay chain (^{238}U). Radon moves through interconnected pores in the soil, and reaches the Earth's surface penetrating into the building interiors. Cracks in the construction systems and poor ventilation conditions favor the indoor radon accumulation. Uranium in rocks and soil beneath the building, building materials, drinking water, and using the cooking gas are the main supply of radon (Ramola et al., 2005). Two independent sources of indoor radon in the surveyed houses were indicated by some authors: one source is coming from the soil and regular building materials, and the second one is uranium waste and local radium reached material used in building construction (Cosma et al., 2005).

Inhalation of radon and its decay products leads to health risk. Among the general public, radon inhalation is labeled as the second cause of lung cancer after smoking (Darby et al., 2005; Krewski et al., 2005; Samet, 2011). Average annual human exposure (effective dose) to all natural radioactive sources is estimated to be 2.4 mSv, and about 52% of this exposure is caused by the inhalation of radon (UNSCEAR, 2008). Previous studies in the area of Kosovska Mitrovica have also shown increased indoor radon concentrations in dwellings; the authors indicated a radon prone area (Gulan et al., 2017; Gulan et al., 2022; Spasić and Gulan, 2022).

The World Health Organization (WHO) recommends that the indoor radon concentration should not exceed 100 Bq m^{-3} (WHO, 2009). At the other side, along with the public protection against radon exposure, there is a recommendation from the Council of the European Union (Directive 2013/59/EURATOM) to EU member states that the national levels of indoor radon concentration should not exceed 300 Bq m^{-3} (EU Council, 2013). Therefore, there is a need to establish building codes, public awareness and to undertake the mitigation measures, if necessary, for reducing indoor radon exposure below the national reference level in the houses with high radon concentration. The aim of this study is to present the results of high indoor radon concentration in a residential house of mining area.

MATERIALS AND METHODS

The measurements were performed in a house located in the area of Kosovska Mitrovica (42.9343°N and 20.8389°E) about 3 km from the „Trepča" mine. A typical one-storey house is built 50 years ago; it has basement of carved stone (delivered from a nearby hill) with a thickness of 50 cm. The house does not have a floor concrete slab, while the ceiling is made of concrete. Only natural ventilation (opening the windows/doors, chimney) exists in the house. The floor of studied bedroom is covered with hardboard slabs (a gap of joints is 0.5 cm). The walls are plastered, covered with paint; the external walls are south-west oriented, while the entrance to the house is east-oriented and leads straight into the bedroom. The window is a double wooden with the height of 50 cm and width of 100 cm.

The region of Kosovska Mitrovica abounds in geological diversity. The formation of the geological structure in the observed area refers to the period from the Ordovician-Silurian to the Quaternary. Strong volcanic activity produced larger masses of intrusive rocks in the past (Dimitrijević, 1997). The study area contains significant deposits of Pb-Zn ore, and mining activities were realized within the industrial complex „Trepča". As a result of magmatic and tectonic activity, there is a deep fault, and a network of seismic faults. Many studies reported increased content of heavy metals and radionuclides in the area (Borgna et al., 2009; Di Lella et al., 2004; Gulan et al., 2013; Nannoni et al., 2011).

Indoor radon levels were annually monitored from 9/07/2022 to 4/07/2023. Radon detector Airthings Corentium Home was placed on shelf away from door/window. The radon data were continuously recorded at the same time of each day (between 3 and 4 PM). Airthings Corentium Home uses alpha spectrometry detection method based on the process of radon diffusion into the chamber; it operates in the range from 0-9999 Bq m^{-3}; the accuracy of device at a typical concentration of 200 Bq m^{-3} is 5-10% for measurement period from 7 days to two months, and uncertainty for one month measurement is less than 10% (Airthings Corentium Home, https://www.airthings.com/home). The detector shows first result after 6-24 hours: long-term average (LTA) and short-term average (STA) radon concentration. The LTA represents average radon value for current measurement, updated once a day and averaged by the detector itself over the entire period of measurement, while the STA shows last-day radon values.

RESULTS AND DISCUSSION

Annual radon measurements conducted in the bedroom of the house are shown in Fig.1. Diurnal radon concentrations varied from 91-3017 Bq/m^3, with an average short-term (STA) radon concentration of 1530 Bq/m^3 (Spasić et al., 2024). There were only a few STA measurements (over the entire period) that were below the reference level recommended by the European Council (EU Council, 2013). The long-term average (LTA) radon concentration during the year was 1499 Bq m^{-3} (Table 1).

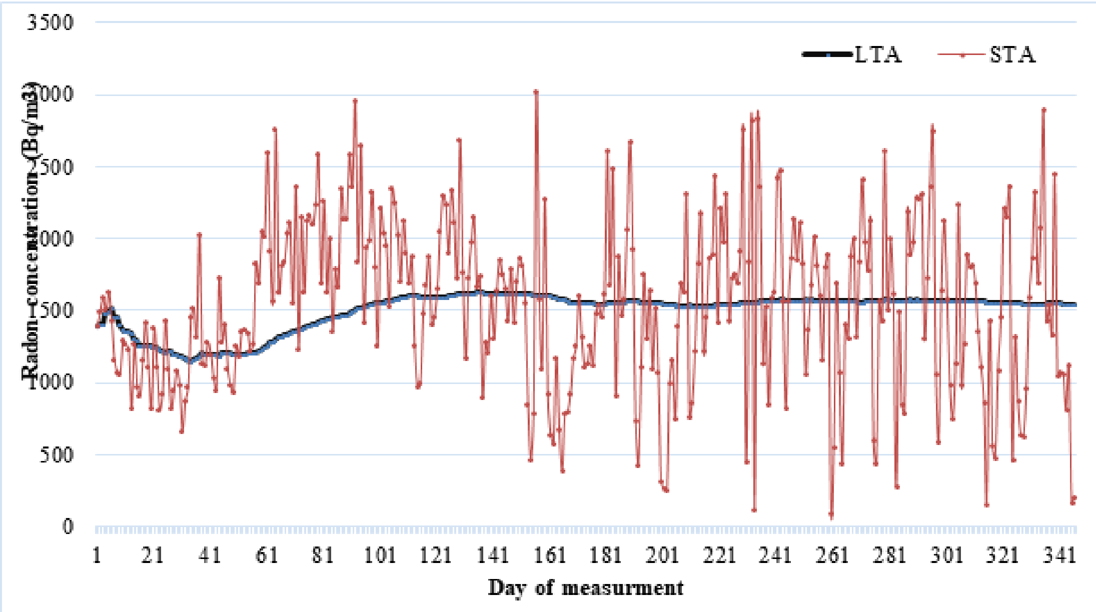


Figure1 Short-term average (STA) and long-term average (LTA) radon concentrations in the bedroom

There is no clearly established pattern according to which the monthly radon values changed. Higher average radon concentrations are observed in the autumn season of the year and lower radon concentrations in the warm periods; an average concentration for periods: Sep-Nov, Dec-Feb, Mar-May, Jun-Aug are 1868, 1443, 1509 and 1246 Bq/m^3, respectively; that is in good agreement with some studies (Denman et al., 2007; Papastefanou et al., 1994; Taşköprü et al., 2023). Indoor radon concentration is mainly influenced by the strength of sources, air exchange rate, activities of the inhabitants, natural ventilation and heating systems. By the analysis of this case, a significant drop in radon concentration was observed in December, as well as large daily fluctuations (Fig.1 and Table 1). This can be because the household members used frequent airing in those days, which influenced decreases in concentrations; besides that the bedroom was poorly heated with an electric heater. However, the opposite relationship with the highest radon levels occurring during the summer are reported in other studies (Spasić and Gulan, 2022; Wilson et al., 1991).

An increased level of natural radionuclides in soil and higher content of radionuclides in stone used for construction have been reported in local area (Spasić and Gulan, 2022). This can be the main cause of radon source in the house, but partly it can be a consequence of technological activities such as the mining operations which led to increase of indoor radon (Wysocka, 2016) or the proximity of a deep fault as some high radon values correspond to sites near active faults (Catalano et al., 2012). Even more, the bank of River Ibar is at the distance of 50 meters, so the increased radon diffusion may be affected by higher porosity of sand and gravel (Yusuff et al., 2019) or by the land-surface slope of house as hillsides have more permeable soils allowing greater radon emanation (Carrion-Matta et al., 2021; Cho et al., 2015).

Table 1 Monthly averaged radon concentrations in the bedroom of the house

Month	Minimum (Bq/m^3)	Maximum (Bq/m^3)	Mean radon concentration (Bq/m^3)	Standard Deviation (Bq/m^3)	Coefficient of Variation (%)
July	805	1629	1214	247	20
August	666	2030	1186	281	24
September	1221	2757	1914	400	21
October	967	2955	1938	461	24
November	899	2683	1747	393	22
December	392	3017	1258	564	45
January	253	2676	1363	633	46
February	111	2837	1735	667	38
March	91	2478	1529	576	38
April	270	2614	1670	609	36
May	157	2752	1337	643	48
June	168	2891	1381	727	53
Annual STA	91	3017	1530	588	38
Annual LTA	1151	1629	1499	131	8.7

The discovery of very high radon concentration in this house requires the prompt implementation of protective actions. In order to reduce existing, evidence-based problem associated with high radon concentration, the several measures, including low-cost alternatives should be proposed.

CONCLUSION

High annual radon concentration (1499 Bq/m^3) is observed in bedroom of an old house near the „Trepča" mine. As radon concentration in this house exceed reference level of 300 Bq/m^3, the cancer risks from prolonged radon exposure for the inhabitants is emphasized. There are several possibilities associated with radon mitigation in this house. Further studies should be focused on the identification of source/route of radon entry, its accumulation and circulation, and the impact of building materials in this and similar houses of the area.

ACKNOWLEDGEMENT

This work was supported by the Ministry of Science, Technological Development and Innovations of the Republic of Serbia under the Project 451-03-65/2024-03/ 200123.

REFERENCES

Airthings Corentium Home: Radon Detector. Oslo, Norway. Corentium AS. https://www.airthings.com/home Accessed 20 Jan 2023.

Borgna, L., Di Lella, L.A., Nannoni, F., Pisani, A., Pizzetti, E., Protano, G., Riccobono, F., Rossi, S., 2009. The high contents of lead in soils of northern Kosovo. J. Geochem. Explor. 101, 137-146.

Carrion-Matta, A., Lawrence, J., Kang, C-M., Wolfson, J.M., Li, L., Vieira, C.L.Z., Schwartz, J., Demokritou, P., Koutrakis, P., 2021. Predictors of indoor radon levels in the Midwest United States. J. Air Waste Manag. Assoc. 71, 1515–1528.

Catalano, R., Imme, G., Mangano, G., Morelli, D., Rosselli, T., 2012. Indoor radon survey in Eastern Sicily. Radiat. Meas. 47, 105–110.

Cho, B-W., Choo, C.O., Kim, M.S., Hwang, J., Yun, U., Lee, S., 2015. Spatial relationships between radon and topographical, geological, and geochemical factors and their relevance in all of South Korea. Environ. Earth Sci. 74, 5155–5168.

Cosma, C., Cucos-Dinu, A., Papp, B., Begy R., Sainz, C., 2013. Soil and building material as main sources of indoor radon in Baita-Stei radon prone area (Romania). J. Environ. Radioact. 116, 174-179.

Darby, S., Hill, D., Auvinen, A., Barros-Dios, J.M., Baysson, H., Bochicchio, F., Deom, H., et al., 2005. Radon in homes and risk of lung cancer:

collaborative analysis of individual data from 13 European case-control studies. Br. Med. J. 330, 223–228.

Denman, A.R., Crockett, R.G.M., Groves-Kirkby, C.J., Phillips, P.S., Gillmore, G.K., Woolridge, A.C., 2007. The value of seasonal correction factors in assessing the health risk from domestic radon-a case study in Northamptonshire, UK. Environ. Int. 33, 34-44.

Di Lella, L.A., Frati, L., Loppi, S., Protano, G., Riccobono, F., 2004. Environmental distribution of uranium and other trace elements at selected Kosovo sites. Chemosphere 56, 861–865.

Dimitrijevic, M.D., 1997. Geology of Yugoslavia. Geol. Inst. GEMINI; Belgrade.

EU Council, 2013. Directive 2013/59/Euratom. Off. J. Eur. Union, L13-1, 1–73.

Gulan, L., Forkapić, S., Spasić, D., *Živković* Radovanović, J., Hansman, J., Lakatoš, R., Samardžić, S., 2022. Identification of high radon dwellings, risk of exposure, and geogenic potential in the mining area of the "TREPČA" complex. *Indoor Air 32(7), e13077.*

Gulan, L., Milenkovic, B., Stajic, J.M., Vuckovic, B., Krstic, D., Zeremski, T., Ninkov, J., 2013. Correlation between radioactivity levels and heavy metal content in the soils of the North Kosovska Mitrovica environment. Environ. Sci.: Processes. Impacts 15, 1735-1742.

Gulan, L., Stajic, J.M., Bochicchio, F., Carpentieri, C., Milic, G., Nikezic, D., Zunic, Z.S., 2017. Is high indoor radon concentration correlated with specific activity of radium in nearby soil? A study in Kosovo and Metohija. Environ. Sci. Pollut. R. 24, 19561-19568.

Krewski, D., Lubin, J.H., Zielinski, J.M., Alavanja, M., Catalan, V.S., Field, R.W., Sandler, D.P., et al., 2005. Residential radon and risk of lung cancer: a combined analysis of 7 North American case-control studies. Epidemiology 16, 137–145.

Nannoni, F., Protano, G., Riccobono, F., 2011. Fractionation and geochemical mobility of heavy elements in soils of a mining area in northern Kosovo. Geoderma 161, 63–73.

Papastefanou, C., Stoulos, S., Manolopoulou, M., Ioannidou, A., Charalambous, S., 1994. Indoor radon concentrations in Greek apartment dwellings. Health Phys. 66(3), 270-273.

Ramola, R., Negi, S., Choubey, V., 2005. Radon and thoron monitoring in the environment of Kumaun Himalayas: survey and outcomes. J. Environ. Radioact. 79, 85–92.

Samet, J.M., 2011. Radiation and cancer risk: a continuing challenge for epidemiologists. Environ. Health. 10(1), 541–549.

Spasić D., Gulan L., Vučković B., 2024. Indoor Radon Testing, Effective Dose and Mitigation Measures in a Residential House of a Mining Area. *Atmosphere* 15(7):745.

Spasić, D., Gulan, L., 2022. High indoor radon case study: Influence of meteorological parameters and indication of radon prone area. Atmosphere 13, 2120.

Taşköprü, C., *İçhedef*, M., Saç, M.M., 2023. Diurnal, monthly, and seasonal variations of indoor radon concentrations concerning meteorological parameters. Environ. Monit. Assess. 195, 25.

UNSCEAR, 2008. United Nations Scientific Committee on the Effects of Atomic Radiation. Annex B: Exposure of the public and workers from various sources of radiation. United Nations; New York.

WHO, 2009. World Health Organization. Handbook on Indoor Radon a Public Health Perspective. WHO press; Geneva.

Wilson, D.L., Gammage, R.B., Dudney, C.S., Saultz, R.J., 1991. Summer time elevation of 222Rn levels in Huntsville, Alabama. Health Phys. 60, 189-197.

Wysocka, M., 2016. Radon problems in mining and post-mining areas in Upper Silesia region, Poland. NUKLEONIKA 61(3), 307-313.

Yusuff, I.M., Adagunodo, T.A., Omoloye, M.A., Olanrewaju, A.M., 2019. Interdependency of soil-gas radon-222 concentration on soil porosity at different soil-depths. J. Phys.:Conference Series 1299, 012099.

MONITORED NATURAL ATTENUATION OF GROUNDWATER CONTAMINANTS: FROM SUBSURFACE PHENOMENA TO RESEARCH-DRIVEN REMEDIATION APPROACH

Nenad Marić

University of Belgrade, Faculty of Forestry, Department of ecological engineering for soil and water resources protection, Kneza Višeslava 1, Belgrade, Serbia,

nenad.maric@sfb.bg.ac.rs

Abstract: Monitored Natural Attenuation (MNA) emerged as a remediation strategy, utilizing natural processes to mitigate contamination without active human intervention. The paper analyses the development of MNA as a cost-effective remediation method, primarily in the United States. The evolution from traditional remediation methods (e.g. pump and treat) to MNA signifies considerable advancements in groundwater management, driven by a deepened understanding of subsurface processes. Regulatory frameworks, notably by the U.S. EPA, have played pivotal roles in legitimizing and expanding MNA's application across various contaminants. Case studies, like the Vitanovac site presented in this paper, underscore MNA's occurrence and effects, demonstrating reduced contaminant concentrations over time. Beginning with petroleum hydrocarbons and chlorinated solvents and extending to metals and radionuclides, understanding natural attenuation's impact on various groundwater contaminants has steadily advanced. MNA's evolution from subsurface phenomena to research-driven remediation practice also exemplifies the evolution of knowledge and its contribution to advancements in policy and engineering practices.

Key words: groundwater, contamination; monitored natural attenuation; research-driven remediation

INTRODUCTION

The protection of groundwater quality is paramount from the scientific and practical standpoint. Groundwater might not meet quality standards due to the presence of substances from both natural sources (e.g., Marić et al., 2014; Mrazovac Kurilić et al., 2015) and human activities (e.g., Zhang et al., 1997; Lawniczak et al., 2016). Fetter (1999) identified a broad range of materials as contaminants in groundwater, including synthetic organic chemicals, hydrocarbons, inorganics, pathogens, and radionuclides. Due to their widespread use, petroleum hydrocarbons are among the most common groundwater contaminants. An increasing stress of petroleum hydrocarbons from underground storage tanks has been evident since the early 1980s (Council on Environmental Quality, 1981). Initially, the most applied remediation strategies for petroleum hydrocarbon releases focused on the physical removal of contamination, such as using pump and treat systems. However, these systems proved to be less efficient than initially envisioned. Thus, the occurrence of "tailing" and "rebound" phenomena, characteristic of pump-and-treat technology, was observed at numerous hydrocarbon-contaminated sites (Figure 1). "Tailing" refers to the gradual decrease in contaminant concentrations in groundwater over time following the initial rapid decline. This tailing occurs because hydrocarbons also reside in low-permeability zones within the subsurface, where they are less accessible to the pumping system. "Rebound," on the other hand, is due to the release of contaminants from residual sources in the soil or aquifer or changes in groundwater flow patterns that mobilize previously stagnant contaminants.

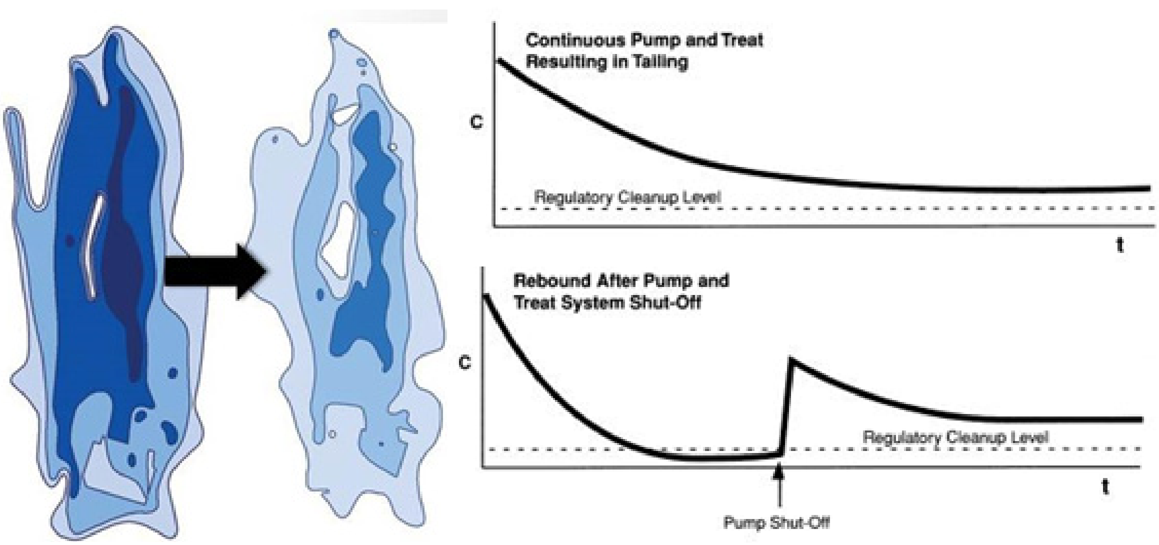


Figure 1. Hydrocarbon plume at the site in the San Francisco Bay Area after 10 years of pump and treat system operation (U.S. EPA, 1989) (left); the tailing and rebound phenomena characteristic of pump-and-treat technology (Wiedemeier et al., 1999) (right).

Among various subsurface processes contributing to the persistence of hydrocarbon contamination, matrix diffusion has received increased attention (Figure 2). This occurs because contaminants can diffuse into the solid matrix of soil or rock, where they become trapped or reside in lower concentrations. These trapped contaminants can act as a long-term source, slowly releasing back into the groundwater over time. These phenomena are characteristic challenges of pump-and-treat technology, highlighting its limitations in achieving complete and long-term remediation of hydrocarbon contamination.

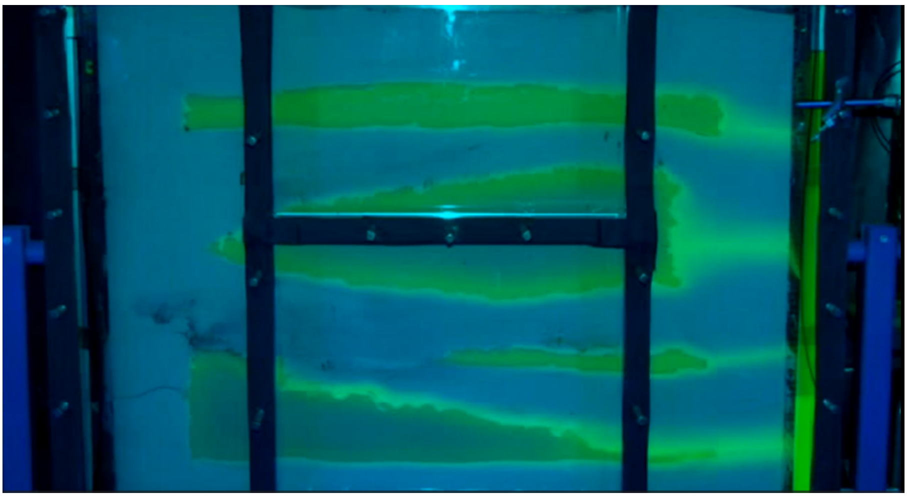


Figure 2. Matrix diffusion effects observed at the laboratory scale at the Center for Contaminant Hydrology, Colorado State University, in research conducted by Tom Sale and Lee Anne Donner

At the same time, numerous studies have documented significant interactions between hydrocarbons and geological media in the subsurface. According to data from 604 sites contaminated with petroleum hydrocarbons in the USA, Newell and Conor (1998) found that approximately 75% of hydrocarbon plumes in groundwater extend less than 70 meters (Figure 3). In other words, geological media containing indigenous populations of microorganisms has a natural capacity to reduce the extent of hydrocarbon contamination.

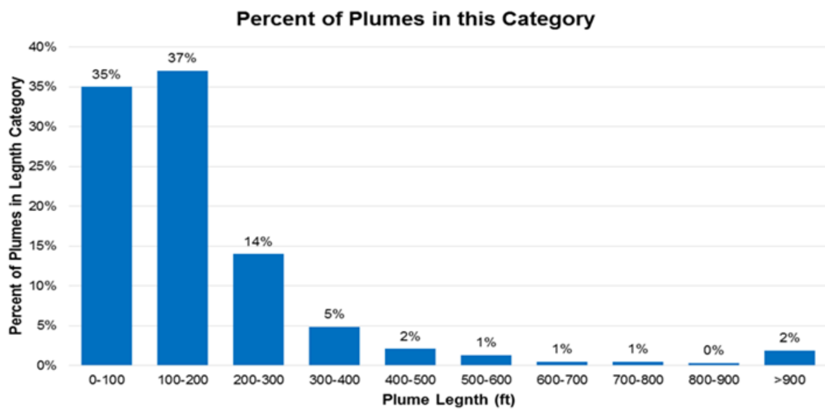


Figure 3. Length of dissolved petroleum hydrocarbon plumes in groundwater in percent (Newell and Conor 1998)

As a result, the emphasis on remediating hydrocarbon-contaminated sites has increasingly turned towards bioremediation methods, including engineered or monitored natural attenuation. Today, it is widely acknowledged that natural attenuation processes significantly impact the fate and transport of hydrocarbons in intergranular aquifers. According to U.S. EPA (1999), natural attenuation includes a variety of physical, chemical, or biological processes that, under favourable conditions and without human intervention, reduce toxicity, mobility, mass, or concentration of contaminants. Thus, monitored natural attenuation (MNA) is an in-situ remediation technology that relies on naturally occurring and demonstrable processes in groundwater, reducing the contaminants' mass and concentration (Jørgensen et al., 2010). The evolution of MNA from applied research to research-driven remediation policy and practice, primarily in the United States, is an excellent example of the evolution of knowledge.

MATERIAL AND METHODS

Data and methodology

The analysis of the MNA development was performed by reviewing technical documents, protocols, and papers for different groundwater contaminants. The effects of natural attenuation processes at the field scale were summarized based on findings from two studies conducted at the Vitanovac site in Serbia (Marić et al., 2018; Marić et al., 2022). During the analysis of MNA development in the United States, special attention has been given to the Environmental Security and Technology Certification Program's FAQ about MNA in groundwater (Adamson and Newell, 2014). The analysis of the MNA situation in Europe is based primarily on the results of the CityChlor Project (Mars, 2013). The other valuable data sources and materials included the online course Natural Attenuation of Groundwater Contaminants: New Paradigms, Technologies, and Applications, which was authorized by Rice University and offered through Coursera.

RESULTS AND DISCUSSION

Key processes behind monitored natural attenuation (MNA) and how to provide evidence of their occurrence

Natural attenuation processes involve the observed decrease in concentrations as contaminants move away from their source in the subsurface (Wiedemeier et al., 1999). Natural attenuation processes in groundwater have been first documented for petroleum hydrocarbon plumes. Thus, an overview of major natural attenuation processes and their effects on petroleum hydrocarbons will be given. Natural attenuation of hydrocarbon contaminants in groundwater depends on non-destructive physical processes (dissolution, advection, dispersion, diffusion, sorption) and, more importantly, on destructive processes such as biodegradation (Scheutz et al., 2011; Lu et al., 2015). In other words, due to physical, chemical, and biological processes without human intervention, the mass and mobility of these contaminants in groundwater will be reduced (Figure 4).

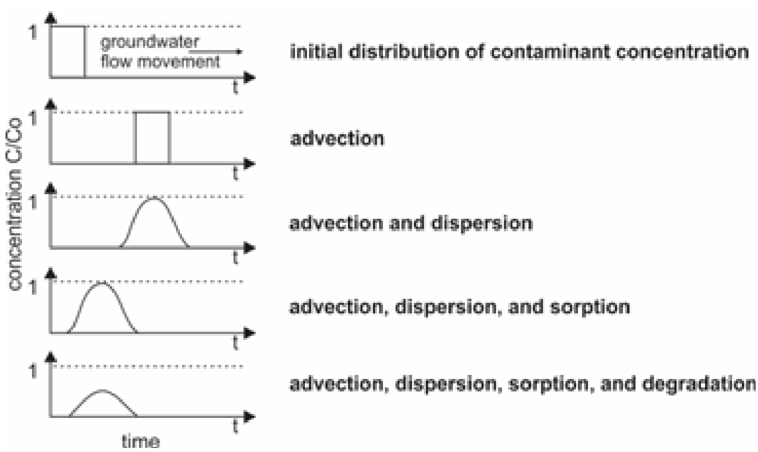


Figure 4. The impact of advection, dispersion, sorption, and degradation on the contaminant transport in porous media (Mersmann, 2003)

As can be seen, non-destructive processes reduce contaminant concentration but not total system mass. On the other hand, destructive processes degrade contaminants. These processes include the biodegradation of petroleum hydrocarbons. Biodegradation can be defined as a process where microbes have the potential to use hydrocarbons as a metabolic source of carbon (Figure 5).

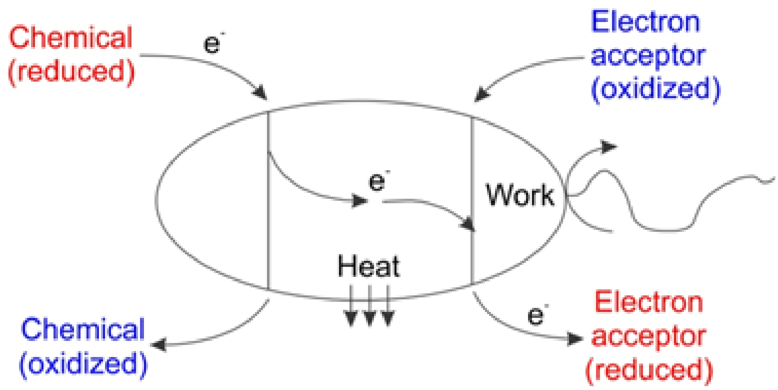


Figure 5. Bacterial oxidation of fuel molecules (Alvarez and Illman, 2006)

In the classical case, hydrocarbons represent an electron donor, while acceptors represent inorganic components which receive electrons. Due to the electron transfer in this reaction, oxidation of the hydrocarbon occurs, while electron acceptors become reduced. Alvarez and Illman (2006) listed the typical sequence of electron acceptor utilization:

$$O_2 \rightarrow NO_3^- \rightarrow Mn^{4+} \rightarrow Fe^{3+} \rightarrow SO_4^{2-} \rightarrow HCO_3^-$$

Thus, in a hydrocarbon-contaminated aquifer, after the depletion of dissolved oxygen, the development of anaerobic and methanogenic processes can be anticipated in the following sequence: denitrification → manganese (IV) reduction → iron (III) reduction → sulfate reduction → methanogenesis. In other words, microorganisms couple the oxidation of the contaminant with the reduction of electron acceptors, to use hydrocarbons as a source of energy.

Overall, natural attenuation results from the integration of all subsurface attenuation processes (both abiotic and biotic) operating at a given site (Wiedemeier et al., 1999). Adamson and Newell (2014) listed three lines of evidence for natural attenuation occurrence at the contaminated site:

Historical Contaminant Mass Reduction: documented decreases in contaminant concentrations over time, indicating natural processes are effectively reducing the contaminant mass.

- **Hydrogeologic or Geochemical Data**: data showing favourable conditions for natural attenuation, such as the presence of electron acceptors and redox conditions.
- **Microcosm Data**: experimental or field studies demonstrating that microbial activity or other natural processes are actively degrading contaminants in situ.

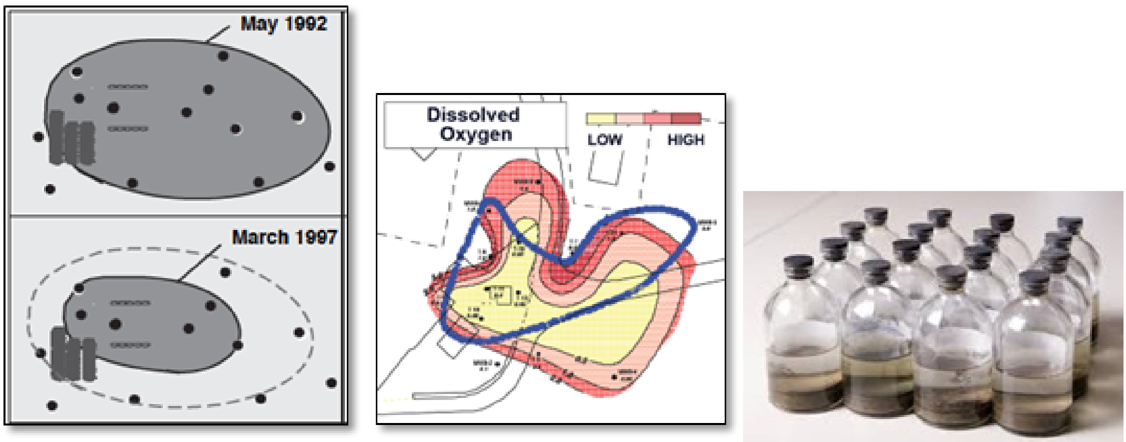


Figure 6. Three lines of evidence of monitored natural attenuation: historical contaminant mass reduction (lefy), hydrogeologic or geochemical data (middle), and microcosm or field data (right), from Adamson and Newell (2014).

The first two lines of evidence are essential for characterizing monitored natural attenuation, while microcosm data, though not mandatory, offer a deeper understanding of the processes involved. The three lines of evidence for MNA registered at the site of historical jet fuel contamination in Vitanovac, Serbia, are summarized below.

Case Study on the Effects of MNA in Groundwater: Historically Contaminated Site in Vitanovac

The leakage of about 540 tons of kerosene-type fuel (Jet A) from the military fuel storage tanks into the subsurface was reported in October 1993 at the site in Vitanovac, near Kraljevo, Serbia (Matić, 1994). From October 2, 1994, to September 29, 1995, about 300 tons of free-phase kerosene were pumped from the subsurface (Kaćanski, 1995).

Figure 7. Remediation works conducted at the kerosene contaminated site in Vitanovac in 1994: (a, b), free phase pumping (c), and storage of pumped free phase (d) (Matić, 1994)

Due to the war circumstances, the rest of the jet fuel was left in the subsurface. From 2013 to 2018, several natural attenuation characterization campaigns were conducted (e.g. Marić et al., 2018; Marić et al., 2020; Marić et al., 2022). The results from the 2013 and 2018 studies are briefly summarized here. The monitoring network in both studies consisted of the same seven piezometers within the unconfined aquifer formed in Zapadna Morava alluvial deposits (Figure 8).

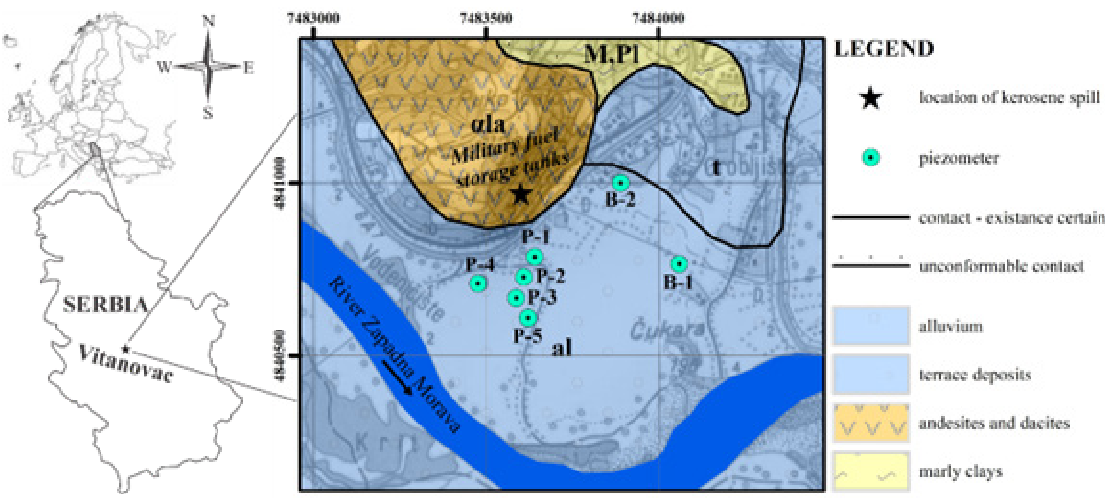


Figure 8. Geographical position and geological map of the site in Vitanovac (Marić et al., 2022)

In both studies, hydrocarbons were registered only in piezometers (P-1, P-2, and P-3) closest to the source of contamination (military fuel storage tanks). Traces of hydrocarbon contamination were found in both 2013 (20 years) and 2018 (25 years) after the accident. In 2013, the concentrations of total petroleum hydrocarbons (TPH) were as follows: P-1 (0.27 mg/L), P-2 (0.16 mg/L), and

P-3 (0.11 mg/L). In the 2018 study (Figure 9), TPH concentrations in the same piezometers were P-1 (0.20 mg/L), P-2 (0.11 mg/L) and P-3 (0.09 mg/L). During the five years between these studies, the TPH concentrations have decreased, thus providing clear evidence regarding the occurrence of natural attenuation processes at this site.

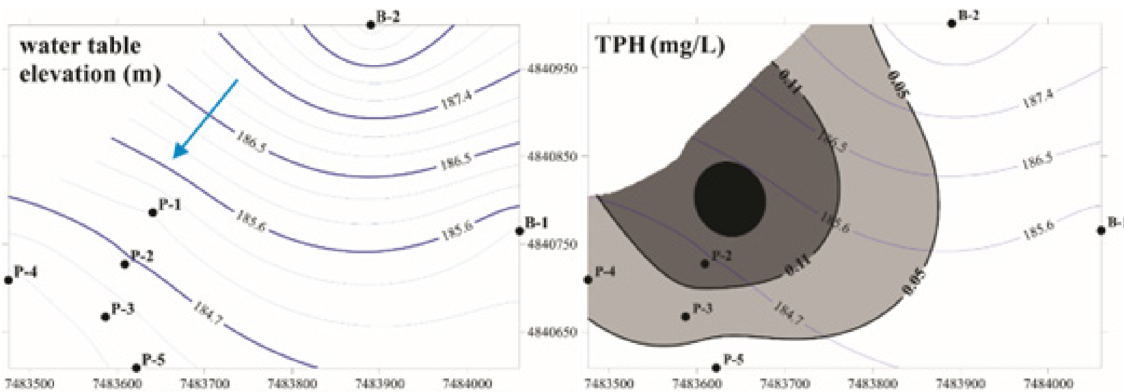


Figure 9. Water table elevation and spatial distribution of TPH in groundwater at the site in Vitanovac in 2018 (Marić et al., 2022)

In both studies, upgradient and downgradient concentrations from the source of contamination returned to their natural values. These results have confirmed the long-term exposure of the groundwater to hydrocarbon contamination, thus providing a basis for the spatial analysis (Figure 10) of the concentrations of electron acceptors (O_2, NO_3^-, SO_4^{2-}, HCO_3^-) and metabolic products of biodegradation (Mn and Fe).

As can be seen in Figure 10, the lowest concentrations of electron acceptors (O_2, NO_3^-, and SO_4^{2-}) and the highest concentrations of microbial metabolic products (Mn and Fe) overlap in the piezometers closest to the source of contamination due to the occurrence of different biodegradation mechanisms. The lowest redox potential values were registered in piezometers P-2 (Eh = -54 mV) and P-1 (Eh = -48 mV). The positive readings (110 to 250 mV) were recorded upgradient and downgradient from this zone (Figure 10). Thus, the development of anoxic conditions in the hydrocarbon-contaminated part of the aquifer was also evidenced by a decrease in redox potential values.

The spatial distribution of chemoorganoheterotrophs, hydrocarbon degraders, and anaerobic bacteria in groundwater exhibited a similar pattern (Figure 11), with the highest content registered in piezometers closest to the source of contamination (P-1, P-2, and P-3).

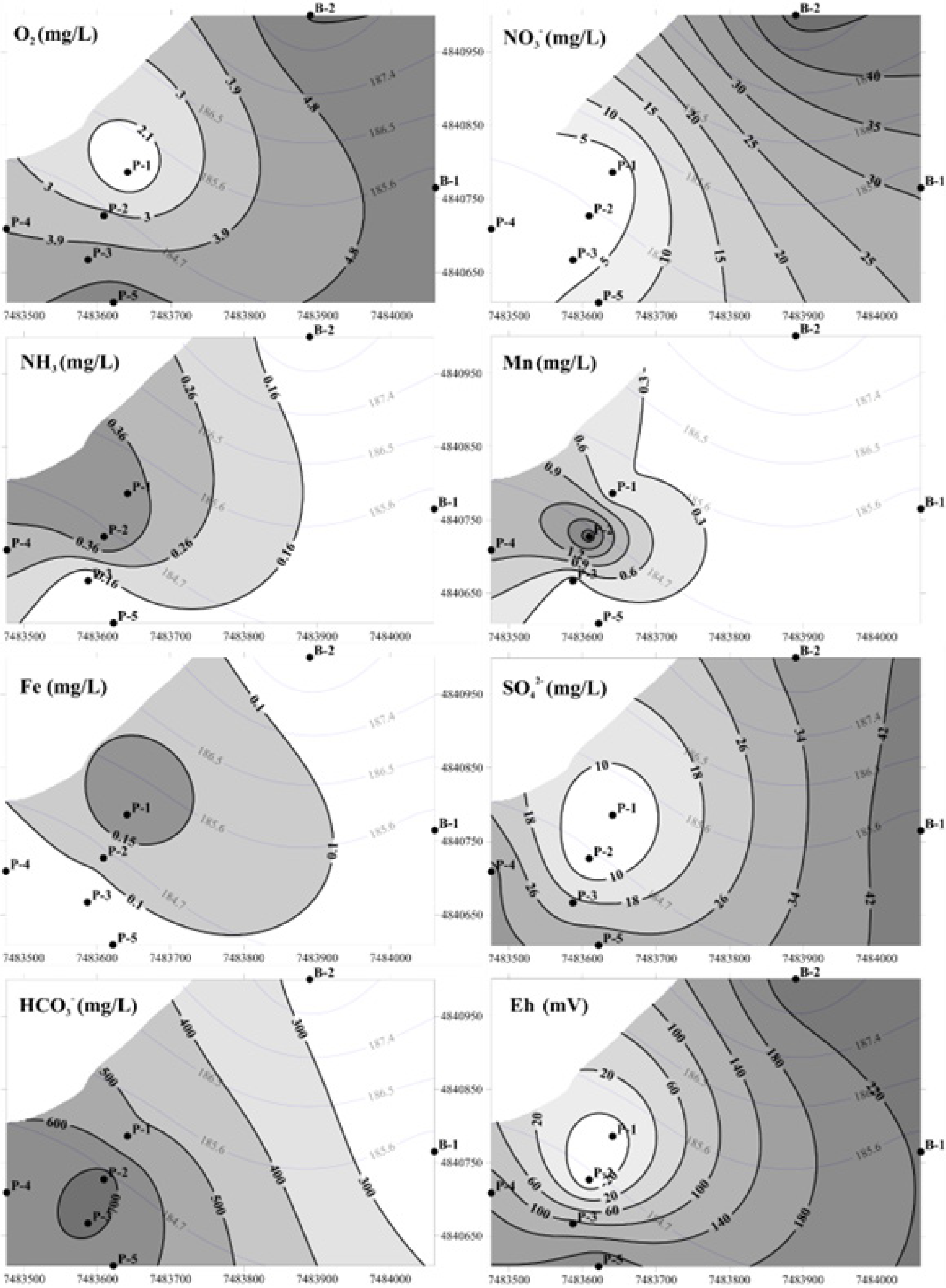


Figure 10. Spatial distribution of biodegradation fingerprints in groundwater at the site in Vitanovac in 2018 (Marić et al., 2022)

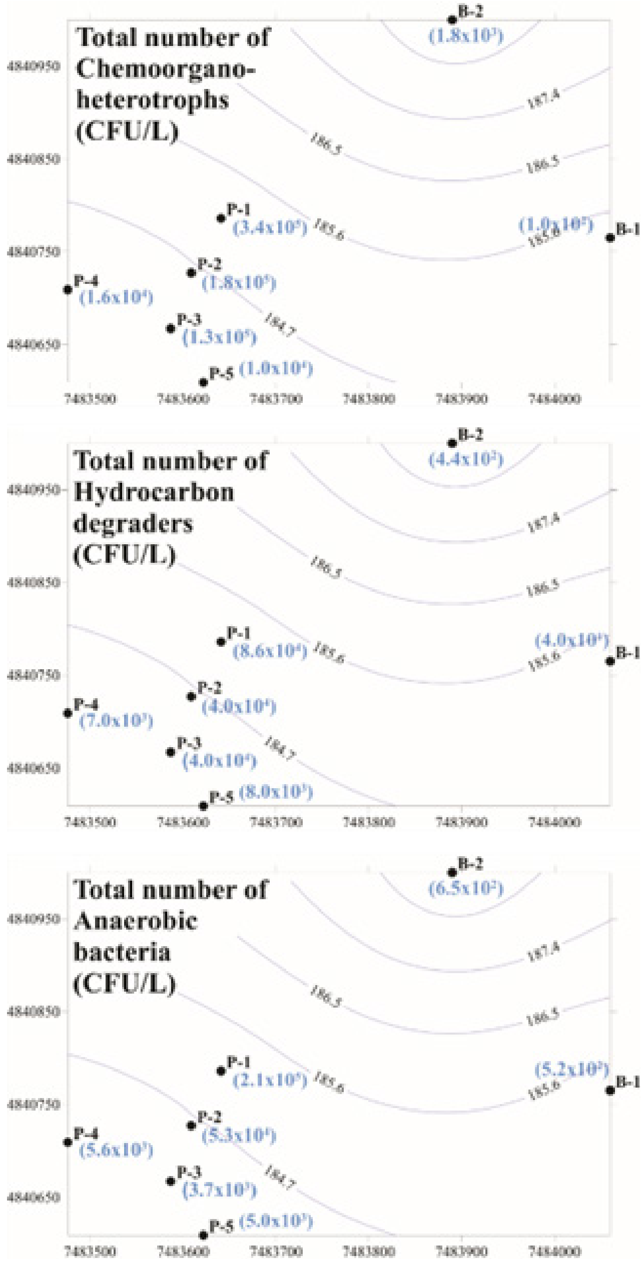


Figure 11. Spatial distribution of chemoorganoheterotrophs, hydrocarbon degraders, and anaerobic bacteria in groundwater at the site in Vitanovac in 2018 (Marić et al., 2022)

Overall, these results provided three lines of evidence of natural attenuation processes and their occurrence caused by historical contamination.

From natural phenomena to research-driven remediation practice

Concerns about contamination from leaking underground storage tanks became evident in the United States in the early 1980s. Numerous field and laboratory studies have confirmed that introducing soluble organic compounds into groundwater triggers a complex series of responses from subsurface micro-organisms. Simultaneously, regulatory pressure has increased interest in groun-dwater remediation technologies. The poor cleanup record of pump-and-treat methods has led to a shift towards using microorganisms for remediation. Thus, during the 1980s, it became clear that indigenous bacteria were physiologically and genetically predisposed to mediate the degradation of pollutants in the sub-surface (Alvarez and Illman, 2006). Bemidji in Minnesota stands out among the numerous sites that have contributed to our understanding of the microbiological role in reducing hydrocarbon contamination. After cleanup efforts were com-pleted at this site in 1980, approximately 400,000 litres of oil remained in the subsurface, offering an excellent opportunity for the scientific community to stu-dy the natural processes that limit this type of contamination. Starting in 1983, studies at the Bemidji Site were among the first to document the importance of natural attenuation processes. Similarly, numerous field studies (e.g., Rice et al., 1995; Wiedemeier et al., 1995; Buscheck et al., 1996; Mace et al., 1997) provi-ded clear evidence that most of the dissolved petroleum hydrocarbon plumes in the shallow subsurface of the United States are either in steady-state equilibrium or receding due to natural attenuation processes (Wiedemeier et al., 1999).

During the 1990s, MNA underwent a remarkable transformation, shifting from experimental studies in laboratories to becoming a widely accepted method for managing sites (see Figure 12). As its application at contaminated sites grew, methodologies were refined to measure and validate its efficacy. In 1995, the U.S. EPA began providing policies to endorse MNA for groundwater remediati-on. Subsequently, regulatory agencies introduced multiple protocols to facilitate the assessment and adoption of MNA as a remedial strategy for diverse contami-nants (see Figure 13).

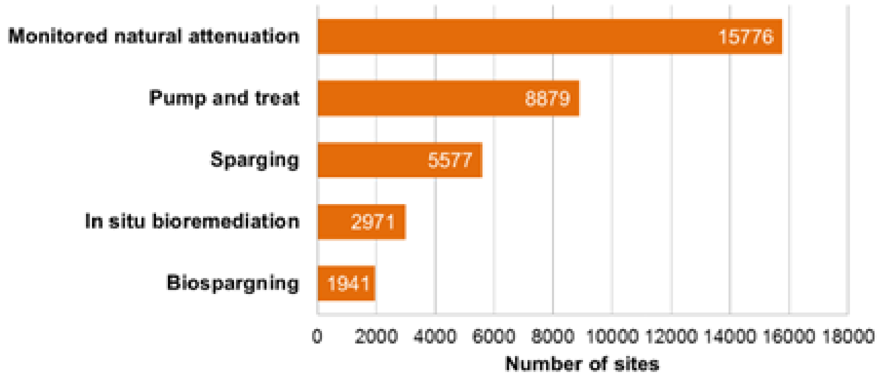


Figure 12. Methods used to clean up groundwater contamination from leaking underground storage tanks as of 1997. (Adapted from Tullis et al., 1998)

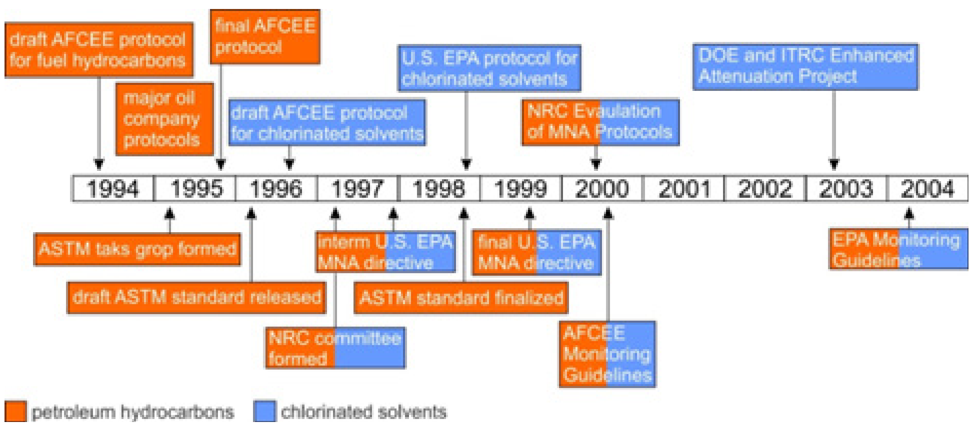


Figure 13. The timeline of MNA development in the United States (Adapted from Adamson and Newell, 2014)

As evident, the initial protocols were developed for petroleum hydrocarbons, followed later by chlorinated solvents. Although all protocols played roles in some part of the MNA development as a remediation strategy, Adamson and Newell (2014) listed these as the most highly cited:

- The 1995 AFCEE's protocol for fuel hydrocarbons
- U.S. EPA's 1998 protocol for chlorinated solvents
- The U.S. EPA's 1999 directive on Monitored Natural Attenuation

The philosophy of MNA as a remediation approach could be summarized here: MNA is an appropriate remediation method only where its use will be protective of human health and the environment, and it will be capable of achieving site-specific remediation objectives within a timeframe that is reasonable compared to other alternatives (U.S. EPA, 1999). Thus, to meet these criteria, it is necessary to monitor and document the effectiveness of attenuation processes in eliminating target contaminants. Overall, improving knowledge has led to a change in remediation policy and practice in the United States. On the other hand, the MNA development in Europe was slower. The results of the CityChlor Project (Mars, 2013) indicate that the MNA concept has been gaining attention during the 2000 decade (Figure 14).

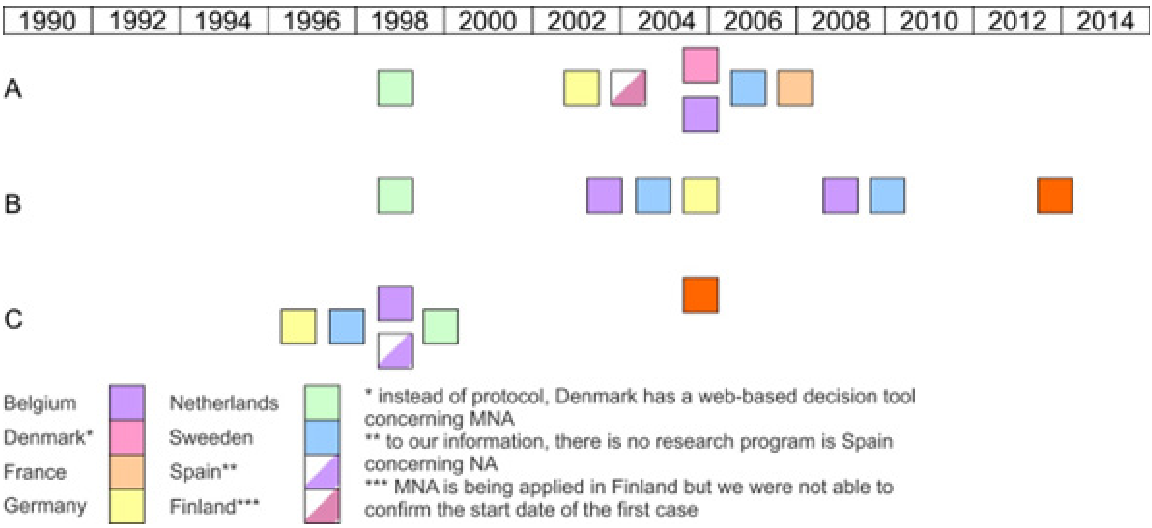


Figure 14. MNA history in Europe: start dates of the most important research programs (A); publication dates of protocols (B) and 1st case applications (C) (Adapted from Mars, 2013)

As evident, the earliest applications of monitored natural attenuation (MNA) in Europe occurred between 1996 and 1998. According to the CityChlor Project (Mars, 2013), independent MNA protocols were established in various European countries: Netherlands (BOS-NA in 1998), Belgium (OVAM in 2003), Germany (LABO in 2005), Sweden (SGI V541-1 for petroleum hydrocarbons in 2004 and SGI V601 for chlorinated aliphatic hydrocarbons in 2009), and the Catalonian region of Spain (in 2008). A protocol was developed in France in 2013, although technical guides were published earlier in 2006. Denmark has a web-based decision tool for the remediation of contaminated sites that incorporates MNA, while Finland currently lacks a specific protocol for evaluating MNA as a remediation option. These examples highlight the policy variations among European countries, with MNA generally applied primarily at smaller or medium-sized contaminated sites.

Simultaneously, it is important to note that MNA continues to be a prevalent remediation strategy in the United States. Originally designed for hydrocarbon plumes dissolved in groundwater, natural attenuation processes are now gaining increased attention for contamination sources such as Natural Source Zone Depletion (NSZD). NSZD occurs through the combined action of natural processes that reduce the mass of LNAPL in the subsurface and can be a sustainable risk-management strategy. According to ITRC (2009), NSZD is significant because engineered remedial actions typically do not always completely remediate soils and NSZD may help address residual hydrocarbon contamination. A typical approach for quantifying NSZD at contaminated sites is using CO2 traps (Figure 16).

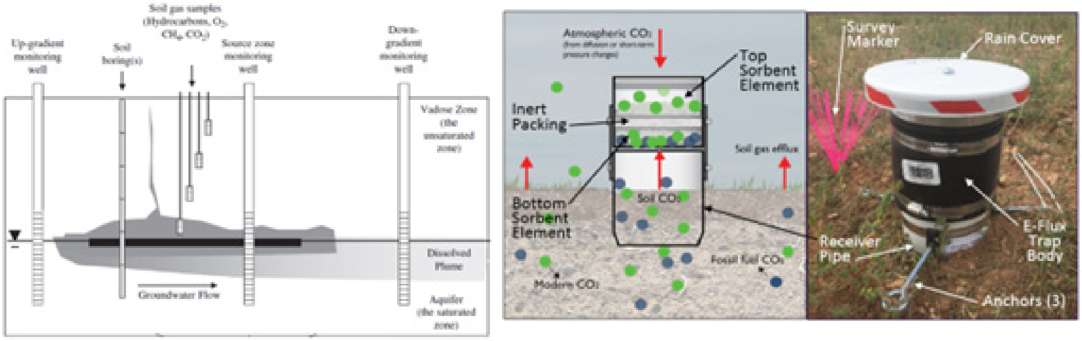


Figure 16. Typical gradient method monitoring setup (Johnson et al. 2006) (left) and passive CO_2 Flux Trap (designed and authored by E-Flux, LLC. Soil Gas Flux) (right)

To capture CO_2 emitted from the subsurface, the CO_2 trap is placed on the shallow ground surface and remains in position for 1–2 weeks. CO_2 traps have been deployed at multiple sites in the United States and have documented large CO_2 fluxes equivalent to 100s to 1000s gallons per acre per year (McCoy et al., 2011; Adamson and Newell, 2014).

Where and how can MNA be applied?

To be considered a remediation approach, MNA has to protect human health and the environment while meeting site-specific remediation objectives within a reasonable timeframe compared to other alternatives. Thus, to meet these criteria, monitoring attenuation processes and documenting their effectiveness in eliminating target contaminants is necessary. Thus, natural attenuation should not be a „do nothing" approach but rather a knowledge-based remedy in which a proper engineering analysis informs the understanding, monitoring, predicting, and documenting of the natural processes. To be more precise, the monitored aspect of MNA refers to the fact that extensive sampling and modelling efforts are typically needed to demonstrate that natural attenuation will be sufficient to meet site cleanup goals. Sites where contaminant plumes are no longer increasing in extent or are shrinking would be the most appropriate for MNA remedies US EPA (1999). In other words, as the presumption for MNA use, the following questions need to be positively answered:

Are the risks acceptable;

Is the plume stable or shrinking;

Is the remediation timeframe acceptable, and

Are cost-benefits acceptable?

The success of MNA relies on a site-specific monitoring program with defined sampling dynamics. According to Wilson (2011), MNA was a component of more than 20% of remedies implemented between 1982 and 2005 at National Priority List (NPL) sites where groundwater is contaminated. The same author refers that from 2005 to 2008, MNA was a component of more than 18% of NPL groundwater contaminated sites. According to Adamson and Newell (2014) MNA will likely become a more important way to manage low-risk sites with matrix diffusion serving as a secondary source of groundwater contamination.

According to US EPA (1999), MNA should not be considered a default or presumptive remedy; it should be applied „very cautiously as the sole remedy," and „source control will be fundamental components of any MNA remedy." However, in the meantime, MNA has been applied at numerous sites in the United States as the sole groundwater remedy. Thus, MNA was used as the sole groundwater remedy at 25 of 60 sites in Texas and 85 of 115 Kansas over the ten years to 2011 (Conor et al., 2011; Adamson and Newell, 2014).

A relatively new concept has emerged in the United States where certain sites can be considered as low risk that can be closed or conditionally closed while the site naturally attenuates (Adamson and Newell, 2014). In other words, while contaminant concentrations may significantly decrease due to remediation and/or natural attenuation, persistent low levels of groundwater contamination above closure criteria can prevent achieving objectives like reaching background concentrations or meeting drinking water standards. However, this residual contamination may pose minimal risk to human health and the environment, considering the site's specific characteristics. Consequently, in some regulatory jurisdictions, a 'low-risk' site may qualify for complete closure or conditional closure, where only limited monitoring is required as the site continues to attenuate. The low-risk site closure framework, a significant development in the field, has been incorporated into state regulatory guidance for several states, including California and Colorado (Adamson and Newell, 2014).

MNA of other contaminants

Knowledge in environmental sciences evolves rapidly, and contaminants previously considered resistant to natural attenuation may achieve this status. For example, methyl tertiary butyl ether (MTBE), a compound added to gasoline, initially appeared resistant to MNA. Studies conducted during the 1990s demonstrating the biodegradation of MTBE under natural conditions were scarce. However, recent plume studies have documented that most MTBE plumes are relatively short and attenuating (e.g., Wilson and Kolhatkar, 2002; Fiorenza and Rifai, 2003; Adamson and Newell, 2014).

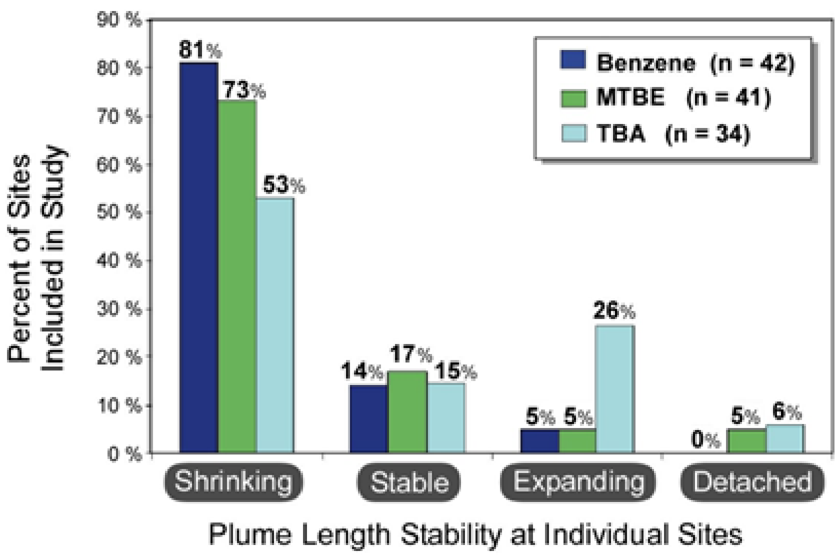


Figure 17. Groundwater plume stability analysis for MTBE, TBA, and Benzene at 48 site study (Kamath et al., 2012)

By 2005, the U.S. EPA had issued a guide for MNA for MTBE7, and the ITRC had evaluated the use of MNA for MTBE3 (Adamson and Newell, 2014). Based on the overall progress of the MNA approach, U.S. EPA in 2007 has released a three-volume protocol for 19 compounds (metals and radionuclides):

- Monitored Natural Attenuation of Inorganic Contaminants in Ground Water, Volume 1 - Technical Basis for Assessment (Ford et al., 2007)

- Monitored Natural Attenuation of Inorganic Contaminants in Ground Water, Volume 2 - Assessment for Non-Radionuclides Including Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Nitrate, Perchlorate, and Selenium (Ford et al., 2007)
- Monitored Natural Attenuation of Inorganic Contaminants in Ground Water, Volume 3 - Assessment for Radionuclides Including Tritium, Radon, Strontium, Technetium, Uranium, Iodine, Radium, Thorium, Cesium, and Plutonium-Americium (Ford and Wilkin, 2007)

Overall, MNA is gaining increasing attention primarily because of its cost-effectiveness. Since the actual remediation costs for excavation, transport, treatment, and deposition are minimal with MNA, further scientific and practical advancements in this approach can be anticipated in the coming years.

CONCLUSIONS

Over the decades, understanding and managing groundwater contamination have evolved significantly. Initially focused on physical removal methods like pump-and-treat, which proved limited effectiveness, attention shifted towards bioremediation methods like MNA. This shift was driven by extensive field studies demonstrating natural processes' ability, including microbial degradation, to reduce contaminant levels in groundwater. Thus, the evolution of MNA is an excellent example of the advancement of knowledge. Regulatory frameworks, such as those introduced by the U.S. EPA in the 1990s, played a pivotal role in legitimizing MNA as a viable remediation strategy. Beginning with petroleum hydrocarbons and extending to chlorinated solvents, metals, and radionuclides, our understanding of MNA for various contaminants has continually advanced. Due to MNA's cost-effectiveness, the results of its research continue to change the remediation policy and practice, primarily in the United States.

lITERATURE:

Adamson, D. T., & Newell, C. J. (2014). Frequently Asked Questions about Monitored Natural Attenuation in Groundwater. ESTCP Project ER-201211. Environmental Security and Technology Certification Program, Arlington, Virginia.

Alvarez, J. P., & Illman, A. W. (2006). Bioremediation and Natural Attenuation: Process Fundamentals and Mathematical Models. John Wiley & Sons, New York, NY.

Buscheck, T. E., Wickland, D. C., & Kuehne, D. L. (1996). Multiple lines evidence to demonstrate natural attenuation of petroleum hydrocarbons. In Proceedings of the 1996 Petroleum Hydrocarbons and Organic Chemicals in Groundwater Conference, Houston, TX, API/NGWA, 445-460.

Connor, J. A., Molofsky, L. J., Paquette, S. M., Hinchee, R. E., Desai, S. P., & Connor, M. K. (2011). Nature, frequency, and cost of environmental remediation at onshore oil and gas exploration and production sites. Remediation, 21, 121–144.

Council on Environmental Quality. (1981). Contamination of ground water by toxic organic chemicals. U.S. Government Printing Office, Washington, D.C.

Fetter, C. W. (1999). Contaminant Hydrogeology (2nd ed.). Prentice Hall, Upper Saddle River, N.J.

Fiorenza, S., & Rifai, H. S. (2003). Review of MTBE Biodegradation and Bioremediation. Bioremediation Journal, 7(1), 1-35.

Ford, R. G., & Wilkin, R. T. (2010). Monitored Natural Attenuation of Inorganic Contaminants in Ground Water, Volume 3 - Assessment for Radionuclides Including Tritium, Radon, Strontium, Technetium, Uranium, Iodine, Radium, Thorium, Cesium, and Plutonium-Americium. National Risk Management Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Ford, R. G., Wilkin, R. T., & Puls, R. W. (2007a). Monitored Natural Attenuation of Inorganic Contaminants in Ground Water, Volume 1 - Technical Basis for Assessment. National Risk Management Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Ford, R. G., Wilkin, R. T., & Puls, R. W. (2007b). Monitored Natural Attenuation of Inorganic Contaminants in Ground Water, Volume 2 - Assessment for Non-Radionuclides Including Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Nitrate, Perchlorate, and Selenium. National Risk Management Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio.

ITRC. (2009). Evaluating Natural Source Zone Depletion at Sites with LNAPL. Interstate Technology and Regulatory Council, Washington, D.C. Retrieved from www.itrcweb.org.

Johnson, P., Lundegard, P., & Liu, Z. (2006). Source Zone Natural Attenuation at Petroleum Hydrocarbon Spill Sites-I: Site-Specific Assessment Approach. Groundwater Monitoring & Remediation, 26(4), 82-92. https://doi.org/10.1111/j.1745-6592.2006.00114.x

Jørgensen, K. S., Salminen, J. M., & Björklöf, K. (2010). Monitored Natural Attenuation. In S. Cummings (Ed.), Bioremediation. Methods in Molecular Biology (Methods and Protocols), vol 599. Humana Press.

Kaćanski, A. (1995). Hydrogeological problems of the groundwater contamination in alluvial deposits of Zapadna Morava in Vitanovac (Kraljevo). Belgrade: Faculty of Mining and Geology.

Kamath, R., Connor, J. A., McHugh, T. E., Nemir, A., Le, M. P., & Ryan, A. J. (2012). Use of Long-Term Monitoring Data to Evaluate Benzene, MTBE, and TBA Plume Behavior in Groundwater at Retail Gasoline Sites. Journal of Environmental Engineering, 138, 458-469.

Lawniczak, A. E., Zbierska, J., Nowak, B., Achtenberg, K., Kowiak, A. G., & Kanas, K. (2016). Impact of agriculture and land use on nitrate contamination in groundwater and running waters in central-west Poland. Environmental Monitoring and Assessment, 188, 172. https://doi.org/10.1007/s10661-016-5167-9

Lu, Q., Zhu, R. L., Yang, J., Li, H., Liu, Y., Lu, S. G., Luo, Q. S., & Lin, K. F. (2015). Natural attenuation model and biodegradation for 1,1,1-trichloroethane contaminant in shallow groundwater. Frontiers in Microbiology, 6, 839. https://doi.org/10.3389/fmicb.2015.00839

Mace, R. E., Fisher, R. S., Welch, D., & Parra, S. P. (1997). Extent, Mass and Duration of Hydrocarbon Plumes from Leaking Petroleum Storage Tank Sites in Texas. Geological Circular 97-1, Bureau of Economic Geology, University of Texas at Austin.

Marić, N., Matić, I., Papić, P., Beškoski, V. P., Ilić, M., Gojgić Cvijović, G., et al. (2018). Natural attenuation of petroleum hydrocarbons—A study of biodegradation effects in groundwater (Vitanovac, Serbia). Environmental Monitoring and Assessment, 190(2), 89.

Marić, N., Mrazovac Kurilić, S., Matić, I., Sorajić, S., & Zarić, J. (2014). Groundwater quality on the territory of Kikinda municipality (Vojvodina, Serbia). Environmental Earth Sciences, 72, 525–534.

Marić, N., Štrbački, J., Mrazovac Kurilić, S., et al. (2020). Hydrochemistry of groundwater contaminated by petroleum hydrocarbons: the impact of biodegradation (Vitanovac, Serbia). Environmental Geochemistry and Health, 42, 1921–1935. https://doi.org/10.1007/s10653-019-00462-9

Marić, N., Štrbački, J., Polk, J., Slavković Beškoski, L., Avdalović, J., Lješević, M., et al. (2022). Spatial–temporal assessment of hydrocarbon biodegradation mechanisms at a contaminated groundwater site in Serbia. Chemistry and Ecology, 38(2), 95–107. https://doi.org/10.1080/02757540.2021.2017903

Mars, J. F. (2013). CityChlor Project: Monitored Natural Attenuation - Option for plume management. pp. 1-26.

Matić, I. (1994). Research activities on the monitoring of accidental groundwater contamination by kerosene in Vitanovac (Kraljevo). Belgrade: Faculty of Mining and Geology.

McCoy, K., Sale, T., & Zimbron, J. (2011). Quantifying Natural LNAPL Source Zone Depletion Using CO2 Traps. University Consortium for Field Focused Groundwater Contamination Research, 2011 Annual Meeting, Guelph, Ontario.

Mersmann, P. (2003). Transport und Sorptionsverhalten der Arzneimittelwirkstoffe Carbamazepin, Clobrinsaure, Diclofenac, Ibuprofen und Propyhenazon in der wassergesattingen und ungesattingen Zone (Thesis). Technical University Berlin.

Mrazovac Kurilić, S., Ulniković, V. P., & Marić, N. (2015). Assessment of typical natural processes and human activities' impact on the quality of drinking water. Environmental Monitoring and Assessment, 187(11), 659.

Newell, C., & Connor, J. (1998). Characteristics of dissolved petroleum hydrocarbon plumes. Groundwater Services, American Petroleum Institute, Washington, DC.

Rice, D. W., Grose, R. D., Michaelsen, J. C., Dooher, B. P., MacQueen, D., Cullen, S. J., Kastenberg, W. E., Everett, L. G., & Marion, M. A. (1995). California leaking underground tank (LUFT) historical case analysis. Environmental Protection Department, No.16.

Scheutz, C., Durant, N. D., Hansen, M. H., & Bjerg, P. L. (2011). Natural and enhanced anaerobic degradation of 1,1,1- trichloroethane and its degradation products in the subsurface—a critical review. Water Resources, 45, 2701–2723.

Tullis, D., Prevost, P. E., & Kostecki, P. (1998). Study points to new trends in use of alternative technologies at LUST sites. Soil Groundwater Cleanup, 7, 12-17.

U.S. EPA. (1999). Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites, OSWER Directive 9200.4-17P. Washington, D.C.: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response.

Wiedemeier, T. H., Rifai, H. S., Newell, C. J., & Wilson, J. T. (1999). Natural attenuation of fuels and chlorinated solvents in the subsurface. New York: Wiley.

Wiedemeier, T. H., Wilson, J. T., Kampbell, D. H., Miller, R. N., & Hansen, J. E. (1995). Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater. U.S. Air Force Center for Environmental Excellence, San Antonio, TX.

Wilson, J. T. (2011). Applications of Monitored Natural Attenuation in the USA (Presentation). Presented at 2011 International Conference on Groundwater Contamination and Water System Security, Beijing, CHINA, December 01-02.

Wilson, J. T., & Kolhatkar, R. (2002). Role of Natural Attenuation in Life Cycle of MTBE Plumes. Journal of Environmental Engineering, 128(9), 876-882.

Zhang, M., Geng, S., Ustin, S. L., & Tanji, K. K. (1997). Pesticide occurrence in groundwater in Tulare County, California. Environmental Monitoring and Assessment, 45(2), 101–127.

SOCIAL DIMENSIONS OF REGENERATIVE ARCHITECTURE: DESIGN SOLUTIONS FOR VULNERABLE POPULATIONS

Vesna Žegarac Leskovar, full prof.dr.

University of Maribor, Faculty of Civil Engineering, Transportation engineering and Architecture, Department for architecture,
vesna.zegarac@um.si

Abstract

This study examines the social dimensions of regenerative architecture, with a particular focus on the design solutions for living environments that are tailored to vulnerable populations, with older adults as a case in point. A case study analysis of two nursing homes in Sweden and one in the Netherlands is presented in order to explore the potential of regenerative design principles to enhance the wellbeing of residents and promote social interaction, inclusion, and community involvement. Qualitative assessment of architectural features is employed as a research method. The findings demonstrate that regenerative architecture has the capacity to enhance the quality of life for residents by fostering social cohesion, while also contributing to the environmental regeneration of the surrounding area. This aligns with the holistic goals of regenerative design.

Keywords: regenerative architecture, regenerative design, social dimensions, older adults, living environments, social interaction , inclusion, community involvement

INTRODUCTION

In recent decades, there has been a notable advancement in design methodologies and green building certification systems, which have emerged as key enablers in the pursuit of a sustainable built environment (Dervishaj, 2023, p.1). Although the sustainable design incorporates three fundamental dimensions of sustainability—environmental, social, and economic—the primary objective of the initiatives to create sustainable built environment has been the alleviation of the intricate challenges posed by climate change. This objective should have been achieved through the implementation of green building frameworks designed to reduce environmental impacts, enhance resource efficiency, and achieve energy neutrality. However, there is a sceptical view of the success of sustainability efforts to prevent the climate crisis. Furthermore, many researchers have expressed reservations about the lack of emphasis on interrelated wholeness in sustainable design, which they refer to as "whole system thinking" (Reed, 2007, p. 675). In response to the shortcomings identified in the field of sustainable design, regenerative design has emerged as a new paradigm in recent years. This approach represents a significant departure from conventional discourse on sustainability, prioritising holistic systems thinking for both human and natural systems. Additionally, numerous concepts within the domain of sustainable architecture, particularly those associated with various design guidelines, were frequently generic and not tailored to the nuances of specific environments, particularly those of a smaller scale. The fundamental tenet of regenerative architecture is that the building can act as a catalyst for positive change within the specific context of its location (Cole, 2011, p. 1), where the concept of location context encompasses more than merely environmental, climatic, or geographic conditions. It is imperative that the social dimension, in particular the socio-cultural state and specific needs of certain social groups, is not overlooked.

This paper addresses the specific needs of living environments for vulnerable groups, such as the elderly, where the social aspect is crucial for their well-being and health. Furthermore, it will be demonstrated how, by applying the principles of regenerative architecture, these environments can not only meet the residents' needs but also give back to the surrounding environment and location, thus creating a surplus in line with the goals of regenerative architecture.

PRINCIPLES OF REGENERATIVE ARCHITECTURE FOR VULNERABLE POPULATIONS WITH AN EMPHASIS ON SOCIAL DIMENSIONS

In contrast to sustainable design, which is concerned with mitigating the adverse effects of construction on the environment, regenerative design aims to reverse the accelerated depletion of planetary resources and restore ecosystems to a state of equilibrium. The objective is to create a built environment that generates a net positive contribution (Cole, 2011, p. 3). The fundamental concept of regenerative design, and indeed regenerative architecture, is to integrate the primary elements through a holistic approach to system thinking. This encompasses a range of interrelated regenerative design elements, including biophilic design, the regeneration of materials and resources, energy systems, water management and regenerative hydrology, regenerative landscapes and urban design, social and cultural regeneration, and the principles of a circular economy, as well as resilience to climate change. The objective is readily comprehensible when viewed through an environmental, material and energy resources lens; however, when the social perspective is considered, its meaning becomes less apparent. Furthermore, regenerative architectural design is predicated on the acceptance and promotion of "place" as the fundamental point of departure for design. This approach seeks to rekindle the connection between individuals and the essence of their surrounding environment, thereby instilling a sense of vitality and intrinsic motivation to preserve and nurture that environment (Mang, 2009, p. 5).

When designing living environments for specific vulnerable groups, including the older adults, it is essential to give particular attention to various quality aspects. It is crucial to comprehend the requirements of an ageing society and to implement measures that facilitate the attainment of a superior quality of life. Given the diverse impairments that the elderly encounter in old age, it is imperative that their living environment be adapted in a manner that is age appropriate. Such adaptations must not only ensure the fulfilment of basic existential needs but also guarantee humane living conditions. The evidence suggests that age-friendly environments have a positive impact on the well-being of older adults (Molina-Martínez et al., 2022, p. 7), as well as on their functioning and health (Yang & Fu, 2019, p.11). Furthermore, it is beneficial to review the quality existing living environments for older adults, as many of them are designed in accordance with various national standards that provide only basic quality and do not focus on the specific requirements and needs of such social groups. In this context, a more regenerative architectural approach represents a significant advancement, encouraging such living environments not only to meet the needs of the users but also to replenish qualities within both nature and society, or the surrounding environment.

CONCEPTS OF LIVING ENVIRONMENTS FOR OLDER ADULTS

The extant concepts of older adults' living environments demonstrate notable variation across multiple dimensions, including the level of care and assistance, size, configuration, and degree of institutionalisation. The variety of existing concepts, which have been adapted in Europe and the United States of America, affords older adults the opportunity to select the one that best suits their needs (Table 1). It is regrettable that different countries have only developed a limited number of older adults' living environment concepts. If countries were to adapt a greater number of concepts, it would facilitate a more gradual transition of this vulnerable population group from home environments to the most institutionalised living environments.

Table 1: The existing concepts of older adults' living environments in select countries within the Europe and the United States of America reflecting the progression of care (Adapted from Mohammadi et al., 2019; Lehning et al., 2010; Seniorval, 2022 a)

RISING LEVEL OF INSTITUTIONALISATION: FROM HOME CARE TO RETIREMENT HOMES					
HOME CARE	SENIOR HOUSING or COMMUNITIES	ASSISTED LIVING or SECURITY HOUSING	CARE HOMES or ADULT FAMILY HOUSES	DAY CARE CENTRES	NURSING/ RETIREMENT HOMES
No regular service and nursing Supportive services and medical care if necessary No age limit	No regular nursing (usually) Functional and simple "age-adapted" housing or communities Age 55+	Assistance in day-to-day activities Supervision No regular nursing (usually) Age 70+ (for Sweden only)	Higher degree of care 24/7 Medical assistance Max. 20-25 residents	Residential day care apartments and inpatient facilities Care and living separated Offering services for the surrounding neighbourhood	Nursing care 24/7 Medical care Services provided (food, cleaning, etc.) Age 65 +

In Europe, nursing homes represent the most institutionalised form of living environment. These facilities can be classified into a number of distinct categories, which vary in terms of their size architectural typology, level of social integration of residents, density of residents per room, level of privacy, and so forth. The range of types is extensive and includes both traditional and alternative options. From a historical perspective, nursing home models can be delineated through the five-generation model scheme (Table 2).

Table 2: The five-generation nursing home model in Europe

NURSING HOMES IN EUROPE - FIVE GENERATION MODEL				
1st GENERATION	2nd GENERATION	3rd GENERATION	4th GENERATION	5th GENERATION
poorhouse	socially isolated infirmary	specialised hospital + comfortable hotel	household group	household group + highest level of privacy

The initial traditional models of the first generation were originally conceived as rudimentary shelters and offered only the most basic forms of care and nursing. Subsequently, second-generation hospital-like models were introduced. The third-generation model represents a significant innovation, with the objective of engaging residents in a range of activities (Michell-Auli, Christine Sowinski, 2012, pp. 10-15). Nevertheless, subsequent developments have led to the emergence of contemporary forms of nursing home, including the fourth- and fifth-generation models. These models prioritise the creation of an environment that is both homelike and therapeutic, with smaller groups of residents, while emphasising privacy, accessibility, and safety. The concept of the fourth-generation model was initially devised with the specific intention of addressing the particular requirements of residents with dementia. These models are based on the structure of the family unit, with daily domestic and social activities conducted in small household groups (typically comprising up to 12 residents) in a central space comprising a living room and kitchen. The aforementioned central space is surrounded by single rooms with private bathrooms, the design of which is intended to evoke the residents' home environment. The architectural design of the fifth-generation model places even greater emphasis on the importance of privacy and the provision of a private space for residents. All rooms are designed for single occupancy. In addition to a bathroom, each room is equipped with a kitchenette, and residents are permitted to supplement the ambience with a piece of furniture from their home environment. Each room is also furnished with a bell and a postbox, which foster a sense of autonomy and privacy for residents (Žegarac Leskovar & Skalicky-Klemenčič, 2023, p. 7). The fourth- and fifth-generation models are designed with the objective of offering the optimal environment for the elderly, with a view to enhancing their quality of life.

CASE STUDIES: EXAMPLES OF BEST PRACTICE FROM SWEEDEN AND NETHERLANDS

The following section will present three examples of best practice, with a particular focus on the social quality dimension. The examples from Sweden have been selected on the basis of a research visit undertaken by the researchers Vanja Skalicky Klemečič and Vesna Žegarac Leskovar as part of the Erasmus + programme. The example from the Netherlands has been selected due to its unique approach to intergenerational cohesion, which has been examined exclusively through a review of relevant literature.

BASIC DESCRIPTION OF CASE STUDIES

Nursing home Hallonhöjden in Sundbyberg, Sweeden

The Hallonhöjden is a recently renovated nursing home, where the original building was extended by the incorporation of extensive glazed balconies, which not only provide an additional space for the daily activities of residents but also contribute to an enhanced energy performance of the building (Figure 1).

Figure 1: The Hallonhöjden nursing home facilities, with private spaces depicted in the images above and semi public spaces in the images below (Source: author's photo archive).

The nursing home of a fourth-generation model comprises 56 single-occupancy apartments, each with an approximate floor area of 30 m², distributed across four floors, with 14 apartments per floor. Every floor is divided into two household units, containing seven apartments, along with a kitchen, dining room, living room, and a large glazed balcony accessible to all residents. The apartments are equipped with a kitchenette, as well as a private bathroom with a shower, toilet, washing machine, and tumble dryer. Some of the appartments are utilised for temporary, short-term stays. These may be occupied by individuals who are seeking to move into the home due to their current circumstances, or by residents of other nursing homes who utilise the rooms as a form of exchange or temporary accommodation.The spacious courtyard features green areas and outdoor furniture. The location of the nursing home is easily accessible by public transport and is equipped with parking facilities. It also offers a range of amenities, including a restaurant, a physical therapy rooms, fitness, and a flexible multipurpose space for exhibitions and dance evenings. These facilities are not solely used by the residents of the nursing home; they can also be used by members of the local community, fostering inclusion, social interaction and community cohesion. The shared facilities contribute to the local environment in terms of social and cultural regeneration. Similarly, the provision of temporary accommodation provides additional benefits and facilitates the involvement of individuals from the surrounding neighbourhood. Operated by the municipal authority of Sundbyberg, the nursing home benefits from a municipal subsidy programme that ensures all individuals aged 65 and above who require care can be accommodated in a nursing home, regardless of their personal financial circumstances (Seniorval, 2024 b).

Nursing home The Gardens, Örebro, Sweden

The nursing home comprises a total of 96 apartments, distributed across a two-storey building. The fifth-generation model is characterised by household units containing a maximum of seven apartments per unit. Each apartment has been designed with the objective of supporting the well-being of elderly residents. This has been achieved through the incorporation of features such as large windows, private bathrooms and kitchenettes, which foster independence. The fundamental rationale behind the design of the Gardens nursing home is the conviction that the wellbeing of older adults in long-term care facilities is significantly influenced by the presence of attractive green outdoor areas and opportunities for social interaction (Figure 2).

Figure 2: The Gardens nursing home facilities, with outdoor areas depicted in the images above and indoor spaces in the images below (Source: author's photo archive).

The nursing home incorporates multiple elements of regenerative design and was planned to achieve LEED Gold certification by utilising sustainable, low-impact materials that require minimal maintenance. The spatial design of this fifth-generation model places an emphasis on the creation of comfortable living environments for the elderly, with convenient access to private gardens, outdoor spaces, and shared facilities. The ground floor residents have direct access to the gardens, while those on the second floor utilise roof terraces. The extensive glazing allows for visual connections to the courtyard gardens, thereby enhancing security and encouraging residents to explore the outdoor environment and interact with others. In addition to the aforementioned social benefits, the design incorporates a variety of environmentally focused regenerative elements. The façades facing the atrium courtyards are clad in wood panelling, which has a low environmental impact and requires minimal maintenance (Archidaily, 2024). Moreover, sections of the roof are planted with sedum, which facilitates the retention and filtration of rainwater, with the water being directed to courtyards, cultivation beds, and surrounding meadows. The integration of vegetation and water serves to enhance local biodiversity, creating habitats for insects and birds. The external façade is finished with fibre cement panels in tones that blend harmoniously with the surrounding landscape (ACE, 2024). The atrium gardens cater to the diverse needs of residents, offering tranquil spaces for those requiring minimal stimuli and larger areas for communal activities and enhanced stimulation. These outdoor spaces are designed for independent use by individuals with functional impairments, thereby reducing the risk of residents with dementia becoming disoriented. Furthermore, the social dimension of the regenerative approach is highlighted by the creation of diverse outdoor spaces that promote movement, independent living, and social interaction among residents, staff, and visitors (LAP, 2024)

Nursing home Humanitas, Deventer, Netherlands

In this instance, the emphasis will not be on the architectural aspects, but rather on a particular intergenerational approach. The development of intergenerational housing was prompted by a number of significant challenges, including the underutilisation of space in nursing homes and the persistent scarcity of affordable student accommodation. In consequence of the reduction in government funding for the care of the elderly in the Netherlands, a considerable number of nursing homes were placed in a financially precarious position, with a concomitant decline in the number of residents and a consequent increase in the number of vacant rooms. Concurrently, the availability of student accommodation remained constrained and costly. These circumstances created an opportunity to rethink the model of care, which led to the integration of students into nursing homes. Currently, the intergenerational living environment of Humanitas consists of six students and 160 elderly residents. This arrangement is mutually beneficial: students receive free accommodation in exchange for community involvement of 30 hours per month, while elderly residents experience reduced isolation and increased social interaction, addressing both housing shortages and enhancing the quality of elderly care with a positive contribution to their mental healh and wellbeing (Arentshorst, et al., 2019, pp.247-248).

Analysis of regenerative architecture in case studies with a focus on social dimensions

The case studies highlight several pivotal aspects of regenerative architecture, with a pronounced emphasis on social dimensions that engender inclusion, interaction, and community well-being. Each project incorporates design strategies that address environmental sustainability and enhance the quality of life for elderly residents. A particularly noteworthy aspect of the regenerative design is its capacity to enhance the quality of life for residents and caregivers while also fostering engagement with the surrounding community. A significant number of the facilities are accessible to the general public, enabling local residents to utilise amenities such as fitness rooms and event spaces, thereby fostering a robust connection between the nursing home and its surrounding neighbourhood. This is consistent with the overarching objectives of regenerative architecture, which strives to guarantee that buildings are seamlessly integrated into their surrounding context, thereby enhancing the social and environmental well-being of the area.

Table 3: Social Dimensions and Impacts of Regenerative Design in Nursing Homes

Nursing homes	Social Dimensions	Impacts
Hallonhöjden	Integration of private and semi-public spaces	Encourages interaction between residents, staff, and the local community
	Inclusion of amenities open to the public	Positions the nursing home as a community hub, promoting social cohesion and enabling cultural regeneration
	Provision of temporary accommodation for individuals from outside the institution	Extends the impact of the nursing home to a wider area
The Gardens	Integration of biophilic design	Facilitates physical and social well-being
	Green spaces, atrium gardens and roof terraces	Encourages interaction and independence among residents
	Liveable outdoor areas design	Promotes movement, social engagement, activation of residents, and reduces isolation, particularly among residents with dementia
Humanitas	Intergenerational living model	Addresses both the underutilization of space in nursing homes and the shortage of affordable student housing.
	Integration of students into the community	Creates a mutually beneficial environment: the older adults benefit from valuable social interaction and support from the students, which has a marked effect on reducing their isolation and enhancing their overall mental wellbeing students gain new social experiences: they develop compassion, tolerance and understanding of people with different needs

The aforementioned examples illustrate that regenerative design approaches are characterised by a focus on enhancing social interaction, community involvement and independent living, while also addressing environmental sustainability. The incorporation of green spaces, shared facilities, and intergenerational housing solutions exemplifies the capacity of regenerative architecture to facilitate both social and environmental regeneration.

CONCLUSION

The present study illustrates the ways in which architectural design can promote both environmental sustainability and social well-being. The case studies from Sweden and the Netherlands illustrate that regenerative design principles can facilitate interaction, inclusion, and community cohesion through the integration of shared spaces, green areas, and innovative housing models that are conducive to social interaction. The presented projects illustrate that, in addition to fulfilling the physical needs of residents, the built environment can act as a catalyst for positive social interactions, thereby promoting independence and reducing isolation. By engaging local communities and encouraging intergenerational living, regenerative architecture has the potential to extend its impact beyond the boundaries of the facility, thereby contributing to the broader social and environmental regeneration of the surrounding neighbourhood. This holistic approach is consistent with the objectives of regenerative architecture, which aims not only to maintain but also to enhance both human and natural systems.

References

Arentshorst, M. E., Kloet, R. R., & Peine, A. (2019). Intergenerational housing: The case of Humanitas Netherlands. *Journal of Housing for the Elderly,* 33(3), 244–256. https://doi.org/10.1080/02763893.2018.1561592

Cole, R. J. (2011). Regenerative design and development: Current theory and practice. *Building Research & Information*, 40(1), 1–6. https://doi.org/10.1080/09613218.2012.617516

Dervishaj, A. (2023). From sustainability to regeneration: A digital framework with BIM and computational design methods. *Architectural Structures and Construction*, 3, 315–336. https://doi.org/10.1007/s44150-023-00094-9

Lehning, A. J., & Austin, M. J. (2010). Long-term care in the United States: Policy themes and promising practices. *Journal of Gerontological Social Work*, 53(1), 43-63.

Mang, N. (2009). Toward a regenerative psychology of urban planning. *Saybrook*

Graduate School and Research Center. San Francisco, CA. http://gradworks.umi.com/33/68/3368975.html

Michell-Auli, P., & Sowinksi, C. (2012). *Die 5. generation: Kda-quartiershäuser: Ansätze zur Neuausrichtung von Alten- und pflegeheimen*. Kuratorium Deutsche Altershilfe Köln.

Mohammadi, M., Dominicus, M., van Buuren, L., Hamers, K., Hammink, C., & Yegenoglu, H. (2019). The evolution of housing typologies for older adults in The Netherlands from 1945 to 2016: An analysis in the context of policy, societal, and technological developments. *Journal of Housing for the Elderly*, 33(3), 205-226. https://doi.org/10.1080/02763893.2019.1561591

Molina-Martínez, M. A., Marsillas, S., Sánchez-Román, M., & del Barrio, E. (2022). Friendly residential environments and subjective well-being in older people with and without help needs. *International Journal of Environmental Research and Public Health*, 19(23), 15832. https://doi.org/10.3390/ijerph192315832

Reed, B. (2007). Shifting from sustainability to regeneration. *Building Research & Information*, 35(6), 674–680. https://doi.org/10.1080/09613210701475753

Seniorval. (2024a). Housing for senior. https://seniorval.se/bra-att-veta/boende (accessed 22.05.2024)

Seniorval. (2024b). Housing for senior. https://seniorval.se/aldreboende/sundbyberg/hallonhojden (accessed 22.05.2024)

Yang, Z., & Fu, Y. (2019). Physical attributes of housing and elderly health: A new dynamic perspective. *International Journal of Environmental Research and Public Health*, 16(24), 4961. https://doi.org/10.3390/ijerph16244961

ACE. (n.d.). The gardens elderly center. https://www.ace-cae.eu/activities/net-arch-programme-and-eu-funded-projects/past-projects/connect-arch/20-projects-architectural-projects-against-climate-change/the-gardens-elderly-center/ (accessed 14.08.2024)

Archidaily. (n.d.). The Gardens care home. https://www.archdaily.com/984946/the-gardens-care-home-marge-arkitekter (accessed 14.08.2024)

LAP. (n.d.). Retirement home Trädgårdarna. https://landezine.com/retirement-home-tradgardarna-by-land-arkitektur/ (accessed 14.08.2024)

COMPARATIVE ANALYSIS OF SECONDARY SCHOOL STUDENTS' AWARENESS OF WAYS THEY INDIVIDUALLY CAN INFLUENCE THE REDUCTION OF ENVIRONMENTAL POLLUTION

A. Ivanov[1], K. Stevanović[2], Ž. Stanković[3], O. Krčadinac[3]

[1]Architectural Technical School, Belgrade, Serbia
[2]Geological and Hydrometeorological School „Milutin Milankovic",
[3]University „Union - Nikola Tesla", Faculty of Informatics and Computer Science, Belgrade, Serbia

ssaanndra09@gmail.com

Abstract: This research shows that continuous education about environmental pollution can positively influence an individual's environmental protection awareness. An online survey of fourth and final-grade students from two secondary schools showed that students who take courses on pollution sources, pollution, water, soil, air, wastewater, and solid waste significantly contribute to environmental protection compared to those who don't consistently attend these courses.

Keywords: air, water, soil pollution, environmental protection, recycling.

INTRODUCTION

Protection of the environment is a vital field aiming to ensure that the needs of the present generation are met in a way that does not compromise the ability of future generations to meet their own needs. Critical awareness of the (mis)use of natural resources and environmental protection only emerged in the last decades of the 20th century when the first large nature reserves were established, and the first ecological control techniques were adopted, following a century of industrial expansion that had unlimitedly exploited natural resources such as land, water, and forests.

Various environmental management systems are being implemented to leverage advanced technologies and new business practices. Companies, industries, and governments are adopting a new business ethic under the pressure of a society that is increasingly aware of environmental issues. Young people play a very important role in facing environmental risks and preserving them for future generations, as well as for their generation, which has a longer life span ahead of them. Formal and informal education of young generations should be crucial in raising awareness about environmental protection.

The education system bears a great responsibility, especially teachers, instructors, and professors, to educate and raise new generations to care for preserving the environment for themselves, their families, and the future. Environmental education plays a crucial role in protecting and improving the environment. Today, it is an integral part of the educational system, in some schools as part of the regular curriculum, and in others as extracurricular activities.

Environmental education has been introduced into the curriculum relatively recently. Depending on the age group, it is studied either as a separate subject or as part of preschool activities, through subjects such as nature and society studies, biology, chemistry, geography, and physics, and as vocational subjects in high schools. The status of subjects in high schools that include environmental content depends on the profession for which the students are being trained.

WORK METHODOLOGY

For this purpose, a survey was conducted in April 2024 with students from the final year of two vocational high schools: the Geological and Hydrometeorological School „Milutin Milanković" and the Architectural Technical School. Students from the Geological School have been attending the „Environmental Protection Technician" program for four years, while students from the Architectural Technical School have been in the „Architectural Technician" program. The survey was completed by 100% of the students from the Geological School and 93% of the students from the Architectural Technical School.

RESULTS AND DISCUSSION

From the Architectural Technical School, the number of boys is 60%, and the number of girls is 40%. In the Geological and Hydrometeorological School, the survey was completed by more girls (75%) than boys (25%). Geological and Hydrometeorological School students are more concerned about environmental pollution and are better informed about ecological pollution sources than students from the Architectural Technical School. Additionally, students from the Geological and Hydrometeorological School are 100% interested in participating in reducing environmental pollution. Regarding the frequency of recycling waste, the results are similar in both schools. However, the percentage of students who never recycle waste is much higher in the Architectural Technical School (24%) compared to the Geological School, where only 6% of students never recycle. Students are primarily informed about recycling through school but frequently obtain information from various sources (school, family, internet, and media). When they find trash on the street, students from the Geological and Hydrometeorological School are more conscientious about disposing of it properly. Students generally lack a culture of recycling or repurposing paper for other uses. The issue of having containers specifically designed for sorting and separating waste is evident among students of both schools. Students from the Geological School are somewhat more likely (59%) to use containers specifically designed for certain types of waste than students from the Architectural School (42%). Diagrams 1, 2, 3, 4, 5, and 6 illustrate the students' technical knowledge in this area.

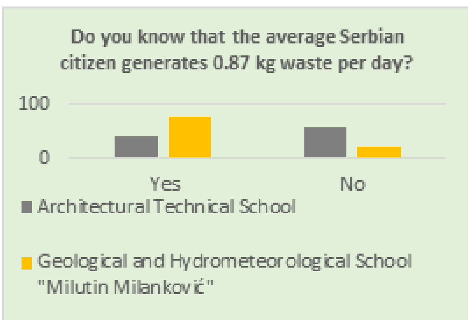


Diagram 1 *Responses to the question regarding the amount of waste the average citizen produces daily*

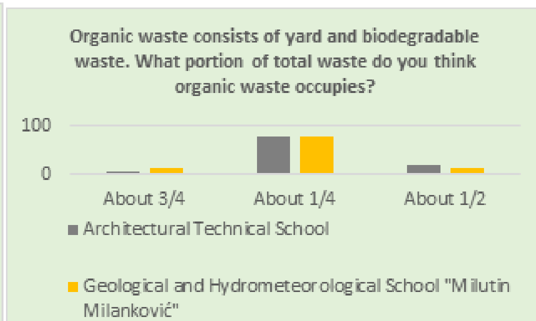


Diagram 2 *Responses to the question about organic waste*

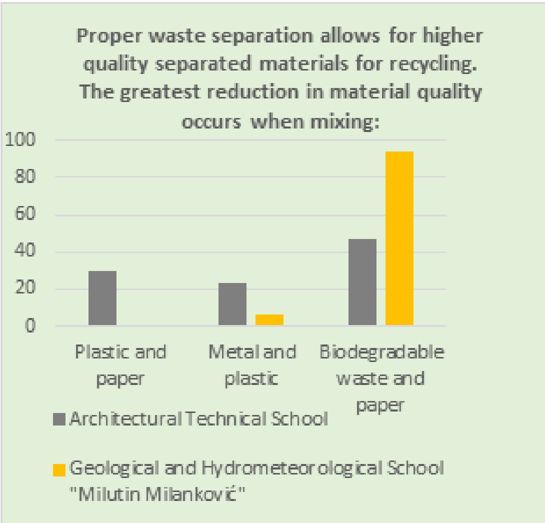


Diagram 3: *Responses to the question about which gas causes global warming*

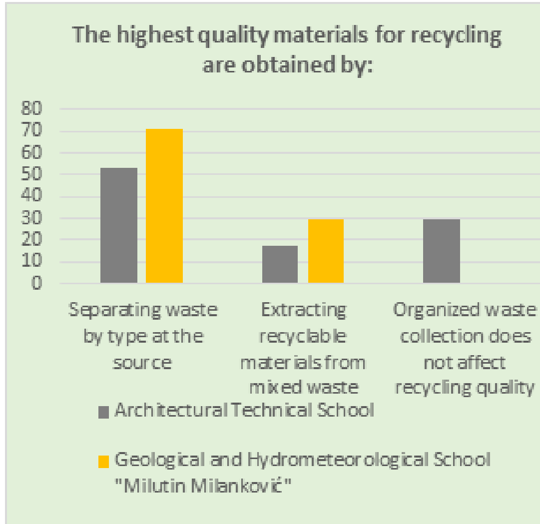


Diagram 4: *Responses to the question about which gas can produce energy*

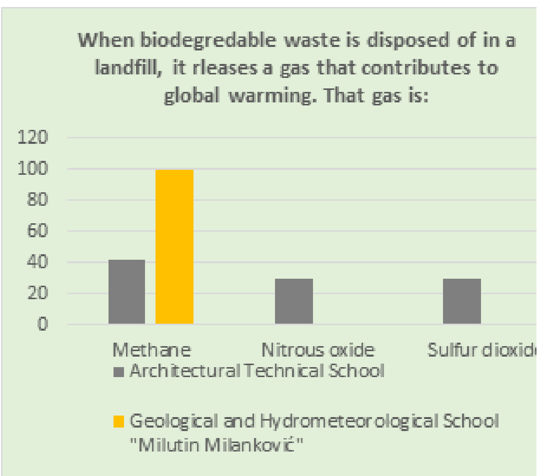


Diagram 3: *Responses to the question about which gas causes global warming*

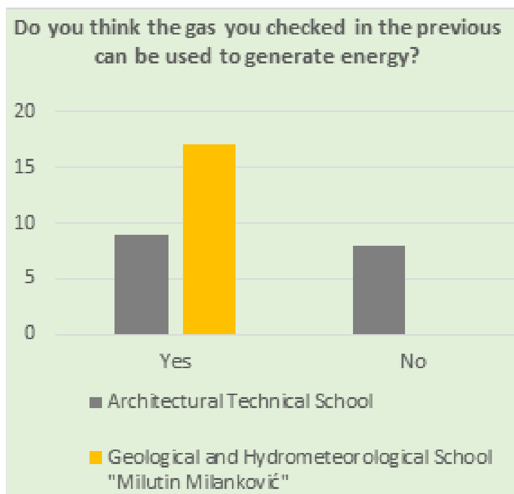


Diagram 4 *Answer the question about the quality of recycling materials*

Regarding the question about the recycling program in Serbia, which can be voluntary or mandatory, and students' opinions on which program is prevalent in Serbia, 35% of students from the Architectural Technical School answered that it is a mandatory recycling program. In comparison, 82% of students from the Geological School identified it as a voluntary recycling program. Additionally, students from both schools support a mandatory recycling program in Serbia.

Geological and Hydrometeorological School students have participated in more environmental protection-related subjects and have been more involved in recycling during school activities. Table 1 shows some activities, how students defined recycling in Table 2, and student opinions on waste separation in Table 3. Table 4 lists the benefits that students expect from the recycling process, and Table 5 shows how their behavior impacts environmental protection.

Table 1 *Activities in which students have participated related to environmental protection.*

What were those activities?	
Architectural Technical School	**Geological and Hydrometeorological School „Milutin Milanković"**
We had organized waste collection on Avala	Class Block, Visit to the wastewater treatment plant
	Planting Roses, Household waste recycling
	Participating in lectures and presenting materials at competitions, while simultaneously educating about existing problems

Table 2 *Data on how students defined recycling.*

How would you define recycling?	
Architectural Technical School	**Geological and Hydrometeorological School „Milutin Milanković"**
Sorting waste and processing it to get new material that we can reuse.	As smart and conscientious reuse of certain resources or materials
Garbage that is destroyed so it doesn't pollute nature.	Reuse of waste materials for making new raw materials
Taking old materials of the same kind that are no longer in use and converting them into the same or similar material that gets a new role and benefits.	I would define recycling as the reuse of natural resources that have already been used.
Recycling is using waste and giving it a new purpose instead of being thrown into the environment or incinerated.	Recycling is a process that involves collecting, separating, processing waste, and making new products
The process by which waste is processed, and we get a new product.	Process by which waste is reused as new products
Reusing used material and thereby reducing the production of new ones.	Renewal process of waste

Sorting, purifying, and processing waste from certain raw materials for the purposes of reuse.	Recycling is the process of renewing old plastic, paper, and other materials, and giving new purpose to that material so it can be reused.
Recycling is something very good for the environment, it will never develop in our country.	Recycling is the process of collecting and processing used materials, such as plastic, paper, and metal, to create new products, thereby reducing waste and conserving natural resources
Utilizing waste for energy recovery.	Old materials are recycled, and new materials are produced from them
Sorting waste.	Sorting and Reusing Recycled Waste
Recycling is a way to renew used materials so they can be useful again	Using Old Items and Materials to Create New Ones
Cleaning up litter from the ground	Recycling involves transforming waste materials into new, usable products
When certain materials are collected, sorted, and reused.	This process reduces the consumption of fresh raw materials, decreases energy usage, lowers greenhouse gas emissions, and minimizes environmental pollution.
Recycling is the reuse of old items.	Reusing old materials to create new ones that are then used again in a continuous cycle.

Table 3 *Students' opinions about the importance of separating organic waste from other types of waste.*

Do you know why it is important to separate organic waste from other waste	
Architectural Technical School	**Geological and Hydrometeorological School „Milutin Milanković"**
Decomposed organic waste pollutes the rest of the waste, i.e., it removes the possibility of recycling	It is essential because packaging waste can be recycled, while organic waste can undergo biological processes such as composting and anaerobic digestion. This way, all waste can be utilized, achieving a circular economy aligned with sustainable development principles.
Biowaste can be „upcycled," used for other purposes such as natural fertilizers or producing certain types of natural fuels.	It is essential because packaging waste can be recycled, while organic waste can undergo biological processes such as composting and anaerobic digestion. This way, all waste can be utilized, achieving a circular economy aligned with sustainable development principles.
Organic waste can be used as compost	Because of the development of microorganisms.
Composting, reducing landfill space.	Because organic waste degrades more easily.

Table 4 *List of benefits that students expect from the recycling process.*

List the benefits of recycling that students are aware of:	
Architectural Technical School	**Geological and Hydrometeorological School „Milutin Milanković"**
Less microplastics, less air pollution	Through recycling, old items gain a new purpose
This material can be used again to make something new. This way, we save material and protect the environment because we don't use resources (thereby avoiding pollution) to obtain the same ones. But there's always that 'but'—that recycled material will never have the physical properties of the original material, so we have to be careful about that, too, because we won't be able to use the same for everything.	Conservation of natural resources, reduction of pollution, raising ecological awareness, sustainable development
Environmental protection	Reuse of used waste
Through recycling, there is no need to produce more materials that pollute the environment, such as plastic.	Reduction of waste amounts, thereby reducing environmental pollution
Giving purpose and life to materials and waste. I don't know. Bottle caps for handicapped people can be made from bottles.	Conservation of natural resources for future generations
Reduced waste, reduced pollution, cleaner environment, obtaining new products, nature protection.	„Very cost-effective (in case of large amounts of waste)
The fact that already used material can be reused instead of being thrown into mass landfills reduces the production of new materials.	Reuse of used waste, conservation of resources, reduction of waste
Multiple uses of a mass of some raw material, reduction of gases emitted from factories that produce plastic and metal products, reduced cut wood consumption used for paper goods production.	Reuse, reduction of environmental pollution... reuse, reduced environmental pollution...
Reduction of pollution, source of energy...	Reuse of used waste"

Table 5 *Students' thoughts on how their behavior impacts environmental protection.*

In what ways does your behavior protect the environment?	
Architectural Technical School	**Geological and Hydrometeorological School „Milutin Milanković"**
I don't smoke, I don't drink from cans. I throw garbage in the bin	I dispose of waste where it should be
I protect the environment by not contributing to its additional pollution.	By trying not to pollute the environment additionally.
I use public transportation and recycling bins when possible, and I use a bicycle for shorter distances.	I try not to pollute more than what is already polluted
I walk, I don't throw trash outside the bin, I don't drive a car but use an electric bicycle.	Cost-effective and preserving natural resources for future generations.

By not littering the streets. Separating waste, saving energy.	I don't throw waste wherever I go.
I always dispose of waste where it's intended.	By disposing of waste in designated bins and controlling the use of plastic.
Ways to dispose of recyclable waste in designated places and not wherever is most straightforward.	Controlled use of stoves and reducing greenhouse gas emissions and pollutant particles.
Like any individual, my behavior towards the environment is insignificant when one considers the big picture and the arrogance of large corporations and wealthy capitalists, who have the most significant impact on our environment.	I try to dispose of waste properly (in bins).
I don't litter the streets or throw trash outside the bins.	By not throwing waste outside the containers.

However, the Architectural Technical School students provided many more practical suggestions to deepen their interest in ecology and improve their knowledge and awareness about environmental protection. Their list of tips is as follows:

- To organize garbage collection in the city where they attend school;
- To organize various workshops on this topic; to have multiple art competitions through which children will realize the importance of environmental conservation;
- To create an application where they will receive digital money to donate to charity every time something is recycled; To organize competitions to see which team can collect more trash.
- Cleaning the schoolyard; extracurricular activity and lecture; cleaning the school, introduction of recycling bins; collecting cigarette filters from the schoolyard, separating waste in classrooms;
- Designated bins for disposing of paper, metal, and plastic bottles. A place for recycling old works; presentation on recycling, and practical work, i.e., going to the field and cleaning polluted Belgrade;
- Some actions for cleaning waste and the introduction of adequate spaces for disposing of garbage and waste;
- Laws and penalties should be introduced for people who throw waste wherever they want.

The students from the Geological and Hydrometeorological School did not have many suggestions for improving the above:

- Collecting trash, education, and practice; to introduce special containers for separating waste and education for students;
- Persistent lectures on pollution until people learn; pictorial representation of pollution in the world and how certain countries prevent it;

- Recycling projects and workshops, ecological excursions, and more fieldwork.

Conclusion

Students who take courses related to environmental protection have a greater individual awareness of it. However, the research results show that this awareness is still not widespread. Even in that school, there is a need for much more work on extracurricular activities, practical courses, and raising awareness about this critical topic. Furthermore, it is concluded that students from the Architectural Technical School, who do not take ecology-related courses, are interested in learning and have provided many suggestions that should be considered. Further research will focus on discussions with teachers about creating extracurricular activities to raise students' environmental protection awareness.

References

Andevski M. Ekološko vaspitanje – Ekološko obrazovanje – Pedagogija partnerstva sa prirodom. Zbornik katedre za pedagogiju, Filozofki fakultet, 2001, Novi Sad.

Dukić D, Mandić, L. Đurović V, Semenov A, Vesković S, Stojanov, M, Mladenović J. Zagađenje životne sredine i zdravlje čoveka, XXVI savetovanje o biotehnologiji, 2011.

Voogt J, Westbroek H, Handelzalts A, Walraven A, McKenney S, Pieters J. Teacher learning in collaborative curriculum design Teaching and Teacher Education, 2011.

Mrmak I. Uticaj škole na razvoj životne sredine. Prosvetni pregled 40; 1979, Beograd.

Stanić S, Buzov I, Recikliranje i zbrinjavanje otpada – stavovi i aktivnosti studenata, Titius, God. 2, 2009; 275-296.

RADON LEVEL IN NATURAL SPRINGS NEAR CHURCHES IN THE WIDER AREA IN THE CITY OF KRALJEVO

Biljana Vučković[1]*, Ivana Penjišević[1], Nataša Todorović[2], Jovana Nikolov[2], Ljiljana Gulan[1]

[1]Faculty of Sciences and Mathematics, University of Priština in Kosovska Mitrovica, Lole Ribara 29, 38220 Kosovska Mitrovica, Serbia
[2]Univesity of Novi Sad, Faculty of Science, Department of Physics, Trg Dositeja Obradovića 3, 21000 Novi Sad, Serbia

biljana.vuckovic@pr.ac.rs

Abstract: The paper presents the results of measuring the radon concentration in water sampled from a tap near churches or in the courtyard of selected churches in the broader area of Kraljevo. Medicinal properties are attributed to the waters from these localities, so people often consume them in smaller or larger quantities. The radon concentration in water was measured using the alpha spectrometric method and the RAD7 measuring system. In further work, annual exposure doses were calculated for different age categories: adults, children, and infants. The research aimed to define the extent to which the population is exposed to radiation based on the annual dose of ingestion.

Keywords: radon, natural springs, annual effective doses of ingestion

INTRODUCTION

The knowledge that certain places or spaces have the power to influence people made them especially respected, visited, maintained, etc. These places are expected to „help" when people need it. Such places are called „holy places" and affect a person's life differently. In the territory of Serbia there are countless such places, among which the underground water sources near churches or in the courtyard are particularly noteworthy. They are called holy or church water; they are attributed to healing powers and are considered beneficial. What makes them attractive for study is the wide distribution and deep belief in the power of holy waters in the modern age in the research area (Romelić & Simić, 2015). People use these holy waters in different ways - they drink, wash themselves, and take them home to help their sick family members. Before reaching the surface, the water passes through various lithographic structures rich in radionuclides, which they dissolve and take with them on their way (Rangaswamy et al, 2016).

It is generally known that radon is one of the significant sources of natural radiation among the products of the uranium decay series. Radon is an inert radioactive gas, which occurs naturally in groundwater as a direct descendant of ^{226}Ra, after the decay of uranium ^{238}U from minerals and rocks. The high level of radon in groundwater is therefore primarily the result of the presence of radium in rocks, but also of numerous other factors: soil porosity, degree of metamorphism and uranium mineralization in rocks (Chobey et al, 2001; Wiegand, 2001; Hajo et al, 2011). The recommended value of radon in groundwater is 100 Bq/l (WHO, 2008; EURATOM, 2013), but when underground spring waters are also used for drinking, the valid reference value is 11.1 Bq/l (USEPA, 1999). In most cases, spring water does not have an exceptionally high level of radon, but the presence of radon in it cannot be ignored. Radon contributes to about half of the total radiation dose exposed to the population. Numerous studies have shown that long-term exposure to radon in water can cause cancer of the gastrointestinal tract, primarily of the stomach, but also of the kidneys (Alomari et al., 2019; Nagabhushana et al., 2019; Gerber et al., 2024). This is one of the very important reasons why natural springs must be regularly controlled, radon concentration measured, and timely reacted if the radon level is exceptionally high. The reference value of exposure to radon from water annually is 0.1 mSv (WHO, 2008).

Study area

In this study, field research was based on examining the presence of radon in holy waters near 10 well-known churches and monasteries in the broader area of Kraljevo (fig1). The territory of the city of Kraljevo is elongated in a north-south direction, stretching between 43°23'25"N and 43°53'29"N and 20°20'17"E and 20°57'50"E and administratively it consists of 92 settlements. With a total area of 1529 km^2, Kraljevo is, after the City of Belgrade, the most spacious in Serbia (Penjišević, 2022). According to the results of the 2022 Census, 110.196 inhabitants live in this area, with an average population density of 72 inhabitants per km^2. The administrative, economic, and educational-cultural center is the urban settlement of Kraljevo, where, according to the 2022 Census, 57.432 inhabitants live (SORS, 2023).

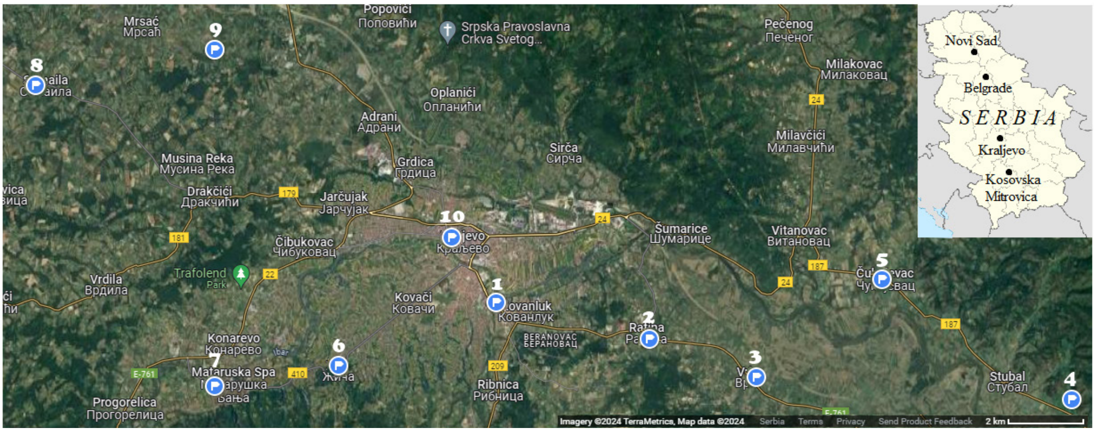


Figure 1 *Map of selected localities in the broader area in the city of Kraljevo*

As the regional center of Western Pomoravlje and the administrative center of the Raška district, Kraljevo is developing in an altitude range from 192 to 210 m, at the contact of the alluvial plains of the Ibar and Western Morava, with the southern slopes of Kotlenik. The terrain is rich in springs of thermal and mineral waters, which, according to residents, have healing effects. The geological structure of the terrain shows that this area is dominated by a scarp, gravel with sand lenses, sandy clay and alluvium, diluvium, and colluvium plains. The terrain is dominated by river terraces with limnic sediments (https://geoliss.mre.gov.rs/prez/OGK/RasterSrbija/).

MATERIAL AND METHODS

The research included eight churches and two monasteries. that are intensively visited by the population were processed. As these waters from natural sources are treated by the people as waters with magical, healing powers, the population approaches the sources with great respect. Following the favorable meteorological parameters, the field work consisted of the following: (1) the water temperature was measured with a digital thermometer (Testo Se & KGaA, Germany), (2) the water was sampled in original glass vials with a volume of 250 ml up to the very top, in order to prevent radon build-up immediately below the cover and (3) the ambient radiation dose equivalent was measured with a digital Geiger counter (RADEX RD1503+, PCE Instruments UK Ltd). As the concentration could not be measured during the sampling itself, it was necessary to deliver the samples as soon as possible to the laboratory, where the concentration of radon in water samples was measured by the RAD7 RAD H2O system

(Durrige Co.) and defining its corrected value - $C_{corr}=C_o e^{\lambda t}$ (Todorović et al, 2012a), which represents the concentration of radon in water if it were measured at the sampling site. A detailed description of sampling and measurement of radon concentration is presented in the paper (Vučković et al, 2024).

The population mostly consumes water from these sources, but also washes with it. They bring it home very often as a medicine, hoping that it will help sick members of the household. Due to the long-term use of these waters, research is further focused on determining the annual received effective dose (ACED) by ingestion of radon for certain ICRP age groups (IAEA, 1996; Koloa et al, 2023):

$$ACED = C_{Rn} \cdot W_{CR} \cdot DCF \quad (1)$$

where: C_{Rn} is the corrected value of radon concentration in water (Bq/l), W_{CR} is water consumption on an annual level (l/y) and DCF is the dose conversion factor (Sv/Bq). For different ICRP age groups, the parameters that define AĆED are as follows: infants (1-2 years) have an average daily intake of 0.71 l, while the annual level is 260 l; children (7-12 years) consume an average of 0.96 l per day, while the annual level is 350 l, and adults (>17 years) consume an average of 2 l per day, while the annual level is 730 l. The DCF value is 2 x 10^{-8} Sv/Bq, while for adults it is 1 x 10^{-8} Sv/Bq (IAEA, 1996).

RESULTS AND DISCUSSION

Table 1 shows the results of research at ten selected locations in the wider area of Kraljevo. The first part of the table shows temperature, ambient dose equivalent, and radon concentration in the samples, while the second part of the table shows the calculated value of the annual received radon ingestion dose - ACED for different ICRP age groups. Temperature and ambient dose equivalent were measured on site, and these values are shown in the table. The minimum, maximum, and mean values of all parameters are also presented.

The mean temperature value of 16˚C indicates that the spring waters sampled from these localities belong to the cold water group. The mean ambient radiation dose equivalent value is 88 nSv/h, which is in the range of natural background radiation.

Table 1 *Summarized results of research at selected sites.*

	Measured sites	T (°C)	D (nSv/h)	C_{corr} (Bq/l)	ACED(μSv/y)		
					infants	children	adults
1	Church of St. Vasilij Ostroski	15	90	1±0.5	5±2	7±3	7±3
2	Church of St. John	16	80	2±0.5	10±2	14±3	14±3
3	Church of St. Nicholas	14	110	16±4	83±21	115±29	117±29
4	Monastery St. Petka	15	80	4±2	21±10	29±14	29±14
5	Church of Holy Mother of God	14	80	5±2	27±10	36±14	36±14
6	Monastery Žiča	18	90	12±3	62±15	86±22	88±22
7	Church of St. Lazarus	17	70	3±1	15±5	22±7	22±7
8	Church of St. Panteleimon	16	110	13±5	68±27	94±36	95±36
9	Church of St. Peter and Paul	14	80	4±1	21±5	29 ±7	29±7
10	Church of Holy Trinity	18	90	7±3	36±15	50±22	51±22
Max		18	110	16±4	83±21	115±29	117±29
Average value		16	88	7±2	35±11	48±16	49±16
Min		14	70	1±0.5	5±2	7±3	7±3

When looking at the radon concentrations measured in water, it can be said that radon is present in them in traces. The value interval ranges from 16±4 Bq/l (site 3) to 1±0.5 Bq/l (site 1), with a mean value of 7±2 Bq/l. These results could be expected if one looks at the geomorphological structure of the terrain, where river terraces, sandy clay and gravel predominate. These radon concentrations are far below the recommended WHO value - 100 Bq/l, but relatively close to the recommended USEPA value - 11.1 Bq/l. At three locations, the radon concentration was in the range of USEPA values: measurement sites 3, 6 and 8, which is 30% of the tested samples. At the other measuring points, the radon concentration is very low, which means that the water from these sources is radiologically safe for use. The results of this research can be compared with data from the literature that also studies the presence of radon in spring waters (Qadir et al, 2021; Vučković et al, 2022; Koloa et al, 2023).

The mutual relations of the measured parameters are expressed through the Pearson correlation coefficient (R^2). The relation between the temperature of water samples and the concentration of radon in water is weakly expressed, only 0.007, but that is why there is a strong mutual conditioning of the ambient radiation dose equivalent and radon concentration - 0.67.

Exposure to radon present in water that is used and consumed very often can cause internal irradiation of the body. The parameter that defines this is the annual dose of radon ingestion - ACED, whose values for different ICRP age groups are determined by equation (1). The results show that the mean values of annual exposure doses are very close: 35±11 μSv/y - for infants, 48±16 μSv/y - for children and 49±16 μSv/y - for adults, which is below the recommended WHO value for the year received doses of 0.1 mSv/y. A very small deviation was recorded at measuring point 3 - 115±29 μSv/y (children) and 117±29 μSv/y (adults), which has only statistical significance. So, according to these values, it can be confirmed that the water from these natural sources can be freely used.

CONCLUSION

This study investigated the presence of radon in spring waters - holy waters - in the wider area of the city of Kraljevo. According to the measured temperature, these waters can be classified as cold waters, and the mean value of the ambient dose equivalent of 88 nSv/h is within the range of the natural background radiation value. The mean value of radon concentration in water sampled from ten localities is 7±2 Bq/l, which is far below the WHO and EURATOM recommended value of 100 Bq/l, but is close to the USEPA recommended value for drinking water of 11.1 Bq/l. The annual radiation dose received by ingestion of radon - ACED was determined for different age groups, with mean values of: 35±11 μSv/y - for infants, 48±16 μSv/y - for children and 49±16 μSv/y - for adults, which is below the recommended WHO value of the annual received dose of 0.1 mSv/y. These data indicate that, from a radiological point of view, the water from these sources is suitable for use.

ACKNOWLEDGMENTS

This study was supported by project No: 451-03-65/2024-03/ 200123.

REFERENCES

Alomari AH, Saleh MA, Hashim S, Alsayaheen A, Abdeldin I. Activity concentrations of ^{226}Ra, ^{228}Ra, ^{222}Rn and their health impact in the groundwater of Jordan. J Radioanal Nucl Chem 2019;322;305–318.

Choubey VM, Bartarya SK, Saini NK, Ramola RC. Radon measurements in groundwater of inter-montane Doonvalley, Outer Himalaya: effects of geohydrology and neotectonic activity. Environ Geol 2009; 40(3);257–266

EURATOM. Council Directive 2013/51/Euratom of 22 October 2013 laying down requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption. *Official Journal of the European Union*, L 296/12; 2019

Gerber AL, Martling S, Voorhees JM, Marchant H, Barnes, ME. Radon levels in three fish rearing buildings at Cleghorn Springs State Fish Hatchery, Rapid City, South Dakota, USA. JERA 2024; 5.

Hajo, I., Isam, S., Sam, A. K., Idriss, H., Salih, I. and Sam, A.K. (2011). "Study of radon in ground water and physicochemical parameters in Khartoum state." *J. Radioanal. Nucl. Chem.* 290: 333–338.

IAEA. International basic safety standards for protection against ionizing radiation and for the safety of radiation sources, Vienna Safety Series 1996; 115.

Koloa MT, Olarinoyea O, Salihub SO, Ugwuanyia HA, Onuchea P, Faladea O, Chibuezea N. Annual Effective Dose and Excess Lifetime Cancer Risk due to Ingestion and Inhalation of Radon in Groundwater of Bosso Community Minna, North-Central Nigeria. J Nig Soc Phys Sci 2023; 5(2); 896.

Nagabhushana SR, Srinivasa E, Suresh S, Sannappa J. Study on Radon Concentration in ground water and Physicochemical parameters of Tumkur industrial areas, Karnataka State, India.*IJSRPAS* 21019;7(2); 44-54.

Penjišević I. Western Pomoravlje - regional development. Historical archive of Kraljevo, Kraljevo 2021 (in Serbian).

Qadir RW, Assad N, Qadir KW, Ahmad ST, Abdullah H. Relationship between radon concentration and physicochemical parameters in groundwater of Erbil city, Iraq. JRRAS 2021;14(1);61-69.

Rangaswamy DR, Srinivasa E, Srilatha MC, Sannappa J. Measurement of radon concentration in drinking water of Shimoga district, Karnataka, India. J Radioanal Nucl Chem 2016;307;907–916.

Romelić, Ž, Simić Z. Holy waters and other cult places in the Kruševac region. Kruševac National Museum, Kruševac; 2015 (in Serbian).

SORS Population Census. Statistical Office of Republic of Serbia. Belgrade; 2023 (in Serbian).

Todorović N, Nikolov J, Forkapić S, Bikit I, Mrdja, D, Krmar M, Vesković M. Public exposure to radon in drinking water in Serbia. Appl Radiat Isot 2012;70(3);543-549.

USEPA. Radon in drinking water health risk reduction and cost analysis, Federal Register, Washington 2019;64;9559–9599.

Vučković, B., Mrazovac Kurilić, S., Nikolić-Bujanović, Lj., Todorović, N., Nikolov, J., Živković Radovanović, J., Milošević, R. and Jokić, A. (2022). "Radon in drinking water from alternative sources of water supply in the north Kosovo." *Radiation Protection Dosimetry*, 1–8.

Vučković, B., Penjišević, I., Todorović, N., Nikolov, J., Radovanović, D. and Valjarević, A. (2024). "Radon in water from private wells and its contribution to internal exposure of population in rural areas at Toplica region, southern Serbia." *Bull. Nat. Sci. Res* 14(1).

WHO (2008). Guidelines for Drinking-water: incorporating 1st and 2nd addenda, Vol. 1, Recommendations. World Health Organization, 2008.

Wiegand, J. (2001). "A guideline for evaluating the soil radon potential based on geogenic and anthropogenic parameters." *Environ. Geol*, 40: 949–963.

EFFICIENT GREEN ELECTRODE MODIFIERS BASED ON NANOCERIA COMPOSITE MATERIALS

Branka B. Petković[1*], Milena Marković[1*], Miloš Ognjanović[2]

[1]University of Priština in Kosovska Mitrovica, Faculty of Sciences and Mathematics, Lole Ribara 29, 38220 Kosovska Mitrovica, Serbia

[2] VINČA Institute of Nuclear Sciences, National Institute of the Republic of Serbia, University of Belgrade, Belgrade, Serbia

milenatasic4@gmail.com

branka.petkovic@pr.ac.rs

Abstract: Nanoceria (cerium oxide nanoparticles - CeO_2 NPs) and its based materials attracted significant research interest due to their various biomedical and industrial applications, based on their antioxidant and microbiological properties, green catalysis, enzyme-like or sensor activity. CeO_2 NPs could be synthesized in different routes, and in this work, they are derived by thermolysis of cerium 1,3,5-benzene-tricarboxylic (CeBTC) metal-organic framework (MOF). This MOF-derived nanoceria, pristine and in composite with AuNPs, graphitic carbon nitride (g-C_3N_4), or graphene nanoribbons (GNR) was applied by drop-casting method on the surface of the screen-printed electrode (SPE). XRPD patterns and FTIR spectra of CeBTC and its derived CeO_2 NPs corresponded to reference data. Electrochemical studies of modified SPEs were done by electrochemical impedance spectroscopy (EIS) and cyclic voltammetry (CV), both of them in $[Fe(CN)_6]^{3-/4-}$ redox system. Obtained cerium oxide nanoparticles were small in size (about 7 nm). CV and EIS study reveals that AuNPs/nanoceria modified SPE has shown the highest electrochemical response, with 10 mg/mL of CeO_2 NPs in the electrode modifier. Concerning nanoceria-modified SPE with different amounts of g-C_3N_4, the best results were achieved at the electrode with CeO_2 NPs/g-C_3N_4 ratio of 3:1. Those two combinations of electrode modifiers were chosen for further construction of reproductive electrochemical sensors sensitive to selected biocompounds.

Keywords: metal-organic frameworks, cerium oxide nanoparticles, gold nanoparticles electrochemical sensors, electrode modifiers

INTRODUCTION

Nanoceria or cerium oxide nanoparticles attracted significant attention among the metal oxide-based nanoparticles. They can be used as an electrochemical sensor thanks to their high mechanical strength, oxygen ion conductivity, oxygen storage capacity, high chemical stability, and non-toxicity. Their structure exhibits strong oxygen storage capacity due to their crystal structure's high number of oxygen vacancy defects. Nanoceria can also act as oxidizing and reducing agents due to the oxidation state of cerium oxide nanoparticles that can vary between +3 and +4. Nanoceria is widely used in biosensing, acting as catalysts to mimic the activity of enzymes in biosensors. Furthermore, combining nanoceria with different nanomaterials was realized to improve sensor performance. Vast nanomaterials were employed in electrochemical sensing with various electrodes and analytes. Biocompatibility of nanoceria helps immobilize biomolecules with low iso-electric points through electrostatic interactions. Nanoceria also enhances sensitivity derived from various signal-strengthening strategies (Hartati et al., 2021a).

Unique characteristics of ceria and nanoceria, e.g., catalytic activity, enzyme mimetic properties, ability to transfer oxygen, switchable redox reactivity, surface coating, and surface reactivity, allow their use in electrochemical sensors. Their high isoelectric point, adsorption capacity, mechanical strength, non-toxicity, and good biocompatibility enable them to adapt to the requirements of sensors employed with biological matrices (Hartati et al., 2021b). These nanoparticles can carry different functions in sensors, e.g., transduction element, amplifier to enhance chemical and electrochemical signals, catalyst and enzyme that can replace biological enzymes, and label in bio-affinity assays (Mayor et al., 2019; Huang, Zhu, 2019). The electrochemical behavior of ceria and nanoceria depends on their morphologies, affected by the growth rates of ceria nanocrystalline relies on solvent composition. Furthermore, shifting between oxidation states of Ce^{3+} and Ce^{4+} enhances the electrochemical properties of nanoceria.

EXPERIMENTAL

Electrode modifiers

Commercially available gold nanoparticles 10 nm diameter, OD 1, stabilized suspension in citrate buffer (Sigma-Aldrich) and graphene nanoribbons, GNR length 2-15 µm, width 40-250 nm (Merck, Germany), were used for SPE modification. MOF-derived CeO_2 NPs and graphitic carbon nitride were also applied as electrode modifiers.

Synthesis of CeBTC and obtaining of MOF-derived CeO_2 NPs

CeBTC was synthesized as it was written before (He et al., 2020). Two solutions were mixed: first, consisting of 0.25 mmol of $CeCl_3 \times 7H_2O$ with ultrapure water until a 50 mL solution, and the second solution which was obtained when 0.25 mmol of benzene-1,3,5-tricarboxylic acid was dissolved in 50 mL of ethanol/water solution (v/v = 1:1) under vigorous stirring at room temperature. CeBTC was obtained as a white precipitate, centrifugated, washed, and dried at 60 °C. CeO_2 NPs were obtained by thermolysis of cerium 1,3,5-benzene-tricarboxylic (CeBTC) metal-organic framework (MOF) in the air at a temperature of 450 °C at 10 °C/min and held at the final temperature for 3 h (He et al., 2020).

Preparation of graphitic carbon nitride

g-C_3N_4 was prepared by heating 5 g of urea in a closed ceramic crucible in a muffle furnace at 550 °C at a 3 °C/min ramp rate for 3 h under ambient pressure in air. This yellow-colored product was used for electrode modification after grounding in agate mortar.

XRPD analysis

The crystal structures of the synthesized MOF and its corresponding oxide were determined through X-ray powder diffraction (XRPD) analysis. Dried powder samples were examined using a high-resolution Smart Lab® diffractometer (Rigaku, Japan) equipped with a CuKα radiation source (λ = 1.5406 Å) operating at 40 kV and 30 mA. Diffraction patterns were collected within the 2θ range of 5-70°.

ATR-FTIR spectroscopy measurements

ATR-FTIR spectroscopy was used to examine the surface chemistry of the prepared MOF and MOF-derived nanoparticles within the mid-infrared region (4000-400 cm^{-1}). A Nicolet iS50 FT-IR spectrometer (Thermo Fisher Scientific, USA) equipped with a Smart iTR ATR accessory was employed for the analysis. Powdered samples were pressed onto a diamond crystal plate using a swivel press to ensure optimal contact with the infrared beam. Background spectra collected from a clean diamond crystal were subtracted using OMNIC™ Specta Software.

Electrochemical measurements

Cyclic voltammetric (CV) and *electrochemical* impedance spectroscopy (EIS) measurements were performed in the presence of a stationary 5 mM $K_3[Fe(CN)]_6/K_4[Fe(CN)]_6$ (1:1) mixture as a redox probe in 0.1 M KCl solution. An electrochemical system Autolab 302 N with corresponding software NOVA 2.0.2 was used for measurements. The electrochemical working cell consisted of a three-electrode system: an Ag/AgCl (saturated KCl) was the reference electrode, a Pt-wire used as a counter electrode and screen-printed electrode (Drop Sens screen-printed electrodes, model DRP 110) was the working electrode, modified with different materials (AuNPs, g-C_3N_4, and graphene nanoribbons (GNR)). Suspension for electrode modification (5 or 10 mg of modifier in 1 mL of N, N-dimethylformamide) was ultra-sonicated for 30 min, and 2 μL of each suspension was added to the electrode surface and let to dry overnight before use. EIS measurements were performed with the frequency changed from $1 \cdot 10^5$ Hz to $1 \cdot 10^2$ Hz with a signal amplitude of 5 mV at the potential of 0.05 V.

RESULTS AND DISCUSSION

The crystal structures of the samples were determined by X-ray powder diffraction (XRPD). Diffraction patterns confirmed the formation of the desired metal-organic framework, Ce-MOF, based on cerium linked to BTC. Following calcination, the resulting metal oxides were also characterized by XRPD. Fig. 1b shows the formation of pure cubic CeO_2 (indexed in Fm-3m, No. 225 crystal phase) with an average crystallite size of approximately 7 nm after the calcination of Ce-MOF. The average crystallite size was estimated using Scherrer's equation on the most intensive diffraction peaks ($B(2\theta) = K\lambda/L \cdot \cos\theta$) where the peak width, $B(2\theta)$, at a particular value of 2θ (θ being the diffraction angle, λ the X-ray wavelength) is inversely proportional to the crystallite size L; the constant K is a function of the crystallite shape but is generally taken as being about 1.0 for spherical particles.

The FTIR spectrum of the Ce-MOF nanocomposite (*black line*, Fig. 1c) exhibits most of the characteristic bands associated with the COO^- groups f the . These include an asymmetric stretching vibration at = 1608 cm^{-1} and symmetric stretching vibrations at = 1432 cm^{-1} and = 1365 cm^{-1}. Additionally, low-intensity bands attributed to Ce-O stretching vibrations are observed in the region of = 400-500 cm^{-1}. The FTIR spectrum of CeO_2 showed its characteristic peaks at

= 1534 cm^{-1} and = 1319 cm^{-1} (*red line*). The vibrations at = 1634 cm^{-1} and = 3400 cm^{-1} were observed due to the adsorbed water on the surface.

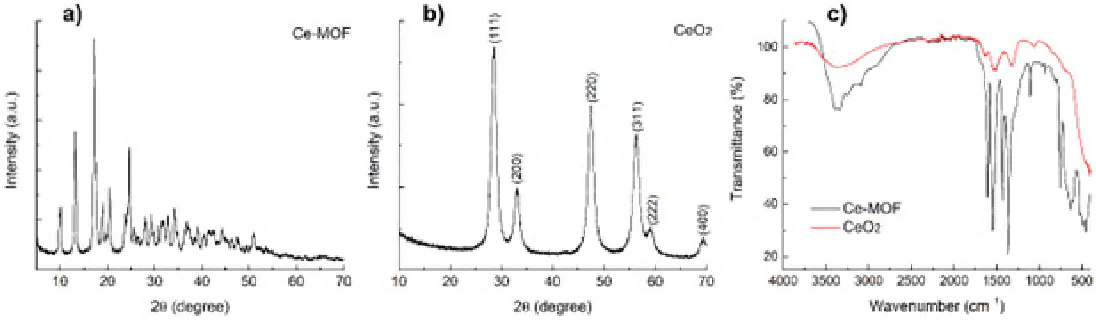


Figure 1 *XRPD diffraction patterns of a) Ce-MOF and (b) MOF-derived cerium oxide after the calcination; c) ATR-FTIR spectra of Ce-MOF and* CeO_2

The effect on the enhancement of the electrochemical response by using different electrode modifiers at SPE was examined by cyclic voltammetric (CV) measurements in $Fe(CN)_6]^{3-/4-}$ redox system (Fig. 2a and b). As can be seen from Fig. 2a, nanoceria in combination with graphene nanoribbons did not prove to be a good solution due to the lowest electrochemical response, even in relation to electrode modification with nanoceria alone. The highest peak current was recorded at SPE modified with AuNPs/CeO_2, while CeO_2/g-C_3N_4 composite, also showed significant improvement of electrochemical response, compared to nanoceria alone and unmodified SPE when the suspension of 10 mg/mL was used for electrode modification (Fig. 2b).

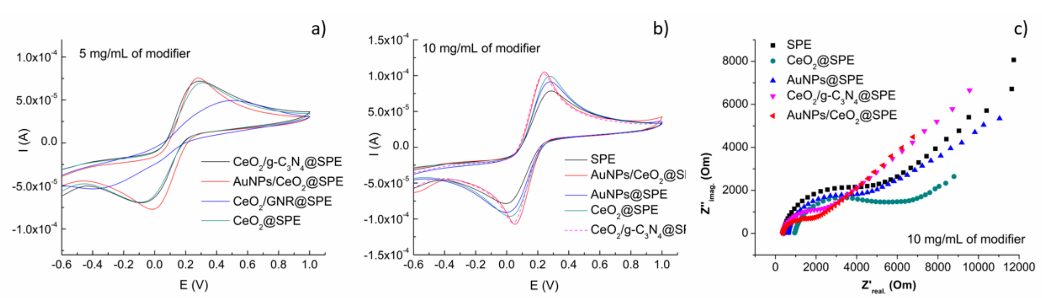


Figure 2 *CV profiles of SPEs modified with a) 5 mg/mL of nanoceria alone or in combination with AuNPs, g-*C_3N_4*, and GNR, and b) 10 mg/mL of the same combination of the materials compared to CV of bare SPE. c) EIS responses of bare SPE and SPE modified with nanoceria and AuNPs alone or nanoceria in binary composite with AuNPs, g-*C_3N_4*, and GNR.*

In Figure 2c, electrochemical impedance spectroscopy responses were recorded in the same solution of $[Fe(CN)_6]^{3-/4-}$ and the typical Nyquist plot was obtained. The diameter of the obtained semicircle corresponds to charge transfer resistance and the smaller semicircle refers to promoted electron transfer at the electrode surface. Based on the results recorded, it is obvious that CeO_2/g-C_3N_4- and, especially AuNPs/CeO_2-modified SPE was the most conductive electrode due to the most promoted electron transfer at the electrode surface.

Fig. 3a shows the CVs recorded at bare SPE and SPEs modified with different quantities of AuNPs/CeO_2 electrode modifier. An increase in peak current is evident with an increase in modifier amount in suspension. The highest electrochemical response was achieved when 10 mg/mL of AuNPs/CeO_2 was used for electrode modification. Fig. 3b shows the CVs recorded nanoceria modified SPE loaded with different amounts of graphene carbon nitride. g-C_3N_4 were used for electrode modification (Fig. 3b), and the best results were achieved at electrode modified with 3 : 1 (CeO_2 NPs : g-C_3N_4) ratio in composite modifier, when 10 mg/mL of modifier is present in modifier suspension.

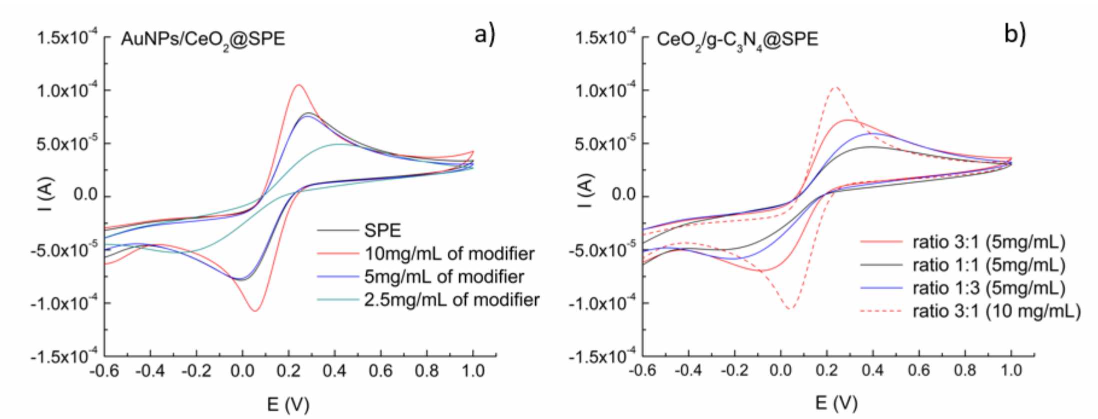


Figure 3 *CV profiles of: a) nanoceria/AuNPs-modified SPEs with different amounts of the modifiers in suspension. b) nanoceria/C_3N_4-modified SPE with different ratios of materials in modifiers*

CONCLUSION

Using nanoparticles in modifying electrodes is a strategy to increase sensitivity, enhance stability, and improve the performance of electrochemical methods. In most cases, the presence of nanoceria increases the surface area because more nanoparticles could attach to the surface and enhance the direct electron transfer rate. This study reveals that AuNPs/CeO_2 nanocomposite and CeO_2NPs/g-C_3N_4 showed promising electrochemical activity when they were applied to modify SPE. Based on obtained results, our further research will focus on the development of electrochemical sensors with these electrode modifiers, employed for the detection of selected biomolecules.

Acknowledgment: Financial support for this study was granted by the Ministry of Education, Science and Technological Development of the Republic of Serbia Grant No. 451-03-65/2024-03/ 200123 and the Faculty of Sciences and Mathematics, University of Priština in Kosovska Mitrovica, Project Number IJ-2301.

REFERENCES

Hartati W, Topkaya NS, Gaffar S, Bahtia HH, Cetin EA. Synthesis and characterization of nanoceria for electrochemical sensing applications. R Soc 2021a;11; 16216-16235.

Hartati YW, Komala DR, Hendrati D, Gaffar S, Hardianto A, Sofiatin Y, Bahti HH. An aptasensor using ceriaelectrodeposited-screen-printed carbon electrodefor detection of epithelial sodium channel proteinas a hypertension biomarker. R Soc 2021b;8;202040.

Mayor I, Gutiérrez AO, García CA, Muñiz EA. Nanoparticles as Emerging Labels in Electrochemical Immunosensors. *Sensors* 2019;*19;* 5137.

Huang, H, Zhu, JJ. The Electrochemical Applications of Rare Earth-Based Nanomaterials. Anlst 2019;23;6789-6811.

He J, Xu Y, Wang W, Hu B, Wang Z, Yang X, Wang Y. Ce(III) nanocomposites by partial thermal decomposition of Ce-MOF for effective phosphate adsorption in a wide pH range. Chem Eng J 2020;379;122431.

QUALITY OF SURFACE WATER FOR BATHING AND RECREATION IN PANČEVO, SERBIA

Đorđel Žuža[1]*, Vladanka Presburger Ulniković[2], Novica Staletović[2], Violeta Nikolić[2]

[1]Zavod za javno zdravlje Pančevo, Pasterova br. 2, Pančevo
[2] Faculty of Ecology and Environmental Protection, University „Union-Nikola Tesla" Cara Dušana 62-64, Belgrade, Serbia

zdjordjel@gmail.com

Abstract: Surface water for bathing and recreation in Pančevo was assessed using the Water Quality Index. The study also aimed to evaluate the bathing water quality in Pančevo according to Serbian standards. The assessment occurred during the bathing season, with field and laboratory measurements establishing local conditions. Laboratory results determined the ecological status of rivers or swimming spots, indicating their suitability for bathing. The findings show that water quality in Pančevo's rivers and lakes varies, emphasizing the need for better environmental preservation to maintain water quality and protect human health.

Keywords: environment, surface waters, microbiological and physical-chemical parameters, ecological status, health safety

INTRODUCTION

Water quality for bathing and recreation is paramount for public health, environmental protection, and local economic development. In the municipality of Pančevo, this issue holds particular significance due to the region's diverse water bodies that attract numerous visitors and support various recreational activities. Ensuring the safety and cleanliness of these waters aligns with national and international legal frameworks designed to protect water quality and public health.

The Republic of Serbia, of which Pančevo is a part, adheres to several legislative acts and guidelines to maintain high water quality standards. These include the Law on Water (RoS 2018), which outlines comprehensive water management, protection, and usage measures. Additionally, the Regulation on Water

Classification (SRS 1968) classifies water bodies based on their intended use and establishes quality parameters to ensure suitability for bathing and recreation.

At the international level, Serbia's commitment to the European Union's Bathing Water Directive 2006/7/EC is noteworthy (European Commission, 2006). This directive sets stringent standards for monitoring and assessing the quality of bathing waters, aiming to protect the health of bathers and enhance the quality of such waters. Compliance with these regulations is critical for Pančevo to provide safe and enjoyable recreational water environments.

Scientific literature emphasizes the importance of maintaining high water quality for recreational purposes. Studies have shown that poor water quality can lead to various health issues, including gastrointestinal illnesses, skin infections, and respiratory problems, particularly in vulnerable populations such as children and the elderly (Prüss, 1998). Regular monitoring and assessment of water quality are crucial in identifying and mitigating potential health risks associated with recreational water use (Bartram & Rees, 2000).

Furthermore, effective water quality management practices, such as the implementation of advanced wastewater treatment technologies and the establishment of buffer zones to prevent agricultural runoff, have been demonstrated to significantly improve the quality of bathing waters (WHO, 2003). These practices are essential for the sustainable use of water resources and the protection of public health.

This work examines the quality of water designated for bathing and recreation within the municipality of Pančevo. It evaluates the current status of these waters, identifies potential sources of contamination, and reviews the effectiveness of existing measures to ensure compliance with relevant legal standards. The findings are supported by data collected through regular monitoring and assessments, as required by the aforementioned legislative frameworks.

Aquatic ecosystems are the most threatened by human activity, and underground and surface waters are receivers of various types of pollution (municipal and industrial wastewater, diffuse sources of pollution, deposition of pollutants). The consequences of different types of pollution are growing pressures on water resources that have contributed to the degradation and disappearance of aquatic habitats and the reduction of biological diversity, as well as the deterioration of water quality and quantity. Adverse health outcomes associated with hazards encountered in recreational aquatic environments may include: infection through ingestion, inhalation or contact with pathogenic bacteria, viruses, fungi and protozoa, which may be present in the water and its environment as a result of faecal contamination carried by participants or animals. Poisonings, toxicoses and other conditions that can occur due to long-term exposure to chemicals. Contact with, inhalation or ingestion of chemically contaminated water, ingestion of algal toxins, and inhalation of chemically contaminated air (WHO, 2006).

The ecological status and quality of water bodies, including those used for bathing and recreation, are assessed using various parameters. These parameters help determine the health of aquatic ecosystems and the safety of water for human use. The assessment typically includes physical, chemical, biological, and microbiological indicators. Only such a comprehensive analysis gives a complete picture of the state of the environment or the analyzed parts (Ostojić & Ćurčić, 2005). The Water Quality Index (WQI) is a composite measure that summarizes water quality data into a single number (Boyacioglu, 2007; Veljković, 2006).

MATERIAL AND METHOD

The study determined the ecological status of surface waters for bathing and recreation in the municipality of Pančevo based on the measured microbiological and physical-chemical indicators of the quality of surface waters for bathing and recreation in the municipality of Pančevo. The quality of surface waters for bathing and recreation in the municipality of Pančevo was determined according to the Serbian water quality index (SEPA, 2024). Sampling was carried out on September 8, 2023 at 9 measuring points. Field and laboratory measurements were carried out and local findings of the bathing area were determined. Monitoring the state of bathing water, which is part of the water body of surface waters, where a large number of bathers are expected, and which is not under a permanent bathing ban due to sanitary inspection, includes its sampling, laboratory testing. tests (physical-chemical, microbiological and biological), as well as an assessment of its hygienic correctness and health safety during the bathing season. A season is a calendar period of the year when a large number of bathers can be expected, in accordance with local weather conditions and local customs. Defined scope of microbiological analyses: fecal coliform bacteria, total coliform bacteria, intestinal enterococci and the number of aerobic heterotrophs (determining the number of cultivated microorganisms). The scope of physical and chemical analysis is defined: water temperature, pH, suspended matter, dissolved oxygen, oxygen saturation, BOD5, HPK (bichromate method), HPK (permanganate method), nitrates, nitrites, ammonium ion, total nitrogen, orthophosphates, total phosphorus. sulfates, chlorides, determination of total residue after evaporation at 105ºC (total mineralization), electrical conductivity at 20ºC, arsenic, total chromium, copper, iron, zinc, lead, cadmium, mercury and nickel, surfactants / anionic detergents.

On September 8, 2023, the Pančevo Institute of Public Health visited and sampled the surface waters used for bathing and recreation in the territory of the city of Pančevo. Based on the results of laboratory tests and expert consideration, the ecological status of rivers or bathing areas is determined from the aspect of the examined parameters, based on which it is taken into account whether they are suitable places for bathing and recreation (table 1).

The applied methodology includes:

- sampling of surface water for bathing and recreation in the territory of the municipality of Pančevo
- examination of microbiological and physical-chemical quality indicators of water samples;
- determination of the ecological status of surface waters for bathing and recreation in the territory of the municipality of Pančevo,

The quality of surface waters for bathing and recreation in the municipality of Pančevo was determined, according to the Water Quality Index of Serbia.

RESULTS AND DISCUSSION

Professional teams of the Institute for Public Health Pančevo performed on September 8, 2023. tour and sampling of surface waters used for bathing and recreation in the territory of the City of Pančevo.

Based on laboratory test results and expert consideration, the ecological status of the rivers or bathing areas is added to the examined parameters, which determines whether they are suitable places for bathing and recreation (Table 1).

Table 1 *Summary of assessment of ecological status and quality index of surface waters for bathing and recreation.*

Location	Measuring point	Sampling cycle	The class							Assessment of ecological status	SWQI	
			General parametres	Oxygen regime	Nutrients	Salinity	Metals	Organic substances	Microbiological parametres		Numerical indicator	Descriptiva indicatpr
River Tamis	Swimming spot Pančevo	VI	I	II	III	I	II	I	II	III	75	GOOD
	Swimming spot Jabuka		I	I	III	I	III	I	II	III	71	BAD
	Swimming spot Glogonj		I	I	III	I	III	I	II	III	79	GOOD
River Dunav	Swimming spot to the left of the peak	VI	I	I	III	I	V	I	II	V	79	GOOD
	Swimming spot to the right of the peak		I	I	III	I	V	I	III	V	78	GOOD
Ponjavica	Swimming spot Omolica	VI	V	V	V	III	III	I	III	V	46	BAD
	Swimming spot Banatski Brestovac		V	V	IV	III	III	I	III	V	42	BAD
Ivanovo	Swimming spot Ivanovo	VI	V	III	IV	I	III	I	III	V	65	BAD
Lake Kačarevo	Swimming spot Kačarevo	VI	I	II	III	I	I	I	II	III	81	GOOD

Based on the results of the laboratory tests, from the aspect of the examined parameters, the ecological status of the rivers or swimming pools is assigned, based on which it is taken into account whether they are suitable places for bathing and recreation: 1. Tamiš (bathing areas in Pančevo, Jabuka and Glogonj) meets the criteria for water bodies type 1 (large lowland rivers) for class III (moderate ecological status) for bathing areas in Pančevo, Jabuka and Glogonj.

According to the microbiological parameters of the test, water samples of the Tamish River in Pančevo, Glogonj and Jabuka meet the requirements for class II (good ecological status). 2. Bela Stena (left and right of the peaks) meet the criteria for water bodies type 1 (large lowland rivers) for class V (poor ecological status) due to elevated iron values. According to the microbiological parameters of the test, the water samples of the Danube river to the left of the points meet the conditions for class II and to the right of the points meet the conditions for class III. 3. Ponjavica (swimming areas in Omoljica and Banatski Brestovac) correspond to class V (bad ecological status) for artificial water bodies due to reduced pH value and dissolved oxygen and increased values of BOD5, COD (bichromate method) and total nitrogen. According to the microbiological parameters of the test, the water sample of Ponjavica in Omoljica and Banatski Brestovac meet the conditions for class III; 4. Ivanovo meets the criteria for class V (poor ecological status) due to the reduced pH value. According to total nitrogen value, this water belongs to class IV. According to the microbiological parameters of the test, the water sample from the swimming spot in Ivanovo meets the conditions for class III (moderate ecological status). 5. Kačarevu, from the examined parameters, meets the criteria for artificial water bodies, for class III (moderate ecological status).

CONCLUSION

The analysis of the surface water quality in Pančevo, Serbia, reveals a varied ecological status across different bathing and recreational sites. The study utilized a comprehensive set of microbiological and physico-chemical parameters to assess the water quality, aligning with both national and international standards, such as the Serbian Water Quality Index and the European Union's Bathing Water Directive.

Key findings indicate that:

- River Tamiš: Bathing areas in Pančevo, Jabuka, and Glogonj generally meet the criteria for moderate ecological status (Class III) and good ecological status (Class II) based on microbiological parameters. This suggests that these sites are generally safe for recreational use.
- River Danube: Sites to the left and right of the peaks showed a poor ecological status (Class V) due to elevated iron values, though microbiological parameters indicated a better status (Class II and III). This dichotomy highlights the need for targeted pollution control measures, particularly concerning heavy metals.

- Ponjavica: Bathing areas in Omoljica and Banatski Brestovac exhibited a bad ecological status (Class V) due to issues with pH, dissolved oxygen, and high levels of BOD5, COD, and total nitrogen. These findings underscore the significant pollution challenges in these areas.
- Ivanovo: The site showed a poor ecological status (Class V) with problems primarily related to pH and total nitrogen levels. This indicates the need for interventions to improve water quality.
- Lake Kačarevo: This site meets the criteria for moderate ecological status (Class III), indicating relatively better conditions than other locations.

Overall, the study highlights the necessity of improving water quality management practices in Pančevo. Enhanced wastewater treatment, stringent monitoring, and the implementation of buffer zones to prevent agricultural runoff are essential to maintaining and improving the quality of surface waters. Continuous efforts are required to ensure these waters remain safe for public health and conducive to recreational activities, contributing to the local economy and environmental sustainability.

REFERENCES

SEPA What is the Serbian Water Quality Index? The concept and significance of the application of environmental indicators Agency for Environmental Protection, Republic of Serbia; 29.05.2024. http://www.sepa.gov.rs/index.php?menu=6&id=8007&akcija=showXlinked

Boyacioglu H. Development of a water quality index based on a European classification scheme. Water SA 2007;33(1);101-106.

Veljković N. Indicators of the Sustainable Development and the Water Resources Management, Andrejević Foundation, Belgrade; 2006.

RoS Law on Water („Official Gazette of RS," No. 30/10, 93/12, 101/16, 95/18); 2018

SRS Regulation on Water Classification („Official Gazette of RS," No. 5/68); 1968

European Commission (2006/7/EC): European Union's Bathing Water Directive; 2006

Ostojić A & Ćurčić, S. Water quality in the Gruža reservoir lake. In: (in Serbian Akumulaciono jezero Gruža) (Eds. Čomić, Lj, Ostojić, A.); 2005; 217-230. PMF Kragujevac

Prüss A. Review of epidemiological studies on health effects from exposure to recreational water. Int J Epidem 2008;27(1);1-9.

Bartram J, & Rees G. Monitoring Bathing Waters: A Practical Guide to the Design and Implementation of Assessments and Monitoring Programmes; 2009.

WHO (2003). Guidelines for Safe Recreational Water Environments Volume 1: Coastal and Fresh Waters. World Health Organization, Geneva

WHO (2006). Guidelines for safe recreational water environments Vol 2: Swimming pools and similar environments, World Health Organization, Geneva

USING SERBIAN WIKIPEDIA IN SECONDARY AND HIGHER EDUCATION

Dudić Dragana[1], Firaunović Ivana[2] and Ratković Nebojša[3]

[1]Faculty of Informatics and Computer Science, University Union Nikola Tesla, Belgrade, Serbia

[2]Šabac Grammar School, Šabac, Serbia

[3]Wikimedia Serbia, Belgrade, Serbia

ddudic@unionnikolatesla.edu.rs

Abstract: The Serbian Wikipedia is the 22nd largest Wikipedia in the world, with 365,959 registered users and over 688,000 articles, making it highly suitable for use across various educational domains. This paper presents the preliminary results from the first year of a collaborative project between the Faculty of Computer Science, Šabac Grammar School, and Wikimedia Serbia. The primary goals of this cooperation are to introduce students to Wikipedia's potential and develop their editing skills. We employed structured questionnaires to assess the initial state and to evaluate students' awareness and involvement in Wikipedia editing after lectures. The results of the first questionnaire identified key challenges in integrating Wikipedia into the educational process. Using this information, we conducted comprehensive lectures on Wikipedia and its editing, allowing students to choose Wikipedia-related assignments based on their interests within their courses. The evaluative questionnaire demonstrated a significant increase in students' understanding of the importance of curating Wikipedia and the proper use of licenses and references across both educational institutions.

Keywords: e-learning, higher education, secondary education, Wikipedia, Serbian language.

INTRODUCTION

Wikipedia is a multilingual, open web-based encyclopedia hosted by the Wikimedia Foundation and collaboratively edited by volunteers worldwide (Wikipedia, 2024). In today's digital age, Wikipedia is one of the most ubiquitous and accessible sources of information available to students and educators alike.

Its comprehensive coverage of various topics and ease of access have made it a go-to resource for many.

It started with the English version of Wikipedia 23 years ago, and now it covers 342 languages. Serbian Wikipedia was created two years after the release of the first Wikipedia version. According to the latest Wikipedia statistics (Serbian Wikipedia statistics, 2024), Serbian Wikipedia has 365,959 registered users and 688.773 articles, which makes it the 22nd largest Wikipedia in the world. These facts are impressive; however, many teachers still mistrust Wikipedia as a reliable source of information due to its open and accessible nature (Vetter, 2024). While these characteristics can be seen as drawbacks, given the potential for incomplete and outdated articles (Meishar-Tal, 2015), they can also be viewed as advantages, allowing anyone to read, edit, and create content (Benjakob, 2022). We must bear in mind that Serbian Wikipedia is edited not only by regular registered users but also by dedicated volunteers organized hierarchically in a functional structure. These volunteers assume various roles, such as admins, supervisors, patrollers, and rollbackers. Specialized technologies are also developed to recognize malicious content (Sáez-Trumper, 2019). To enhance its credibility, Wikipedia employs licensing and referencing mechanisms, which help ensure information security and allow users to verify stated facts. Despite these measures, Wikipedia is still not widely recognized in educational institutions at all levels.

In this paper, we present the results of the pilot cooperation between the Faculty of Computer Science of the University Union Nikola Tesla, Šabac grammar School, and Wikimedia Serbia. The primary objectives of this collaboration are to introduce Wikipedia's potential, foster collaborative learning, and cultivate students' editing skills within higher and secondary educational institutions.

MATERIALS AND METHODS

We selected two groups of students with strong backgrounds in computer science and research skills. One group comprised 20 third-year students from the Faculty of Computer Science and Informatics at University Union Nikola Tesla, while the other group included 20 fourth-year students specializing in information technology at Šabac Grammar School. All selected students willingly participated in this research project.

We divided our research into four main phases: the initial phase, the informative phase, the proactive phase, and the evaluation phase. All phases are intended to be executed sequentially, with partial dependence on the results of the preceding phase. The main goal of the first phase is to reflect the current state of the student's awareness and Wikipedia usage behavior. Initial phase results directed the informative phase training content, enabling us to focus on emerging problems in the selected groups of students. The informative phase was organized by Wikimedia Serbia and conducted by their representatives. All lectures and training sessions in the informative phase are meticulously tailored to match the surveyed students' age, knowledge level, and interests. The impact of the informative phase is anticipated to be long-term, although its immediate effects can be assessed through the proactive and evaluation phases. In collaboration with the students participating in this survey, we identified topics with either no or few articles on Serbian Wikipedia for inclusion in the proactive phase. For university students, the selected topic is: "Internet tools and services," and for grammar school students, it is: "Operating systems."During the proactive phase, students were tasked with creating, rather than editing, at least one Serbian Wikipedia page on a topic of their choosing based on their preferences and interests. Throughout this phase, students were supervised and, if necessary, guided by representatives from Wikimedia Serbia. Upon completing their assignments, during the evaluation phase, students provide feedback on the lectures, training sessions, and their experience with Wikipedia editing, highlighting any challenges encountered. This process enables us to assess progress during the evaluation phase and identify areas that may require improvement in preceding phases.

We are employing structured questionnaires in the form of surveys as a quantitative method for both the first and fourth phases. Due to our small population, we designed online surveys using the SurveyMonkey platform. Surveys were distributed using university institutional emails for university students and private emails for high school students. Both questionnaires are in Serbian language and contain 10 basic yet informative questions. These questions are divided into three groups: the first group pertains to Wikipedia in general, the second group focuses on copyright licenses, and the third group addresses referencing.

We collected questionnaire responses separately from grammar school students and university students and used descriptive statistics to analyze respondents' perceptions of Wikipedia usage.

RESULTS

The questionnaire in the first phase provided us with insights into the current status of student perceptions of Wikipedia and its usage. At the same time, we anticipate using the questionnaire in the fourth phase to demonstrate our progress in the Wikipedia education process. The first five questions aimed to reveal students' general knowledge about Wikipedia, and answers showed us that students are interested and used them for educational purposes. Still, very few of them tried to edit Wikipedia by themselves.

We found that referencing and copyright licensing serve as critical trust mechanisms. Figure 1 presents detailed results regarding students' views on copyright in general and copyright licensing.

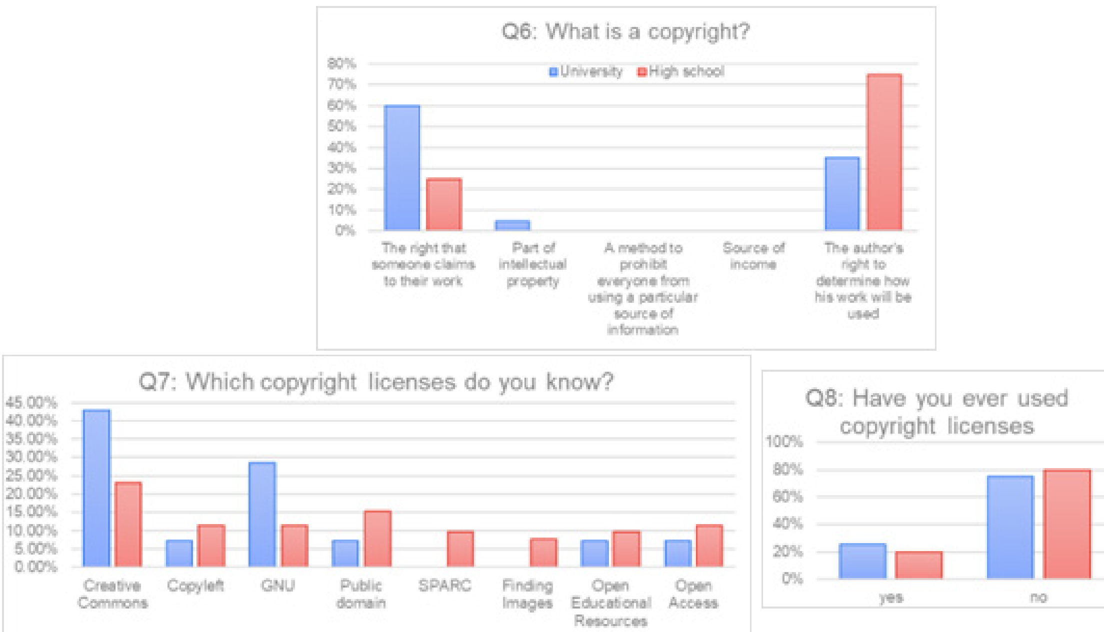
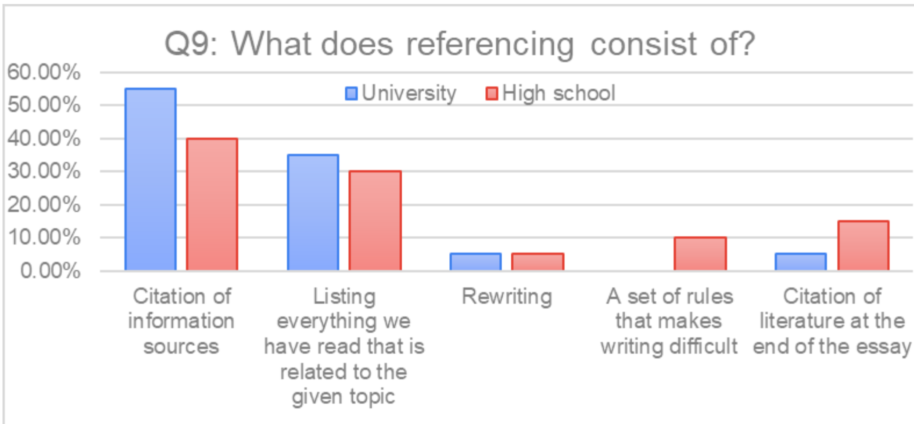


Figure 1 *Informational phase results of the questions Q6-Q8*

Figure 2 outlines students' attitudes and insights concerning referencing practices, illustrating their comprehension and views on the importance of proper citation in academic work.

The first six questions of the evaluation phase address the student's perception of the usefulness of the informative phase. The responses to the first four questions indicate that students rated highly the quality of the training and the instructors' commitment to the cause. Answers to the following two questions show that students know the importance of the referencing and licensing mechanisms and find editing Wikipedia interesting, helpful, and easy, but it requires careful attention. The following three questions focus on improving students' abilities in proper referencing, and the results are presented in Figure 3.

The last question of the evaluation phase concerns the students' understanding of using copyright licenses, and the results show clear improvement in this domain (Figure 4).



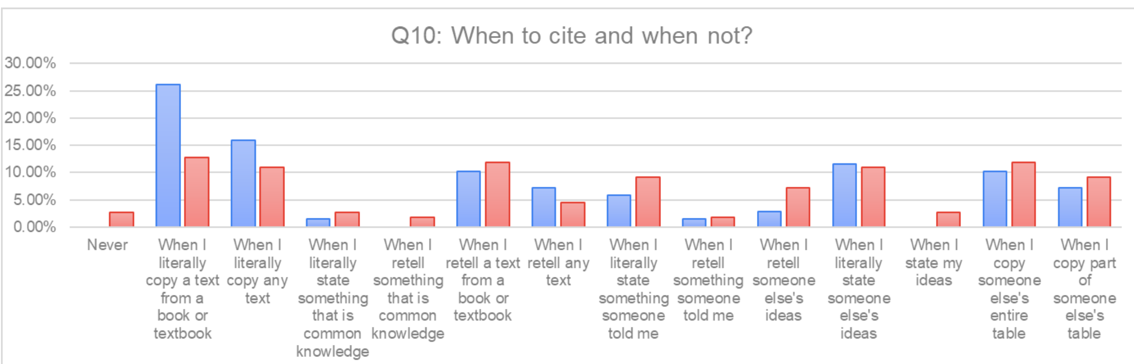


***Figure 2** Informational phase results of the questions Q9 and Q10*

Figure 3 *Evaluation phase results for the questions Q7-Q9*

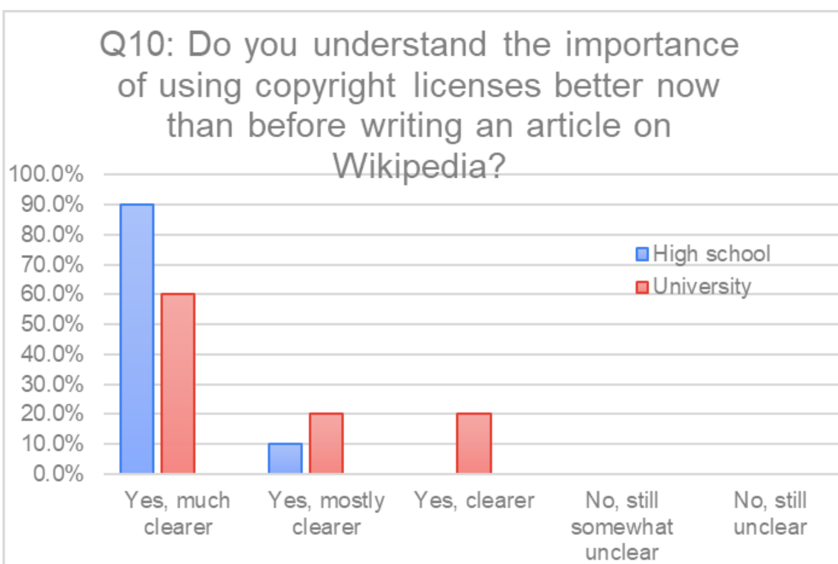


Figure 4 *Evaluation phase results for question Q10*

CONCLUSION

After successfully completing the first year of this research, we achieved promising outcomes. Findings from the initial phase guided the study, enabling us to address emerging issues effectively. Results from the evaluation phase indicated a notable increase in understanding among students at both higher and secondary educational levels regarding the importance of curating Wikipedia, adhering to licensing requirements, and using proper references.

According to the aforementioned, Wikipedia serves as a valuable resource in secondary and higher education, offering students and educators a convenient and comprehensive starting point for research and learning. Its accessibility and breadth of information make it an invaluable tool for the initial exploration of topics.

The obtained results encourage us to continue our work, expand this research, and include more students, domains, and languages.

REFERENCES

Wikipedia 2024; Available at: https://en.wikipedia.org/wiki/Wikipedia:Aboute. Accessed 2 July 2024.

Serbian Wikipedia statistics 2024; https://stats.wikimedia.org/#/sr.wikipedia.org Accessed 2 July 2024.

Vetter MA. Teaching Wikipedia: Appalachian Rhetoric and the Encyclopedic Politics of Representation. College English 2018; 80(5); 397–422.

JSTOR, https://www.jstor.org/stable/26773390.

Meishar-Tal H. Teachers' Use of Wikipedia with Their Students." 2015. AJTE 2015; 40(12);

Benjakob O, Aviram R, Aryeh Sobel R. Citation needed? Wikipedia bibliometrics during the first

wave of the COVID-19 pandemic. GigaScience 2022;11;1–13.

Sáez-Trumper D. Online Disinformation and the Role of Wikipedia. ArXiv 2019; abs/1910.12596, doi:10.48550/arXiv.1910.12596.

ROLE OF BIOINFORMATICS IN SUSTAINABLE AGRICULTURE

Dudić Dragana[1], Banović-Đeri Bojana[2], Nikolic Ana[3], Samardžić Jelena[2], Vančetović Jelena[3], Delić Nenad[3]

[1]Faculty of Informatics and Computer Science, University Union Nikola Tesla, Belgrade, Serbia

[2]Institute of Molecular Genetics and Genetic Engineering, University of Belgrade, Belgrade,Serbia

[3]Maize Research Institute "Zemun Polje", Belgrade, Serbia

ddudic@unionnikolatesla.edu.rs

Abstract: Sustainable agriculture has become one of the critical concepts of agricultural development, with crop resilience as one of the main goals. The availability of vast amounts of different types of omics data in the agricultural domain enabled bioinformatics, as a combination of biology with computer science technologies and methods, to be involved in the creation of sustainable agriculture. Maize is an important crop worldwide, and its yield is negatively affected by a wide range of abiotic and biotic stresses. Plant stress can be overcomed in an invasive way of intensive use of pesticides and nitrates. Another way is non-invasive and includes the use of bioinformatics tools and practices. To show the impact of bioinformatics in creating sustainable agriculture, we sequenced the transcriptome of 46 maize inbred lines from Maize Research Institute "Zemun Polje" to identify resilient maize crops. Obtained results include transcripts for 27 protein-coding genes as significant for maize drought and cold tolerance, revealing 2 lines both tolerant to drought and cold, other 2 lines are drought tolerant but cold sensitive. The other 2 lines are cold tolerant but drought sensitive, showing that producing resilient maize crops while leaving soil healthy, as sustainable agriculture promotes, is possible.

Keywords: bioinformatics, sustainable agriculture, RNAseq, maize.

INTRODUCTION

Sustainable agriculture is increasingly recognized as a crucial approach to meeting the food demands of a growing global population while preserving environmental health and ensuring economic viability. Central to advancing sustainable agricultural practices is integrating cutting-edge technologies that enhance productivity, resilience, and resource efficiency. Among these technologies, bioinformatics is a transformative tool that leverages computational techniques to analyze and interpret vast amounts of biological data (Edwards & Batley, 2010).

Bioinformatics, the interdisciplinary field that merges biology, computer science, and information technology, has the potential to revolutionize agricultural practices. By utilizing genomic, proteomic, and metabolomic data, bioinformatics provides insights into plant genetics, disease resistance, and environmental interactions (Kersey et al., 2016). This information is essential for developing crops that are more resilient to climate change, pests, and diseases, thereby reducing the reliance on chemical inputs and promoting ecological balance (Varshney et al., 2018).

Maize is a staple crop with significant economic and nutritional importance worldwide. As a model organism in plant research, maize offers a valuable case study to explore the applications of bioinformatics in sustainable agriculture. The vast genetic diversity and complex genome of maize present unique opportunities for bioinformatics to enhance crop improvement efforts (Schnable et al., 2009).

In this paper, we examine the role of bioinformatics in sustainable agriculture through the lens of Zea mays. We use bioinformatics tools and techniques to analyze the maize transcriptomes during drought and cold to identify resilient maize crops.

MATERIALS AND METHODS

Our study involves maize total leaf transcriptome data obtained via Illumina MiSeq platform and 150bp paired-end sequencing for 46 maize inbred lines from the elite core collection of from Maize Research Institute "Zemun Polje" where all plants were grown in the greenhouse under optimal conditions until reaching V4 phase, when the 3rd leaves of three plants per each inbred line were sampled and frozen in liquid nitrogen and prepared for sequencing. All selected lines are characterized by good combining ability: Lancaster group vs. several other heterotic groups like BSSS, Iowa dent, Ohio – referred from now on as a Non-Lancaster group.

Obtained transcripts are preprocessed using FastQC and Trimmomatic v0.39, and mapped to Zea mays B73 reference genome v5 using STAR v2.7.10a. Gene level analysis is conducted using DESeq2, EdgeR and limma R packages.

Differentially expressed genes (DEGs) were annotated using BLAST2GO. According to obtained DEGs, we made subsets of initial heterotic groups and formed new ones in order to reveal genes responsible for drought and cold resistance (Figure 1).

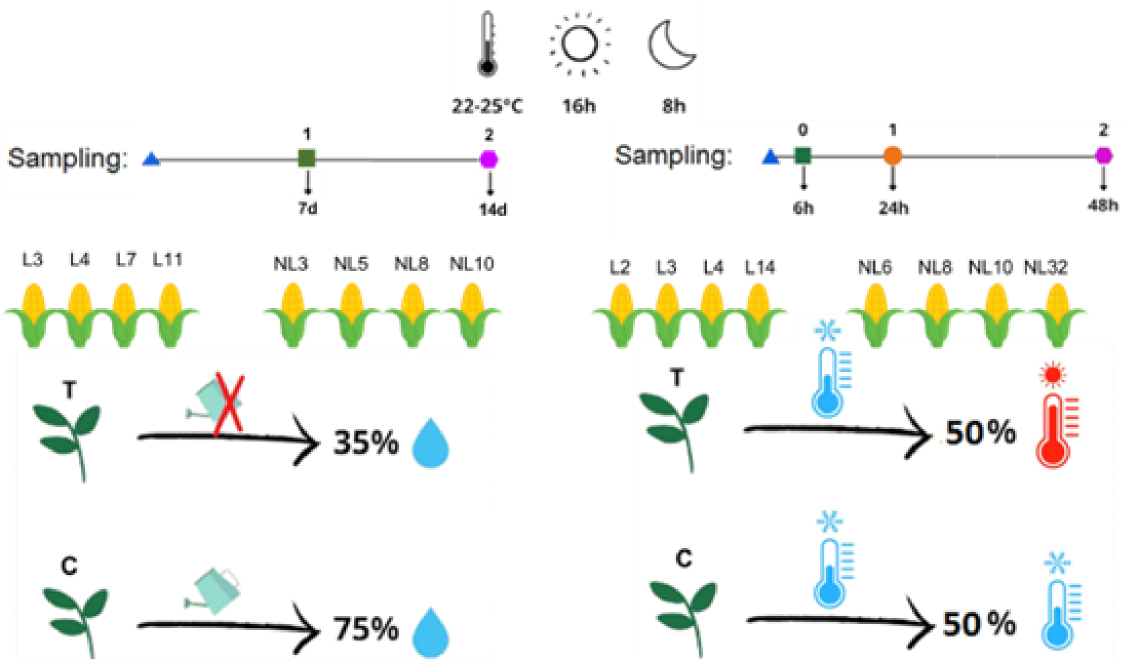


Figure 1 *Experimental setup details*

All results are validated with qPCR. Before all statistical calculations, the data obtained from qPCR experiment were screened for normality (Shapiro–Wilk and Kolmogorov–Smirnov test), homogeneity of variance (Levene's test) and outliers were excluded from further analysis. General Linear Model (GML) was performed, considering genetic background and time period as the main effects. Bonferroni test was carried out for mean comparison with a significance level at $p < 0.05$. Statistical processing of the data was performed using SPSS 21.

RESULTS

Obtained raw whole transcriptome data are accessible through GEO Series accession number GSE164078.

Overall GC content in all transcripts was 50.08%. Out of 551,403 obtained reads 37,820 contigs with N50 value of 1,065 bp, maximum contig length of 22,801 bp and the average contig length of 289.33 bp were assembled. Most of the contigs were 150-600 bp in length (120,693). The number of contigs of 600-1,200 bp in length was 49,140, the number of contigs of 1,200-2,000 bp in length was 19,283, the number of contigs of 2,000-3,000 bp in length was 7,142 and the number of contigs larger than 3,000 bp was 5,109. The FPKM (Fragments Per Kilobase of transcript per Million mapped reads) values ranged from 0 to 83,701,772.55, with the median FPKM value of 11.37 and 43,948 transcripts showing FPKM values greater than 1.000. Differential gene expression analysis revealed 77 genes that were differentially expressed between two tested maize genetic backgrounds (Figure 2)

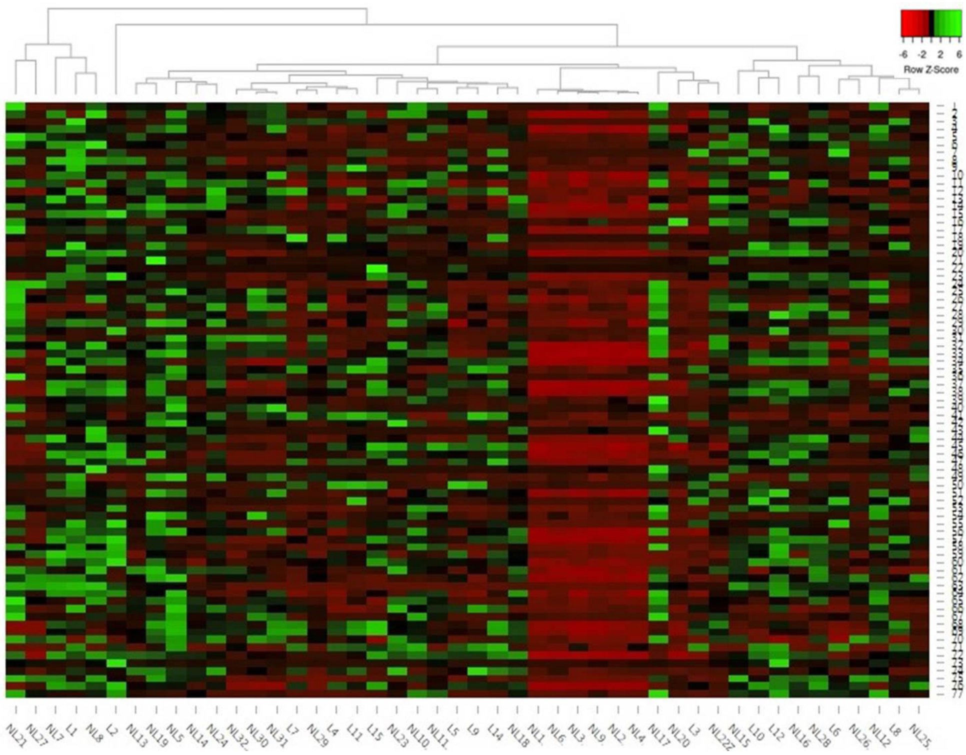


***Figure 2** Heatmap of revealed DEGs*

Further analysis involved forming two subsets of four Lancaster and four non-Lancaster lines, one to test drought tolerance and the other to test cold tolerance. The obtained results revealed 27 protein-coding genes closely related to cold, drought, and cold and drought tolerance (Table 1), corresponding to the statistically significant different regulation of the gene expression level of selected DEGs.

Table 1 *Proteins related to cold and drought tolerance*

Drought	**Cold and Drought**
alanine-glyoxylate aminotransferase 2 homolog 1	trifunctional UDP-glucose 4,6-dehydratase/UDP-4-keto-6-deoxy-D-glucose 3,5-epimerase/UDP-4-keto-L-rhamnose-reductase RHM1
alpha/beta-Hydrolases superfamily protein	Protein kinase superfamily protein with cticosapeptide/Phox/Bem1p domain
CBL-interacting protein kinase 10-like	cytochrome P450 71A1
terpene synthase 7	Wall-associated receptor kinase 2
Probable plastid-lipid-associated protein 2	L10-interacting MYB domain-containing protein-like
abscisic stress-ripening protein 5-like	putative gag-pol polyprotein
Cytochrome b559 subunit alpha	zinc finger BED domain-containing protein RICESLEEPER 2-like
hypothetical protein SORBI_3003G299500	putative amino alcohol phosphotransferase
photosystem I and II reaction center proteins	S-adenosylmethionine synthase 1
mannose-6-phosphate isomerase 1-like	hypothetical protein BGU76_00460
cytochrome c oxidase subunit 6b-3-like	retroviral aspartyl protease
fruit protein PKIWI502	**Cold**
Cysteine-rich receptor-like protein kinase 37	NADH-plastoquinone oxidoreductase subunit 4
calvin cycle protein CP12-2	uncharacterised protein

CONCLUSION

The integration of bioinformatics into sustainable agriculture, has shown immense potential in addressing the global challenges of food security and environmental sustainability. Bioinformatics tools and techniques have enabled comprehensive analysis of the maize transcriptome, providing deep insights into genetic diversity, disease resistance, and environmental adaptability. These insights are crucial for developing maize varieties that can thrive under varying climatic conditions and resist pests and diseases, thus reducing the need for chemical inputs and enhancing ecological balance.

The case of maize illustrates the broader implications of bioinformatics in sustainable agriculture. By optimizing crop management practices and enabling precise genetic improvements, bioinformatics supports the development of more sustainable agricultural systems. This not only ensures a stable food supply but also promotes environmental conservation and resource efficiency.

In conclusion, bioinformatics plays a pivotal role in the advancement of sustainable agriculture. The success observed in maize research serves as a testament to its transformative impact, highlighting its importance in fostering agricultural innovation and sustainability. As bioinformatics continues to evolve, its contributions will be integral to building a resilient and productive global food system.

REFERENCES

Edwards D, Batley J. Plant genome sequencing: applications for crop improvement. Plant Biotechnol J 2010;8(1);2-9.

Kersey PJ, Allen JE, Christensen M, Davis P, Falin LJ, Grabmueller C, Staines DM. Ensembl Genomes 2016: more genomes, more complexity. Nucleic Acids Res 2016;44(D1); D574-D580.

Schnable PS, Ware D, Fulton RS, Stein JC, Wei F, Pasternak S, Wilson RK. The B73 maize genome: complexity, diversity, and dynamics. Sci 2009;326(5956);1112-1115.

Varshney RK, Roorkiwal M, Sorrells ME. Genomic selection for crop improvement: challenges and opportunities. Plant Genome 2018;11(3),1800010.

THE ROLE OF BRASSINOSTEROIDS IN PHYTOREMEDIATION: IMPROVING HEAVY METAL AND ARSENIC UPTAKE IN WHEAT

Hadi Waisi [1, 2], Miloš Marinković[1], Aleksandar Marinković[1], Marko Milojković[3], Slavica Blagojević[4], Aleksandra Radulović[1] Bogdan Nikolić[5]

[1]Institute of General and Physical Chemistry, Studentski trg 12/V, P.O. Box 45, 11158 Belgrade, Serbia

[2] Faculty of Ecology and Environmental Protection, University UNION-Nikola Tesla, Cara Dušana 62-64, 11000 Belgrade, Serbia

[3]Public utility enterprise-Veterinary Belgrade, Bulevar Despota Stefana 119, 11000 Belgrade

[4]University of Belgrade - Faculty of Pharmacy, Vojvode Stepe 450, 11221 Belgrade, Serbia

[5]Institute for Plant Protection and Environment, University of Belgrade, Teodora Drajzera 9, 11000 Belgrade, Serbia

hadiwaisi@yahoo.com

Abstract: Rapid industrial development and poor waste management have led to widespread soil contamination with heavy metals and metalloids, including nickel (Ni), cadmium (Cd), and arsenic (As). These contaminants pose significant risks to both plant and human health. Phytoremediation, an environmentally friendly approach using plants to absorb and detoxify pollutants, offers a promising solution. Wheat (Triticum aestivum L.) has potential in phytoremediation due to its ability to uptake various contaminants. This study investigates the role of brassinosteroids (BRs), a plant hormone class, in enhancing wheat's phytoremediation capacity for Ni, Cd, and As. Results indicate that BR treatment significantly increases the uptake of these contaminants without adversely affecting plant biomass, suggesting improved stress tolerance. Specifically, BRs enhance the expression of metal transporter genes and the synthesis of metal-binding compounds, facilitating higher metal accumulation in plant tissues. The findings demonstrate the potential of BR-treated wheat in remediating soils contaminated with multiple heavy metals and metalloids, providing a dual benefit of soil decontamination and sustained plant growth. This research offers new

insights into sustainable agricultural practices and environmental remediation strategies.

Keywords: brassinosteroids, phytoremediation, heavy metals, arsenic, soil contamination

INTRODUCTION

The rapid industrial development and improper waste management have led to significant soil contamination with heavy metals and metalloids, such as nickel (Ni), cadmium (Cd), and arsenic (As). These contaminants pose a serious threat to plant life and human health, as they can enter the food chain through contaminated crops. Heavy metals and metalloids like nickel, cadmium, and arsenic cannot be biologically degraded, leading to their accumulation in ecosystems and the urgent need for effective remediation methods (Pilon-Smits, 2005).

Phytoremediation, the process by which plants absorb, accumulate, and detoxify contaminants from soil, water, and air, is an environmentally friendly method for removing these pollutants from affected environments (Ali, 2013). Wheat (*Triticum aestivum* L.), one of the most widely cultivated cereals in the world, has shown potential for use in phytoremediation due to its ability to absorb various pollutants, including heavy metals and metalloids. However, the effectiveness of phytoremediation can vary depending on several ecophysiological factors, including specific plant hormones (Vardhini, 2015).

Arsenic, a highly toxic metalloid, is particularly concerning due to its widespread presence in contaminated soils, often resulting from mining activities, pesticide application, and industrial waste disposal. Chronic exposure to arsenic through contaminated water and food sources is linked to severe health issues, including cancer. This makes arsenic a priority target for remediation efforts. Phytoremediation offers a promising approach to mitigate arsenic pollution. Still, the efficiency of this method depends on the plant's ability to tolerate and accumulate high levels of arsenic without significant growth inhibition.

Brassinosteroids, a class of plant hormones, play a crucial role in regulating plant growth, development, and responses to various stresses, including those induced by heavy metals and metalloids. Their ability to enhance plant resistance to biotic and abiotic stresses has been extensively studied. Recent research suggests that brassinosteroids may significantly influence the uptake and accumulation of heavy metals and metalloids, such as arsenic, in plants, making them a potential tool for enhancing phytoremediation (Bajguz, 2009). This research's main hypothesis is that treating wheat with brassinosteroids could increase its ability to absorb nickel, cadmium, and arsenic from contaminated soil. Brassinosteroids may enhance the expression of genes associated with the transport and accumulation of these contaminants, as well as improve overall plant growth under stress caused by their presence.

This paper aims to examine the impact of brassinosteroids on the phytoremediation potential of wheat in the context of nickel, cadmium, and arsenic removal from soil. Through a series of experiments, changes in the absorption of these metals and metalloids will be analyzed, along with the physiological responses of wheat to the presence of brassinosteroids and contaminants. The results of this research are expected to provide new insights into the potential application of brassinosteroids as agents for improving the efficiency of phytoremediation, thereby contributing to the development of environmentally sustainable methods for the remediation of polluted environments.

Additionally, understanding the mechanisms by which brassinosteroids affect the absorption of nickel, cadmium, and arsenic could open new perspectives for improving agricultural practices, enabling simultaneous food production and soil remediation. This research may lay the foundation for further investigations and the development of new technologies in environmental protection and sustainable agriculture.

MATERIALS AND METHODS

The influence of different concentrations of 24-EBL (The product "Epin-Extra", obtained from "Galenika-Fitofarmacija" a.d. Zemun Company, manufactured in Russia) on the contaminated wheat plants (Purchased from Maize Research Institute "Zemun Polje", named Aurelia – winter bread wheat variety) was examined. Growth parameters, Microwave digestion and the ICP-OES determination was conducted as modification described in our previous work (Waisi, 2017). All chemicals were purcheased from Merck KGaA Frankfurter Str. 250.

RESULTS AND DISSCUSION

An approach based on using brassinosteroids in phytoremediation could represent a significant step towards addressing soil contamination with heavy metals and metalloids, particularly arsenic, while ensuring the safety of the food chain and the preservation of natural resources. Below is the table that includes arsenic (As) along with nickel (Ni) and cadmium (Cd) content, and the total biomass of wheat plants under different treatment conditions.

Table 1 *Effect of Brassinosteroid Treatment on Heavy Metal and Arsenic Uptake and Biomass of Wheat Plants*

Treatment	Nickel (Ni) Content (mg/kg DW)	Cadmium (Cd) Content (mg/kg DW)	Arsenic (As) Content (mg/kg DW)	Total Biomass (g DW)
Control (no metals)	0.15 ± 0.02	0.05 ± 0.01	0.02 ± 0.01	10.0 ± 0.2
Ni + Cd + As (no BRs)	3.25 ± 0.10	1.45 ± 0.08	2.50 ± 0.12	9.8 ± 0.3
Ni + Cd + As + BRs (0.1 µM)	6.50 ± 0.20	3.10 ± 0.15	5.20 ± 0.18	9.7 ± 0.4
Ni + Cd + As + BRs (1.0 µM)	7.80 ± 0.25	3.85 ± 0.20	6.45 ± 0.25	9.6 ± 0.3

Note:

- *DW* stands for Dry Weight.
- *Control*: Wheat plants grown in soil without added heavy metals or arsenic, and without brassinosteroid treatment.
- *Ni + Cd + As (no BRs)*: Wheat plants grown in soil with added nickel, cadmium, and arsenic, without brassinosteroid treatment.
- *Ni + Cd + As + BRs (0.1 µM)*: Wheat plants grown in soil with added nickel, cadmium, and arsenic, treated with 0.1 µM brassinosteroids.
- *Ni + Cd + As + BRs (1.0 µM)*: Wheat plants grown in soil with added nickel, cadmium, and arsenic, treated with 1.0 µM brassinosteroids.

The table presents the impact of brassinosteroid (BRs) treatment on the uptake of heavy metals (nickel and cadmium) and a metalloid (arsenic) by wheat plants, along with the resulting biomass.

The data clearly show that the uptake of all three contaminants—nickel, cadmium, and arsenic—increased significantly with brassinosteroid treatment. In the *Ni + Cd + As (no BRs)* treatment, nickel, cadmium, and arsenic concentrations in the plant tissue were 3.25 mg/kg, 1.45 mg/kg, and 2.50 mg/kg DW, respectively. This represents the baseline uptake in the absence of brassinosteroids. The application of 0.1 µM BRs almost doubled the absorption of nickel and cadmium (6.50 mg/kg and 3.10 mg/kg DW, respectively) and led to a more than twofold increase in arsenic uptake (5.20 mg/kg DW). The higher concentration of BRs (1.0 μM) further enhanced metal and metalloid absorption, with nickel reaching 7.80 mg/kg DW, cadmium 3.85 mg/kg DW, and arsenic 6.45 mg/kg DW. This indicates a dose-dependent relationship between BRs concentration and metal uptake.

Despite the increased uptake of these potentially toxic elements, the total biomass of the wheat plants remained relatively unchanged across treatments. The control group showed a biomass of 10.0 g DW, which slightly decreased to 9.6-9.8 g DW in treated groups. The small variation in biomass suggests that the presence of nickel, cadmium, and arsenic did not substantially inhibit plant growth, even at elevated levels of metal absorption. This indicates that the brassinosteroids not only enhanced metal uptake but also conferred some level of protection to the plants, allowing them to maintain growth (Fariduddin, 2003). The results indicate that brassinosteroids can significantly enhance the capacity of wheat to absorb heavy metals and arsenic from contaminated soils. This makes wheat treated with brassinosteroids an excellent candidate for phytoremediation, especially in environments contaminated with multiple metals and metalloids.

The ability of wheat to accumulate higher concentrations of metals without a significant reduction in biomass is particularly important. It suggests that grain can be used effectively in phytoremediation without compromising its growth, which is critical for maintaining the plant's overall health and sustainability during the remediation process. Furthermore, the dose-dependent increase in metal uptake with higher concentrations of brassinosteroids provides flexibility in optimizing treatment levels based on specific contamination scenarios. This underscores the dual benefits of brassinosteroids in increasing the uptake of contaminants while preserving plant health, making it a promising strategy for environmental remediation efforts.

The results presented in this study suggest that brassinosteroids (BRs) significantly enhance the phytoremediation potential of wheat by increasing the uptake of heavy metals (nickel and cadmium) and arsenic from contaminated soil. The increase in metal uptake was dose-dependent, with higher concentrations of BRs leading to more significant accumulation of these contaminants in the plant tissues. This finding aligns with previous studies that have demonstrated the role of brassinosteroids in modulating plant responses to heavy metal stress.

The increased uptake of nickel, cadmium, and arsenic in BR-treated plants supports the hypothesis that BRs can enhance gene expression in metal transport and sequestration. Brassinosteroids have been shown to upregulate the expression of metal transporter proteins, such as members of the heavy metal ATPase (HMA) family and the natural resistance-associated macrophage protein (NRAMP) family, which are crucial for metal ion uptake and translocation within plants (Anwar, 2018). Moreover, BRs may promote the synthesis of phytochelatins and metallothioneins, which bind heavy metals and facilitate their sequestration in vacuoles, reducing metal toxicity in the cytoplasm. This mechanism not only aids in metal detoxification but also in the overall accumulation of metals within the plant tissues (Hasan, 2016).

Brassinosteroids are known to mitigate the oxidative stress typically associated with heavy metal exposure by enhancing the activity of antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) . The stabilization of biomass observed in this study may be attributed to the enhanced antioxidant defense system, which protects the plants from oxidative damage induced by heavy metals and arsenic (Cao, 2005).

The significant increase in arsenic uptake in BR-treated plants is particularly noteworthy, as arsenic is a metalloid with severe toxicity and a major environmental contaminant. Previous studies have shown that BRs can modulate the uptake and translocation of arsenic by altering root architecture and increasing the expression of arsenite transporters in plants like rice. The similar effects observed in wheat suggest that BRs may universally enhance arsenic uptake across different plant species (Sharma, 2012).

The ability to accumulate higher levels of arsenic without significant growth inhibition is critical for the effective use of wheat in arsenic phytoremediation. This study's results contribute to the growing body of evidence that BRs could be employed as a practical tool to enhance the phytoremediation of arsenic-contaminated soils, particularly in agricultural regions where food safety is a concern.

The dual role of BRs in enhancing both metal uptake and stress tolerance presents a promising strategy for integrating phytoremediation with agricultural production. In contaminated agricultural lands, applying BRs could enable the simultaneous production of crops and remediation of soils, thereby addressing food security while mitigating environmental contamination. Furthermore, using BRs as a treatment strategy could be fine-tuned to optimize the uptake of specific contaminants, depending on the local soil contamination profile. This approach could be precious in regions with mixed contamination of heavy metals and metalloids, as demonstrated by the increased uptake of nickel, cadmium, and arsenic in this study.

CONCLUSION

The results of this study highlight the potential of brassinosteroids as enhancers of phytoremediation in wheat, particularly for the uptake of nickel, cadmium, and arsenic. By improving metal uptake without compromising plant growth, BRs offer a viable strategy for the remediation of contaminated soils in a sustainable and environmentally friendly manner. Future research should focus on the molecular mechanisms underlying BR-mediated metal uptake and the long-term effects of BRs on plant health and soil ecology. This approach could be valuable to current phytoremediation strategies, offering a sustainable and efficient method for cleaning up metal-contaminated soils.

ACKNOWLEDGMENT

This research was funded by the Ministry of Science, Technological Development and Innovation, Republic of Serbia through Grant Agreement with Institute of General and Physical Chemistry, No 451-03-47/2023-01/200051, University of Belgrade - Faculty of Pharmacy No 451-03-65/2024-03/ 200161.

REFERENCES

Pilon-Smits E. Phytoremediation. Annual Review of Plant Biology, 56, 15-39.

Ali H, Khan E, & Sajad MA. Phytoremediation of heavy metals—Concepts and applications. Chemosphere 2013;91(7); 869-881.

Vardhini BV, & Anjum NA. Brassinosteroids make plant life easier under stress. Plant Physiol Biochem 2015;94; 37-42.

Bajguz A & Hayat S. Effects of brassinosteroids on the plant responses to environmental stresses. Plant Physiol Biochem 2009;47(1);1-8.

Waisi HK, Petković AZ, Nikolić BR, Janković BZ, Raičević V, Lalević B, Giba ZS. Influence of 24-epibrassinolide on seedling growth and distribution of mineral elements in two maize hybrids. Hem ind 2017;71(3); 201-209.

Fariduddin Q, Ahmad A, & Hayat S. Salicylic acid and brassinosteroids mitigate the adverse effects of cadmium and nickel in Brassica juncea. Chemosphere 2003;60(8);1042-1049.

Anwar A, She M, Wang K. Brassinosteroids regulate growth and stress responses in plants under harsh environments and crop productivity. Plant Stress 2018;2; 100016.

Hasan MK, Ahammed GJ, Yin L. Melatonin mitigates cadmium phytotoxicity through modulation of phytochelatin synthesis and antioxidative capacity in tomato. Fron Plant Sci 2016;7;1906.

Cao S, Xu Q, Cao Y, Qian K, & An K. Brassinosteroids stimulate plant immunity and protect plants from oxidative stress. Plant Physiol Biochem 2005;45(2);119-124.

Sharma, I. (2012). „Brassinosteroids: A promising option in deciphering remediation processes in plants under heavy metal stress." *Biologia Plantarum*, 56(3), 537-543.

INNOVATIONS IN THE DEVELOPMENT OF MATERIALS FOR CURRENT SOURCES: THE POSSIBILITIES OF FERRATE AS A CATHODE MATERIAL.

Ljiljana Nikolić-Bujanović[1] , Miloš V. Simičić[2], Sanja Mrazovac Kurilić[1]

[1]University „Union - Nikola Tesla", Faculty of Ecologi and Evironmental Protection, Belgrade, Serbia

[2]Alibrandi Impianti, Tripoli, Libya

ljnikolicbujanovic@unionnikolatesla.edu.rs

Abstract: The paper focuses on innovations in developing materials for energy sources, particularly emphasizing the potential application of ferrates as cathode materials. Advances in battery development, such as lithium-ion, lithium-sulfur, and lithium-air batteries, are crucial for various industries. Ferrates (VI) have been studied for their potential applications in batteries due to their unique characteristics, such as high theoretical capacities. However, challenges related to cycle stability and safety require further research.

The study's experiment involves producing entirely new „plastic-bound" cathodes based on electrochemically synthesized ferrates. Modifiers based on Magnéli oxides improve capacity and stability, while TiOx exhibits high conductivity. The results show that cathodes modified with Magnéli oxides have higher specific capacity and more stable operating potentials than other variants. The research suggests that ferrates modified with Magnéli oxides have potential applications in high-current and secondary energy sources.

This research opens up opportunities for further development of battery technologies that will be more efficient, have a longer lifespan, and lower costs.

Keywords: electrochemical energy sources, battery, ferrates, super iron battery

Introduction

The development of advanced batteries is one of the most active research areas in power sources. Progress in this area has many applications, including electric vehicles, stationary energy storage, portable electronics, and many others. These efforts can significantly reduce greenhouse gas emissions and improve the sustainability of the energy system.

Research in the development of new materials for batteries is crucial for improving the performance, safety, and cost-effectiveness of battery technologies (Schalkwijk, 2002, Yoshio, 2009, Salden, 2010, Bensalah, 2016). There are several key trends and achievements in this field. One of the trends is the development of various lithium battery technologies:

- **Lithium-ion batteries (Li-ion):** These remain the dominant technology for mobile devices and electric vehicles, but researchers are working on improving their capacity, safety, and cost. Increasing energy density and reducing weight are priorities.
- **Lithium-sulfur batteries (Li-S):** These batteries have the potential for higher capacity and lower cost than Li-ion batteries. Research focuses on solving issues related to cyclic stability and low conductivity.
- **Solid-state lithium-ion batteries (Solid-state Li-ion):** These batteries use solid electrolytes instead of liquid ones, improving safety and stability. Research is being conducted to enhance conductivity and reduce production costs.
- **Lithium-air batteries (Li-air):** These batteries have the potential for extremely high energy density but face challenges related to electrolyte stability and cyclic longevity.

In addition to lithium batteries, researchers are exploring new materials for anodes, cathodes, and electrolytes to improve performance and reduce costs. This includes graphene, silicon, sulfur, and other advanced materials. The use of nanomaterials can enhance battery performance. Researchers are investigating the application of nanotechnology in developing new materials for anodes, cathodes, and electrolytes to improve capacity, charging speed, and battery life.

These research efforts aim to improve existing battery technologies and enable the development of new generations of batteries with higher performance, longer life, lower costs, and greater safety. These batteries could significantly impact a wide range of industries, including electric vehicles, stationary energy storage, and portable electronics (Reddy, 2011).

Ferrate (VI) or iron(VI) oxide is one of the materials being studied as a possible anode material in batteries. This material has potential applications in lithium-ion batteries and other types of batteries due to its unique characteristics. Solid ferrates, such as Li_2FeO_4, K_2FeO_4, $SrFeO_4$, and $BaFeO_4$, in a three-electron exchange, achieve a theoretical capacity of 600, 406, 380, and 313 mAh/g, respectively, in the reaction shown by the equation:

$$FeO_4^{2-} + 5/2H_2O + 3e- \rightarrow 1/2Fe_2O_3 + 5OH^- \quad (1)$$

The theoretical Faraday capacity of Ag_2FeO_4, at nearly 400 mAh/g in a five-electron exchange (two additional one-electron exchanges of silver ions), also makes this solid ferrate attractive for application in electrochemical power sources (EIEE), although its exceptional sensitivity to light has been observed, necessitating storage and handling under complete light protection.

Research and development of ferrates as a cathodic electroactive material are generally divided into three major areas of application: 1) for alkaline batteries where the anode is most commonly based on Zn, 2) metal-hydride accumulators, and 3) lithium-ion accumulators. These EIEEs are referred to in the English literature as „super iron batteries."

One of the key challenges in using ferrates (VI) as an anode material is ensuring cycle stability. Researchers are working on solving this problem by optimizing the structure and synthesis process of the material. Additionally, the charging speed of batteries can be improved using materials with high lithium conductivity, such as ferrate (VI). This is important for applications where fast charging is crucial, such as electric vehicles. Safety is critical in batteries, mainly when potentially reactive materials like ferrate (VI) are used. Researchers are also focusing on developing safety mechanisms to minimize the risk of thermal and electrochemical failures. The cost of production is another critical factor in the commercial application of battery technologies. Research is focusing on developing synthesis processes that can reduce the production costs of ferrate (VI) and make it commercially competitive.

Although ferrate (VI) has potential as an anode material in batteries, it is currently being researched to overcome challenges and improve material performance (Licht, 2004, 2005). Further research will provide a better understanding of the possibilities and limitations of ferrate (VI) as an anode material, which may lead to its broader application in battery technologies.

EXPERIMENTAL WORK

Ferrate-based cathodes in all literature references belong to the group of pressed or pasted electrodes (Licht, 2001). The subject of this technical solution is the production of completely new „plastic bonded" cathodes based on ferrate-(VI) as the active material in the form of thin foils for use in high-current „spiral wound" constructions of alkaline electrochemical power sources by applying modifiers based on Magnéli oxides Ti_4O_7 and Ti_5O_9, which possess exceptional conductivity (comparable to graphite), high overvoltage for oxygen and hydrogen evolution reactions, as well as high corrosion stability in alkaline solutions over a wide range of potentials, which has not been covered in the literature so far.

Description of the Electrode Fabrication Process

Fabrication of „Plastic Bonded" Cathodes Based on Electrochemically Synthesized Solid $BaFeO_4$

The first step in the production of porous „plastic bonded" cathodes based on electrochemically synthesized solid $BaFeO_4$ is the homogenization in a laboratory homogenizer of 70 wt% of electrochemically synthesized solid ferrate $BaFeO_4$ (Licht, 2004, Nikolić Bujanović, 2012) and 25 wt% of T-44 graphite for 30 minutes, after which the remaining 5 wt% of the binding component, polytetrafluoroethylene (PTFE) powder - CD1, and an appropriate volume of isopropyl alcohol as a wetting and pore-opening agent are added to the mixture. The mass is then homogenized in a ceramic mortar with a pestle, after which it is passed between two horizontal stainless steel rollers rotating in opposite directions with a spacer set to a thickness of 1 mm. The mass is kneaded again in the mortar, folded, and re-extruded into a foil with a thickness of about 1 mm until a fibrous, well-connected structure is formed, which is finally developed into a thin foil through rollers with a spacer set to 0.2 mm. The electrodes are cut with a punch and then pressed into a nickel foam matrix (Ni foam) with a force of 3 MPa for 1 minute. Each electrode is vacuum-impregnated with a 5M aqueous KOH solution before electrochemical characterization. For simplicity, this type of cathode will be abbreviated as BAFE in the text.

Fabrication of „Plastic Bonded" Cathodes Based on Electrochemically Synthesized Solid $BaFeO_4$ Modified by Applying Modifiers Based on Magnéli Oxides Ti_4O_7 and Ti_5O_9 (~ 40:60 wt%)

The fabrication process for these cathodes is the same as described in section 2.1.1, except that the composition of the mass in the first step is as follows: 60 wt% electrochemically synthesized solid ferrate $BaFeO_4$, 10 wt% Magnéli oxides Ti_4O_7 and Ti_5O_9 (~ 40:60 wt%) synthesized by the procedure we presented in detail (Veljković, 2008), and 25 wt% T-44 graphite. For simplicity, this type of cathode will be abbreviated as BAFEM in the text.

Preparation of Porous Plastic Bonded Barium Ferrate Cathode Mixed with Non-Stoichiometric TiO_x ($0.92 < x < 1.19$), a Cubic Titanium Monoxide Additive (Cathode is Referred to as BAFETIO Hereinafter)

The procedure is the same as that applied for the porous plastic bonded barium ferrate cathode, except that the composition in the first step was 60 wt% $BaFeO_4$ material, 10 wt% TiO_x, and 25 wt% T-44 graphite.

Fabrication of „Plastic Bonded" Zinc-Based Anodes for Testing the Zn/$BaFeO_4$ Cell

The fabrication process for these anodes is the same as described in section 2.1.1, except that the composition of the mass in the first step is as follows: 45 wt% zinc powder (purity > 98%) and ZnO powder (purity > 99%).

All electrochemical measurements were performed with a potentiostat/galvanostat SP-150, BioLogic Inc. The potentials of the cathode were measured against the reference Hg/HgO electrode (1M KOH), with a platinum mesh used as the auxiliary electrode. Current densities were calculated based on the geometric surface area of the cathode. During the examination of the reversibility of the cathode, the charging and discharging current densities were set to 1 mA/cm, with discharging being interrupted at a potential of 150 mV relative to the reference Hg/HgO electrode, and charging ceased when the cathode was charged to 130% of the discharge capacity in the previous cycle. The cell characteristics were tested under conditions of excess aqueous 5M KOH electrolyte relative to the „plastic bonded" zinc-based anode, which was in excess.

The electrodes were separated by a Viledon FS2125 polypropylene separator.

RESULTS AND DISCUSSION

In this research, a procedure was developed to improve the performance of the cathode made from electrochemically synthesized barium ferrate using non-stoichiometric binary titanium oxides: adding titanium monoxide (TiO_x) and Magnéli phase oxides (Ti_nO_{2n-1}), which is performed during the preparation of the cathode strip. TiO_x is a very interesting ceramic material with conductivity comparable to pure titanium and high resistance to corrosion (Schoen J.M., 1969). Additionally, conductive materials of the Magnéli phase oxides, such as Ti_nO_{2n-1} ($4 < n < 10$), have been investigated as electrode materials or conductive supports in electrochemical systems due to their high conductivity and relatively high resistance to corrosion in aggressive acidic and alkaline electrolytes (Chen G.Y. et al., 2002; Farndon E.E., Pletcher D. 1997). Among this series of different valence oxide mixtures, Ti_4O_7 shows the highest electrical conductivity, greater than 1000 S/cm at room temperature, which is even higher than the 727 S/cm of graphite carbon (Smith J.R. et al., 1998).

After 2 hours of grinding the initial powder mixtures for the non-stoichiometric synthesis of binary titanium oxides, XRD analysis shows that the reactions are complete and only peaks of nano-crystalline cubic TiO_x, as well as Ti_4O_7 and Ti_5O_9, are identified. The powders consist of an amorphous phase with broad diffuse peaks and traces of crystalline phase dispersed in the amorphous matrix. After 24 hours of heating at 900°C (TiO_x) and 1100°C (Ti_4O_7 + Ti_5O_9), the mechanically synthesized samples undergo a structural change and growth into larger crystalline blocks. XRD diagrams for cubic TiO_x and (Ti_4O_7 + Ti_5O_9) are shown in Figure 1a and Figure 1b, respectively.

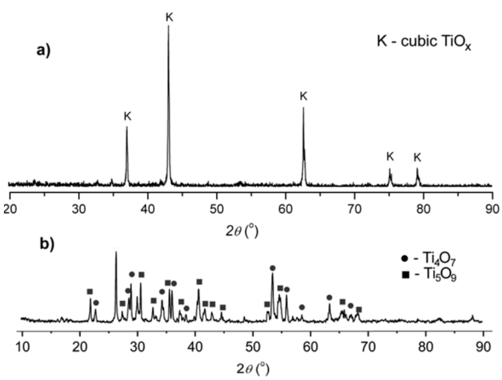


Figure 1 *XRD diagrams of TiOx and Ti_4O_7 + Ti_5O_9 mixture after annealing*

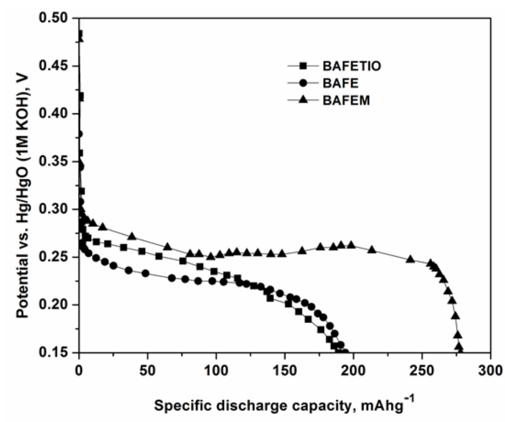


Figure 2 *Initial discharge curve of BAFETIO, BAFE and BAFEM cathodes at 1 mA/cm² mode*

Figure 2 shows a comparison of the initial discharge curve in the first cycle of the samples at a constant current density of 1 mA/cm². The BAFE (bonded barium ferrate cathode), BAFETIO (bonded barium ferrate cathode mixed with non-stoichiometric TiO_x), and BAFEM (plastic bonded barium ferrate cathode mixed with Magnèli phases) electrodes exhibit specific discharge capacities of 194, 189, and 278 mAh/g, respectively. The results show that the BAFEM cathode provides the highest capacity (about 89% of the theoretical specific capacity for BaFeO4) and gives a long plateau region above 255 mV relative to the Hg/HgO reference electrode. The BAFETIO cathode has a sloping voltage profile, unlike the flat profile of BAFE and BAFEM. The BAFEM cathode ensures stable operating potentials that are 20-30 mV higher than those of BAFE. This flat discharge potential profile is characteristic of the coexistence of two different solid phases, Fe(VI) and Fe(III), each with a composition stability range, as opposed to non-stoichiometric electrode materials that generally exhibit a sloping profile.

The cell cycle in this study was applied using an excess of electrolyte only as a first approach, as it is expected that the capacity under these conditions will rapidly decrease with the number of cycles due to the reaction components dissolving in the electrolyte and diffusing into the bulk electrolyte. The results of cyclic experiments are summarized in Table 1.

A significant loss of capacity during the first five cycles was observed for the BAFE and BAFETIO cathodes. The maximum discharge capacity of 284 mAh/g (about 91% of the theoretical specific capacity of BaFeO4) is achieved by the BAFEM cathode in the second cycle. It can be clearly seen that the capacity of BAFEM gradually decreases to a value of 194 mAh/g (about 62% of the theoretical specific capacity) in the fifth cycle.

Table 1 *Specific discharge capacity of BAFETIO, BAFE, and BAFEM cathodes in relation to the number of cycles.*

Cathode materials	**Specific discharge capacity (mAh/g) in relation to the number of cycles**				
	1st	2^{nd}	3rd	4th	5th
BAFE	194	142	101	42	21
BAFETIO	189	127	87	52	12
BAFEM	278	284	248	222	194

Cyclic voltammograms for the porous partially discharged cathodes are shown in Figure 3. The cyclic voltammograms stabilize after 2–3 cycles and do not change with further cycling. For all cathodes, a single anodic oxidation peak begins before the oxygen release reaction, and one cathodic reduction peak is observed on the CV diagrams. The redox peaks can be attributed to the electron transfer process described by reaction (1):

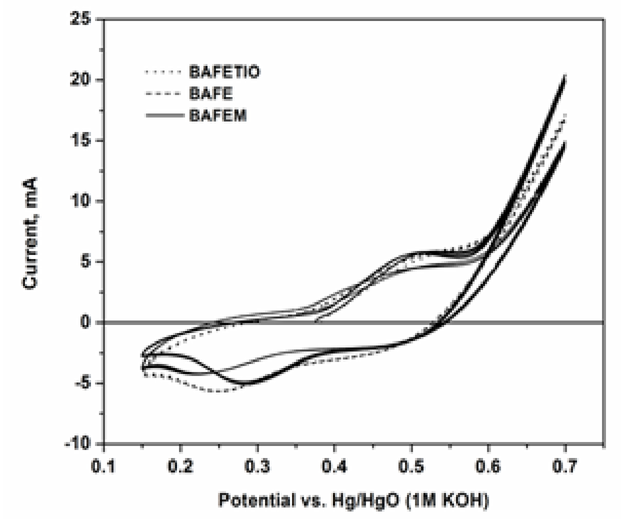


Figure 3 *CV diagram of the BAFETIO, BAFE and BAFEM cathodes at a scan rate of 100 mV/s from 0.15 V to 0.7 V vs*

Usually, the difference between oxidation and reduction potentials can be used to characterize the reversibility of a redox reaction. A more minor potential separation indicates that the electrode reaction is more reversible. As can be seen in Figure 3, the differences between the oxidation and reduction peak potentials follow the trend: BAFEM (~225 mV) < BAFETIO (~265 mV) < BAFE (~300 mV). This indicates that the charging and discharging process of the BAFEM cathode is more reversible than that of the BAFETIO and BAFE cathodes. Additionally, the equilibrium potentials of the ferrate(VI)/ferrate(III) redox pair obtained by adding the potentials of the anodic and cathodic peaks and dividing by 2 showed the following order: 397 mV vs Hg/HgO (BAFEM), 388 mV vs Hg/HgO (BAFETIO), and 370 mV vs Hg/HgO (BAFE). The obtained electrochemical results show that the composition of the BAFEM cathode material offers a combination of high specific capacity, good reversibility, and a more positive equilibrium potential compared to the BAFE and BAFETIO cathode materials. The final composition of the discharge products depends on the depth of discharge.

The inclusion of conductive Magnéli phase oxide materials as additives in the cathode has been shown in this early stage of research to improve the capacity of the BAFEM cathode material as well as its rechargeability. It is believed that the Magnéli phase oxide material increases the connectivity of the active

$BaFeO_4$ and acts as a reinforcement for the active mass, thereby helping to retain characteristics and porosity during cycling, improving the reaction kinetics at the electrode. On the other hand, the nano-crystalline cubic titanium monoxide as an additive in the BAFETIO cathode material shows only its role as a conductive additive due to its high conductivity (Smith J.R. et al., 1998; Nikolić Bujanović Lj. et al., 2012).

In this study, a complete alkaline super-ionic cell ($BaFeO_4$/Zn) was created to evaluate its electrochemical properties. The open-circuit voltage is 1.84 V. In the first galvanostatic discharge of the $BaFeO_4$/Zn cell (Figure 4), the characteristic plateau value of the discharge curve is at 1.55 V, and the cell's specific capacity is 208 mAh/g.

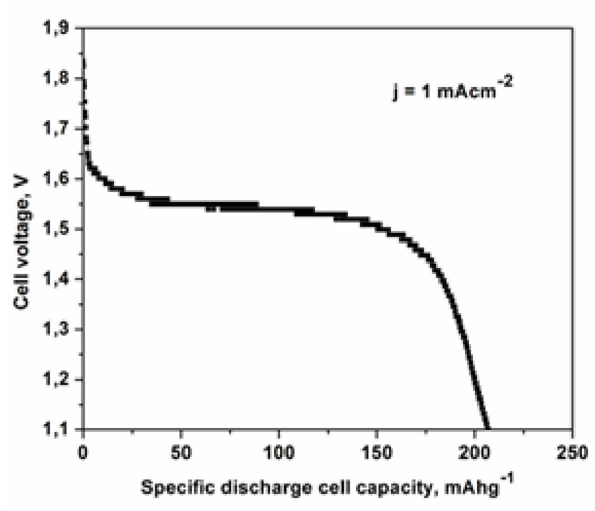


Figure 4 *Typical discharge characteristic of a BaFeO4/Zn alkaline super-ion cell*

CONCLUSION

This research has demonstrated that by implementing 'plastic bonded' cathodes based on ferrates with an open-circuit voltage of 1.84 V, a discharge curve plateau of 1.55 V, and a specific discharge capacity of 208 mAh/g, it is possible to create 'wound' structures for the production of elements for high-current discharges with completely environmentally friendly reaction products. The application of Magnéli oxide-based modifiers significantly enhances these characteristics, and it has been shown that such modified ferrate-based cathodes also exhibit a significant reversible character, making them suitable candidates for use in secondary power sources.

Acknowledgements: This paper is the result of a project REINFORCING from The European Platform for Open and Responsible Research and Innovation Practices (ORRI)

REFERENCES

Bensalah N, Dawood H. Review on synthesis, characterizations, and electrochemical properties of cathode materials for lithium ion batteries. J Mater Sci Eng 2016*;* 5(4)

Licht S, TelVered R, Halperin L. Toward Efficient Electrochemical Synthesis of Fe(VI) Ferrate and Super-Iron Battery Compounds. J Electrochem Soc 2004;151(1); A31-A39.

Licht S, Naschit V, Halperin L, Halperin N, Lin L, Chen J, Ghosh S, Liu B. Analysis of ferrate(VI) compounds and super-iron Fe(VI) battery cathodes: FTIR, titrimetric, XRD, UV/VIS, and electrochemical characterization. J Power Sources 2001;101; 167-176.

Licht S, Yang L, Wang B. Synthesis and analysis of Ag2FeO4 Fe(VI) ferrate super-iron cathodes, Electrochem Commun 2001;7; 931-936.

Nikolić Bujanović Lj, Simičić M, Cekerevac M. Electrochemical Preparation of Solid Ferrates(VI). Hem Ind 2012;66(4);455–460.

Saldan I. Primary estimation of metal hydride electrode performance. J. Solid State Electrochem 2014;14; 1339-1350

Raddy TB. An Introduction to Secondary Batteries. Chapter 15 in Linden's handbook of batteries*,* eds. Tomas B. Reddy& David Linden, Fourth Edition, The McGraw-Hill Companies, Inc; 2019.

Schalkwijk WA, Scrosati B., eds. Advances in lithium-ion batteries, Kluwer Academic Publishers; 2012.

Smith JR, Walsh FC, Clarke RL. Electrodes based on Magnéli phase titanium oxides: the properties and applications of Ebonex1 materials. J Appl Electrochem *2018;*28; 1021–1033

Veljković I, Poleti D, Zdujić M, Karanović Lj. Mechanochemistry of Titanium Oxides. Hem, ind *2009;* 63(3); 247–251.

Yoshio M, Brodd RJ, Kozawa A. Lithium-Ion Batteries Science and Technologies. Springer science + Business Media, LLC; 2009.

HYDROXYAPATITE/POLY(VINYL ALCOHOL)/CHITOSAN/GENTAMICIN COATINGS FOR BIOMEDICAL APPLICATIONS

Marija Djošić[1], Ana Janković[2], Milena Stevanović[2], Maja Vukašinović-Sekulić[2], Vesna Kojić[3], Vesna Mišković-Stanković[4]

[1]Institute for Technology of Nuclear and Other Mineral Raw Materials, Bulevar Franš d'Eperea 86, Belgrade, Serbia

[2]Faculty of Technology and Metallurgy, University of Belgrade, Karnegijeva 4, 11000 Belgrade, Serbia

[3]Oncology Institute of Vojvodina, University of Novi Sad, Put Dr Goldmana 4, 21204 Sremska Kamenica, Serbia

[4]Faculty of Ecology and Environmental Protection, University Union - Nikola Tesla, Cara Dušana 62-64, 11158 Belgrade, Serbia

vesna.miskovicstankovic@unionnikolatesla.edu.rs

Abstract: Biocomposite hydroxyapatite/poly(vinyl alcohol)/chitosan/gentamicin (HAP/PVA/CS/Gent) coating was fabricated on titanium by electrophoretic deposition process (EPD) from aqueous suspension using a constant voltage method. The bioactivity of HAP/PVA/CS/Gent coating after immersion in simulated body fluid (SBF) at 37 °C, i.e. the growth of a new phase of hydroxyapatite, was proved using scanning electron microscopy with field emission (FE–SEM) and Fourier transform infrared spectroscopy (FT–IR) analysis. Antibacterial activity was demonstrated against *Staphylococcus aureus* TL and *Escherichia coli* ATCC 25922 bacterial strains. DET tests on MRC-5 and L929 fibroblast cell lines tested cytotoxicity. The results showed the high applicability potential of biocomposite hydroxyapatite/poly(vinyl alcohol)/chitosan/gentamicin coating in orthopedic surgery.

Keywords: coatings, hydroxyapatite; poly(vinyl alcohol); chitosan; gentamicin; antibacterial activity.

INTRODUCTION

The main focus in bone implant materials research and production is based on the principle of multifunctionality, where it is necessary to meet the excellent mechanical characteristics of the bulk metal with the bioactive, especially antibacterial properties of metals' surface, through the surface modification with bioactive coatings, capable of accelerating the process of the implant integration with surrounding tissue along with minimizing the risk of infection (Zhao, 2009; Qin, 2018). The similarity of synthetic hydroxyapatite (HAP) to the inorganic part of natural bone, as well as having excellent bioactivity and biocompatibility and high potential to stimulate the osteoconductive process with no side-effects (inflammation or toxicity), makes HAP the material of choice for The metallic The implants The' surface modification (Jeong, 2019; Varadavenkatesan, 2021). As a brittle material, HAP needs to be combined with polymers. Biocompatible polymers chitosan (CS) and poly(vinyl alcohol) (PVA) are often used for soft and hard tissue reparation, as drug carriers, or as part of composite coatings on the metallic implants' surface. The antibiotic-loaded implants' surface coatings enable the delivery of high drug concentrations directly at the infection site, reducing the possibility of side effects, which may occur during systemic antibiotic administration. Gentamicin is the most often used antibiotic for implant coating incorporation (local administration), having broad-spectrum activity, rapid and dose-dependent activity, and minimal host tissue toxicity.

MATERIALS AND METHODS

Titanium foils were employed as substrates for the electrophoretic deposition process (EPD). Aqueous suspensions for the EPD of composite coatings contained hydroxyapatite powder (particles <200 nm), chitosan powder (medium molecular weight 190-310 kDa, 75-85% deacetylation degree), poly(vinyl alcohol) (medium molecular weight 89-98 kDa, 99% hydrolyzed), and gentamicin sulfate solution (50 mg/mL in dH2O), all purchased from Sigma Aldrich, USA. Before electrophoretic deposition, Ti plates were mechanically polished and ultrasonicated in acetone and ethanol for 15 and 5 min, respectively.

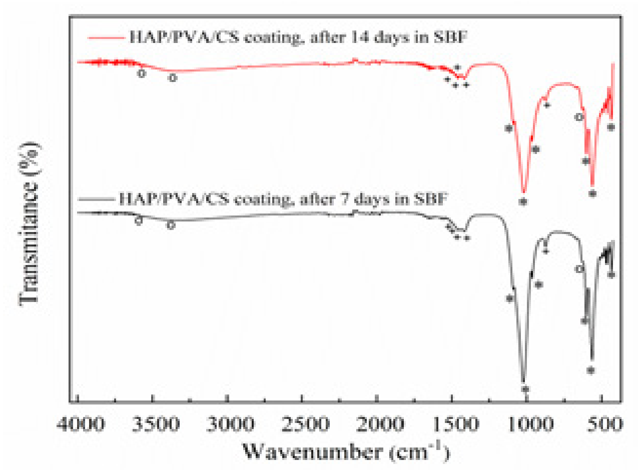
Electrophoretic deposition

The bath for EPD of HAP/PVA/CS composite coating was 1 wt% HAP powder, 0.1 wt% PVA, and 0.05 wt.% CS. In the bath for deposition of HAP/PVA/CS/Gent composite coatings with antibiotic, 0.1 wt.% of gentamicin sulfate was added. pH values were measured to be 4.23. EPD was performed at a constant voltage of 7 V and for a deposition time of 12 min. Deposited coatings were air-dried for 24 h at room temperature (Djošić, 2023).

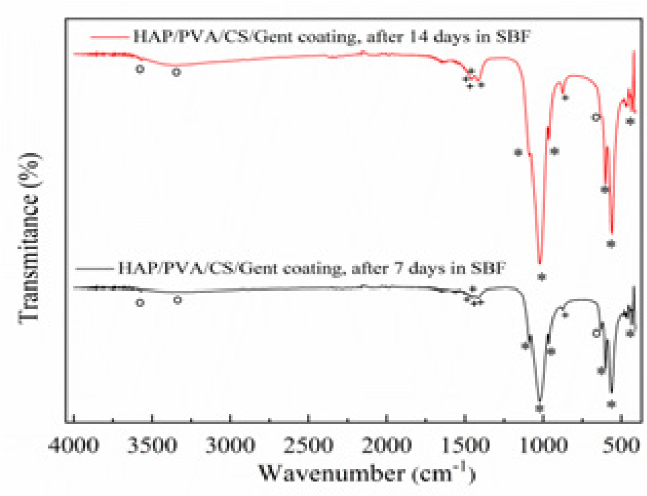
Fourier transform infrared (FTIR) spectroscopy was performed by a Nicolet IS-10 (Thermo Fisher Scientific) in ATR mode (400–4000 cm^{-1} range). Field-emission scanning electron microscopy (FE-SEM) was performed in combined SE-BSE mode using Mira 3 XMU FEG-SEM (Tescan, CESKA), operating at 20 kV voltage acceleration. Antibacterial activity was evaluated against *Staphylococcus aureus* and *Escherichia coli* by quantitatively monitoring changes in the viable number of bacterial cells in suspension. DET cytotoxicity test was performed on fibroblast cell lines - mouse L929 and human lung MRC-5 (Djošić, 2023; Jaćimović, 2023).

RESULTS AND DISCUSSION

Biocomposite HAP/PVA/CS and HAP/PVA/CS/Gent coatings on Ti substrate were successfully obtained by electrophoretic deposition (EPD). Homogeneous coatings of uniform thickness were assembled at a constant deposition voltage of 7 V for 12 min. The bioactivity of both HAP/PVA/CS and HAP/PVA/CS/Gent coatings after immersion in simulated body fluid (SBF) at 37 °C, i.e., the growth of a new phase of hydroxyapatite, was proved from FT-IR (Fig. 1) and FE-SEM analysis. In addition, FTIR spectra confirmed the presence of characteristic carbonate bands and AB-type substitution in HAP structure, as well as B-type substitution (Jaćimović, 2023).



(a)



(b)

Figure 1 *FTIR spectra of (a) HAP/PVA/CS and (b) HAP/PVA/CS/Gent coatings after soaking in SBF at 37 ºC for 7 and 14 days (bands denotation: * PO_4^{3-}; + CO_3^{2-}; º OH^-) (reprinted from Jaćimović, 2023 with permission from the Society of Chemists and Technologist of Macedonia)*

Both HAP/PVA/CS and HAP/PVA/CS/Gent coatings proved non-cytotoxic against two fibroblast cell lines: human MRC-5 and mouse L929 (Fig. 2), while the HAP/PVA/CS/Gent coating exhibited antibacterial activity against *Escherichia coli* and *Staphylococcus aureus* bacterial strains (Fig. 3a and b).

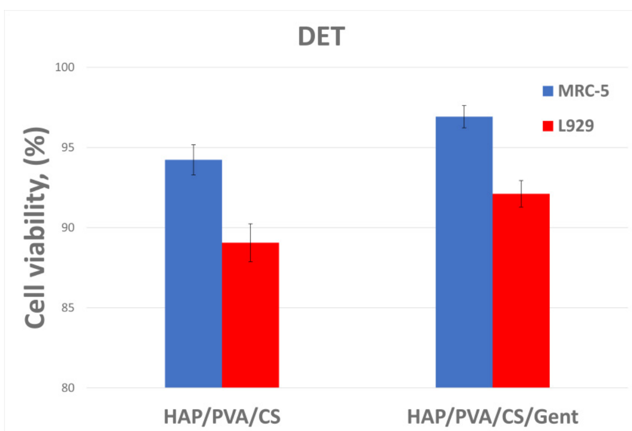
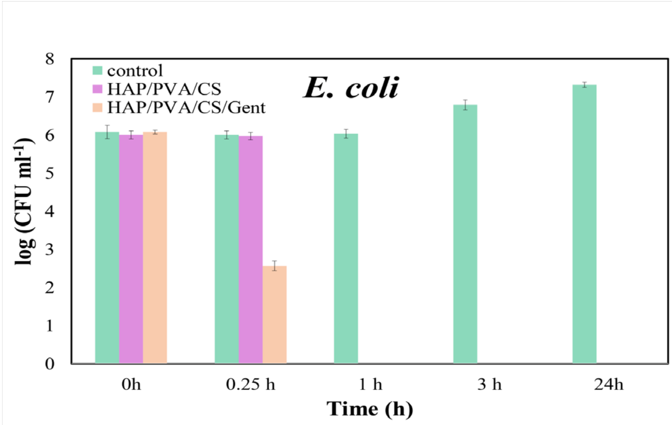
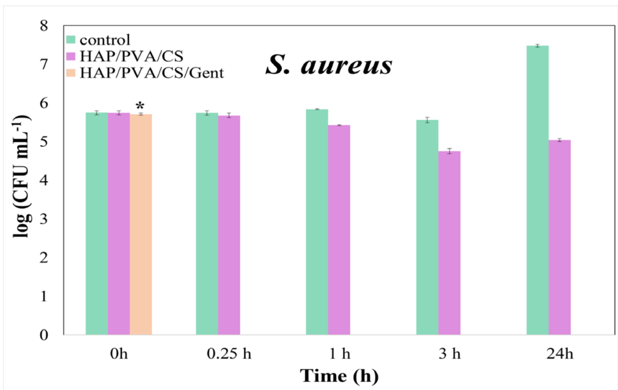


Figure 2 *MRC-5 and L929 cells viability in the presence of HAP/PVA/CS and HAP/PVA/CS/Gent coatings (reprinted from Jaćimović, 2023 with permission from the Society of Chemists and Technologist of Macedonia).*



(a)



(b)

Figure 3 *Antibacterial activity of HAP/PVA/CS and HAP/PVA/CS/Gent coatings against E.coli (a) and S.aureus (b) (reprinted from Jaćimović, 2023 with permission from Elsevier)*

CONCLUSION

The antibacterial activity of the HAP/PVA/CS/Gent coating was validated against the bacterial strains *S. aureus* and *E. coli*. In contrast, the DET test confirmed non-toxicity, proving its potential medical applications as a complex tissue implant.

REFERENCES

Zhao L, Chu PK, Zhang Y, Wu Z. Review Antibacterial Coatings on Titanium Implants. J. Biomed Mater Res B 2009;91;470–480.

Qin S, Xu K, Nie B, Ji F, Zhang H. Approaches based on passive and active antibacterial coating on titanium to achieve antibacterial activity. J Biomed Mater Res A 2018; 106;2531–2539.

Jeong J, Kim JH, Shim JH, Hwang NS, Heo CY. Bioactive calcium phosphate materials and applications in bone regeneration. Biomater Res 2019;23;1–11.

Varadavenkatesan T, Vinayagam R, Pai S, Kathirvel B, Pugazhendhi A, Selvaraj R. Synthesis, biological and environmental applications of hydroxyapatite and its composites with organic and inorganic coatings. Prog Org Coatings 2021;151 106056.

Djošić M, Janković A, Stevanović M, Stojanović J, Vukašinović-Sekulić M, Kojić V, Mišković-Stanković V. Hydroxyapatite/poly(vinyl alcohol)/chitosan coating with gentamicin for orthopedic implants. Mater Chem Phys 2023;303;127766.

Jaćimović N, Djošić M, Janković A, Grujić S, Matić-Bujagić I, Stojanović J, Vukašinović-Sekulić [M], Kojić V, Mišković-Stanković V. Single-step, electrophoretically deposited hydroxyapatite/poly(vinyl alcohol)/chitosan/gentamicin coating for biomedical applications. *Maced J Chem Chem Eng* 2023*;*42;249-262.

PHOTOCATALYTIC DEGRADATION OF METHYLENE BLUE BY THE MODIFIED TiO_2-Zr CATALYST

Marija Vasić Jovev[1], Marjan Ranđelović[1], Radomir Ljupković[1], Miloš Marinković[2], Hadi Waisi[2,3], Aleksandra Zarubica[1]

[1]University of Niš, Faculty of Science and Mathematics, Department of Chemistry, Višegradska 33, 18000 Niš, Serbia

[2]University of Belgrade, Institute of General and Physical Chemistry, Studentski trg 12/V, P.O. Box 45, 11158 Belgrade, Serbia

[3]University UNION-Nikola Tesla, Faculty of Ecology and Environmental Protection, Belgrade, Serbia

marija.vasic@pmf.edu.rs

Abstract: The TiO_2-based catalyst was synthesized by a modified sol-gel process and chemically modified using zirconium as a selected dopant. Physico-chemical characterizations of the prepared catalyst were investigated. Structural properties, crystallization, and phase determination were examined using X-ray diffraction, and morphological properties were studied using the SEM method. The photocatalytic activity of the modified TiO_2-Zr catalyst was tested in the reaction of Methylene Blue (MB) degradation. The obtained results showed that the prepared TiO_2-Zr-based catalyst is characterized by good crystallinity, mixed crystalline phases, and suitable morphology that ensures favorable photocatalytic activity in the decomposition of Methylene blue dye under relatively mild reaction conditions.

Keywords: doping, heterogeneous catalysis, methylene blue, titania, zirconium.

INTRODUCTION

Water pollution is a global problem. Numerous chemicals in different industrial processes can be very dangerous for marine life and the environment and disturb the ecological balance. One such substance is Methyl Blue dye, which is widely used in various industrial processes, including producing materials, textiles, paper printing, etc. (Bhattacharyya and Sharma, 2005; Mohapatra and Parida, 2006; Vasić, 2017).

Various methods can be used for waste water purification treatment, and heterogeneous catalysis stands out among them (Jain and Shrivastava, 2008). As part of heterogeneous catalysis, one of the most studied materials is TiO_2-based catalyst, which is characterized by its numerous advantages in terms of preparation method and price, as well as simplicity of application in photocatalytic reactions (Fan et al., 2011; Jain and Shrivastava, 2008; Vasić, 2017). However, its activity is limited by UV radiation due to its band gap energy of approximately 3,2 eV (Franco et al., 2009; Vasić, 2017). To improve the activation process and activity, numerous methods are used to modify pure TiO_2-based catalyst, and one of the methods that stands out is doping with appropriate (transition) metal (Kapusuz et al., 2013; Vasić, 2017). Among the metals that can be used for titania doping is zirconium due to its similar properties to titanium, as they both belong to same group of elements, and it is considered that zirconium can improve physico-chemical and photocatalytic properties of TiO_2 in their joined interaction (Kapusuz et al., 2013; Lukáč et al., 2007; Vasić, 2017).

This work aimed to synthesize a modified/doped TiO2-Zr catalyst with optimal physicochemical characteristics and test it in the photocatalytic reaction of Methylene Blue (MB) dye decomposition (Vasić, 2017).

MATERIAL AND METHODS

The TiO2-based material was prepared by a modified sol-gel method using Titanium isopropoxide as a precursor. During the synthesis process, the pH value was adjusted to 10, and the calcination temperature applied after the precipitation process was 650 °C. After that, the prepared TiO2 sample was doped with 2.5 wt. % of zirconia using ZrOCl2 x 8H2O. The doped sample, denoted as TiO_2-Zr, was dried and then calcined at 800 °C (Vasić, 2017).

Structural properties of the prepared TiO_2-Zr catalyst were examined using the XRD method, and morphological characteristics by using the SEM method. In order to test its photocatalytic activity, Methylene Blue (MB) dye solution was used as a model pollutant. For activation of as prepared TiO_2-Zr catalyst in the photocatalytic reaction of MB dye degradation, UV radiation was employed with the use of a UV lamp (16 W, λ=366 nm). Before the testing photocatalytic activity, adsorption of the MB dye on the catalyst surface was performed without the presence of UV radiation in the dark till the adsorption/desorption equilibrium was reached. The changes in MB dye concentration during the reactions were monitored on a UV/VIS spectrophotometer (Vasić, 2017).

RESULTS AND DISCUSSION

Based on the results of the structural properties, presented in Figure 1. (Vasić, 2017) it can be noted that the TiO_2-Zr-based catalyst is characterized by the most intense peaks ~25° and ~27° Bragg diffraction angle corresponding to the anatase and rutile crystal phase, respectively (according to JCPD Cards No. 21-1272 for anatase and 21-1276 for rutile) (Arbuj et al., 2010; Gao et al., 2016; Koelsch et al., 2002; Vasić, 2017). Furthermore, a diffraction peak at ~30° Bragg angle can be observed, corresponding to either brookite TiO_2 crystal phase and/or monoclinic ZrO_2 phase. The TiO_2-Zr catalyst is characterized by the peaks of high intensity, which indicates a favorable crystal structure (Vasić, 2017). All discussed structural properties influence the performance of the synthesized TiO_2-Zr-based catalyst in the tested photocatalytic reaction of Methylene Blue decomposition (Vasić, 2017).

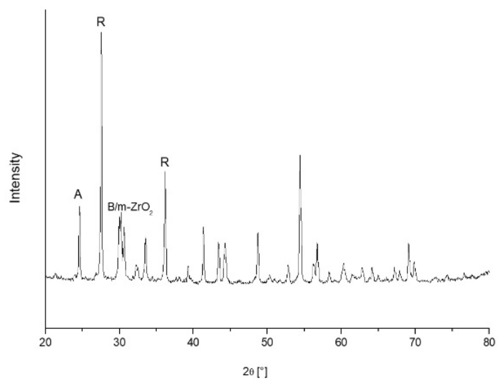


Figure 1 *XRD spectrum of TiO_2-Zr catalyst (Vasić, 2017).*

Figure 2 presents an SEM image of the prepared TiO2-Zr catalyst (Vasić, 2017). The prepared TiO2-Zr catalyst surface contains a small number of spherical and a larger number of rod-shaped primary particles formed as a result of intense crystallization at elevated calcination temperatures. The primary particles mentioned tend to form agglomerates. Furthermore, the porosity of the prepared material is characterized by inter-agglomerate pores and the appropriate porosity (Vasić, 2017).

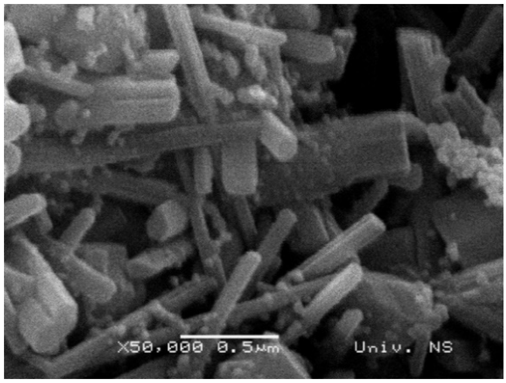


Figure 2 *SEM image of TiO_2-Zr catalyst (Vasić, 2017).*

The photocatalytic degradation of Methylene Blue dye by the prepared TiO_2-Zr catalyst is shown in Figure 3. It can be noted that after 22 hours almost complete decolorization of Methylene Blue dye was achieved, under relatively mild conditions, the original pH of the dye solution, and relatively low UV irradiation. This can be related to the appropriate structural and morphological properties. Namely, TiO_2-Zr catalyst has favorable crystallinity, the presence of mixed crystalline phases and acceptable morphological properties (Vasić, 2017).

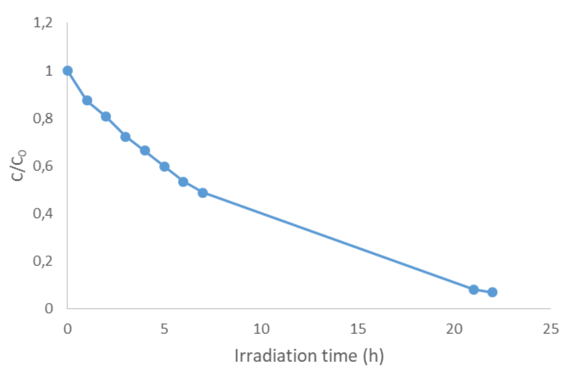


Figure 3 *The photocatalytic degradation of Methylene Blue dye with the use of TiO_2-Zr catalyst*

CONCLUSION

In the scope of this work, TiO_2-Zr catalyst was prepared using a relatively simple synthesis technique (Vasić, 2017). The prepared TiO_2-Zr catalyst showed good activity in the tested photocatalytic reaction of Methylene Blue dye decomposition. The activity presented in this paper is correlated with its physico-chemical characteristics, good crystal structure, presence of mixed crystalline phases, and appropriate morphology. Namely, almost complete degradation of the tested MB dye was achieved in relatively mild reaction conditions (Vasić, 2017). It can be noted that TiO_2-Zr-based material is a promising material for future research because it is efficient and it can be prepared relatively easily.

ACKNOWLEDGEMENT

The work was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract numbers: 451-03-65/2024-03/200124, 451-03-66/2024-03/200124 and 451-03-66/2024-03/200051) and by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Project number: ON 172061).

REFERENCES

Arbuj S, Hawaldar S, Mulik RR, Wani UP, Amalnerkar BN, Waghmode SB. Preparation, characterization and photocatalytic activity of TiO_2 towards methylene blue degradation. Mater Sci Eng B 210;168; 90-94.

Bhattacharyya K, Sharma A. Kinetics and thermodynamics of Methylene Blue adsorption on Neem (Azadirachta indica) leaf powder. Dyes Pigm 2005;65;51-59.

Fan HJ, Lu C, Lee WL, Chiou MR, Chen, CC. Mechanistic pathways differences between P25-TiO_2 and Pt-TiO_2 mediated CV photodegradation. J Hazard Mater 2011;185

Franco A, Neves MC, Carrott MM, Mendonca MH, Pereira MI, Monteiro OC. Photocatalytic decolorization of methylene blue in the presence of TiO_2/ZnS nanocomposites. J Hazard Mater 2009;161;545-550.

Gao R, Jiao Z, Wang Y, Xu L, Xia S, Zhang H. Eco-friendly synthesis of rutile TiO_2 nanostructures with controlled morphology for efficient lithium-ion batteries. Chem Eng J 2016;304;156-164.

Jain R, Shrivastava M. Photocatalytic removal of hazardous dye cyanosine from industrial waste using titanium dioxide. J Hazard Mater 2008;152;216-220.

Kapusuz D, Park J, Ozturk A. Sol–gel synthesis and photocatalytic activity of B and Zr co-doped TiO_2. J Phys Chem Solids 2013;74;1026-1031.

Koelsch M, Cassaignon S, Guillemoles JF, Jolivet, JP. Comparison of optical and electrochemical properties of anatase and brookite TiO_2 synthesized by the sol–gel method. Thin Solid Films 2002;403–404;312-319.

Klementová M, Bezdička P, Bakardjieva S, Šubrt J, Szatmáry L, Bastl, Z, Jirkovsky J. (2007). Influence of Zr as TiO_2 doping ion on photocatalytic degradation of 4-Chlorophenol. App Catal B: Environ 2007;74; 83–91

Mohapatra P, Parida K. Photocatalytic activity of sulfate modified titania 3: Decolorization of methylene blue in aqueous solution. J Mol Catal A: Chem 2006;258; 118–123.

Vasić M. Optimisation and photocatalytic application of nanostructured TiO_2. Niš. Doctoral dissertation; 2017.

SAPROPHYTIC MICROORGANISMS AS INDICATORS OF SOIL POLLUTION

Marko Milojković[1*], Hadi Waisi [2,3], Miloš Marinković [2], Aleksandar Marinković [2], Slavica Blagojević[4], Bogdan Nikolić[5], Marija Vasić Jovev[6]

[1] Public utility enterprise-Veterinary Belgrade, Bulevar Despota Stefana 119, 11000 Belgrade, Serbia

[2] Institute of General and Physical Chemistry, Studentski trg 12/V, P.O. Box 45, 11158 Belgrade, Serbia

[3] Faculty of Ecology and Environmental Protection, University UNION-Nikola Tesla, Cara Dušana 62-64, 11000 Belgrade, Serbia

[4] University of Belgrade - Faculty of Pharmacy, Vojvode Stepe 450, 11221 Belgrade, Serbia

[5] Institute of Plant Protection and Environment, University of Belgrade, Teodora Drajzera 9, 11000 Belgrade, Serbia

[6] University of Niš, Department of Chemistry, Faculty of Science and Mathematics, Višegradska 33, 18000 Niš, Serbia

*markomilojkovic24@yahoo.com

Abstract: Soil pollution is a critical environmental concern, and the role of microorganisms in indicating the extent of contamination is increasingly recognized. This study investigates the dynamics of saprophytic microorganisms in soils with varying degrees of pollution. Elevated carbon levels accelerate the reproduction of saprophytic bacteria, while *Bacillus mesentericus*, typically absent in uncontaminated soils, proliferates in environments rich in organic matter of fecal origin. Our findings indicate that the presence and quantity of specific microorganisms, particularly *Bacillus mesentericus*, can be reliable indicators of soil pollution. The total microbial count in uncontaminated soils does not exceed 1.6×10^6 per gram, whereas in polluted soils, saprophytic bacteria can reach concentrations of 40×10^6 per gram. These results underscore the importance of microbial indicators in environmental monitoring and soil quality assessment.

Keywords: oil pollution, saprophytic microorganisms, environmental monitoring, soil quality

INTRODUCTION

Assessing soil pollution through biological indicators, particularly saprophytic microorganisms, has become an essential approach to environmental monitoring. Soil pollution in populated areas often leads to an increase in carbon content, which accelerates the reproduction of saprophytic bacteria. Studies have shown that in soils contaminated with nitrogenous organic matter, there is often a significant shift in the ratio of bacterial cells to spores, with a reduction in spore formation compared to uncontaminated soils (Selivanovskaya & Galitskaya, 2011). This variability suggests that uniform standards for soil cleanliness may not be applicable across different environments.

Globally, the use of saprophytic bacteria as indicators of soil pollution is widely recognized in environmental science. In regions such as Europe and North America, these microorganisms, particularly Bacillus species like *Bacillus mesentericus*, are used to assess the impact of organic pollutants on soil health. These bacteria are typically scarce in remote, unpolluted soils but proliferate in areas with high organic input, such as near septic tanks or where manure is applied. This application highlights the critical role of saprophytic bacteria in monitoring soil quality and guiding remediation efforts.

Uncontaminated soils generally harbor lower bacterial populations, with counts around 10^6 bacteria per gram of soil (Schloss & Handelsman, 2006). However, in polluted environments, the bacterial load increases significantly, making these organisms valuable bioindicators of soil pollution. The increase in bacterial populations following organic contamination has been well-documented, and over time, these populations can provide insights into the soil's self-purification capacity. This approach has been utilized in various global contexts, from agricultural lands to urban environments, where the presence of these bacteria indicates both the level of pollution and the progress of natural soil remediation processes. In pristine environments, such as undisturbed forests and meadows, the bacterial counts are typically lower, reflecting the absence of significant organic pollution. These conditions, often associated with high humus content, show that clean soils maintain a delicate balance of microbial life (Acea et al., 1988; Hoorman, 2011). The depth-dependent decrease in bacterial populations in clean soils further illustrates the natural stratification of microorganisms and the minimal impact of human activities. In contrast, soils in urban or industrial areas, often subjected to pollution, exhibit a rapid increase in both saprophytic and fecal bacteria, sometimes even in deeper soil layers. This trend is linked to the diffusion of organic pollutants, which stimulate microbial growth. The global application of saprophytic microorganisms as bioindicators underscores their importance in assessing soil health, identifying pollution sources, and informing remediation practice. Taking into account the constant need to determine soil contamination by microorganisms, the following work objectives were set:

1. Determining the number of saprophytic bacteria in soil at different stages of pollution

2. Monitoring the dynamics of the abundance of saprophytic bacteria

3. Calculation of the number of saprophytic bacteria in different cultivated soils

4. To determine the content of microorganisms in different soil layers of populated areas

MATERIALS AND METHODS

Cultivable and non-cultivable plots in the village of Vukašinovac, municipality of Aleksinac, were used for the purpose of this study. The collection of soil samples was carried out in the period 01.03.2024. until 10.08.2024. Bacteria and spores were counted at the Institute of Physical Chemistry in Belgrade. A Peteroff-Hauser bacteria counter was used. The soil sample was diluted with distilled water. The bacteria in the sample are exposed to light, absorbing or reflecting light. The amount of light passing through the sample is measured by a detector which was converted into a numerical value representing the concentration of bacteria (Andani, 2016).

Detection of pathogenic bacteria was done on Petri dishes. After dilution with distilled water, sowing was done on blood agar and MacConkey agar by following formulas.

Blood agar (Columbia Blood Agar Base, Oxoid Ltd., UK):

Strach	23 g
NaCl	5 g
Agar	10 g
dH_2O	1000 mL

After autoclaving, 5% sterile defibrillated sheep blood was added.

MacConkey agar (Oxoid Ltd., UK i Hi-Media, Indija):

Peptone	20 g
Lactose	10 g

Bile salts	5 g
Neutral red, $C_{15}H_{17}ClN_4$	0,075 g
Agar	10 g
dH_2O	1000 mL

RESULTS AND DISSCUSION

The data demonstrate a clear correlation between soil pollution and the proliferation of saprophytic bacteria. In uncontaminated soils, the total bacterial count is low, with a relatively stable spore percentage. In contrast, soils contaminated with organic matter, such as those near septic tanks or manure deposits, show significantly higher bacterial counts, particularly of *Bacillus mesentericus*.

Table 1 *Number of saprophytic bacteria in soil at different stages of pollution*

Place of sampling	Total No. of bacteria	Number of spores	Spores %	Number *Bacillus mesentericus*
Forest	750	250	33,33	0
Forest near the settlement	2500	630	25,2	0
Yard	4800	1255	26,14	35
Soil next to the street	4750	723	15,22	25
Soil near the septic tank	8300	1350	16,26	327
Soil 10 m from the manure	1900	290	15,26	175
Soil from the manure	5100	310	6,07	34

Table 2 *Dynamics of the abundance of saprophytic bacteria in the soil of the experimental tomato plot*

Control				Soil with feces			Soil with manure		
Date	Total No. of bacteria	Number of spores	Spore %	Total No. of bacteria	Number of spores	Spores%	Total No. of bacteria	Number of spores	Spores %
10.03.	910	350	38,46	-	-	-	-	-	-
11.04.	2100	398	18,95	42680	1780	4,17	31568	1200	3,8
05.05.	1879	321	17,08	72650	2235	3,07	9543	1345	14,09
01.06.	1500	254	16,93	34530	985	2,85	2697	435	16,14
25.06.	350	168	48	6700	1124	16,77	1345	875	66,05
25.07.	290	95	32,75	1230	650	52,84	345	279	80,86

Table 3 *Dynamics of the abundance of saprophytic bacteria in different soils (U 10^3/l g of soil)*

Soil	Date of sampling			
	11.03.	15.04.	17.05.	28.06.
Unpolluted, control	410	875	543	378
Contaminated with sheep excrement, untreated	620	1124	1345	1780
Contaminated with sheep excrement, processed	3200	1156	435	532

Table 4 *Content of microorganisms in different soil layers of populated areas*

Place of sampling	Sampling depth	Total number of bacteria, 10^3/lg of soil	Coli-titer
Cornfield	0-0,25	578	1,0
	0,25-50	623	1,0
	50-1	712	2,0
Shepherd	0-0,25	32000	0,0002
	0,25-50	2134	0,01
	50-1	3456	0,002
A place where manure is deposited	0-0,25	42780	0,0001
	0,25-50	15690	0,02
	50-1	45630	0,00001

Park	0-0,25	780	2,3
	0,25-50	458	2,2
	50-1	210	2,3
Channelized household	0-0,25	1230	1,9
	0,25-50	568	1,8
	50-1	764	2,9
Non-channelized household	0-0,25	21340	0,001
	0,25-50	9870	0,001
	50-1	7680	0,001
Company territory	0-0,25	45890	0,002
	0,25-50	23450	0,002
	50-1	2340	1
The territory of the animal feed company	0-0,25	12000	0,01
	0,25-50	10980	0,001
	50-1	2134	1,0

The soil in populated areas often contains elevated levels of organic carbon, which promotes the accelerated proliferation of saprophytic bacteria. In particular, Bacillus species are known to thrive in soils contaminated with nitrogenous organic matter, with a smaller proportion of the population existing in the form of spores under these conditions (Selivanovskaya & Galitskaya, 2011). In contrast, the ratio of vegetative bacteria to spores in uncontaminated soils tends to shift, indicating the absence of consistent standards for assessing soil cleanliness across different locations. The presence and abundance of specific microorganisms can serve as reliable indicators of soil pollution. For instance, *Bacillus mesentericus* is either absent or present in minimal quantities in soils distant from human settlements (Table 1). However, these bacteria multiply rapidly in soils surrounding septic tanks and manure heaps. In uncontaminated soils, bacterial counts typically range around 10^6 CFU/g of soil (Schloss & Handelsman, 2006). However, this number increases markedly in response to organic pollution. *Bacillus mesentericus*, among other microbes, can thus be employed to indicate the soil's sanitary condition. Introducing fecal matter or manure into the soil leads to a notable rise in total bacterial counts (Table 2). Bacterial proliferation is more pronounced in soils treated with feces due to its higher organic content than manure. The number of spores also increases, but at a slower rate compared to the overall bacterial population (Table 2). As time progresses, asporogenous bacteria tend to decline, while bacilli persist, leading to a relative increase in spore numbers, eventually stabilizing near control levels.

Soil contamination with organic matter typically increases saprophytic bacteria and a concomitant decrease in spore numbers. As the trial progressed, bacterial counts and spore ratios began to approach control values, though complete normalization occurred later.

The data indicate bacterial proliferation was most intense in the tilled plot, leading to a more rapid self-cleaning process (Table 3). These findings align with results reported by other researchers (Pešaković et al., 2003). The total bacterial count in uncontaminated soils does not exceed 1.6×10^6 exceed CFU/g (Acea et al., 1988). In forest and meadow soils not treated with manure, bacterial counts do not exceed 2.5×10^6 CFU/g in the 0-30 cm layer (Hoorman, 2011). Bacterial numbers decline with increasing soil depth (Table 4).

In clean soils, the titer of intestinal group bacteria does not fall below 0.1. However, fecal contamination leads to a significant increase in fecal bacteria. The number of saprophytic bacteria in polluted soils can reach 40×10^6 CFU/g, as shown in Table 4. The number of saprophytic and fecal bacteria increases rapidly in areas subject to pollution, such as streets and industrial sites that generate organic waste. This proliferation is often observed even at a depth of 1 meter, where an increased microbial load can be detected. The elevated number of saprophytic bacteria in deeper soil layers can be attributed to the diffusion of organic matter through the soil, which stimulates the growth of these microorganisms.

CONCLUSION

Based on the present, we can conclude that the influence of soil pollution with organic substances acts on saprophytic bacteria in the way that it leads to an increase in their number. Also, it increases the percentage of asporogenic bacteria and influences the transition of bacterial spores to the vegetative state, and thus, the percentage of spores decreases about the total number of bacillary forms. Given the increase in the number of *Bacillus mesentericus* bacteria in soil with organic matter, it could, along with other microorganisms, be used as an indicator of sanitary pollution.

ACKNOWLEDMENT

The work was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract numbers: 451-03-65/2024-03/200124, 451-03-66/2024-03/200124, 451-03-66/2024-03/200051, University of Belgrade - Faculty of Pharmacy No 451-03-65/2024-03/ 200161).

REFERENCES

Acea MJ, Moore CR, & Alexander M. Survival and growth of bacteria introduced into soil. Soil Biol 1988;20(4);509-515.

Andani R. Pengaruh jarak sumur dengan septic tank terhadap populasi escherichia coli di lingkungan Jempong Timur dan Jempong Barat sebagai kajian mata kuliah mikrobiologi (Doctoral dissertation, IAIN Mataram); 2016.

Hayakawa M. Studies on the isolation and distribution of rare actinomycetes in soil. Actinomycetologica 2008; 22(1); 12-19.

Hoorman, JJ. The role of soil bacteria. Ohio State University Extension. Columbus 2011; 1-4.

Kindaichi T, Ito T, & Okabe S. Ecophysiological interaction between nitrifying bacteria and heterotrophic bacteria in autotrophic nitrifying biofilms as determined by microautoradiography-fluorescence in situ hybridization. Appl Environ Microb 2004; 70(3); 1641-1650.

Mandić L, Đukić D, & Stevović V. The effect of different kinds of fertilizers on the number of Azotobacters in the smonitza type of soil under maize and the yield of maize; 2005

Mandić L, et al. „Mikrobiološka ocena sanitarnog stanja zemljišta." Zbornik radova 1, 24. Savetovanje o biotehnologiji sa međunarodnim učešćem, Čačak, 15-16. mart 2019; 351-355.

Pešaković M, Mandić L, & Đukić D. Soil ammonification activity in the conditions of mineral and organic fertilizer use. Acta Agric Serb 2003;8(16);49-56

Schloss PD, & Handelsman, J. Toward a census of bacteria in soil. PLoS Comput Biol 2006; 2(7); e92.

Selivanovskaya SY, & Galitskaya PY. Ecotoxicological assessment of soil using the *Bacillus pumilus* contact test. Eur J Biol 2011;47(2);165-168.

Seo G, Akimoto Y, Hamashima H, Masuda K, Shiojima K, Sakuma C, Arai T. A new factor from Bacillus mesentericus which promotes the growth of Bifidobacterium. Microbios;2009; 101(399);105-114.

ROAD RECONSTRUCTION IN NOVI SAD PM10 RISK EXPOSURE ASSESSMENT

Miljan Šunjević, Boris Obrovski, Nikolina Tošić, Dunja Istrat

Faculty of Technical Sciences, University of Novi Sad

msunjevic@uns.ac.rs

Abstract

Road reconstructions pose significant environmental challenges, particularly in relation to airborne particulate matter (PM) emissions. High concentration levels generated on these construction sites requires advanced assessment to PM10 exposure. The PM10 levels were modeled using the EMEP EEA Tier 1 emission factors for road reconstruction. The obtained high PM concentration levels show necessity to understand the risk it poses to the environment and humans (both workers and people living in the vicinity). The research concentrates on the health risks associated with elevated PM10 concentration levels, which are primarily generated during earth excavation and construction processes. Assessment is conducted applying the dose-response functions, Time-Weighted Average (TWA) comparisons with Occupational Exposure Limits (OELs), and Air Quality Index (AQI) calculations. The results indicate extensive health risks increase associated with elevated PM10 levels. The research highlights the need for application of mitigation models to protect public health and the environment during road reconstruction activities.

Keywords: road reconstruction, PM exposure, risk assessment.

INTRODUCTION

Air pollution, particularly particulate matter (PM) emissions, poses a significant environmental and health challenge globally. World Health Organization (WHO) has defined particulate matter as one of the crucial air pollutants in the modern society (WHO, 2021). Numerous researches have proven that PM has adverse health effects (Cohen et al., 2017; Kim et al., 2015; Pope & Dockery, 2006; Requia et al., 2018; Yadav et al., 2022)including India. The nationwide lockdown was imposed in India from March 25 to May 31, 2020 to prevent the transmission of COVID-19. The study intends to assess the impact of the absence of major anthropogenic activities during the various phases of the COVID-19 lockdown (LDN. The most important PM is classified as fine particles, because due to its size it can easily penetrate deep into the respiratory system, causing a wide range of health problems, including cardiovascular and respiratory diseases. Particularly, researchers observe PM classified as PM10 (≤10 µm in diameter) and PM2.5 (≤2.5 µm) (WHO, 2021). Construction activities are a major source of PM emissions in urban environments, contributing to poor air quality and associated health risks for workers and surrounding communities (Sunjevic et al., 2022, 2023). Among various construction activities, road reconstruction has high impact due to its high levels of dust generation and prolonged exposure to PM emissions (GLA, 2014).

Road reconstruction activities involve extensive excavation, material transportation, demolition, and use of heavy machinery, which all generate significant quantities of PM. The emissions are further enhanced by the use of diesel-powered equipment, which contributes not only to PM but also to nitrogen oxides (NOx) and other harmful pollutants. In densely populated urban areas, road construction and reconstruction projects can have immediate and long-term impacts on local air quality, with potentially severe consequences for public health. Understanding the threat it poses is the first step toward adequate mitigation of PM emissions.

Recent advancements in air quality monitoring, have enabled more accurate and real-time tracking of PM emissions on construction sites (Crilley et al., 2018)for these low-cost sensors to be useful for these types of studies their accuracy and precision needs to be quantified. We evaluated the Alphasense OPC-N2, a promising low-cost miniature optical particle counter, for monitoring ambient airborne particles at typical urban background sites in the UK. The precision of the OPC-N2 was assessed by co-locating 14 instruments at a site to investigate the variation in measured concentrations. Comparison to two different reference optical particle counters as well as a TEOM-FDMS enabled the accuracy of the OPC-N2 to be evaluated. Comparison of the OPC-N2 to the reference optical instruments demonstrated reasonable agreement for the measured mass concentrations of PM₁, PM_{2.5} and PM₁₀. However, the OPC-N2 demonstrated a significant positive artefact in measured particle mass during times of high ambient RH (> 85 %. The monitoring systems provide data that can be used to assess exposure risks, evaluate the effectiveness of mitigation measures, and develop predictive models that anticipate changes in air quality based on construction activity and environmental conditions. Despite the availability of the advanced monitoring technologies, in Serbia construction sites monitoring is non existing. This is mostly because PM emissions from construction sites are not recognized by legislatives. Because of the monitoring problem, there are several predictive models, where EMEP Tier 1 model has shown the most matching results to the measured values in Europe (EEA, 2019).

Managing PM emissions on construction sites is a very complex challenge in developing countries such is Serbia, whereas it is intricate even in developed countries. Meteorological factors such as wind speed, humidity, and temperature can influence the dispersion of particulate matter in environment (Barmpadimos et al., 2011; Jang et al., 2017). The intensity and type of construction activities directly affect PM levels.

Besides real-time monitoring and predictive modeling, the health risks associated with PM emissions on construction sites can be assessed using dose-response functions, which quantify the relationship between PM exposure and health outcomes. Comparing Time-Weighted Averages (TWA) of PM concentrations against Occupational Exposure Limits (OELs) provides a benchmark for evaluating worker safety, while Air Quality Index (AQI) calculations offer a more generalized assessment of air quality impacts on the surrounding population. These tools are crucial for ensuring that construction activities comply with environmental and occupational safety standards.

MATERAL AND METHODS

Location

The road reconstruction took place from March 6th to 10th on part of Bulevar Slobodana Jovanovića in Novi Sad, Serbia (figure 1.). The construction zone spanned from the intersection of Bulevar Jovana Dučića and Radomira Raše Radujkova to Bulevar Vojvode Stepe, with a street length of 520 meters and a width of 18 meters. This area is a critical section for traffic flow, and the reconstruction works involved significant infrastructure improvements, including resurfacing, but did not include any dust suppression measures to minimize PM10 emissions during the project.

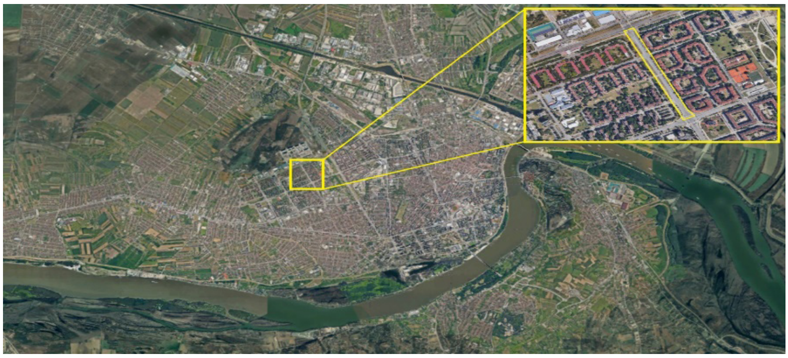


Figure 1. *Road reconstruction location in city of Novi Sad*

Pm emission modeling

The modeling of PM10 emissions during the observed road reconstruction project, the EMEP/EEA Tier 1 methodology was utilized. The approach relies on standardized emission factors and activity data, and is ideal for primarily assessments when detailed site-specific information is limited. The monitored road reconstruction has the affected area 9,360 m², with construction activities lasting five days, from March 6th to March 10th. The control efficiency for dust suppression measures was set at 0.5. Key input parameters included a silt content of 35.4 μg/m³ (Sunjevic et al., 2023), which contributed significantly to the overall PM10 emissions from both earth-moving activities and the movement of vehicles across the construction site. The average PM10 concentration modeled during the project was 263.75 μg/m³, reflecting the impact of construction activities on air quality.

Dose – response calculation

The dose-response calculation was performed to assess the potential health impact of PM10 exposure on individuals and workers present near the road reconstruction site. This method relies on estimating the relationship between pollutant exposure levels and the associated health risks, using established dose-response functions that quantify the likelihood of adverse health outcomes resulting from various concentrations of airborne pollutants.

For this assessment, the average PM10 concentration measured during the road reconstruction project was 263.75 μg/m³, a value that significantly exceeds recommended air quality standards set by WHO and the European Union (EU). The population at risk included not only workers on-site but also nearby residents and pedestrians who could be exposed to elevated PM10 levels during the construction period.

The calculation is based on the general dose-response relationship for PM10 exposure, often expressed as an increase in relative risk (RR) per 10 μg/m³ of PM10. According to epidemiological studies, for every 10 μg/m³ increase in PM10 concentration, the risk of respiratory illnesses and cardiovascular events increases by a certain percentage, typically around 0.6% to 1.5% depending on the health outcome being studied. The research focused on respiratory morbidity, using a relative risk (RR) factor of 1.06 per 10 μg/m³, as reported in literature. The dose-response function is given by the equation: $RR=1+\beta(C-C0)$. Where RR is the relative risk, β is the slope of the dose-response function (for PM10, $\beta = 0.006$ for respiratory diseases), C is the average concentration of PM10 in the affected area (263.75 μg/m³), and C0 is the reference concentration, typically taken as the baseline air quality standard or natural background level (20 μg/m³). The calculation was performed using the selected data showing the relative increase in health risk associated with the elevated PM10 levels during the 5-day construction period. RR coefficient has been calculated to 2.4625.

Occupational exposure limit (OEL)

To evaluate the occupational exposure to PM10 during the road reconstruction project, the Time-Weighted Average (TWA) and Occupational Exposure Limit (OEL) were calculated. The TWA is a critical parameter used to assess the average concentration of a hazardous substance that workers are exposed to over a specified work period, typically an 8-hour shift. The OEL, on the other hand, represents the maximum permissible concentration of a substance to which workers can be exposed without experiencing adverse health effects defined by health regulations. In the research an 8-hour workday was applied as the exposure duration for workers involved in the road reconstruction activities. The PM10 concentration was modeled at an average of 263.75 μg/m³ during the 5-day construction period. The TWA was calculated with formula: $TWA=C\times T/T_{total}$; where C is the measured PM10 concentration (263.75 μg/m³), T is the duration of exposure during the shift (8 hours), and T_{total} is the total duration of the shift (8 hours). TWA was calculated as 263.75 μg/m³. This value represents the average PM10 concentration to which workers were exposed during each shift over the course of the project.

The TWA was compared to established OELs for PM10. The OEL for PM10, as recommended by the Occupational Safety and Health Administration (OSHA) and WHO, is generally set at 50 μg/m³ for an 8-hour workday. The comparison between the calculated TWA (263.75 μg/m³) and the OEL (50 μg/m³) revealed that the workers were exposed to PM10 concentrations 5.275 times higher than the permissible limit.

Air quality index (AQI)

The Air Quality Index (AQI) is a standardized system used to communicate the quality of the air in a specific location based on the concentration of various pollutants. It is designed to provide the public with an easy-to-understand scale that indicates potential health risks associated with air pollution levels. The AQI takes into account common pollutants, such as particulate matter (PM10 and PM2.5), ozone, nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO). Each pollutant is given an AQI score, and the highest score represents the overall air quality level. The AQI for the PM10 emitted during the road reconstruction was calculated to 154 using the online tool provided on the website (https://aqicn.org/calculator/).

RESULTS AND DISSCUSION

The results (Table 1.) from the dose-response, TWA, and AQI analyses collectively indicate a high risk associated with PM10 exposure during the road reconstruction. Elevated PM10 levels pose significant health risks, particularly for vulnerable populations such as children, the elderly, and individuals with preexisting health conditions.

Table 1. Research results

Applied model	Average PM10	Dose-response	OEL	AQI
Results	263.75 μg/m³	2.4625	5.275	154

The dose-response analysis revealed a significant health risk associated with PM10 exposure during the road reconstruction project. The results indicates that the individuals present in the vicinity of the roadworks were subject to a 146.25% higher risk of respiratory complications, such as asthma exacerbations and bronchitis. The relative risk of mortality associated with the PM10 concentration of 263.75 μg/m³ is approximately 2.46. This means that the risk of mortality due to exposure to calculated PM10 level is about 2.46 times higher.

This significant exceedance of the OEL indicates a substantial occupational health risk for workers involved in the project. Prolonged exposure to PM10 concentrations at these levels can result in respiratory illnesses, reduced lung function, and other adverse health outcomes. The calculation of TWA and its comparison to the OEL underscores the need for stringent dust control measures, such as the use of personal protective equipment (PPE), localized air filtration, and enhanced dust suppression technologies to reduce workers' exposure to harmful particulate matter.

The AQI for PM10 during the road reconstruction was calculated to be 154, which falls into the „Unhealthy" category. This AQI level indicates that sensitive groups, particularly individuals with respiratory diseases such as asthma, are at heightened risk. The general population may also experience increased respiratory symptoms. Health effects at this level include the aggravation of existing lung conditions and the potential onset of respiratory issues for a broader range of individuals. The AQI was calculated using the online tool provided by the AQICN website (https://aqicn.org/calculator/).

CONCLUSION

The modeled value for PM10 emission during road reconstruction activities in Novi Sad, Serbia was 263.75 µg/m³. The results significantly exceeding World Health Organization and European Union air quality standards. The high concentration posed serious health risks to both workers and nearby residents, with the relative risk (RR) of respiratory complications being calculated at 2.46 times higher than normal. Occupational Exposure indicates that workers were exposed to PM10 concentrations 5.275 times higher than the recommended limit, making it imperative to implement dust control measures and protective equipment. The AQI of 154 was classified as „Unhealthy," indicating significant risks to sensitive populations, particularly those with respiratory conditions. Health risks has shown a 146.25% higher risk of respiratory conditions such as asthma, bronchitis, and reduced lung function.

AKNOWLEGMENT

This research has been supported by the Ministry of Science, Technological Development and

Innovation (Contract No. 451-03-65/2024-03/200156) and the Faculty of Technical Sciences,

University of Novi Sad through project "Scientific and Artistic Research Work of Researchers in Teaching and Associate Positions at the Faculty of Technical Sciences, University of Novi Sad" (No. 01-3394/1).

REFERENCES

Barmpadimos, I., Hueglin, C., Keller, J., Henne, S., & Prévôt, A. S. H. (2011). Influence of meteorology on PM10 trends and variability in Switzerland from 1991 to 2008. Atmospheric Chemistry and Physics, 11(4), 1813–1835. https://doi.org/10.5194/acp-11-1813-2011

Cohen, A. J., Brauer, M., Burnett, R., Anderson, H. R., Frostad, J., Estep, K., Balakrishnan, K., Brunekreef, B., Dandona, L., Dandona, R., Feigin, V., Freedman, G., Hubbell, B., Jobling, A., Kan, H., Knibbs, L., Liu, Y., Martin, R., Morawska, L., … Forouzanfar, M. H. (2017). Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. The Lancet, 389(10082), 1907–1918. https://doi.org/10.1016/S0140-6736(17)30505-6

Crilley, L. R., Shaw, M., Pound, R., Kramer, L. J., Price, R., Young, S., Lewis, A. C., & Pope, F. D. (2018). Evaluation of a low-cost optical particle counter (Alphasense OPC-N2) for ambient air monitoring. Atmospheric Measurement Techniques, 11(2), 709–720. https://doi.org/10.5194/amt-11-709-2018

EEA. (2019). 2.A.5.b Construction and demolition. In EMEP/EEA Air Pollutant Emission Inventory Guidebook.

GLA (Greater London Authority). (2014). the Control of Dust and Emissions During Construction and Demolition. July, 113.

Jang, E., Do, W., Park, G., Kim, M., & Yoo, E. (2017). Spatial and temporal variation of urban air pollutants and their concentrations in relation to meteorological conditions at four sites in Busan, South Korea. Atmospheric Pollution Research, 8(1), 89–100. https://doi.org/10.1016/j.apr.2016.07.009

Kim, K. H., Kabir, E., & Kabir, S. (2015). A review on the human health impact of airborne particulate matter. Environment International, 74, 136–143. https://doi.org/10.1016/j.envint.2014.10.005

Pope, C. A., & Dockery, D. W. (2006). Health effects of fine particulate air pollution: Lines that connect. Journal of the Air and Waste Management Association, 56(6), 709–742. https://doi.org/10.1080/10473289.2006.10464485

Requia, W. J., Adams, M. D., Arain, A., Papatheodorou, S., Koutrakis, P., & Mahmoud, M. (2018). Global Association of Air Pollution and Cardiorespiratory Diseases: A Systematic Review, Meta-Analysis, and Investigation of Modifier Variables. American Journal of Public Health, 108(S2), S123–S130. https://doi.org/10.2105/AJPH.2017.303839

Sunjevic, M., Reba, D., Rajs, V., Vujic, B., Neducin, D., & Vojinovic-Miloradov, M. (2022). Pm mitigation measures utilization trends on building sites in Novi Sad, Serbia during 2019-2022. Facta Universitatis - Series:

Architecture and Civil Engineering, 20(2), 193–201. https://doi.org/10.2298/FUACE221004015S

Sunjevic, M., Reba, D., Rajs, V., Vujic, B., Ninkov, M., & Vojinovic-Miloradov, M. (2023). Assessment of detected in situ and modeled PM10/2.5 concentration levels during the urban transformation process in Novi Sad, Serbia. Thermal Science, 27(3 Part B), 2275–2286. https://doi.org/10.2298/TSCI220215108S

WHO. (2021). WHO global air quality guidelines. Coastal And Estuarine Processes, 1–360.

Yadav, R., Vyas, P., Kumar, P., Sahu, L. K., Pandya, U., Tripathi, N., Gupta, M., Singh, V., Dave, P. N., Rathore, D. S., Beig, G., & Jaaffrey, S. N. A. (2022). Particulate Matter Pollution in Urban Cities of India During Unusually Restricted Anthropogenic Activities. Frontiers in Sustainable Cities, 4. https://doi.org/10.3389/frsc.2022.792507

CONSTRUCTING THE NEW CITY BLOCK - THE PM10 EXPOSURE

Miljan Šunjević, Boris Obrovski, Nikolina Tošić, Dunja Istrat

Faculty of Technical Sciences, University of Novi Sad
msunjevic@uns.ac.rs

Abstract

Modern societies thieve in the development and urbanization. The urbanization processes often include forming of the new city blocks with their own micro urban environments, The construction of new city blocks in urban areas poses significant environmental challenges, particularly regarding airborne particulate matter (PM) emissions, such as PM10. High concentration levels generated during construction activities necessitate a detailed assessment of PM10 exposure risks. The research shows the modeled PM10 emissions for a new city block construction project in Novi Sad. The analysis focuses on health risks associated with elevated PM10 levels produced during earth-moving and building activities, comparing the Time-Weighted Average (TWA) to Occupational Exposure Limits (OELs) and calculating the Air Quality Index (AQI). Results indicate a substantial increase in health risks, underscoring the need for effective mitigation measures to safeguard public health and the environment during construction activities.

Keywords: construction, PM exposure, risk assessment.

INTRODUCTION

The worldwide rapid urbanization has dictated the construction of new city blocks, which often involves extensive building and infrastructure development (Garde, 2020). While these projects are vital for economic growth and urban expansion, they also pose significant environmental challenges, particularly concerning air quality (Mukherjee & Agrawal, 2017). Construction activities are beside combustion, a major source of air pollution in urban environments (Kinsey & Cowherd, 2005). PM10—particles with a diameter of 10 micrometers or less— are considered as a significant hazard due to its ability to remain airborne for long periods and penetrate deep into the human respiratory system (Raaschou-Nielsen et al., 2016; WHO, 2021). Understanding the PM10 emissions during construction is significant for public health and adequate mitigation of air pollution.

PM10 is primarily generated from construction activities such as earth excavation, demolition, material handling, and the use of heavy machinery (Araújo et al., 2014). In urban environments, construction sites are among the leading contributors to PM10 levels, especially when activities like soil disturbance, concrete mixing, and on-site vehicle movement are not properly managed (Kinsey & Cowherd, 2005). Since the particles are inhalable, prolonged exposure can lead to severe health issues, such as respiratory and cardiovascular diseases, asthma, and other respiratory complications (Clifford et al., 2018; Ghanizadeh et al., 2018; Mabahwi et al., 2014).

The World Health Organization (WHO) and the European Environment Agency (EEA), have set stringent guidelines for PM10 concentrations to mitigate their impact on public health. The WHO's global air quality guidelines suggest that average PM10 concentrations should not exceed 20 µg/m³ annually and 50 µg/m³ over a 24-hour period (WHO, 2021). The construction activities can often lead to localized PM10 concentrations that exceed these limits, especially when dust suppression measures are inadequate or absent, such is situation in Serbia (Sunjevic et al., 2022). Which is particularly concerning in densely populated urban areas, where construction projects can significantly impact local air quality and health outcomes in a long run (Sunjevic et al., 2023).

The construction of a new city block presents unique challenges in managing PM10 emissions. Unlike isolated construction sites, these projects are often embedded within densely populated neighborhoods, increasing the likelihood of exposure for a larger number of people. The emissions from construction activities can also interact with other urban pollution sources, such as vehicular traffic and industrial emissions, further exacerbating air quality problems.

MATERAL AND METHODS

Location

The construction project involves building a new city block in Novi Sad, Serbia (figure 1.) with a parcel size of 63,000 m², affecting a build area of 19,000 m². The project duration is approximately 12 months, with eight buildings planned for construction. PM10 emissions are primarily generated during site preparation, excavation, material handling, and building activities. The block started building in 2020 and finished in 2021.Due to size of the project and the lack of the work force, there were many foreign workers included in the project, affecting the possibility of the mitigation measures application (Sunjevic et al., 2022).

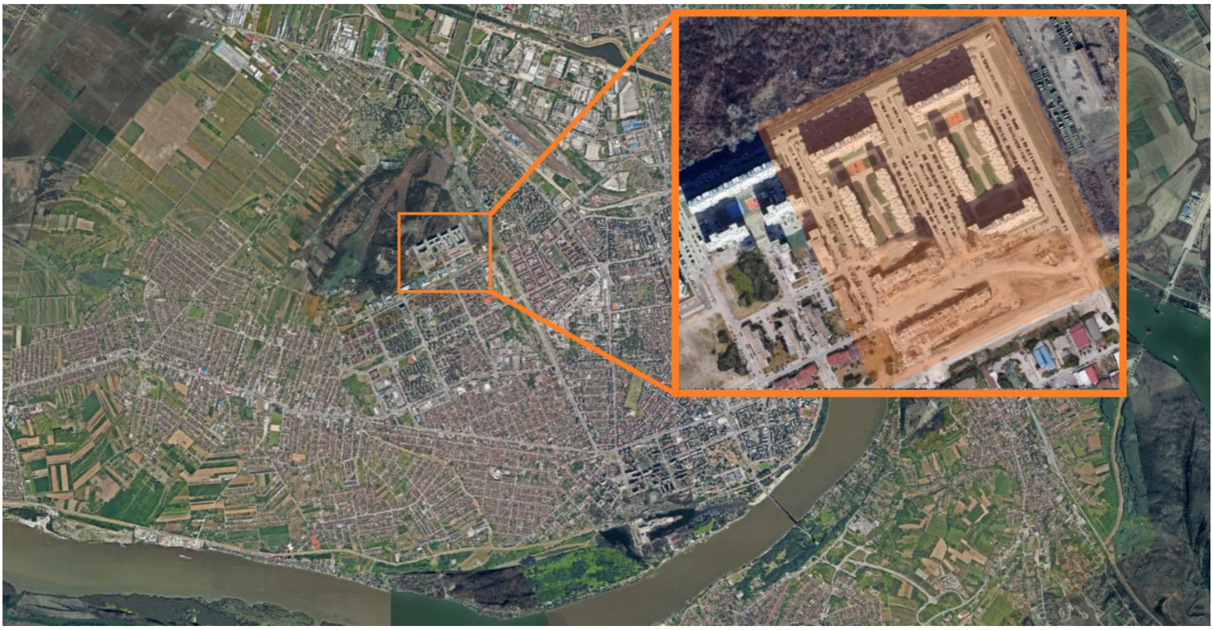


Figure 1. *New city block in Novi Sad, Serbia*

Pm emission modeling

Defining the average PM10 emission values required the application of the EMEP/EEA Tier 1 methodology (EEA, 2019). The approach relies on standardized emission factors and activity data, making it suitable for preliminary assessments when detailed site-specific information is not available. The construction of the new city block affects an area of 19,000 m^2, with activities expected to last approximately one year. The control efficiency for dust suppression measures is set at 0.5. Key input parameters include a silt content of 35.4% (Sunjevic et al., 2023). The average modeled PM10 concentration during the project is 201.7 $\mu g/m^3$

Dose – response calculation

To evaluate the potential health effects of PM10 exposure during the construction of the new city block in city of Novi Sad, a dose-response analysis was applied. This approach helps in estimating the health risks associated with varying concentrations of airborne pollutants by applying well-established dose-response functions. The functions are vital in determining the likelihood of negative health outcomes resulting from different levels of PM10 exposure.

In the research the modeled average PM10 concentration during the construction activities was modeled as 201.7 µg/m³, a level that considerably surpasses the air quality standards recommended by the WHO and EEA (EEA, 2021; WHO, 2021). The elevated PM10 levels pose a risk not only to construction workers on-site but also to the surrounding population, including nearby residents, who may be exposed to these high concentrations throughout the construction period.

The analysis employs a standard dose-response relationship that links PM10 exposure to increased health risks, typically expressed as the relative risk (RR) per 10 µg/m³ increase in PM10 concentration. Studies have shown that each 10 µg/m³ rise in PM10 levels correlates with an increase of about 0.6% in the risk of respiratory conditions and cardiovascular issues. The dose-response relationship is defined by the formula $RR=1+\beta(C-C0)$, where RR represents the relative risk, β is the coefficient for the dose-response slope ($\beta=0.006$ for respiratory diseases in the case of PM10), C is the average PM10 concentration at the construction site (201.7 µg/m³), and C0 is the reference or background concentration (commonly set at 20 µg/m³). Appling the values, the relative risk (RR) of developing respiratory diseases due to the increased PM10 levels during construction is calculated to 2.0902.

This result suggests a 109% increase in the risk of respiratory diseases for those exposed to the PM10 levels during the construction period. Such a pronounced rise in health risk underlines the necessity for implementing robust dust control strategies and frequent air quality assessments to mitigate the impact on both workers and local communities.

Occupational exposure limit (OEL)

To assess the level of PM10 exposure that workers are subjected to during the construction of the new city block, the Time-Weighted Average (TWA) and Occupational Exposure Limit (OEL) for PM10 were calculated. The TWA represents the average concentration of a hazardous substance that workers are exposed to over the course of a typical work shift, which in this case is set to 10 hours. The OEL defines the maximum concentration of a substance that workers can be exposed to without significant risk of adverse health effects, as outlined by health and safety regulations.

The basic data for the research is modeled value of the PM10 concentration set at 201.7 µg/m³. The TWA is calculated using the formula: $TWA=C\times T/$

T_{total}, where C is the average concentration of PM10 (201.7 µg/m³), T is the duration of exposure during a 10-hour work shift, and T_{total} is the total duration of the shift, which is also 10 hours in this case. The TWA is calculated as 201.7µg/m³.

The calculated TWA indicates that the average PM10 concentration to which workers are exposed over a 10-hour shift remains 201.7 µg/m³. When compared to the recommended OEL for PM10, which is generally set at 50 µg/m³ for an 8-hour workday by organizations such as the Occupational Safety and Health Administration (OSHA) and WHO, the workers' exposure is approximately 4.034 times above the limit values.

Air quality index (AQI)

The Air Quality Index (AQI) serves as a standardized tool for measuring and communicating air quality levels based on the concentrations of various air pollutants. The AQI uses a scale that ranges from „Good" to „Hazardous," providing a clear understanding of the potential health risks associated with air pollution in a given area. Using the modeled average PM10 concentration of 201.7 µg/m³ during the construction period, the AQI for PM10 was calculated at 123 by online AQI Calculator (https://aqicn.org/calculator/).

RESULTS AND DISSCUSION

The findings from the dose-response analysis, TWA and OEL calculations, and AQI (Table 1.) assessment collectively highlight the substantial health risks associated with PM10 exposure during the construction of a new city block. The elevated PM10 levels, as modeled at an average concentration of 201.7 µg/m³, demonstrate a substantial impact on air quality, which poses potential health risks to both workers and residents in the vicinity of the construction site.

Table 1. Research results

Applied model	Average PM10	Dose-response	OEL	AQI
Results	201.70 µg/m³	2.0902	4.034	123

The dose-response analysis indicated that the relative risk (RR) for respiratory diseases increases significantly with the PM10 concentration observed during the construction period. The calculated RR of approximately 2.09 suggests that individuals exposed to these PM10 levels face a more than double risk of developing respiratory issues, such as asthma, bronchitis, or other lung conditions.

The Time-Weighted Average (TWA) of PM10 exposure for construction workers, calculated over a 10-hour shift, was found to be 201.7 µg/m³. This value is about 4.034 times higher than the recommended OEL of 50 µg/m³ for PM10 over an 8-hour workday. The exceedance of the OEL by such a margin underscores the potential for adverse health effects on workers who are exposed to these concentrations regularly. Without proper protective measures and dust control interventions, prolonged exposure at these levels could lead to chronic respiratory problems and other health complications.

The AQI for the PM10 levels during construction was calculated to be 123, placing it in the „Unhealthy for Sensitive Groups" category. The AQI level suggests that sensitive groups, including individuals with respiratory diseases, children, and the elderly, are likely to experience health effects. Even those without preexisting conditions could face minor respiratory symptoms if exposed for extended periods.

CONCLUSION

The PM10 emission assessment during the construction of a new city block in Novi Sad highlights significant potential health risks for workers and nearby residents. The average PM10 concentration of 201.7 µg/m³ significantly exceeds both ambient air quality and occupational exposure limits, emphasizing the importance of implementation of effective dust control measures and protective strategies. The calculated relative risk (RR) of 2.09 suggests a more than double increase in respiratory complications in individuals exposed to these levels of PM10. The TWA also exceeds the occupational exposure limit by over four times, suggesting a need for stringent controls and protective measures for construction workers.

AKNOWLEGMENT

This research has been supported by the Ministry of Science, Technological Development and Innovation (Contract No. 451-03-65/2024-03/200156) and the Faculty of Technical Sciences, University of Novi Sad through project "Scientific and Artistic Research Work of Researchers in Teaching and Associate Positions at the Faculty of Technical Sciences, University of Novi Sad" (No. 01-3394/1).

REFERENCES

Araújo, I. P. S., Costa, D. B., & de Moraes, R. J. B. (2014). Identification and characterization of particulate matter concentrations at construction jobsites. Sustainability (Switzerland), 6(11), 7666–7688. https://doi.org/10.3390/su6117666

Clifford, S., Mazaheri, M., Salimi, F., Ezz, W. N., Yeganeh, B., Low-Choy, S., Walker, K., Mengersen, K., Marks, G. B., & Morawska, L. (2018). Effects of exposure to ambient ultrafine particles on respiratory health and systemic inflammation in children. Environment International, 114(November 2017), 167–180. https://doi.org/10.1016/j.envint.2018.02.019

EEA. (2019). 2.A.5.b Construction and demolition. In EMEP/EEA Air Pollutant Emission Inventory Guidebook.

EEA. (2021). Air quality in Europe 2021. European Environment Agency.

Garde, A. (2020). New Urbanism: Past, Present, and Future. Urban Planning, 5(4), 453–463. https://doi.org/10.17645/up.v5i4.3478

Ghanizadeh, G., Khoshniyat, R., Karmi, F., Haghshenas, M. reza, Abdollahi, M., Rahimi, M., & Hamidi, E. (2018). Short-term Effects of PM10 to Increase Rate of Hospital Admission Cardiovascular and Respiratory of Sanandaj, Iran During 2015. Iranian Journal of Health, Safety and Environment, 5(2), 957–965.

Kinsey, J. S., & Cowherd, C. (2005). Particulate emissions from construction activities. Journal of the Air and Waste Management Association, 55(6), 772–783. https://doi.org/10.1080/10473289.2005.10464669

Mabahwi, N. A. B., Leh, O. L. H., & Omar, D. (2014). Human Health and Wellbeing: Human Health Effect of Air Pollution. Procedia - Social and Behavioral Sciences, 153, 221–229. https://doi.org/10.1016/j.sbspro.2014.10.056

Mukherjee, A., & Agrawal, M. (2017). World air particulate matter: sources, distribution and health effects. Environmental Chemistry Letters, 15(2), 283–309. https://doi.org/10.1007/s10311-017-0611-9

Raaschou-Nielsen, O., Beelen, R., Wang, M., Hoek, G., Andersen, Z. J., Hoffmann, B., Stafoggia, M., Samoli, E., Weinmayr, G., Dimakopoulou, K., Nieuwenhuijsen, M., Xun, W. W., Fischer, P., Eriksen, K. T., Sørensen, M., Tjønneland, A., Ricceri, F., de Hoogh, K., Key, T., … Vineis, P. (2016). Particulate matter air pollution components and risk for lung cancer. Environment International, 87(July 2015), 66–73. https://doi.org/10.1016/j.envint.2015.11.007

Sunjevic, M., Reba, D., Rajs, V., Vujic, B., Neducin, D., & Vojinovic-Miloradov, M. (2022). Pm mitigation measures utilization trends on building sites in Novi Sad, Serbia during 2019-2022. Facta Universitatis - Series: Architecture and Civil Engineering, 20(2), 193–201. https://doi.org/10.2298/FUACE221004015S

Sunjevic, M., Reba, D., Rajs, V., Vujic, B., Ninkov, M., & Vojinovic-Miloradov, M. (2023). Assessment of detected in situ and modeled PM10/2.5 concentration levels during the urban transformation process in Novi Sad, Serbia. Thermal Science, 27(3 Part B), 2275–2286. https://doi.org/10.2298/TSCI220215108S

WHO. (2021). WHO global air quality guidelines. Coastal And Estuarine Processes, 1–360.

GREEN BUILDING COMPOSITE MATERIAL AS THE FUTURE OF CONSTRUCTION

Miloš Marinković[1*], Hadi Waisi[1,4], Marija Vasić Jovev[2], Aleksandar Marinković[2], Marko Milojković[3], Stevan Blagojević[1], Jelena Senćanski[1]

[1]Institute of General and Physical Chemistry, Studentski trg 12/V, P.O. Box 45, 11158 Belgrade, Serbia

[2]University of Niš, Department of Chemistry, Faculty of Science and Mathematics, Višegradska 33, 18000 Niš, Serbia

[3]Public utility enterprise-Veterinary Belgrade, Bulevar Despota Stefana 119, 11000 Belgrade

[4]Faculty of Ecology and Environmental Protection, University Union-Nikola Tesla, Cara Dušana 62-64, 11000 Belgrade, Serbia

*milosmarinkovic83@gmail.com

Abstract: Hempcrete, a bio-composite material made from the hemp plant's woody core (shiv), water, and a lime-based binder, has gained attention as a sustainable construction material. This study examines the mechanical properties of different hempcrete mixtures and their potential as a green building solution. The results indicate that while hempcrete offers lower compressive strength compared to traditional concrete, its thermal insulation properties, CO_2 emissions impact, and low environmental impact make it a viable option for sustainable construction. Future research should focus on optimizing the material's mechanical properties and scaling up its application in the construction industry. The mechanical and physical properties of the obtained composite materials mostly depend on the mutual ratio of the shiv and CaO mass fraction. Based on the measurements, it was concluded that the best ratio is 2:1-binder to shiv. The granulate fraction influences the mechanical and physical properties, i.e., the size of the particles that enter the formation of hempcrete. Based on the measurements, it was shown that the most suitable granulate fractions are 1-40 mm.

Keywords: Hempcrete, sustainable construction, mechanical properties, green building materials, CO_2 emissions.

INTRODUCTION

The construction industry is one of the largest consumers of natural resources and a significant contributor to global carbon dioxide (CO_2) emissions, accounting for approximately 39% of energy-related carbon emissions worldwide (United Nations Environment Programme. 2019). As the demand for sustainable building practices grows, there is increasing interest in eco-friendly construction materials that can reduce the environmental impact of buildings. Hempcrete, a bio-composite material made from the woody core (shiv) of the hemp plant (Cannabis sativa), water, and a lime-based binder, has emerged as a promising alternative to traditional construction materials due to its low environmental footprint and unique properties. Hempcrete offers several advantages over conventional materials such as concrete. Unlike concrete, which has a high embodied energy due to the intensive energy required for cement production, hempcrete is characterized by a negative carbon footprint. This is because hemp plants absorb more CO_2 during their growth than is emitted during the production and curing of the lime binder (Mikulandrić et al., 2016). Studies have shown that hempcrete can sequester between 110 and 165 kg of CO_2 per cubic meter, depending on the specific mix and conditions (Ip et al., 2012). Additionally, hemp is a rapidly renewable resource, with a growth cycle of just four months, making it a sustainable option for large-scale construction (Evrard et al, 2003). Due to its low thermal conductivity, hempcrete provides excellent insulation, reducing the need for additional insulating materials and contributing to energy efficiency in buildings. Thermal conductivity values for hempcrete typically range between 0.08 and 0.12 W/m·K, depending on the density and binder content (Walker et al., 2014). This makes it particularly suitable for use in temperate climates, where thermal regulation is essential for reducing energy consumption in buildings. However, one of the primary limitations of hempcrete is its relatively low compressive strength, which is significantly lower than that of traditional concrete. Typical compressive strength values for hempcrete range from 0.4 to 3.5 MPa, depending on the mixture and curing conditions (Eires et al, 2016). As a result, hempcrete is generally used for non-load-bearing walls, insulation, and as an infill material rather than for structural components. Despite this limitation, the material's low density, high vapor permeability, and resistance to mold and pests make it an attractive option for sustainable construction. This paper investigates the mechanical properties of different hempcrete mixtures, focusing on their potential as a green building material. By examining the effects of varying binder-to-shiv ratios and other parameters, this study aims to provide a comprehensive understanding of hempcrete's performance and its suitability for broader application in the construction industry. The findings will contribute to ongoing efforts to develop more sustainable building practices and reduce the environmental impact of construction.

MATERIALS AND METHODS

Hempcrete material selection

On the basis of preliminary studies, it was concluded that the reduction of the dimensions of the particles has a positive effect on the mechanical properties of the formed hempcrete, and the dimension in the range from 1 mm to 40 mm was selected. CaO (Aldrich Co., 99%) was used as binder. Fibers and shiv were dried and sieved to a selected fraction. Three mixing ratios of industrial hemp, CaO binder, and water were defined in order to form a hempcrete with excellent performance and also in order to determine the influence of the ratio on the mechanical and physical properties of the formed hempcrete. The mass ratios of the mixture components are described in Table 1.

Table 1 *Mass ratios of mixture components in formed hempcrete*

	Mass ratio of hempcrete components	Low ratio of binder (A)	Middle ratio of binder (B)	High ratio of binder (C)
1	Binder to Shiv (CaO/Hemp Shiv)	1.0	2.0	3.0
2	Initial density (kg/m^3)	635	839	913
3	Water to binder (H_2O/CaO)	0.55	0.85	0.95

The properties of the obtained hempcrete will be examined in terms of mechanical properties, i.e., the following properties: strength, elasticity, toughness, and hardness. An examination of the obtained hempcrete will be performed as a function of the changes that take place during high-temperature treatments, volumetric mass, water absorption, apparent porosity, strength at pressure, and bending. The thermal performance of hemp-based materials was analyzed through the density and thermal conductivity of the samples. The density of the material is calculated as the ratio of mass and volume of the composite, i.e.

hempcrete. Thermal conductivity was measured using the Fok 200 device. The samples used to determine thermal conductivity were 150 x 150 mm with a thickness of 30 mm. The sample was placed between two temperature-controlling plates, and the method used was the heat flow measurement method.

RESULTS AND DISCUSSION

Based on the selection of the shiv fraction in terms of particle size in the range from 1mm to 40mm and the previously defined mixing ratios of the hempcrete components, three different hempcrete were formed with different proportions of binder (Low content of binder (A), Medium content of binder (B) High content of binder (C)), and the same were tested in terms of mechanical properties, i.e. the following properties: strength, elasticity, toughness and hardness. Table 2 shows the mentioned properties of gained hempcrete(s).

***Table 2** The results of compression and bending tests of the formed hempcrete, according to the mass ratio of binder, as well as, a function of the aging of the hempcrete.*

Low binder content (A)	Bending strength (range) (N/mm^2)	Compression strength (range) (N/mm^2)	Ratio Bending/ Compresion
14 Days	**2.6** (2.4 – 2.7)	**5.1** (4.8 – 5.6)	**1.96**
28 Days	**3.6** (3.4 – 3.9)	**9.4** (8.9 – 10.1)	**2.61**
Medium binder content(B)			
14 Days	**5.3** (5.2 – 5.5)	**25.1** (24.6 – 25.8)	**4.73**
28 Days	**7.3** (7.0 – 7.6)	**31.1** (29.6 – 32.8)	**4.26**
High binder content(C)			
14 Days	**3.7** (3.5 – 3.8)	**11.8** (11.5 – 12.2)	**3.18**
28 Days	**4.6** (4.5 – 4.8)	**14.9** (13.8 – 15.3)	**3.23**

Based on the results shown in Table 2., it can be concluded that the proportion of binder in the hempcrete is of great importance for the mechanical properties of the formed material. According to the compressive and bending endurance test, it can be observed that the ratio of binder to shiv (CaO/Hemp shiv) of 2 to 1, with the medium proportion of binder (B) is significantly better than the ratio with low and high proportion of binder, in terms of the mechanical properties of the resulting hempcrete. A trend of hardening of the obtained hempcrete as a function of aging can also be observed.

The parameters analyzed for the thermal behavior of the elements are density and thermal conductivity. Thermal conductivity is directly related to the density of samples. For this reason, the sample with the smallest proportion of adhesive agent-CaO has the lowest thermal conductivity of 0.061 W / m^2, and the hempcrete with the largest proportion of adhesive agent is even 0.1 W / m^2. If the thermal conductivity value increases, the thermal performance of the sample is lower. The tested sample with a medium viscosity of the adhesive according to the lower grain size gave the best test results.

There are currently no recommended empirical standards or guidelines for characterizing the water absorption characteristics of organic aggregates such as hemp. Absorption tests were performed to characterize the water absorption properties and capacity. The total soaking time of the hemp shiv was almost 14 days. By seven days, the shiv samples had reached saturation capacity, where subsequent slight mass variations appeared to depend on the technique used to remove free water. Before immersion in a container of water, the average initial moisture content of the hemp was 11.4%. After seven days of immersion, an average increase in mass of 388% was observed. During the first minute of immersion, there was a very rapid absorption of water, where on average 37% of the total absorption of water occurred. After 15 minutes, hemp absorbed an average of 205% of its weight in water, which increased to 216% after 64 minutes. It is possible to identify three different absorption phases, with three different approximately linear absorption rates. The fast absorption rate observed in the first minute can be attributed to the absorption of water into the macropore structure. The transitional period between phase 1 and 2 occurs between one and two and a half minutes after immersion. Between two and a half minutes and 1600 minutes after immersion, the absorption curve can approach a linear absorption rate. This slower absorption rate can be attributed to micropore absorption and to a lesser extent to cellular absorption.

The resistance of the selected hempcrete to the effects of high temperatures was also evaluated. The decrease in the value of each property was calculated as the difference between the initial and residual mass. In table 3. are presented the results of hempcrete performance in terms of strength and elasticity during the heat treatment.

Table 3 *Initial values and values after heating*

Feature		Temperature (°C)	%
Compressive strength	Initial (MPa)	20	100
	Reduction (%)	420	28
Elasticity	Initial (MPa)	20	100
	Reduction (%)	420	45
Loss of mass	Initial (MPa)	20	100
	Reduction (%)	420	5

According to thermal analysis, the hempcrete experienced complete thermal degradation at a temperature slightly higher than 400 ^{o} C. However, hemp shiv can still improve the fire resistance of concrete through another mechanism. Namely, cracks start to appear in the hempcrete block at a temperature of 400 o C, and incompletely ignited hemp shiv at this temperature can be used to prevent further expansion of cracks at higher temperatures, which improves the fire resistance of concrete.

CONCLUSION

In terms of environmental acceptability when using shiv made of industrial hemp for the formation of hempcrete, i.e. composite material, the conclusion is that the material is completely Eco-friendly due to the unknown content of polluting substances in the sample. The formed hempcrete have an excellent potential for CO_2 adsorption, which is a function of the mass fraction of binder in the hempcrete. The mechanical and physical properties of the obtained composite materials mostly depend on the mutual ratio of the mass fraction of hemp shiv and CaO. Based on the measurements, it was concluded that the best ratio is 2:1-binder to shiv. The granulate fraction influences the mechanical and physical properties, i.e., the size of the particles that enter the formation of hempcrete. Based on the previously conducted measurements, it was shown that the most suitable granulate fractions are 1-40 mm. By observing the thermal conductivity, the formed hempcrete achieved significant and favorable thermal insulation characteristics. Also, the formed hempcrete showed significant resistance in terms of overcoming high temperatures. The resulting hempcrete in terms of mechanical, thermal, insulation and physical characteristics has been significantly improved by selecting the dimensions of the shiv granulate and selecting the mass fraction of the components in the composite material. The resulting hempcrete block is ready for commercial use in this format and recommended dimensions of 20x30x20mm. According to our assumptions and literature knowledge, there is an additional possibility of improving hempcrete, which would be based on the introduction of various additional components such as pozzolan, Al_2O_3, MgO, cellulose acetate, which would further improve all the characteristics of hempcrete. It is necessary to perform a techno-economic analysis of the profitability of adding various components and additives to achieve the necessary economic profitability for the improved hempcrete block.

ACKNOWLEDGMENT

The authors wish to thank to Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract numbers: 451-03-66/2024-03/200051, 451-03-66/2024-03/200124 and 451-03-65/2024-03/200124).

REFERENCES

United Nations Environment Programme. (2019). 2019 Global Status Report for Buildings and Construction. Retrieved from https://www.unep.org/resources/publication/2019-global-status-report-buildings-and-construction

Mikulandrić, R., Pukšec, T., Mathiesen, B. V., & Duić, N. Comparative life cycle assessment of hempcrete and conventional materials for building envelopes. *Journal of Cleaner Production*, 2016; 137; 1443-1451.

Ip, K., & Miller, A. Life cycle greenhouse gas emissions of hemp–lime wall constructions in the UK. *Resources, Conservation and Recycling*, 2012; 69; 1-9.

Evrard, A. Transient hygrothermal behavior of lime-hemp materials. *Journal of Building Physics*, 2003; 34(1); 5-25.

Walker, R., & Pavía, S. Mechanical properties and durability of hemp-lime concretes. *Construction and Building Materials*, 2014; 61, 340-348.

Eires, R., Jalali, S., & Branco, F. Compressive behavior of hemp concrete. *Infrastructures*,2016; 1(1); 3.

POTASSIUM-PROMOTED ALUMINA AS A PROMISING HETEROGENEOUS CATALYST FOR GREEN BIODIESEL PRODUCTION

Miloš Marinković[1*], Hadi Waisi[1, 4], Marija Vasić Jovev[2], Aleksandra Zarubica[2], Marko Milojković[3], Stevan Blagojević[1], Jelena Senćanski[1]

[1]Institute of General and Physical Chemistry, Studentski trg 12/V, P.O. Box 45, 11158 Belgrade, Serbia

[2]University of Niš, Department of Chemistry, Faculty of Science and Mathematics, Višegradska 33, 18000 Niš, Serbia

[3]Public utility enterprise-Veterinary Belgrade, Bulevar Despota Stefana 119, 11000 Belgrade

[4]Faculty of Ecology and Environmental Protection, University UNION-Nikola Tesla, Cara Dušana 62-64, 11000 Belgrade, Serbia

*milosmarinkovic83@gmail.com

Abstract: This study focuses on the synthesis of an innovative and highly efficient heterogeneous catalyst, utilizing an aluminum oxide support enhanced with potassium iodide (KI) as an active dopant, which is crucial for the catalyst's high activity. The aluminum oxide support was synthesized using modified sol-gel method, with aluminum isopropoxide as the precursor. The γ-Al_2O_3 support and KI/γ-Al_2O_3 catalyst samples were characterized using TG/DTA experimental technique. The study evaluated the effects of type of reaction mixture stirring, as well as reusability of examined catalyst. The results demonstrated that using of ultrasound at 40 kHz, resulting in a superior catalytic performance in the transesterification of grape seed oil. Under relatively mild conditions—12:1 methanol-to-grape seed-oil molar ratio, 2.5 wt.% catalyst loading, ultrasound mixing 40 kHz, and a 3-hour reaction time—the catalyst achieved a maximum conversion of 99.99% from triglycerides to methyl esters.

Keywords: heterogeneous catalysis; biodiesel production; potassium loaded alumina; transesterification

INTRODUCTION

Over the past few decades, human society has increasingly needed to integrate green technologies for energy production. The predominant method employed for biodiesel production is the transesterification of oils sourced from plants (Meher, 2006). This process is particularly effective because the conversion of triglycerides into fatty acid methyl esters is high, and the reaction time is relatively short (Thirumarimurugan, 2012). On an industrial scale, biodiesel production via base-catalyzed transesterification commonly utilizes homogeneous catalysts, such as potassium hydroxide (KOH) or sodium hydroxide (NaOH), along with methanol, to convert vegetable oils or fats into biodiesel. This method offers significant advantages, including high yields under mild conditions and a relatively brief reaction time (Meher, 2006). Various oils, both edible and non-edible, such as soybean (Li, 2006), sunflower oil (Arzamendi, 2008), and jatropha (Tiwari, 2007), have been successfully transesterified to produce biodiesel (Thirumarimurugan M 2012). However, the main challenge associated with industrial-scale production using homogeneously catalyzed transesterification is related to quality control issues and waste water produced (Tiwari, 2007).

In contrast, heterogeneous catalysis is recognized as a green technology due to several key benefits: easier separation of biodiesel from glycerol, catalyst reusability/recyclability, and a significant reduction in wastewater generation during the process (Sarma, 2008). A wide range of heterogeneous catalysts have been researched for transesterification, including metal hydroxides, metal complexes, metal oxides, zeolites, hydrotalcites, and supported catalysts (Sarma, 2008). Among the most extensively studied are alkaline earth metal oxides (Mootabadi, 2010), transition metal oxides and their derivatives (Yang, 2007), mixed metal oxides and their derivatives (Ngamcharussrivichai, 2008), basic zeolites, and alkali metal-loaded alumina (Alonso, 2007). The primary objective of this study was to synthesize a newly developed heterogeneous base catalyst by improved modified sol-gel method, from aluminum isopropoxide as the precursor in catalyst synthesis. This study investigates the catalytic performance in the transesterification reaction, as well as impact of different types of mixing reaction mixture and possible reusability and regeneration of heterogeneous catalyst, to ensure valuable data for future industrial applications of catalyst. The reaction test was conducted in batch reactor.

MATERIALS AND METHODS

Preparation of potassium iodide γ-Al_2O_3-supported catalysts

Preparation of potassium iodide γ-Al_2O_3-supported catalysts was detailed described in previously published work (Marinković, 2016).

Thermal analysis

In order to determine the thermal stability of the tested catalysts, as well as the phase transformation, differential thermal analysis (DTA) and thermogravimetric analysis were performed analysis (TG). An instrument was used to test the thermal properties of the catalyst Derivatograph MOM (M-1000), and the measurements were made in static and temperature conditionsrange 25-1000 °C with a heating rate of 10 °C min^{-1}.

Transesterification reaction

In this study grape seed oil from producer "Monini" was used. The transesterification reaction was carried out on the magnetic stirrer (in case of mechanical mixing) in standard 250 mL glass flask equipped with a condenser, charged with calculated volume of oil, and fixed volume of anhydrous methanol (precisely, molar ratio 1:12 oil to methanol) and fixed quantity of freshly prepared catalyst 2.5 wt. %. at 65 °C, and stirred at predetermined mixing rate of 600 rpm in case of mechanical mixing and at 40 kHz in case of ultrasound mixing.

Reaction monitoring

^{1}H NMR spectroscopy (Bruker, 400 MHz) (Bruker, Billerica, Massachusetts, US) was used to know the progress of the reaction run. The procedure of preparing samples for analysis is described in detail in a previously published paper (Marinković, 2016).

Catalyst recovery, reusability and regeneration

The synthesized catalyst was repeatedly used for ten cycles. Between each cycle, it was recovered from the reaction mixture by centrifugation, washed vigorously with n-hexane, and dried at 110 ° C for reutilization.

RESULTS AND DISCUSSION

Thermal characteristics of γ-Al_2O_3-based catalyst support

To determine the thermal stability of the tested catalysts, as well as possible phase transformation at high temperatures, thermogravimetric analysis (TG) was performed and differential thermal analysis (DTA).

From Figure 1. a) (TG curve), it can be observed that the boehmite total mass loss of 32%. Also, this mass loss is beyond the theoretical, which is related to the hygroscopicity of the obtained boehmite and the possible remains of the organic phase (isopropyl alcohol) that was used in the synthesis. Dehydration of boehmite can be described in three steps/stages. The first phase of mass loss at temperatures from 60 to 170 °C is associated with the loss/removal of physisorbed water (surface-bound water) and/or with the evaporation of possibly residual organic solvent, it is accompanied by the appearance of an asymmetric endothermic peak (endothermic effect) at temperature of about 100 °C (Figure 1 b) (DTA curve). The mass loss registered in the temperature range of 180 to 410 °C is related to by the removal of chemisorbed water and/or the formation (and growth) of an amorphous alumina phase (Marinković, 2018). In the last stage of dehydration of boehmite, at temperatures above 410 °C, phase transformation of boehmite in γ-Al_2O_3, which is accompanied by the appearance of a symmetric endothermic peak (endothermic effect) in the temperature range from 450 to 600 °C.

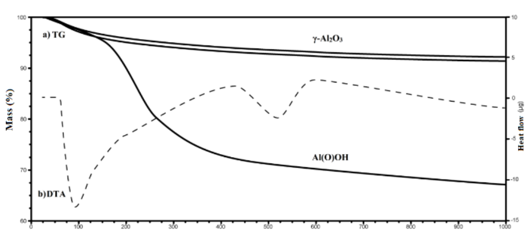


***Figure 1** Thermal analysis of catalyst support*

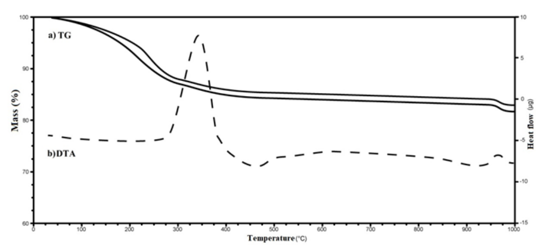


***Figure 2** Thermal analysis of KI-promoted catalyst*

Results of the thermogravimetric analysis (TG), as well as differential thermal analysis (DTA) of the catalyst based on potassium-iodide promoted/ modified nanostructured γ-Al2O3, are shown In Figure 2. A loss of mass can be registered in the temperature range from ~ 250 to ~ 450 °C, which is accompanied by the appearance of a symmetrical peak (exothermic effect) associated with the KI decomposition and likely formation of new catalytically active chemical species K_3AlI_6 and/or K_2O, created during the synthesis and catalyst activation. Also, the same endothermic effect is observed in the temperature range from ~ 400 to 500 °C, as likely consequence of removal/dehydroxylation of residual hydroxyl groups. Loss of mass at temperatures above 960 °C can be associated with decomposition formed by catalytically active chemical species, which is accompanied by the appearance of a symmetrical exothermic effect of weak intensity.

Transesterification reaction

Based on previous experiences related to this catalytic system, the synthesized catalyst is expected to have a high activity. As expected in such a catalytic system consisting of three different immiscible liquid-liquid-solid phases, the influence of the mixing type was significant in terms of the tested catalyst's performance and final catalytic activity.

Table 1 *Influence of stirring type on the catalytic performance of KI promoted alumina*

Mixing type	Conversion (%)				
Reaction time	**1h**	**2h**	**3h**	**4h**	**5h**
Mechanical stirring 600 RPM	45,36	63,25	81,04	97,84	99,99
Ultrasonic stirring 40 kHz	69,24	89,69	99,99	99,99	99,99

As seen from the table, the influence of the type of mixing on the conversion is significant because in the case of applying ultrasound after only three hours under relatively mild reaction conditions, complete conversion of triglycerides into methyl esters occurs. Even in the case of mechanical mixing, full conversion of triglycerides was achieved after only 5 hours. This high catalytic activity is in accordance with the formation of K2O and K3AlI6 chemical species on the synthesized catalyst mentioned in TG/DTA analysis. An increase in the total mass fraction of these chemical species in the catalyst can be associated with an increase in the number of catalytically active base centers, which are the main cause of the presented activity. Mass transfer limitations are increased at mechanical mixing of the reaction mixture at 600 rpm. Also, it was observed that the application of ultrasonic mixing has an advantage on the catalytic performance of the synthesized catalysts, probably due to decreased internal diffusion limitations due to more effortless mass transfer. Table 2 shows the results of testing the reuse of the catalyst, with inter-cycle treatment of the catalyst, without inter-cycle treatment of the catalyst, and regeneration of the catalyst.

As can be seen from the table, there is a drastic difference in the catalytic activity of the tested catalyst in this catalytic system if inter-cyclic treatment of the catalyst is carried out, so that the catalyst is separated from the reaction mixture after the reaction, washed in n-hexane, dried, and then reused.

Table 2 *Influence of reuse of catalyst on the catalytic performance of KI promoted alumina*

Number of cycles	Without inter-cycle treatment Conversion (%)	With inter-cycle treatment Conversion (%)	Before regeneration	After regeneration
1	99,99	99,99	30,08	99,99
2	99,99	99,99		
3	97,52	99,99		
4	82,12	99,99		
5	60,14	99,99		
6	48,12	95,12		
7	42,15	87,65		
8	38,54	75,12		
9	35,10	65,15		
10	30,08	45,12		

This fact is related to the blocking of active centers in the porous system of the catalyst, which can be prevented by washing the catalyst with *n*-hexane, in which both reaction products and reactants are perfectly soluble. In this way, the high catalytic activity of the tested catalyst is maintained in as many as five consecutive reactions. It can also be noted from the presented results that complete regeneration of the catalyst is possible and that the regenerated catalyst is fully restored to its expected catalytic performance.

CONCLUSION

Modified sol-gel syntheses were used for preparing γ-Al_2O_3 support sample from the aluminum isopropoxide precursor and KI-doped alumina-based mesoporous nanostructured material as promising highly active catalyst for transesterification of grape seed oil with methanol. Pronounced activity is in accordance with the formation of K2O and K3AlI6 chemical species into the catalyst, which are the main basic active centers for heterogeneously catalyzed transesterification of grape seed oil. It was concluded that the impact of stirring type is noticeable in the final catalytic activity of newly synthesized catalyst based on improving mass transfer limitations on the examined heterogeneous catalytic system. Conducted tests on catalyst reuse and regeneration gave promising results in using this catalytic system in green biodiesel production. Compared to recently reported results, the presented approach allows biodiesel production with high efficiency, which was applicable on the more significant – industrial scale levels. Also possibility of commercialization of the synthesized catalyst is high based on tests on the reuse of the catalyst, the possibility of its regeneration, and its application in flow reactors.

ACKNOWLEDGMENT

The work was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract numbers: 451-03-65/2024-03/200124, 451-03-66/2024-03/200124 and 451-03-66/2024-03/200051) and **by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Project number: ON 172061).**

REFERENCES

Meher LC, Sager DV, Naik SN. (2006) Technical aspects of biodiesel production by transesterification — A review. Renew Sust Energ Rev;10:248-268.

Thirumarimurugan M, Sivakumar VM, Merly Xavier A, Prabhakaran D, Kannadasan T. (2012) Preparation of biodiesel from sunflower oil by transesterification. Int J Biosci Biochem Bioinf;2(6);441-444.

Li H, Xie W. (2006) Transesterification of soybean oil to biodiesel with Zn/I_2 catalyst. Catal Lett;107;25-30.

Arzamendi G, Arguinarena E, Campo I, Zabala S, Gandia LM. (2008) Alkaline and alkaline-earth metals compounds as catalysts for the methonolysis of sunflower oil. Catal Today;133-135:305-313.

Tiwari AK, Kumar A, Raheman H. (2007) Biodiesel production from jatropha oil (jatropha curcas) with high free fatty acids: an optimized process. Biomass Bioenerg;31:569-575.

Sarma AK, Sarmah JK, Barbora L, Kalita P, Chatterjee S, Mahanta P. (2008) Recent inventions in biodiesel production and processing: A review. Recent Patent Eng;2:47-58.

Mootabadi H, Salamatinia B, Bhatia S, Abdullah AZ. (2010) Ultrasonic-assisted biodiesel production process from palm oil using alkaline earth metal oxides as the heterogeneous catalysts. Fuel;89;1818-1825.

Yang Z, Xie W. (2007) Soybean oil transesterification over zinc oxide modified with alkali earth metals. Fuel Process Technol;88;631-638.

Ngamcharussrivichai C, Totarat P, Bunyakiat K. (2008) Ca and Zn mixed oxide as a heterogeneous base catalyst for transesterification of palm kernel oil. Appl Catal A General;341;77-85.

Alonso DM, Mariscal R, Moreno-Tost R, Poves MD, Granados M. (2007) Potassium leaching during triglyceride transesterification using K/γ-Al2O3 catalysts. Catal Commun;8;2074-2080.

Marinković MM, Zarubica AR. (2016) The significance of textural and structural properties of pottasium loaded γ-alumina catalyst on the final catalytic efficiency in the transesterification of sunflower oil. Adv Technol;5(2):05-11.

Miloš Marinković (2018) Biodiesel production using catalyst based on chemically modified Al2O3 with potassium based compounds: A correlation between physicochemical properties of catalyst, process parameters and biodiesel yield, Niš, Doctoral dissertation.

ISOLATIONS AND CHARACTERIZATION OF AUTOCHTHONOUSBACTERIAL SPECIES FROM *CYPRINUS CARPIO* FOR MICROPLASTIC BIODEGRADATION

Teodora Marković[1], Nikola Pilipović[1], Luka Dragičević[2], Mina Popović[1]*

[1]Faculty of ecology and environmental protection, University "Union-Nikola Tesla", Cara Dušana 62-64, Belgrade 11000, Serbia

[2]Institute of Virology, Vaccines and Sera, Torlak, Vojvode Stepe 458, 11000 Belgrade, Serbia

mpopovic@unionnikolatesla.edu.rs

Abstract: Bacterial communities of beneficial bacteria and pathogens in the gastrointestinal tract (GIT) of people and animals can induce favorable effects when in balance. Probiotics are microorganisms that impart advantageous benefits to the host and are typically located in the gastrointestinal tract (GIT). A potential application of bacterial species from the gastrointestinal tract of Cyprinus Carpio in the biodegradation of microplastics was investigated in this work. The study revealed that the bacterial population of *Cyprinus Carpio* consists of several species specifically identified by 16SrRNA sequencing. The biodegradation study utilizes the *Hafnia parallel*UUNT_MP29 species, one of the ten discovered species. The batch experiment revealed that this strain reached its highest point on the 15th day with a polystyrene. This strain reached its highest point on the 15th day of the batch experiment, with an incubation rate of 1.3x108 CFU/mL. After that, the microorganism entered a stationary phase until the experiment ended on the 20th. These data indicate that this strain is the novel indigenous strain capable of biodegrading polystyrene.

Keywords: *Cyprinuscarpio, Hafnia paralvei*, 16S rRNA sequensing, polystyrene, biodegradation

INTRODUCTION

The gastrointestinal tract (GIT) is a primary reservoir of human and animal bacteria, viruses, and fungi. The microbiota, a complex community of microorganisms, plays a critical role in maintaining health by facilitating digestion, regulating the immune system, and protecting against disease. This delicate balance can be influenced by age, diet, environment, pollution, and medication. An imbalance in this microbial community can lead to various diseases and health conditions (Sender et al.,2016; Yatsunenko et al.,2012) . According to the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO), probiotics are defined as „live microorganisms which, when administered in adequate amounts, confer a health benefit on the host" (Hill et al., 2014). Lactic acid bacteria (LAB), including strains from the *Lactobacillus* genus and *Bifidobacterium*, are the most widely used probiotics. They have been demonstrated to remove harmful compounds and promote health in their hosts (Huang et al., 2015).

Furthermore, the worldwide apprehension regarding plastic trash, particularly microplastics (MPs) and nanoplastics (NPs), has intensified because of their widespread existence in the environment and inability to break down. Microscopic particles (MPs) and nanoparticles (NPs) are present in water, soil, air, and the bodies of humans and animals, which may result in health problems, including organ damage and inflammation (Zhao et al.,2023; Ragusa et al., 2021). Among the most widespread microplastics (MPs), polystyrene (PS) is a synthetic polymer frequently employed in packaging, medical equipment, and building materials. Its extensive use and inability to break down significantly contribute to environmental pollution (Zajac et al., 2023). Although the precise mechanisms remain largely unknown, the biodegradation of PS by microorganisms, which can involve biofilm formation and enzymatic breakdown, has garnered considerable scientific interest (Pitt et al., 2018; Kumar et al., 2021).

MPs' persistent contamination of aquatic environments poses an increasingly severe threat to marine animals and human settlement. Hence, it is imperative to investigate the potential biodegradation of PS using microorganisms from aquatic environments to create more effective microbiological solutions for plastic pollution. An abundant species in European freshwater systems, the common carp (*Cyprinuscarpio*) has a unique microbiome that may harbor novel microbial strains capable of decomposing PS (Chang et al., 2023).

A recent study has examined the probiotic properties of isolated strains of *Hafniaparalvei* obtained from *Cyprinuscarpio*. These strains have shown promise in their capacity to target bacterial illnesses and offer potential health benefits. Using probiotics and biodegradation techniques presents novel opportunities for enhancing the management of pathogenic microorganisms and environmental pollutants (Legrand et al., 2020).

MATERIALS AND METHODS

Isolation of autochthonous species from the gastrointestinal tract of *Cyprinus Carpio*

Originating bacterial strains from the gastrointestinal tract (GIT) of *Cyprinus Carpio* were identified by collecting samples from the fish market ''DTD'' in Belgrade, Serbia. Live samples were transported to the laboratory and then euthanized. On average, the fish samples weighed between 1700 and 1850 g. The longitude sectioning of the samples was performed under aseptic conditions, and the abdominal surfaces of all samples were meticulously cleansed with 70 vol.% ethanol. The specimens are washed three times and dissected aseptically to remove the intestines. The samples' intestines were longitudinally incised and extensively rinsed with sterile phosphate buffer saline (PBS) to eliminate feed debris, dirt, and other contaminants. The weight of the intestines was measured, and then samples were macerated using sterile scissors. The homogenization was done in sterile PBS (1:10 wet/vol) using a vortex mixer. Homogenized samples were serially diluted in PBS and plated aseptically using the pour plate technique on Man Rogosa Sharpe (MRS) agar plates. The samples are incubated at 37 ˚C for 48 hours under aerobic conditions. Colonies exhibiting distinct morphological variations, including differences in size, color, and form, were chosen and isolated by streaking two consecutive passages onto MRS plates. The pure strains were grown overnight (16 hours) in MRS broth, and 50% glycerol (Sigma-Aldrich) was added to make a glycerol stock. These strains are stored at - 80 ˚C until the further experiments (Sender et al.,2016; Yatsunenko et al.,2012).

Gram staining

Pure isolated colonies of all samples were streaked on MRS plates, incubated for 48h at 37 ˚C aerobically, and then these isolated strains were identified with Gram staining assay using the manufacturer's protocol.

Catalase assay

All samples were assessed using a catalase assay using 3,0 wt.% hydrogen peroxide. Pure colonies were streaked on microscopic glass, dropped with 3% hydrogen peroxide, and observed to detect the presence of the baubles on the samples.

Species identification by 16S rRNA gene sequencing

The cultures were identified using Sanger sequencing of the 16S rRNA gene with standard primers (1492R-ACGGYTACCTTGTTACGACTT, 27F-AGAGTTTGATCCTGGCTCAG). DNA fragment amplification was performed using thermal cycler Mastercycler Pro (Eppendorf) in the following manner: initial denaturation at 94 °C for 5 min, followed by 30 cycles consisting of denaturation at 94 °C for 1min, annealing at 55 °C for 30 s, and polymerization at 72 °C for 1 min, and a final extension at 72 °C for 7 min. Conformation of DNA fragments was done using electrophoresis. Five µL of the amplified samples were loaded onto 1% agarose gel in TAE buffer (40 mM Tris-acetate, 1 mM EDTA, pH 8.2). Gel was stained with (500 ng/mL) and visualized under UV light (EZEE gelONE, Cleaver Scientific). DNA fragments were sized with gene ruler (GR), GeneRuler DNA Ladder Mix, from 100 to 10000 bp. Sanger sequencing was performed on an Applied Biosystems 3500 Genetic Analyzer. The PCR product clean-up was done using ExoSAP-IT PCR Product Cleanup Reagent following the manufacturer's protocol.The sequencing reaction setup was done using the BigDye Terminator v3.1 Cycle Sequencing Kit according to the manufacturer's protocol. Centri-Sep columns (Applied Biosystems) were used for reaction clean-up before loading onto the device. To 2 µL of the cleaned product, 15 µL of formamide was added, and this mixture was loaded onto capillary electrophoresis. The Basic Local Alignment Search Tool (BLAST, https://blast.ncbi.nlm.nih.gov/Blast.cgi) algorithm was used to determine the most related sequences in the NCBI nucleotide sequence database (PMID: 34850941).

Biodegradation of polystyrene with *Hafniaparalvei* UUNT_MP29

Degradation experiments were performed in triplicates in a 250 mLconical flask containing 100 mL of mMRSand a PS film (1.0 × 1.0 cm) for every 5-day interval up to 20 days. PS film incubatedin mMRS without bacterial inoculum of the strain *Hafniaparalvei* UUNT_MP29served as the control. Thelog phase grown isolates 1% (v/v) were inoculated in 100 mL of MRS. The initial absorbance of bacterial suspension was maintained as 0.08 at 600 nm and incubated at 22 °C with a constant shaking of120 rpm. A set of triplicate flasks were removed at regular intervals, andthe following analyses were done.

RESULTS AND DISCUSSION

Identification of samples and 16S rRNA sequencing

After isolating the bacterial samples from the GIT of *Cyprinuscarpio*, ten different species were detected in 46 samples. The following species were identified with molecular method 16S rRNA sequencing: *Citobacterfreundii, Serratialiquefaciens, Baciluspumilus, Kocuriatytonicola, Hafniaalvei, Enterococcusxiangfangensis, Serratiaplymutica*, *Hafniaparalvei,* and*Koruciarhizophila*. According to the size, color, shapes, and numbers, the strain *Hafniaparalvei* UUNT_MP29 was chosen for further experiments.

Gram staining and catalase assay

The Gram staining of all samples revealed rod-shaped Gram-negative cells as the most representative, with three coccus Gram-negative strains present (Fig. 1). The second method of identification was the catalase assay. This test is employed to identify organisms that synthesize the enzyme catalase. This enzyme catalyses the detoxification of hydrogen peroxide by its decomposition into water and oxygen gas. All samples exhibited catalase negativity, confirming these bacteria's Gram-negative nature.

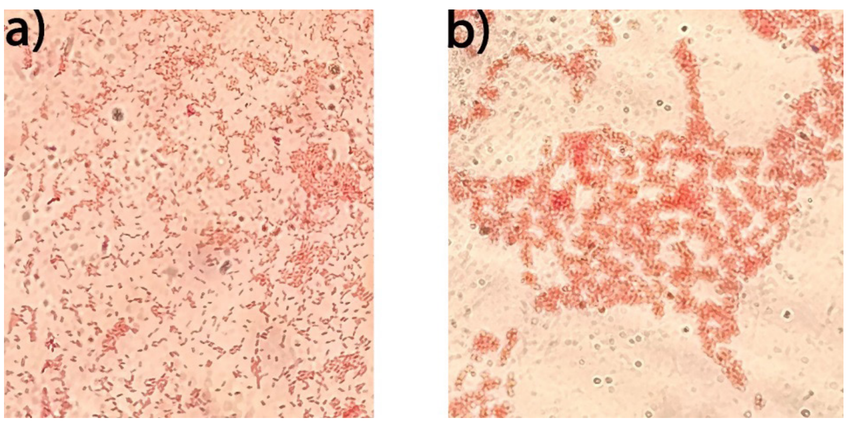


Figure 1*Gram staining of samples isolated from Cyprinus carpioat at magnification 100x: a) Hafnia paralvei UUNT_MP29Gram-negative rod shape b) Enterococcus Xianfangensis UUNT_MP38Gram-negative coccus shape*

According to the results obtained from the previous experiments, the strain Hafniaparalvei UUNT_MP29, a novel autochthonous strain, was used for the biodegradation experiment. In this batch experiment with 4-time points, *Hafniaparalvei* UUNT_MP 29 showed that polystyrene could use polystyrene as the sole carbon source.The gradual increase in growth of the bacterium was observed from the 5th day onwards, and it reached the stationary phase on the 20th day, with a maximum of 1.3x10^8 CFU/mL on the 15th day. This may be due to the lag phase adaptation period required for the strain *Hafnia paralvei* UUNT_MP 29 to use PS as the sole carbon and energy source. In the lag phase, the amount of PS degradation was low, which can be correlated with the initial acclimatization phase; however, in the log phase, the metabolic activity of the strain increase-d,which accelerated the degradation process. The growth andmetabolism of the strain decreased after reaching the stationaryphase (Figure 2).

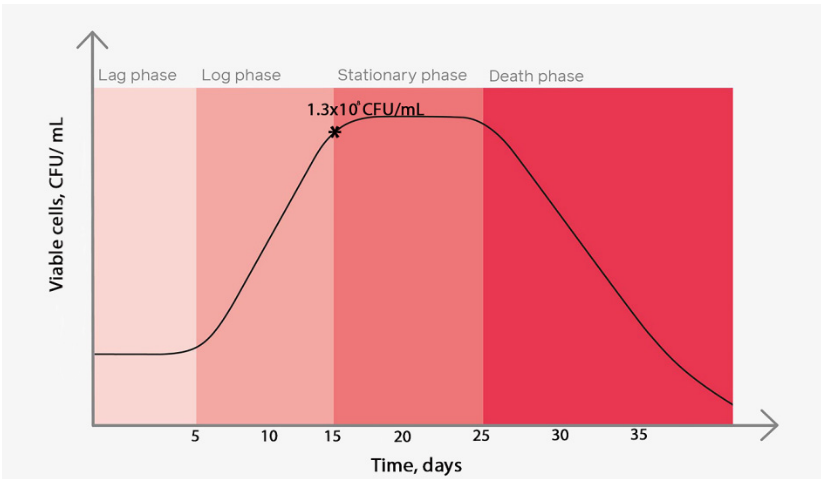


Figure 2 *Biodegradation of polystyrene; the growth curve of Hafnia paralvei UUNT_ MP29 on polystyrene*

CONCLUSTION

Upon isolation from the freshwater, it was determined that *Hafniaparalvei* UUNT_MP 29 is a Gram-negative, rod-shaped strain without a catalytic enzyme. A newly isolated *Hafniaparalvei* UUNT_MP 29 indigenous strain demonstrated efficient growth on the PS medium during 20 days of treatment till reaching a stationary phase. The results on biodegradation offer a novel biotechnological approach to foster the development of sophisticated technologies for the bioremediation of synthetic polymers. The following investigation will be carried out on several categories of plastics found in the aquatic environment, employing this particular strain for the purpose of biodegradation. Thus, the metabolites from this strain will be thoroughly described.

References

A. Ganesh Kumar, Manish Hinduja, KanradSujitha, N. NivedhaRajan, G. Dharani. Biodegradation of polystyrene by deep-sea *Bacillus paralicheniformis* G1 and genome analysis. Science of the Total Environment 2021;774:.

Antonio Ragusa, Alessandro Svelato, CriseldaSantacroce , Piera Catalano, Valentina Notarstefano, OlianaCarnevali, Fabrizio Papa, Mauro Ciro Antonio Rongioletti, Federico Baiocco, SimonettaDraghi, ElisabettaD'Amore, Denise Rinaldo, Maria Matta and ElisabettaGiorgini. Plasticenta: First evidence of microplastics in human placenta. Environ Int2021;146.

Colin Hill, Francisco Guarner , Gregor Reid, Glenn R. Gibson, Daniel J. Merenstein, Bruno Pot, Lorenzo Morelli, Roberto BerniCanani, Harry J. Flint, Seppo Salminen, Philip C. Calder and Mary Elln Sanders. Expert consensus document: The international scientific association for probiotics and prebiotics consensus statement on the scope and appropriate use of the term probiotic. Nat Rev Gastroenterol Hepatol 2014;11:506–514.

Jordan A. Pitt , Jordan S. Kozal, NishadJayasundara, Andrey Massarsky, Rafael Trevisan, Nick Geitner, Mark Wiesner, Edward D. Levin, Richard T. Di Giulio. Uptake tissue distribution and toxicity of polystyrene nanoparticles in developing zebrafish (Danio rerio). Aquatic Toxicology 2018;194:185–194.

Lili Zhao,Qingnan Dou, Shiyue Chen, Yinbin Wang, Qingxiang Yang, Wanrong Chen, Hao Zhang, Yirong Du, MengfeiXie. Adsorption abilities and mechanisms of *Lactobacillus* on various nanoplastics. Chemosphere 2023;320:.

Marcin Zając, Joanna Kotyńska, GrzegorzZambrowski, Joanna Breczko, Piotr Deptuła, Mateusz Cieśluk, Monika Zambrzycka, IzabelaŚwięcicka, Robert Bucki and Monika Naumowicz. Exposure to polystyrene nanoparticles leads to changes in the zeta potential of bacterial cells. Sci Rep 2023;13:.

Renhui Huang , Xueying Tao , Cuixiang Wan , Shengjie Li, Hengyi Xu, Feng Xu, Nagendra P. Shah, Hua Wei. In vitro probiotic characteristics of *Lactobacillus plantarum* ZDY 2013 and its modulatory effect on gut microbiota of mice. J Dairy Sci 2015;98:5850–5861.

Romain Legrand, Nicolas Lucas,Manon Dominique, SaidaAhzar, Camille Deroissart, Marie-Anne Le Solliec, Julie Rondeaux, SéverineNobis, CharlèneGuérin, Fatima Léon, Jean-Claude do Rego, Nicolas Pons, Emmanuelle Le Chatelier, S.Dusko Ehrlich, Gregory Lambert, Pierre Déchelotte and Sergueï O.Fetissov Commensal *Hafniaalvei* strain reduces food intake and fat mass in obese mice—a new potential probiotic for appetite and body weight management. Int J Obes2020;44:1041–1051.

Ron Sender, ShaiFuchs ,Ron Milo. Revised Estimates for the Number of Human and Bacteria Cells in the Body. PLoSBiol 2016;14:.

Songhuan Chang, Jiali Wang,Chuanju Dong, Yangliang Jiang. Intestinal microbiota signatures of common carp (*Cyprinuscarpio*) after the infection of *Aeromonashydrophila*. Aquac Rep 2023;30:.

Tanya Yatsunenko, Federico E Rey, Mark J Manary, Indi Trehan, Maria Gloria Dominguez-Bello, Monica Contrereas, Magda Magris, Gilda Hidalgo , Robert N Baldassano, Andrey P Anokhin, Andrew C Health, Barbara Warner, Jens Reeder, Justin Kuczynski, J Gregory Coporaso, Catherine A Lopuzone, Christian Lauber, Jose Carlos Clemente, Dan Knights, Rob Knight, Jeffrey I Gordon. Human gut microbiome viewed across age and geography. Nature 2012;486:222–227.

ACTIVITY OF RADIOSTRONTIUM IN LEAVES OF SOME FRUIT SPECIES

Nataša B. Sarap[1], Stefana N. Dejković[1], Maja Vukić[2], Marija M. Janković[1], Hadi Waisi[3,4]

[1]University of Belgrade, Vinča Institute of Nuclear Sciences − National Institute of the Republic of Serbia, Department of Radiation and Environmental Protection, Belgrade, Serbia

[2]University of Belgrade, Faculty of Physical Chemistry, Belgrade, Serbia
[3]University UNION − Nikola Tesla, Faculty of Ecology and Environmental Protection, Belgrade, Serbia
[4]University of Belgrade, Institute of General and Physical Chemistry, Belgrade, Serbia

natasas@vin.bg.ac.rs

Abstract: This study focuses on the determination of ^{90}Sr content in leaves of three fruit species: apricot, fig and vine (from Serbia and Iraq), by radiochemical analytical method. This method was validated in the Department of Radiation and Environmental Protection of the Vinča Institute of Nuclear Sciences, and accredited according to ISO/IEC 17025. The detection of ^{90}Sr was performed by beta spectrometry using a low level gas proportional counter. The results of the conducted study are initial and present part of the planned detailed research extended to other commonly used fruit species.

Keywords: Radiostrontium, Beta spectrometry, Fruit leaves

INTRODUCTION

Radiostrontium, ^{90}Sr is an artificial radionuclide with a half life of 28.8 y produced by nuclear fission (Froidevaux et al., 2021). It undergoes β^- decay, giving an electron with energy of 546 keV and ^{90}Y as decay products. This β− particle emitter that has a long half life and is retained by living organisms, is one of the most hazardous radionuclides (Amano et al., 2016). After incorporation of ^{90}Sr, harmful beta particles induce internal radiation exposure in organisms. Radiostrontium in the environment acts on living organisms either from external sources or after absorption. If it enters an organism, mostly by ingestion of contaminated food or water, about 70–80 % gets excreted, but the remaining amount deposits in bones, teeth and bone marrow, causing calcium loss and increasing risk of bone cancer, cancer of nearby organs and leukemia (Niedrée et al., 2013).

When incorporated by plants, it enters the food chain and causes primary threat to human health and the environment (Burger and Lichtscheidl, 2019). In general, strontium is absorbed by plants because of its physico–chemical similarity to calcium, although there is no function known for plant nutrition. ^{90}Sr enters plants via root absorption from soil and water, but it is also taken up by leaves from air especially after fallout. The high level of strontium translocation to leaves results in high accumulation of this element in the parts of plants that are above ground (Dresler et al., 2018). Absorption of stable, as well as radioactive strontium by a plant is shown in Fig 1.

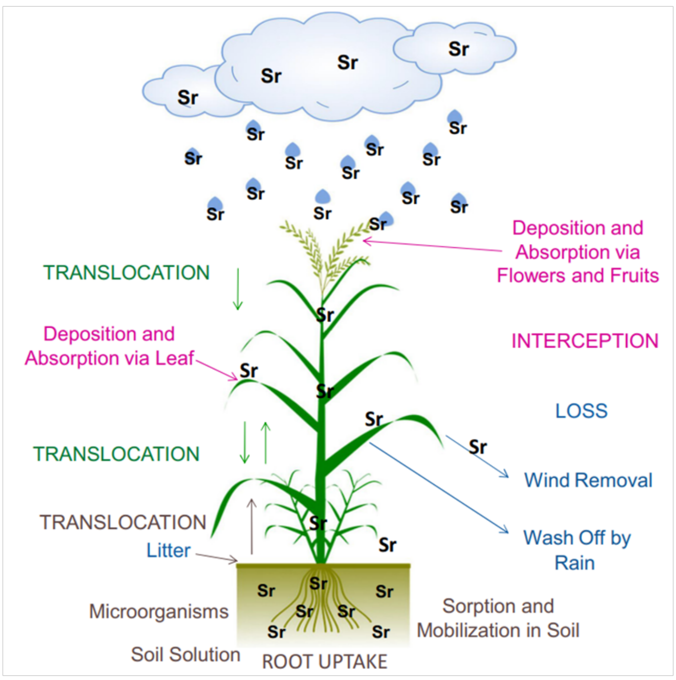


Figure 1 *Absorption of strontium by a plant (Figure is taken from Burger and Lichtscheidl, 2019)*

Isotopes of radiostrontium have been released to the environment since the development of the nuclear industry in the beginning of the 20th century. In the second half of the 20th century researchers recognized the importance of the uptake of radiostrontium by chain "plant–animal–human" and started to test plant reactions towards radiostrontium (Burger and Lichtscheidl, 2019). After the accidents at nuclear power plants, such as Chernobyl/Ukraine in 1986 (Fesenko et al., 2007) and Fukushima/Japan in 2011 (Ashraf et al., 2014), the need for extensive research of ^{90}Sr was emerged.

Many studies were carried out in order to identify effects of different factors influencing radiostrontium uptake by plant roots and leaves from the soil, water and air (Arapis et al., 1997; Maskalchuk et al., 2014; Burger and Lichtscheidl, 2019; Sarap et al., 2024a). Due to the fact that the presence of radionuclides in fruit represents the way for their transfer into the human body over a food chain, the aim of this paper was to study the content of the artificial beta−emitting radionuclide ^{90}Sr in fruit species.

EXPERIMENTAL

This study included 3 leaf species: apricot, vine and fig from two countries, Republic of Serbia (Belgrade region) and Iraq (Sulaymaniyah, Kurdistan region). These leaf species belong to woody trees. Sampling was carried out during summer of 2018.

The collected samples were air−dried at room temperature for three weeks and then ashed at 450 °C for 24 hours in a muffle furnace. An aliquot of approximately 20 g ashed sample was taken for radiochemical procedure of determination of ^{90}Sr. Detailed information on the used method has been described by Sarap et al. (2024b).

Radiochemical analysis was performed at the Radiation and Environmental Protection Department of the Vinča Institute of Nuclear Sciences in laboratory for radiation measurements which is accredited according to ISO/IEC 17025.

The measurement of samples was performed immediately after established of radioactive equilibrium between ^{90}Sr and ^{90}Y, using a low level gas proportional counter *Thermo Eberline FHT 770T* (Erlangen, Germany). The time interval for sample counting was 5400 s (in three replicate series). The background was measured by counting an empty planchet immediately before the sample counting.

Calibration a low level gas proportional counter for beta spectrometry was performed using a point calibration source for ^{90}Sr (9031−OL−335/11, issued by the Czech Metrology Institute) traceable to BIPM (International Bureau of Weights and Measures).

RESULTS AND DISCUSSION

The results of the determination of ^{90}Sr activity in selected leaf species: apricot from Serbia (denoted as S1) and Iraq (denoted as S2); vine from Serbia (denoted as S3) and Iraq (denoted as S4); fig from Serbia (denoted as S5) and Iraq (denoted as S6) are shown in Fig. 2. The lowest measured value for the investigated leaves samples was 1.4 Bq/kg dry matter, while the highest measured value was 7.6 Bq/kg dry matter (Fig. 2). The measured values were expressed with an expanded measurement uncertainty that was presented with a coverage factor k=2, representing an approximate confidence level of about 95% (Rondahl and Ramebäck, 2018).

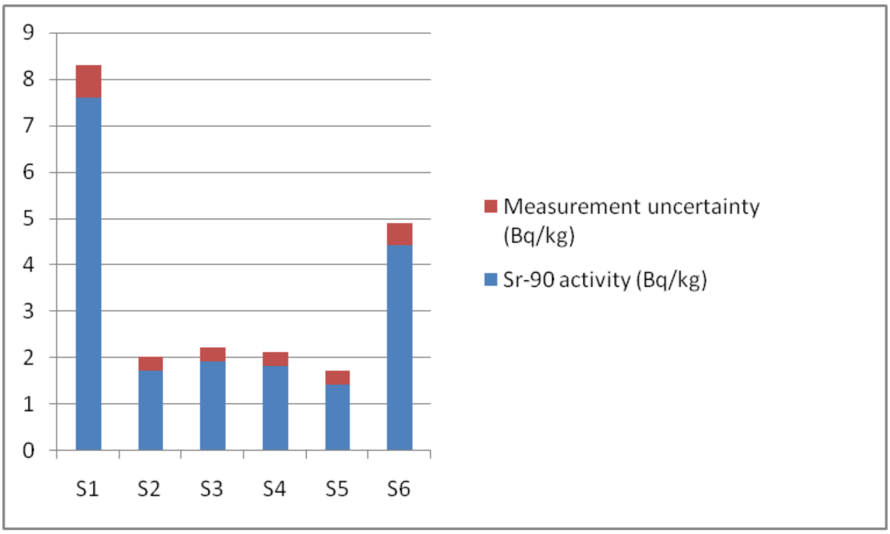


Figure 2 *The activity of ^{90}Sr in different leaf species*

It is evident that the measured values are similar only for vine leaves in the both countries. It can be observed that for apricot leaves sample activity of ^{90}Sr is approximately 4.5 times higher for sample from Serbia than from Iraq, while for fig leaves sample from Iraq the value is approximately 3 times higher than for sample from Serbia. In general, the results of determination of ^{90}Sr activity in this study are in line with the results reported in other papers (Amano et al., 2016; Burger and Lichtscheidl, 2019; Sarap et al., 2024a).

Acknowledgement

This work was partially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Annex of the Contract No. 451−03−66/2024−03/200017).

CONCLUSION

Understanding the mechanisms of plants for radiostrontium uptake and retention is essential for decision making concerning agriculture. Genomic engineering develops new plant varieties with high or low uptake capacities of radiostrontium.

The data presented in this research provide information on the beta−emitting radionuclide ^{90}Sr and contribute to increasing databases on radioactivity in fruit. Since the radionuclides present in fruit can be transferred into the human body via consummation of fruit, the fruit species must be strictly controlled on radionuclide presence in order to minimize harmful contaminants and increase the safety of consumers.

REFERENCES

Amano, H., Sakamoto, H., Shiga, N., Suzuki, K. Method for rapid screening analysis of Sr−90 in edible plant samples collected near Fukushima, Japan. Appl Radiat Isot 2016; 112;131–135.

Arapis, G., Petrayev, E., Shagalova, E., Zhukova, O., Sokolik, G., Ivanova, T. Effective migration velocity of ^{137}Cs and ^{90}Sr as a function of the type of soils in Belarus. J Environ Rad 1997; 34: 171–185.

Ashraf, M., Akib, S., Maah, M., Yusoff, I., Balkhair, K. Cesium−137: radio−chemistry, fate, and transport, remediation, and future concerns. Environ Sci Tech 2014; 44;1740–1793.

Burger, A. and Lichtscheidl, I. "Strontium in the environment: Review about reactions of plants towards stable and radioactive strontium isotopes. Sci Total Environ 2019;653; 1458−1512.

Dresler, S., Wójciak−Kosior, M., Sowa, I., Strzemski, M., Sawicki, J., Kováčik, J., Blicharski, T. Effect of long−term strontium exposure on the content of phytoestrogens and allantoin in soybean." Int. J. Mol. Sci. 2018; 19 (12);3864.

Fesenko, S., Jacob, P., Ulanowsky, A., Chupov, A., Bogdevich, I., Sanzharova, N., Kasparov, V.,

Panov, A., Zhuchenka, Y. Justification of remediation strategies in the long term after the Chernobyl accident." J Environ Rad 2013; 119: 39–47.

Froidevaux, P., Pittet, P.A., Bühlmann, D., Bochud, F., Straub, M. "Ion−

imprinted resin for use in an automated solid phase extraction system for determining ^{90}Sr in environmental and human samples." JNRS Journal 2021;330;797−804.

Maskalchuk, L.N., Baklai, A.A., Konoplev, A.V., Leontieva, T.G. "Migration of ^{90}Sr in the solid phase of the soil−soil solution−plant systems and ways to reduce it." Radiochem 2014; 56; 222−225.

Niedrée, B., Berns, A.E., Vereecken, H., Burauel, P. "Do Chernobyl−like contaminations with ^{137}Cs and ^{90}Sr affect the microbial community, the fungal biomass and the composition of soil organic matter in soil? J Environ Rad 2013;118;21−29.

Rondahl S. H. and Ramebäck H. "Evaluation of different methods for measuring ^{89}Sr and ^{90}Sr: Measurement uncertainty for the different methods as a function of the activity ratio." Appl Radiat Isot 2018;140; 87–95.

Sarap, N.B., Daković, M.Ž., Djalovic, I., Dolijanović, Ž.K., Prasad, P.V.V., Janković, M.M.. Application and experimental substantiation of the radioecological model for prediction in behavior ^{90}Sr in cultivated soil−crop system; a case study of two experimental agricultural fields. Plants 2024a; 13;1798.

Sarap, N.B., Nodilo, M., Štrok, M., Grahek, Ž., Janković, M.M. "Comparison of some of the analytical techniques and their applications to environmental radiostrontium determination. JNRS Journal 2024b; 333;2697−2707.

ASSESSMENT OF GROUNDWATER CONTAMINATION IN THE SOUTH INDUSTRIAL ZONE OF PANČEVO

Nenad Marić[1*], Hiroshi Takashima[2,3], Takeshi Nakano[4,5], Vesna Jerkov[6], Latinka Slavković Beškoski [7], Vladimir Beškoski[8]

[1] University of Belgrade, Faculty of Forestry, Department of Ecological Engineering for Soil and Water Resources Protection, Kneza Višeslava 1, 11000 Belgrade, Serbia, nenad.maric@sfb.bg.ac.rs

[2,3] Daiichi Institute of Technology, Faculty of Engineering/ The Geo-pollution Control Agency, Chiba, 3-5-1, Inagekaigan, Mihama-ku, Chiba city, 261-0005, Japan,

h-takashima@daiichi-koudai.ac.jp

[4,5] Osaka University, Research Center for Environmental Preservation/Hyogo Environmental Advancement Association, 3-1-27, Yukihira-cho, Suma-ku, Kobe, 654-0037, Japan,

ntakeshi@jrl.eng.osaka-u.ac.jp

[6] Secretariat for Environmental Protection of Pancevo, Trg kralja Petra I br. 2-4, 26101 Pancevo, Serbia, vesna.petkovic-borovnica@pancevo.rs

[7] Anahem Ltd., Mocartova 10, Belgrade, Serbia

[8] University of Belgrade, Faculty of Chemistry, Department of Biochemistry, Studentski trg, 11000 Belgrade Studentski trg 12-16, 11158 Belgrade, Serbia, vbeskoski@chem.bg.ac.rs

Abstract

This study investigates groundwater contamination within the South Industrial Zone (SIZ) of Pančevo through sampling campaigns conducted in June and October 2023. Sampling was conducted at 25 piezometers to assess contamination hotspots and groundwater quality. The analysis focused on parameters exceeding remediation threshold concentrations (RTCs), highlighting critical areas necessitating immediate attention. Results indicate RTC exceedances near HIP Petrohemija and NIS Refinery Pančevo, notably in PA-3/15, PA-3/25, PA-3/45, PA-4/25, P-738, and PA-1/7 piezometers in October 2023. Contaminants, including arsenic and dense nonaqueous phase liquids (DNAPLs), like vinyl chloride, predominantly affected deeper piezometers. No exceedances were found downgradient within the study area, indicating localized contamination near the mentioned industrial plants. Continued monitoring is essential to understand contamination dynamics and implement effective mitigation strategies. Active industry involvement is crucial for sustained groundwater quality management in the SIZ of Pančevo.

Key words: groundwater quality, intergranular aquifer, DNAPL, Pančevo

INTRODUCTION

The South Industrial Zone (SIZ) of Pančevo is located south of the city, housing the key industrial plants, including HIP Petrohemija, HIP Azotara, and the NIS Refinery Pančevo (Figure 1). These industrial facilities are closely clustered, potentially impacting a large agricultural area nearby. The soil and groundwater in this region are particularly vulnerable to contamination, primarily due to the environmental risks posed by the daily discharge of wastewater, minor leaks, and occasional spills from these plants. The most significant pollution event in the SIZ Pančevo area occurred in 1999, during the NATO bombing, which resulted in substantial environmental contamination. Since then, several cleanup and remediation programs have been implemented to address the most severely affected industrial zones. Despite these efforts, ongoing monitoring and assessment are crucial to managing and mitigating environmental impact.

This study assesses groundwater contamination's current extent and intensity in the SIZ Pančevo. We present the results from the sampling campaigns conducted in June and October 2023. Groundwater sampling was carried out at 25 piezometers using a comprehensive approach to ensure a thorough understanding of the contamination hotspots and overall groundwater quality in the area. The analysis focused on identifying the parameters that exceeded the remediation threshold concentrations (RTC), highlighting the critical areas that require immediate attention

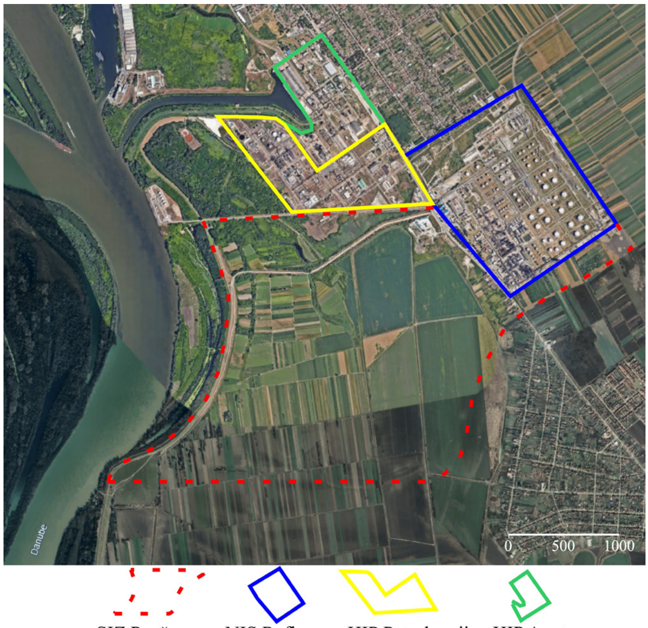


Figure 1. Geographical position of the SIZ Pančevo

STUDY AREA

The Quaternary deposits covering most of the study area consist of Pleistocene and Holocene sediments, including fluvial, marsh, alluvial, and aeolian origin deposits. Alluvial-lacustrine gravelly sands and subclays, though not visible on the terrain surface, form the foundation of the Quaternary sediments. They predominantly exhibit fine-grained to medium-grained granulometric compositions, occasionally gravelly in lower zones. In the vertical cross-section, the layers are distinguished as follows (UNDP, 2010):

- Organic humus layer or anthropogenic fill (up to 2 meters thick),
- Alluvial soils (5 to 8 meters thick),
- Sandy or silty loams (2 to 12 meters thick),
- Fine-grained and silty sands (2 to 12 meters thick),
- Fine- to medium-grained, locally gravelly sands (5 to 60 meters thick).

The study area is situated within the left fluvial plain of the Danube River. It belongs to the broader Danube basin region, influencing groundwater recharge and drainage patterns. From a hydrogeological perspective, the natural terrain comprises a dual-layer system: a superficial layer of low permeability and an underlying sandy aquifer with intergranular porosity (riverbed facies). Beneath the alluvial deposits lie Neogene clays. Under natural conditions, groundwater flows predominantly from northeast to southwest, following the courses of the Danube and Tamis rivers. Changes in groundwater flow direction occur within a few hundred meters of the Danube's course, influenced by fluctuations in the river's water levels, thus causing a shift between recharge and drainage patterns. The regional water table contours based from the CETMA (2006) study is provided in Figure 2.

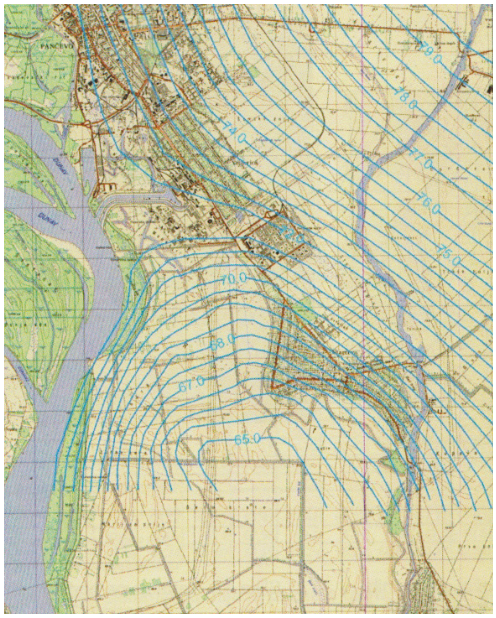


Figure 2. Regional water table contours in the area surrounding SIZ Pančevo (CETMA 2006)

The general groundwater flow direction is observed to be northeast-southwest with a hydraulic gradient of 0.0045. Adjacent to the Danube and the direction of underground water movement, drainage canals also contribute to groundwater flow, directing it towards the lowest point in the landscape, typically the canal. According to data from the UNDP study (UNDP, 2010), the hydraulic conductivity coefficients for the primary hydrogeological environments are as follows:

- Surface low permeability layer: 2.81×10^{-7} to 1×10^{-8} cm/s,
- Main aquifer: 3.00×10^{-4} to 1×10^{-5} cm/s,
- Lower impermeable layer: 3.00×10^{-9} to 7.1×10^{-8} cm/s.

Considering the presence of four arrays equipped with piezometers at various depths, the findings from the UNDP study are summarized as follows (UNDP, 2010):

- Piezometer cluster PA-1: Water levels in these four synchronized piezometers indicate a quasi-homogeneous environment, with oscillations of about 2.5 meters.
- Piezometer cluster PA-2: Water level fluctuations reflect variations in the underlying basin layer and the influence of precipitation infiltration.
- Piezometer cluster PA-3: Oscillations suggest significant drainage influence from nearby secondary drains.
- Piezometer cluster PA-4: Synchronized oscillations imply all piezometers are in an aquifer, though confirmation via drilling logs is unavailable.
- Individual piezometers Pp-738, Pp-739, SDC-5, SDC-6, Lp-720, Pp-721, and P-III-3 exhibit predictable oscillations influenced by their locations and proximity to drainage channels.

The sampling campaign involved 25 piezometers distributed across 13 locations within the study area (Figure 2). These cluster piezometers enabled the evaluation of potential impacts from various industrial plants. The placement of piezometer clusters near these industrial facilities allowed a detailed delineation of the possible effects at different depths within the aquifer.

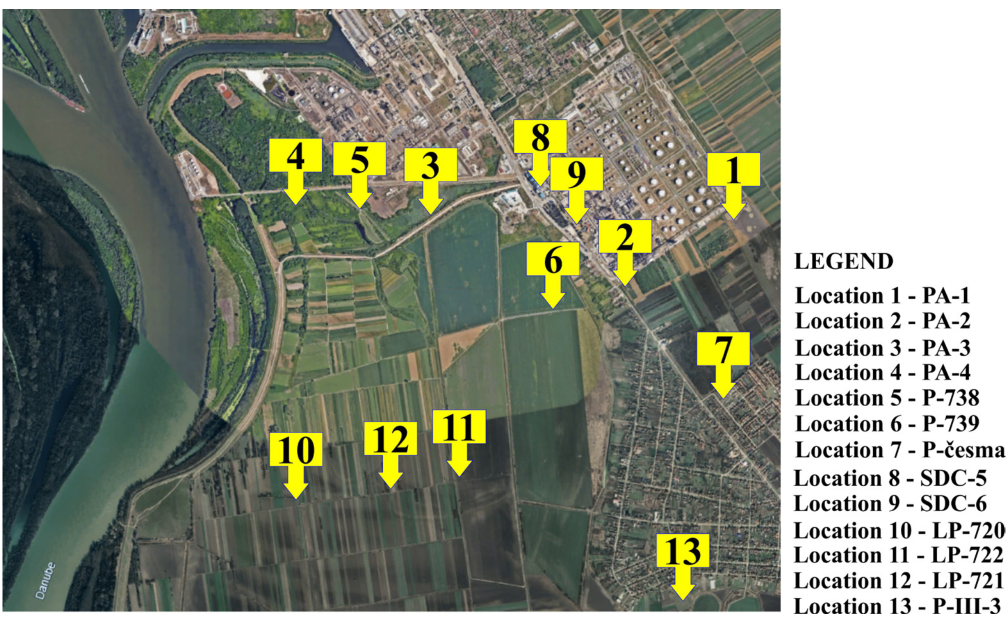


Figure 2. Groundwater sampling locations within the SIZ Pančevo

MATERIAL AND METHODS

Groundwater samples were collected from 25 piezometers using standard sampling procedures to ensure consistency and accuracy. Before sampling, the piezometers were purged to stabilize groundwater parameters, thereby ensuring that the samples accurately reflected the current conditions. Samples were collected in pre-cleaned, labeled bottles to avoid contamination and to preserve the integrity of the samples. These samples were then analyzed for a variety of physicochemical parameters using established analytical methods at the Pančevo Institute for Public Health (2023a and 2023b). In situ measured parameters included temperature, pH, turbidity, oxygen content, and saturation levels. These measurements provided immediate data on the groundwater conditions at each sampling point.

Rigorous quality assurance and quality control measures were implemented throughout the study to ensure data accuracy and reliability. Tables 1 and 2 comprehensively summarize the analytical methods and procedures used for groundwater characterization. These tables also include the remediation threshold values stipulated by Serbian regulations (Official Gazette of RS. 2018), providing a clear benchmark for assessing contamination levels.

Table 1. Methods and procedures of the field characterization parameters (Pančevo Institute for Public Health, 2023a, 2023b)

Parameter	**Method**	**Unit**	**Remediation threshold value (RTC)**
Temperature	SRPS H.Z.1. 106:1970	°C	-
pH	SRPS EN ISO 10523:2016	-	-
Turbidity	-	-	-
Oxygene content	DMI-101	mg/L	-
Oxygene saturation	DMI-101	%	-

Table 2. Methods and procedures of the laboratory-analyzed parameters (Pančevo Institute for Public Health, 2023a, 2023b)

Parameter	**Method**	**Unit**	**Remediation threshold value (RTC)**
Turbidity	HDMI-003	NTU	-
Electrical Conductivity	HDMI-011	µS/cm	-

Ammonium	HDMI-029	mg/L	-
Nitrate	HDMI-005	mg/L	-
Chloride	SRPS ISO 9297:1997 SRPS ISO 9297/1:2007	mg/L	-
Sulfate	Manual method III/20	mg/L	-
Potassium permanganate consumption	HDMI-009	mg/L	-
Iron	SRPS EN ISO 17294-2:2017 SRPS EN ISO 15587-2:2009	mg/L	-
Manganese	SRPS EN ISO 17294-2:2017 SRPS EN ISO 15587-2:2009	mg/L	-
Total Organic Carbon (TOC)	SRPS ISO 8245:108	µg/L	-
Polychlorinated Biphenyls (PCBs)	VDM-0005	µg/L	0.01
Polycyclic Aromatic Hydrocarbons (PAHs)			
Total Polycyclic Aromatic Hydrocarbons (Total PAHs)	VDM-0005	µg/L	-
Fluoranthene	VDM-0005	µg/L	1
3,4-Benzfluoranthene	VDM-0005	µg/L	-
11,12-Benzfluoranthene	VDM-0005	µg/L	-
1,12-Benzoperylene	VDM-0005	µg/L	-
Indeno(1,2,3-cd)pyrene	VDM-0005	µg/L	0.05
Benzo(a)pyrene	VDM-0005	µg/L	0.05
Total Petroleum Hydrocarbons (TPH)			600
C6-C10	VDM-0132	µg/L	-
C10-C28	VDM-0133	µg/L	-
C10-C40	SRPS EN ISO 9377-2:2009	µg/L	-
Aromatic Hydrocarbons			
Benzene	SRPS EN ISO 15680:2009	µg/L	30
Toluene	SRPS EN ISO 15680:2009	µg/L	1000
Ethylbenzene	SRPS EN ISO 15680:2009	µg/L	150
Xylene	SRPS EN ISO 15680:2009	µg/L	70

MTBE (Methyl tert-butyl ether)	SRPS EN ISO 15680:2009*	µg/L	9200
Chlorinated Alkanes			
1,2-Dichloroethane	SRPS EN ISO 15680:2009**	µg/L	400
Dichloromethane	SRPS EN ISO 15680:2009**	µg/L	1000
Carbon Tetrachloride	SRPS EN ISO 15680:2009**	µg/L	10
1,1,2,2-Tetrachloroethane	SRPS EN ISO 15680:2009**	µg/L	-
Chlorinated Alkenes			
1,1-Dichloroethene	SRPS EN ISO 15680:2009**	µg/L	10
1,2-Dichloroethene	SRPS EN ISO 15680:2009**	µg/L	-
Trichloroethene	SRPS EN ISO 15680:2009**	µg/L	500
Tetrachloroethene	SRPS EN ISO 15680:2009**	µg/L	40
Vinyl chloride	SRPS EN ISO 15680:2009**	µg/L	5
Chlorinated Hydrocarbons -Total Dichlorobenzyl	SRPS EN ISO 15680:2009	µg/L	50
Mercury	HDMI-326	µg/L	0.3
Copper	SRPS EN ISO 17294-2:2017 SRPS EN ISO 15587-2:2009	µg/L	75
Zinc	SRPS EN ISO 17294-2:2017 SRPS EN ISO 15587-2:2009	µg/L	800
Chromium	SRPS EN ISO 17294-2:2017 SRPS EN ISO 15587-2:2009	µg/L	30

Cadmium	SRPS EN ISO 17294-2:2017 SRPS EN ISO 15587-2:2009	µg/L	6
Nickel	SRPS EN ISO 17294-2:2017 SRPS EN ISO 15587-2:2009	µg/L	75
Lead	SRPS EN ISO 17294-2:2017 SRPS EN ISO 15587-2:2009	µg/L	75
Arsenic	SRPS EN ISO 17294-2:2017 SRPS EN ISO 15587-2:2009	µg/L	60

RESULTS AND DISCUSSION

Before groundwater sampling, water table measurements were conducted at the piezometers within the study area, as detailed in Table 3 and Figures 3 and 4.

Table 3. Water table measurements in June and October 2023

Piezometer	X (m)	Y (m)	Piezometer elevation (m.a.s.l.)	June 2023		October 2023	
				Water table depth (m)	Water table elevation (m.a.s.l.)	Water table depth (m)	Water table elevation (m.a.s.l.)
PA-2 (7)	7475758,86	4964460,78	73,69	2,17	71,52	3,00	70,69
PA-2 (15)	7475758,53	4964461,66	73,69	3,37	70,32	3,18	70,51
PA-2 (25)	7475757,98	4964462,89	73,65	2,93	70,72	3,15	70,5
PA-2 (45)	7475757,49	4964464,06	73,65	3,20	70,45	2,90	70,75
PA-1 (7)	7476554,13	4964909,78	75,17	3,14	72,03	3,10	72,07
PA-1 (15)	7476554,76	4964908,75	75,24	3,37	71,87	3,60	71,64

PA-1 (25)	7476555,54	4964907,75	75,11	3,24	71,87	3,50	71,61
PA-1 (45)	7476555,87	4964907,33	75,23	3,29	71,94	3,56	71,67
SDC-6	7475399,36	4964845,46	74,51	4.00	70,51	4,10	70,41
SDC-5	7475132,88	4965142,24	76,37	5,84	70,53	5,20	71,17
PA-3 (25)	7474380,94	4964990,59	73,68	3,87	69,81	4,10	69,58
PA-3 (7)	7474382,20	4964991,37	73,82	4,10	69,72	4,30	69,52
PA-3 (15)	7474383,37	4964992,09	73,79	4.00	69,79	4,10	69,69
PA-3 (45)	7474386,18	4964994,60	73,74	4,27	69,47	4,32	69,42
PA-738	7473834,88	4965017,97	71,49	1,50	69,99	1,70	69,79
PA-4 (45)	7473355,85	4965003,56	71,88	1,53	70,35	2,10	69,78
PA-4 (7)	7473354,51	4965004,62	71,86	1,50	70,36	2,10	69,76
PA-4 (15)	7473353,48	4965005,04	72,03	1,60	70,43	2,20	69,83
PA-4 (25)	7473352,09	4965005,96	71,93	1,60	70,33	2,20	69,73
LP-721	7474081,03	4962986,93	70,81	2,20	68,61	2,60	68,21
LP-722	7474523,45	4963039,28	70,65	2,10	68,55	4,30	66,35
P-III-3	7475780,21	4961839,70	70,69	2,47	68,22	2,80	67,89
P-739	7475232,81	4964280,73	70,65	1,50	69,15	1,30	69,35

As shown in Figures 4 and 5, the general direction of groundwater flow is northeast to southwest. Groundwater flow movement towards the south is characteristic of the western part of the study area. Unfortunately, water elevation measurements of the Danube were not conducted during these campaigns. Including the Danube elevation would enhance the accuracy of the flow field in the western and northwestern sections of the study area. Based on the aquifer's hydraulics, there is a significant potential for the spread of contamination from the industrial plants downgradient towards the rest of the study area.

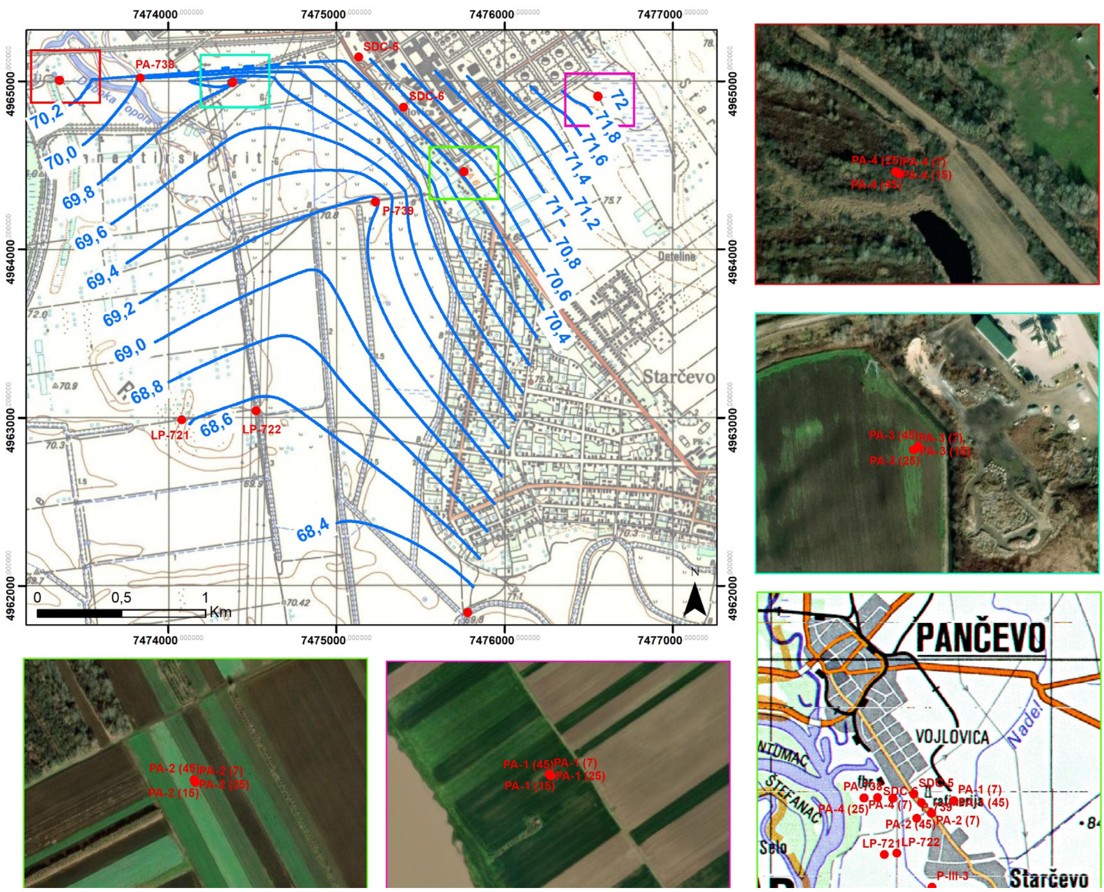


Figure 3. Water table contours in the SIZ of Pančevo (June 2023)

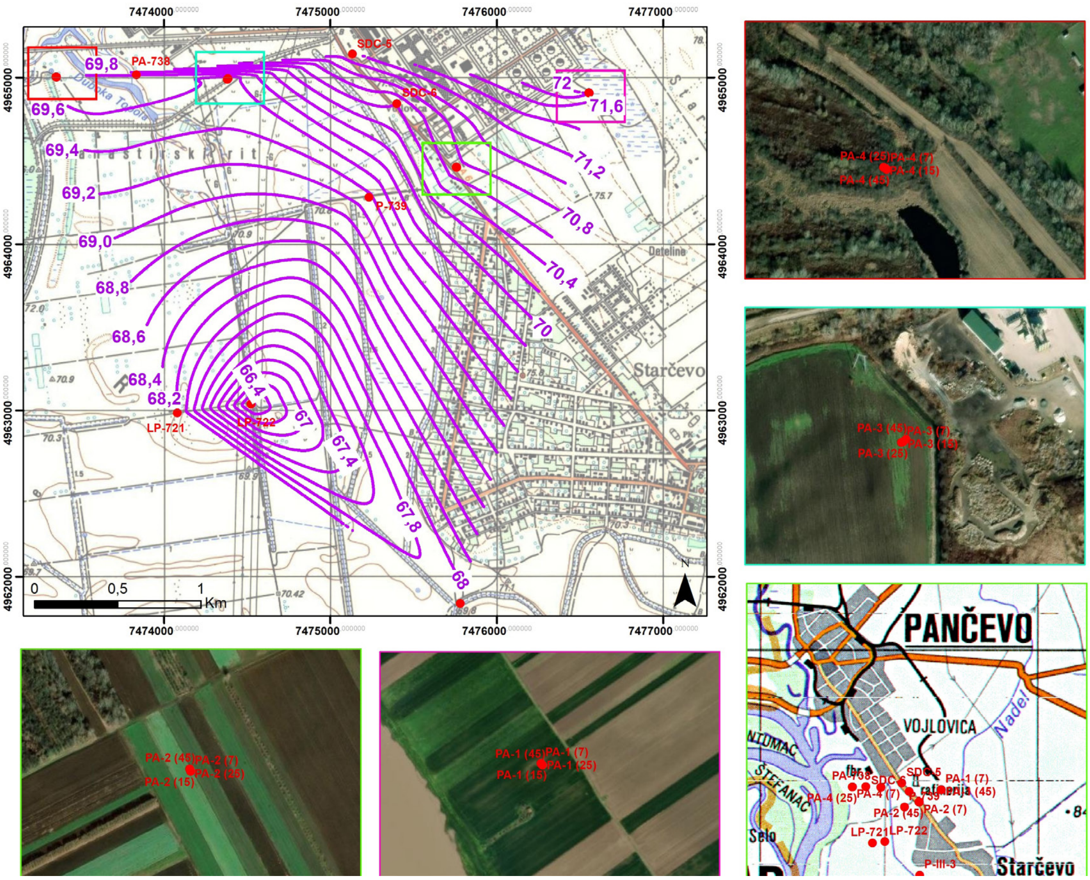


Figure 4. Water table contours in the SIZ of Pančevo (October 2023)

The samples were analysed for various parameters, as detailed in Tables 1 and 2. Given the study's objective to provide an overview of the current extent and intensity of groundwater contamination in this industrial zone, only the parameters that exceeded the threshold values are listed in Tables 4 and 5. Consequently, this indicates that the groundwater quality in all remaining piezometers (not listed in Tables 4 and 5) met the remediation guidelines set by Serbian regulations. This comprehensive sampling and analysis approach ensures a clear understanding of the contamination hotspots and the overall groundwater quality in the SIZ Pančevo area. The study highlights the critical areas that require immediate attention by focusing on the parameters that exceeded the threshold values.

Table 4. Groundwater quality parameters which exceeded the remediation threshold values (RTC) in June 2023

Parameter	Unit	June 2023				
		PA-3/15	PA-3/25	PA-3/45	PA-4/25	P-738
Total Petroleum Hydrocarbons	μg/L	< RTC	< RTC	< RTC	< RTC	890
Benzene	μg/L	< RTC	< RTC	43.3	< RTC	< RTC
1,1-Dichloroethene	μg/L	< RTC	< RTC	1772.5	< RTC	< RTC
Vinyl chloride	μg/L	243.4	8.8	3275	< RTC	< RTC
Mercury	μg/L	< RTC	< RTC	1.3	< RTC	< RTC
Arsenic	μg/L	< RTC	83	354.7	71.1	97.7

Table 5. Groundwater quality parameters which exceeded the remediation threshold values (RTC) in October 2023

Parameter	Unit	October 2023				
		PA-1/7	PA-3/15	PA-3/25	PA-3/45	P-738
Benzene	μg/L	< RTC	< RTC	< RTC	44	< RTC
1,2-Dichloroethane	μg/L	< RTC	< RTC	< RTC	755	< RTC
1,1-Dichloroethene	μg/L	< RTC	14.05	1772.5	1042	< RTC
Vinyl chloride	μg/L	< RTC	590	60.21	4754.16	< RTC
Mercury	μg/L	< RTC	< RTC	1.3	< RTC	< RTC
Arsenic	μg/L	93.5	60.1	354.7	389.6	66.1

During both sampling campaigns, remediation threshold values (RTCs) were exceeded in several piezometers located near the HIP Petrohemija facility. These piezometers include PA-3/15, PA-3/25, PA-3/45, PA-4/25, and P-738. An additional exceedance was recorded in piezometer PA-1/7, which is situated near the NIS Refinery Pančevo, in October 2023. Notably, the deepest piezometers, specifically PA-3/25 and PA-3/45, exhibited the highest levels of exceedance. This significant contamination can be partially attributed to the density of contaminants present in the groundwater. To elucidate further, the majority of the detected contaminants belong to the category of dense nonaqueous phase liquids (DNAPLs). Among the various contaminants identified, vinyl chloride and arsenic emerged as the most prevalent. The elevated contamination levels in the deeper piezometers suggest that the contaminants with high density are likely to settle at greater depths. No exceedances were recorded in the piezometers located in the downgradient portion of the SIZ Pančevo. Contamination is currently limited to the piezometers near HIP Petrohemija and NIS Refinery Pančevo.

Continued monitoring and comprehensive analysis are crucial to understanding the contamination migration dynamics and implementing appropriate measures. The data collected from these piezometers will play a vital role in formulating strategies to mitigate the impact of these hazardous substances on the environment. Moreover, active participation and involvement of HIP Petrohemija and NIS Refinery Pančevo are crucial for achieving and maintaining groundwater quality in the SIZ Pančevo area. Without their involvement, it will be challenging to address the contamination issues effectively and ensure the long-term safety of this local environment.

CONCLUSIONS

This study has provided a comprehensive assessment of groundwater contamination within the South Industrial Zone (SIZ) of Pančevo, focusing on sampling campaigns conducted in June and October 2023. Through groundwater sampling at 25 piezometers, the study identified critical contamination hotspots. The findings underscore the presence of contaminants exceeding remediation threshold concentrations (RTCs) in several piezometers adjacent to HIP Petrohemija and NIS Refinery Pančevo facilities, notably PA-3/15, PA-3/25, PA-3/45, PA-4/25, P-738, and PA-1/7 in October 2023. The contamination, primarily driven by arsenic and dense nonaqueous phase liquids (DNAPLs), such as vinyl chloride, shows elevated levels in deeper piezometers, suggesting significant accumulation at greater depths. Notably, piezometers in the downgradient portion of the SIZ did not record RTC exceedances, indicating localized contamination near industrial sources. The involvement of key stakeholders, particularly HIP Petrohemija and NIS Refinery Pančevo, is crucial for sustained efforts to improve groundwater quality in the SIZ Pančevo area. Their active participation is vital to addressing contamination issues effectively and ensuring the long-term environmental safety of this area. Continued monitoring and detailed analysis are imperative to grasp the dynamics of contamination migration and implement effective mitigation strategies.

Funding

This study was supported by the JICA Partnership Program for Environmental Improvement in Pančevo, Serbia, Through the Collaborations Among Academia, Government, Industry and Citizens.

lITERATURE:

CETMA. (2007). Implementation of the Pancevo Action Program: The NIS Oil Refinery Remediation of Hydrocarbons Contamination Feasibility Study/Conceptual Design. D'Appolonia.

Pančevo Institute for Public Health. (2023a). Report on Groundwater Characterization in the Area South of the Industrial Zone of Pancevo, June 2023.

Pančevo Institute for Public Health. (2023b). Report on Groundwater Characterization in the Area South of the Industrial Zone of Pancevo, October 2023.

Official Gazette of RS. (2018). Regulation on Limit Values for Pollutants, Harmful and Hazardous Substances in Soil. („Official Gazette of RS" No. 30/18 and 64/19, Annex 2). Pancevo.

UNDP. (2010). Assessment of Polluted Environmental Sites - Hydrogeological Aspect of Pancevo South Industrial Zone. Belgrade.

RISK ASSESSMENT MANAGEMENT AND ENVIRONMENTAL PROTECTION PLANNING IN THE SOLAR PANELS PRODUCTION USING FMEA METHOD

Novica Staletović, Violeta Nikolić, Vladanka Presburger Ulniković, Ana Pavlović

Faculty of Ecology and Environmental Protection, University „Union-Nikola Tesla" Cara Dušana 62-64, Belgrade, Serbia

nstaletovic@unionnikolatesla.edu.rs

Abstract: Integrated approach to environmental planning and management are crucial in many industries, including the solar panels manufacturing process. The environmental management system standard ISO 14001: 2015 includes a requirement that obliges the company to identify and evaluate environmental aspects based on risk analysis. However, it does not explicitly specify which method to apply. In this paper, the concept of environmental protection planning, based on preventive and proactive activities, was developed and applied using the Failure Mode and Effects Analysis (FMEA) method adapted for the identification, analysis, and assessment of environmental risks in the production of solar - photovoltaic panels (PVPs). Recently, challenges and controversies have surrounded photovoltaic panels production. While some argue that the environmental benefits certainly outweigh the negative impacts, others raise concerns about the carbon footprint of the PVP manufacturing and disposal process. Applying the FMEA method in environmental risk assessment provides a preventive approach and control of assessed environmental risks. The proposed concept can be used in other similar situations and activities, and could be improved with IT support. In this way, a company that applies this concept becomes ready to implement operational activities and can manage environmental aspects with an increased environmental risk priority number.

Keywords: FMEA method, risk assessment, photovoltaic panels

INTRODUCTION

Risk assessment management should enable the company's top-level management to foresee potential dangers in its operations and to react preventively and proactively. In addition to legal requirements, risk assessment has become an essential tool within the standards for QMS management systems EMS, OHSMS and EnMS (Standard ISO 9001, 2015). ISO/IEC Directive, Annex SL (Standards ISO/IEC Directives, 2015) defines the structure of all standards related to management systems. Strategic and operational risk assessment and management has a key role in the success of any company's business, according to SRPS ISO 31000: 2019, ISO Guide 73, 2009.

It is well known that generating electricity from solar energy is a clean, renewable energy source. However, different mineral raw materials are extracted for photovoltaic panel production. The mining and processing of these raw materials can result in significant environmental consequences, including habitat destruction, soil erosion, water pollution, and emission of greenhouse gases (Green.org, 2024). In addition, increased production and use of PVPs can impact local ecosystems and biodiversity. Also, disposal of decommissioned PVPs can lead to environmental contamination and potential health risks. Therefore, as PVPs end their lifespan, proper waste management becomes crucial.

The company DoMi Eko Solar is the first factory for PVP production in Serbia. At the beginning of 2024, it decided to harmonize its operations in accordance with the standards ISO 9001: 2015, ISO 14001: 2015, ISO 45001: 2018, and ISO 50001: 2018. Therefore, this company was obliged to develop a methodology for risk assessment and management for quality, environment, safety and health at work, and energy management.

This paper aimed to present a simple and proactive model for risk assessment management using the FMEA method. Based on the research objective, the following tasks were set:

1) Defining the context, concept, and flowchart of environmental risk assessment management;
2) Criteria development for environmental risk assessment;
3) Conducting the environmental risk assessment;
4) Options selection for treatment and management of environmental risk assessment.

Known research methods are used for the research objective and task, namely:

- Method of general system theory and system approach,
- Theory and practice method of analysis,
- Descriptive method of observing and describing the production process.

METHODOLOGY DEVELOPMENT

An effective integrated management system (QMS, EMS, OHSMS and EnMS) implies adequate identification, analysis, assessment and control of risk assessment with appropriate risk management principles (Standards ISO/IEC Directives, 2015). To determine the importance of some risks, it is necessary to determine the risk priority number (RPN) (Staletović, 2009). Based on the determined RPN, the risk level, categorization, and characterization are determined. In this case, the FMEA method with specially established criteria, relevant for determining RPN, was applied to the risk assessment and management of product quality, environment, safety and health at work, and energy. Other authors also used this approach (Toljaga et al., 2018; Ralcheva, 2019).

The cycle of risk assessment management with this methodology is provided in six steps, namely: 1) determining the context; 2) defining the goals; 3) risk assessment; 4) risk assessment control; 5) monitoring, measurement, evaluation and improvement of established risk control measures; 6) communication and reporting regarding risks (Staletović, 2006). This concept fulfils the guidelines given by the ISO 31000: 2019 standard. Based on this, the environmental risk assessment management concept is defined, and the flowchart is shown in Figure 1.

Optimisation of FMEA method and environmental risk assessment criteria

The FMEA method and criteria defined in this paper were used to identify and evaluate the significance of environmental aspects. The primary setting of the FMEA method in the function of analysing environmental aspects is simple. It consists of the following factors, to determine the environmental RPN by analytical methods, namely:

- Risk factor R_1 – the probability of occurrence of an environmental aspect,
- Risk factor R_2 – the severity of consequences that can be caused by an environmental aspect,
- Risk factor R_3 – the probability of detection and elimination of the negative impact of an environmental aspect.

Ratings 1-10 are used to evaluate risk factors (other ranges can also be used). Table 1 gives criteria and rules for evaluating individual risk factors.

The risk priority number (RPN) is calculated using the formula RPN = R_1 x R_2 x R_3.

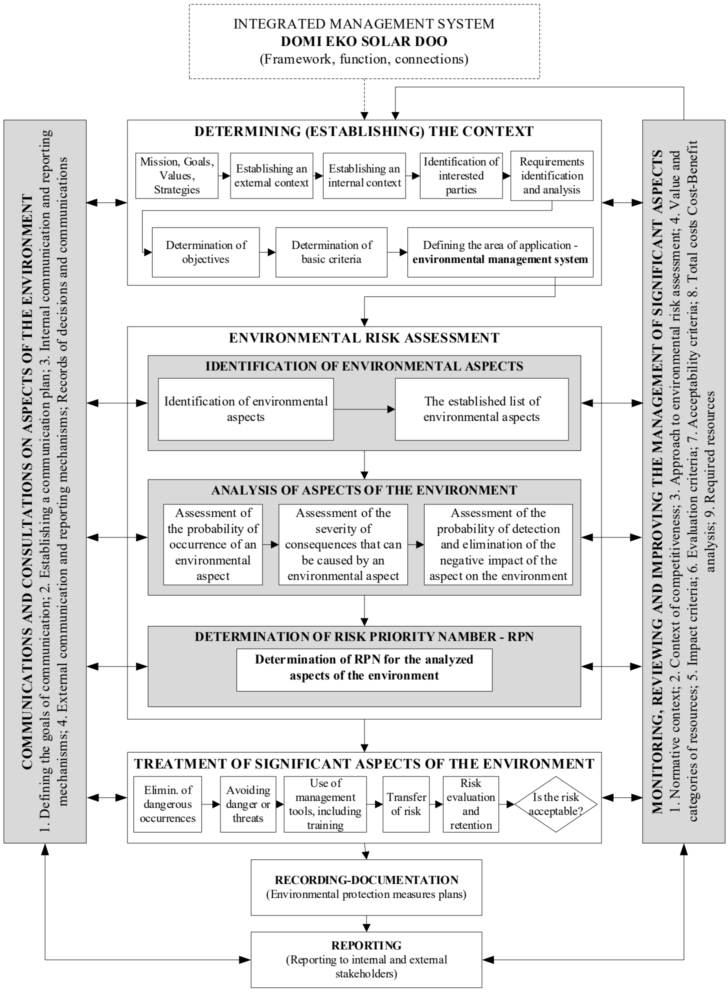


Figure 1 *Flowchart for determining the importance of environmental aspects based on risk analysis*

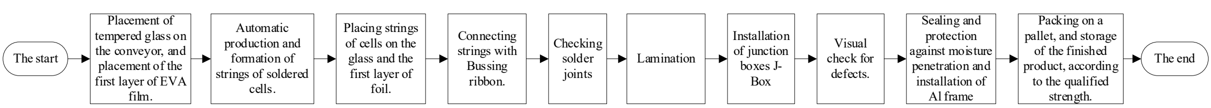


Figure 2 *Flowchart PVP production*

Table 1 *Environmental risk register for the production of photovoltaic panels*

<table>
<tr><td colspan="5" rowspan="4">NAME OF PLAN, PROJECT, PROCESS, ACTIVITY, OPERATION:
- PHOTOVOLTAIC PANEL production</td><td>Analysis number:</td></tr>
<tr><td>Date:</td></tr>
<tr><td>Created by:</td></tr>
<tr><td>Approved by:</td></tr>
<tr><td rowspan="2">Actual or potential impact of environmental aspects (EA)</td><td colspan="3">Analysis of environmental aspects</td><td rowspan="2">RPN – risk priority number</td><td rowspan="2">Environment Management Plan for aspects with identified environmental risk (Elimination of hazards/threats; Avoidance of hazards/threats; Use of engineering management and work reorganisation; Use of administrative management, including training; Risk transfer; Risk retention)</td></tr>
<tr><td>R_1 – the probability of occurrence of an EA</td><td>R_2 –the severity of consequences that can be caused by an EA</td><td>R_3 – the probability of detection and elimination of the negative impact of an EA</td></tr>
<tr><td>Generation of the original film - EVA</td><td>7</td><td>4</td><td>1</td><td>28
Very low</td><td rowspan="9">1) Mandatory preparation of the waste management plan;

2) Mandatory to set up - Daily records of waste - DRW 1

3) Designate a place to dispose of non-hazardous waste (waste film, etc.)

4) Appoint a responsible person for managing non-hazardous and hazardous waste;

5) Characterise the identified waste;

6) Sign contracts with the authorised operator for non-hazardous and hazardous waste management

7) Mandatory issuance of a document on the movement of non-hazardous and/or hazardous waste

8) Sign a contract with a local operator for municipal waste disposal</td></tr>
<tr><td>Generation of background film waste - from backsheet</td><td>7</td><td>4</td><td>1</td><td>28
Very low</td></tr>
<tr><td>Generation of photovoltaic cell waste</td><td>7</td><td>4</td><td>1</td><td>28
Very low</td></tr>
<tr><td>Generation of wire waste</td><td>7</td><td>4</td><td>1</td><td>28
Very low</td></tr>
<tr><td>Generation of glass waste from PVP</td><td>7</td><td>4</td><td>1</td><td>28
Very low</td></tr>
<tr><td>Generation of PVP waste</td><td>7</td><td>4</td><td>1</td><td>28
Very low</td></tr>
<tr><td>Generation of aluminium frame waste</td><td>7</td><td>4</td><td>1</td><td>28
Very low</td></tr>
<tr><td>Generation of silicon waste</td><td>7</td><td>4</td><td>1</td><td>28
Very low</td></tr>
<tr><td>Generation of municipal waste</td><td>7</td><td>4</td><td>1</td><td>28
Very low</td></tr>
</table>

<table>
<tr><td colspan="2">Criteria R_1</td><td colspan="2">Criteria R_2</td><td colspan="2">Criteria R_3</td><td colspan="2">RISK ASSESSMENT</td></tr>
<tr><td colspan="2">Probabillity of occurrence of an environmental aspect (EA)</td><td colspan="2">Severity of consequences that can be caused by EA</td><td colspan="2">Probability of detection and elimination of the negative impact of an EA</td><td colspan="2">RPN (Risk Priority Number)</td></tr>
<tr><td>No probability
(0)</td><td>=1</td><td>No consequences</td><td>=1</td><td>Can certainly be detected or removed</td><td>=1</td><td>Negligible risk</td><td>from
1 - 10</td></tr>
</table>

Extremely unlikely (1/10000-20000)	=2	Insignificant	=2	Very high probability	=2	**Very low risk**	**from 10 - 100**
Unlikely (1/2000-10000)	=3	Negligible	=3	High probability	=3		
Low (1/1000-2000)	=4	Very small	=4	Relatively high probability	=4	**Low risk**	**from 100-200**
Relatively low 1/200-1000)	=5	Small	=5	Moderate probability	=5		
Possible (1/200)	=6	Medium	=6	Relatively low probability	=6	**Increased risk**	**from 200 - 400**
Relatively high (1/100)	=7	Relatively major	=7	Low probability	=7	**High risk**	**from 400 - 500**
High (1/50)	=8	Major	=8	Very low probability	=8		
Very high (1/10)	=9	Very Major	=9	Unlikely	=9	**Extremely high risk**	**from 500-1000**
Certain (1/2)	=10	Catastrophic consequences	=10	Hardly or not detected or removed	=10		

DISCUSSION

The paper presents the environmental risk assessment and management model for the photovoltaic panels production process at the company DoMi ECO SOLAR D.O.O. Environmental risk register for the photovoltaic panels production is shown in Table 1, based on the analysis of the photovoltaic panels production process (Figure 2). Based on this model, the following documented information was defined and presented in the environmental management plan for the aspects with identified environmental risks. Environmental risk assessment (given in Table 1) and the appropriate selection of options for treating the environmental elements are also defined. In this way, for all activities and operations with an increased ecological risk priority number, mechanisms for controlling the identified risks are established. These mechanisms reduce ecological risk to an acceptable level.

The significance of the proposed/applied concept and model of environmental risk assessment and management is that the company's management can make rational decisions regarding the planning, establishment, maintenance, and improvement of the environmental management system. For the application of this model related to PVP production, the environment risk assessment team must be multidisciplinary and composed of experts and qualified persons with specific knowledge in the fields of quality, environment protection, health and safety at work, and energy management. The results presented in this paper meet the requirements of ISO 14001: 2015 standard. The effectiveness and efficiency of the environment protection management system can be achieved by applying this concept and the FMEA method with optimised parameters.

CONCLUSIONS

Even though the application of photovoltaic panels represents a renewable source of energy, the PVP production process must be carefully considered to reduce the harmful effects on the environment. By applying this concept, model, and method in the phase of planning the implementation of operational activities, the plans for controlling the identified risks will be ready in time, both for the implementation of operational activities and for dealing with emergencies. Also, with the application of this concept, plans for the control of environmental risk assessment can be improved. Preventive action based on an ecological risk assessment leads to more reliable budgeting for implementing operational activities. By applying the assessment and management of environmental risks for the process of PVP production, as shown in Table 1, it can be concluded that the proposed model fulfills the purpose and gives satisfactory results. Accordingly, the proposed model respects the recommendations and guidelines defined by ISO 31000: 2019 standard and meets the requirements of ISO 14001:2015 standard related to planning, analysis, and environmental risk assessment. The product of environmental risk assessment management is documented information - An environmental risk register based on decisions made at all relevant levels of the company. Based on this proactive model of environmental risk assessment and management, as defined in this paper, the company management team is able to:

- Approve the environmental protection policy;
- Report to all interested parties about all assessed and accepted environmental risks;
- Define control mechanisms over the assessed and accepted environmental risks that correspond to the company's performance;
- Ensure the distribution of the necessary resources for the management of the assessed and accepted environmental risks;
- Ensure compliance with the requirements of ISO 14001:2015 standard;
- Ensure compliance with legal and other requirements.

The proposed concept, model, and FMEA method can be applied in another company with the same or similar activities that aim to plan, establish, maintain, and improve its environmental management system.

LITERATURE

ISO Guide 73: 2009 - Risk management – Vocabulary

SRPS ISO 9001: 2015 - Quality management system - Requirements

Standards ISO/IEC Directives, Part 1, Consolidated ISO Supplement, Appendix 2; 2015

SRPS ISO 14001: 2015 - Environmental management system - Requirements with guidance for use

SRPS ISO 45001: 2018 – Occupational health and safety management system - Requirements with guidance for use

SRPS EN ISO 50001: 2018 – Energy management system - Requirements with guidance for use

SRPS ISO 31000: 2019 - Risk management - Guidelines

Ralcheva D. FMEA Methodology Capabilities in Environmental Risk Management; International Journal of Engineering Research & Science (IJOER) ISSN: [2395-6992] [Vol-5, Issue-5]; 2019

Staletović N. Razvoj metoda ocene i modela upravljanja ekološkim rizikom u funkciji održivog razvoja, Doktorska disertacija, Univerzitet u Novom Sadu; 2006.

Staletović N. Ocena OH&S rizika u funkciji preventivnog inženjeringa i integrisanih sistema menadžmenta (QMS/EMS/OHSAS); Tehnika – Menadžment 2009;59(3); 8-14.

Toljaga-Nikolić D, Todorović M, Bjelica D. Application of the FMEA technique in a project risk analysis; European Project Management Journal 2018;8(2);36-42.

https://green.org/2024/01/30/the-environmental impact-of solar-panel-production/ (retrieved July, 30, 2024)

TERRITORIAL DISTRIBUTION OF CAPACITIES OF PFE „FORESTS OF REPUBLIC OF SRPSKA" IN THE SYSTEM OF FOREST PROTECTION AGAINST FOREST FIRES

Olja Krčadinac[1], Saša Ljubojević[2], Branko Latinović[3], Željko Stanković[3], Dragana Božilović Đokić[1]

[1]The University "Union - Nikola Tesla", 11000 Belgrade, Cara Dusana 62-64, Republic of Serbia

[2]JPŠ „**Šume** Republike Srpske", 78000 Banja Luka, Trg Republike Srpske 8/11, Republic of Srpska

[3]Pan-European University APEIRON, 78 000 Banja Luka, Pere Krece 13, Bosnia and Herzegovina

okrcadinac@unionnikolatesla.edu.rs

Abstract: Public Forestry Company „Forests of the Republic of Srpska" a.d. Sokolac, with its organizational parts, forms a unique system of forest fire protection. The organizational parts are well equipped and have a significant number of educated people for extinguishing forest fires. In this paper, the territorial distribution and capacities of the Public Company by organizational parts are analyzed. The methodological approach is based on geospatial analysis of organizational parts with a particular focus on the ratio of the number of people who can be engaged in extinguishing forest fires and areas managed as forests and forest land. The results of this research can be helpful to decision-makers and relevant entities dealing with forest fire protection. This research can also serve as a basis for further and more comprehensive research on the issue of forest protection.

Keywords: Forests, analysis, GIS, forest fire

INTRODUCTION

Public Forestry Company „Forests of the Republic of Srpska" a.d. Sokolac with its organizational parts makes a unique and most important system of forest protection against fire. State forests in the Republic of Srpska are managed by

the Public Enterprise „Forests of the Republic of Srpska" a.d. Sokolac. The total area of forests and forest land in the Republic of Srpska is 1,307,790.65 ha, of which 77% is state-owned, or 1,000,608 ha. 23% or 307,182 ha of forests and forest land are privately owned (Krčadinac et al, 2023).
As part of the Public Enterprise, they operate:

- 28 forest farms.
- Center for Karst Management
- Center for Seed and Nursery Production
- R&D and Project Center
- Directorate of Public Enterprise
- Forestry house „Ognjište"

Forest holdings and the Karst Management Center are obliged to develop forest fire protection plans for each business year. An integral part of these plans is personnel conditions. Personnel conditions represent clearly defined units for extinguishing fires in emergencies and are a set of all workers of the organizational part who are capable and trained to extinguish fires, i.e. for appropriate tasks related to firefighting.

METHODOLOGY

In this paper, the data recorded in the Cadastre of Forests and Forest Land, which was made by the Public Company for 2023, as well as the official fire protection plans that were made by the organizational parts, were used. As a form of control of these data, records of personnel conditions were collected from organizational parts, which refer to the number of persons capable and trained to extinguish forest fires. For the purposes of this paper, the relationship between the area of forests and forest land and the number of people who can participate in extinguishing fires is analyzed. The results obtained are presented in tabular and spatial ways using a geographic information system.

DATA ANALYSIS

Forest fires pose the greatest danger in the forest due to the speed of their spread and their enormous scale. Almost instantly, huge areas of forests disappear, which brings a change in the appearance of the habitat where the fire occurred. Vast areas under forests and greenery create burnt areas and bare areas, and in economic terms, this represents a huge financial loss. Many factors are responsible for forest fires, and the main, or the biggest cause, is a man who does not have a sufficiently developed awareness of the importance of forests as a common good. In addition, forest fires occur in cases where all preventive measures have been taken, so their occurrence can be seen as a regular occurrence that must be taken into account.

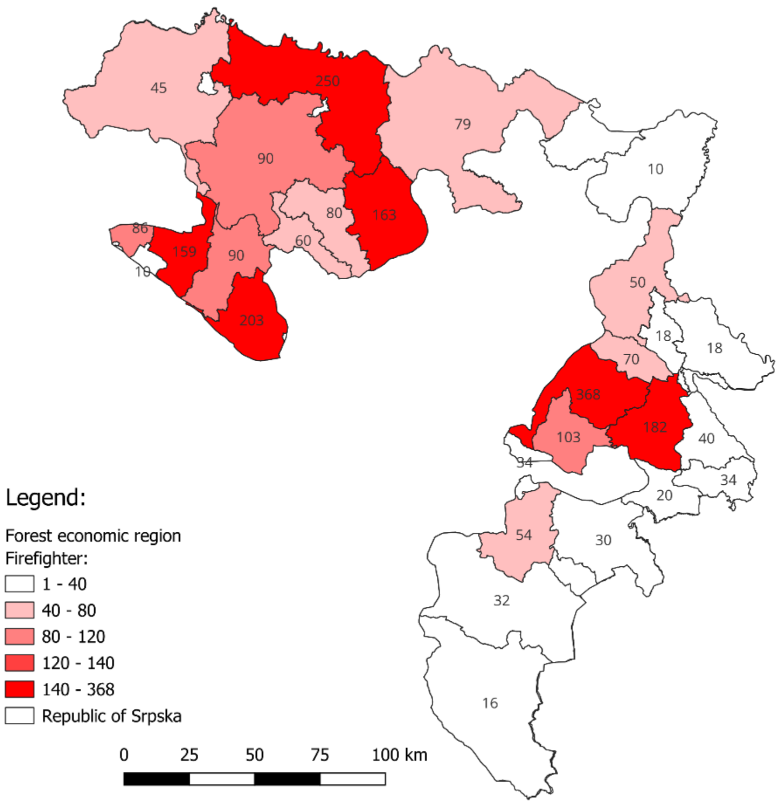
When a forest fire occurs, the first response is made by the employees of the Public Company, i.e. the persons whose task it is. The table below shows the number of people who are tasked with extinguishing the fire.

Table 1: Number of firefighters by organizational units

Number:	**Organizational units**	**Number of firefighters**
1	Banja Luka	90
2	Oštrelj-Drinić	86
3	Panos	40
4	Birač	50
5	Gradiška	250
6	Doboj	79
7	Zelengora	54
8	Čemernica	60
9	Vrbanja	80
10	Majevica	10
11	Lisina	90
12	Botin	32
13	Jahorina	103
14	Prijedor	45
15	Ribnik	159
16	Sjemeć	182
17	Romanija	368
18	Drina	18
19	Maglić	30
20	Borja	163
21	Visočnik	70
22	Vučevica	20
23	Gorica	203
24	Trnovo	34

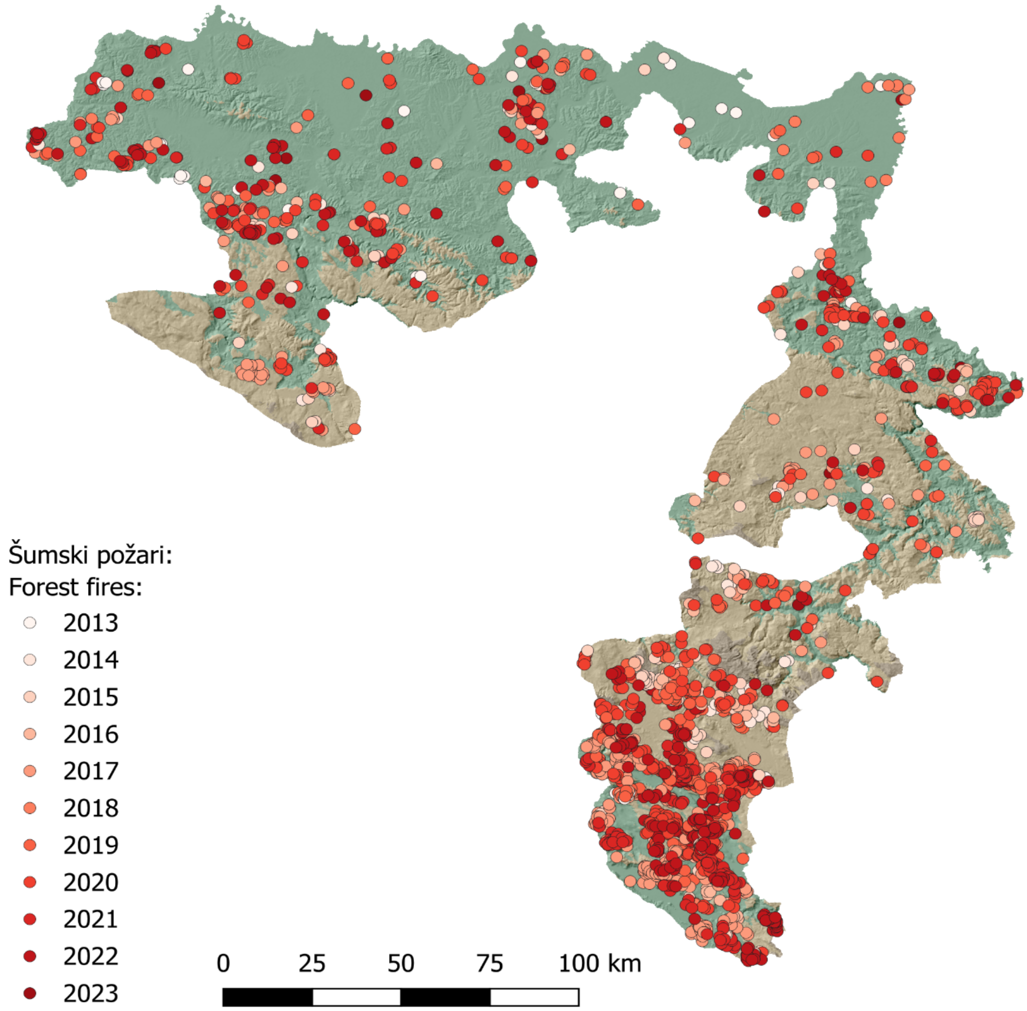
25	Klekovača	10
26	Milići	18
27	Rudo	34
28	Center for krast managament	16

In order to clearly show the territorial distribution of the data from the table, a map was created using a geographic information system. On the map, the relationship between the territory and the number of people for extinguishing the fire is more clearly visible.



Map 1: Number of firefighters by organizational units

On the map shown, it is clearly visible that in the eastern part of the Republic of Srpska, which is the most endangered part, there is the smallest number of people in charge of extinguishing forest fires. In order to visually get the impression of the territorial distribution of fires (Ljubojević et al., 2021), Map 2 shows the locations of detected forest fires in the territory of the Republic of Srpska in the period from 2013 to 2023 (Milanovıće et al, 2020).



Map 2: Forest fires on the territory of Republic of Srpska in the period 2013-2023

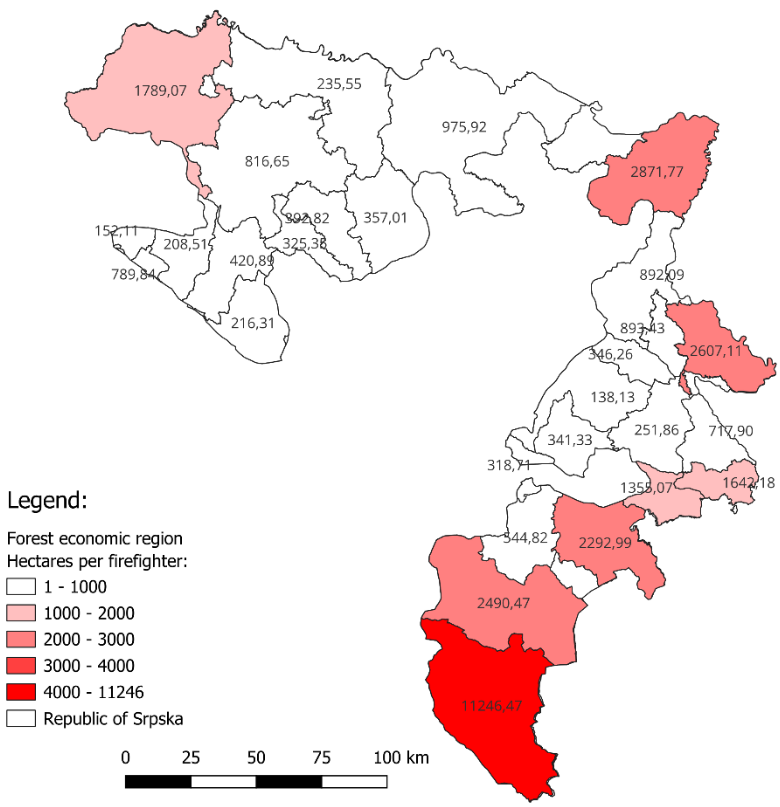
Looking at Map 2, it is clearly visible that the largest number of fires is in the eastern part of the Republic of Srpska, i.e. in the area of karst, when looking at Map 1, we can see that the organizational parts located in that territory are in the lowest group of persons in charge of extinguishing forest fires (Ljubojević et al., 2022). If we look at all organizational parts of the Public Company, we can say that it has a total of 2394 people who are capable and trained to extinguish forest fires. When an analysis of the number of people and the total territory under the forest of 1,307,790 ha is done, the result is that the Public Company has 0.0018 people per hectare of forest for extinguishing fires. If we were to present the results in a different way, i.e. invert the relationship, we come to the result that there is 546.25 ha of forest for one person in charge of extinguishing fires. These data refer to the entire territory of the Republic of Srpska. When looking at the organizational parts individually, there are differences in the number of available persons per hectare (Public Forest Enterprise „ Sume Republike Srpske „ JSC Sokolac, 2023).

Table 2: Number of firefighters by organizational units, forest area and analysis

Number:	Organizational units	Number of firefighters	Forest area (ha)	Ratio of people per hectare	Ratio of hectares to people
1	Banja Luka	90	73.498,93	0,0012	816,65
2	Oštrelj-Drinić	86	13.081,15	0,0066	152,11
3	Panos	40	28.715,89	0,0014	717,90
4	Birač	50	44.604,48	0,0011	892,09
5	Gradiška	250	58.888,08	0,0042	235,55
6	Doboj	79	77.097,35	0,0010	975,92
7	Zelengora	54	29.420,07	0,0018	544,82
8	Čemernica	60	19.520,74	0,0031	325,35
9	Vrbanja	80	31.425,40	0,0025	392,82
10	Majevica	10	28.717,66	0,0003	2871,77
11	Lisina	90	37.880,40	0,0024	420,89
12	Botin	32	79.694,90	0,0004	2490,47
13	Jahorina	103	35.157,27	0,0029	341,33
14	Prijedor	45	80.508,01	0,0006	1789,07
15	Ribnik	159	33.153,88	0,0048	208,51
16	Sjemeć	182	45.838,30	0,0040	251,86
17	Romanija	368	50.833,41	0,0072	138,13
18	Drina	18	46.928,05	0,0004	2607,11
19	Maglić	30	68.789,61	0,0004	2292,99
20	Borja	163	58.192,62	0,0028	357,01
21	Visočnik	70	24.238,27	0,0029	346,26
22	Vučevica	20	27.101,43	0,0007	1355,07

23	Gorica	203	43.910,74	0,0046	216,31
24	Trnovo	34	10.836,19	0,0031	318,71
25	Klekovača	10	7.898,42	0,0013	789,84
26	Milići	18	16.081,74	0,0011	893,43
27	Rudo	34	179.943,59	0,0002	1642,18
28	Center for krast managament	16	55.834,07	0,0003	11246,47

The table shows the differences in the ratio of the number of people trained to extinguish fires per hectare, as well as the area per person for firefighting, for each organizational part individually. From the data presented in the table, there is a disproportion between organizational parts. In order to make the presentation of these data clearer, a spatial analysis and a representation of hectares under the forest per person for fire extinguishing was done on Map 3.



Map 3: Spatial distribution of the ratio between forest area and firefighters

By looking at Map 3, it can be seen again that the worst situation is in the eastern part of Republic of Srpska, where the largest number of fires occurs. All the analyses done and presented in this paper unequivocally indicate the lack of persons who can be engaged in extinguishing forest fires (Novaković, 2022).

CONCLUSION

In this paper, data on the area of forests and forest land by organizational parts of the Public Company were collected, as well as data on the number of capable and trained persons for extinguishing forest fires. Observing the results obtained, it can be concluded that the Public Company has a total of 2,394 persons who are capable and trained to extinguish forest fires. After the analysis of the ratio of the number of people and the total territory under the forest, with an area of 1,307,790 ha, the results are that the Public Company has 0.0018 people per hectare of forest for extinguishing fires, i.e. there is 546.25 ha of forest for one person in charge of extinguishing fires. The above data refer to the entire territory of the Republic of Srpska. When viewed individually by organizational parts, it is clearly visible that the eastern part of the Republic of Srpska represents the most endangered part of the territory. All the results indicate an insufficient number of people who can be engaged in extinguishing forest fires. The results of this work should be taken into account for future planning of activities, as well as when developing forest fire protection plans.

LITERATURE

Krčadinac, O., Ljubojević, S., Latinović, B. (2023) The Third international conference on sustainable environment and technologies "Create sustainable community", University Union Nikola Tesla, Belgrade.

Ljubojević, S., Stanković, Ž. (2021) ITeO – XIII International scientific-expert meeting „Information technology for e-education Proceedings, Pan-European University „Apeiron" Banja Luka, 248-253

Mr. Milanović, Mr. M. Valjarević, Mr. A. Lukić, T. (2020) Remote detection within the environment, University of Belgrade - Faculty of Geography, Belgrade.

Ljubojević, S., Latinović, B. (2022) The second international conference on sustainable environment and technologies "Create sustainable community", University Union Nikola Tesla, Belgrade.

Mr. Novaković, I. (2022) GIS Analysis – practicum, University of Belgrade - Faculty of Geography, Belgrade.

Forest of RS. (2023). *Area Cadastre PFE.* Sokolac: Forests of the Republic of Srpska.

INTEGRATED REMEDIATION STRATEGIES FOR URBAN AND INDUSTRIAL POLLUTION: INSIGHTS AND APPLICATIONS IN THE INCEL PROJECT

Ilić Predrag[1*], Sanja Mrazovac Kurilić[2], Zain Mushtaq[3], Abdur Rashid[4,5], Nataša Marić[6], Tibela Landeka Dragičević[7], Dijana Grgas[7], Stojanović Bjelić Ljiljana[8], Nešković Markić Dragana[8], Nenad Malić[9], Zia Ur Rahman Farooqi[10,11], Muhammad Yousuf Jat Baloch[12], Tariq Mehmood[13], Zahid Ullah[14], Sobia Riaz[10]

[1] PSRI Institute for Protection and Ecology of the Republic of Srpska, Banja Luka, Vidovdanska 43, Banja Luka, Republic of Srpska, Bosnia and Herzegovina,
[2] University Union-Nikola Tesla, Cara Dušana 62-64, Beograd, Serbia,
[3] Department of Soil Sciences, Faculty of Agricultural Sciences, University of the Punjab, Lahore, Pakistan;
[4] State Key Laboratory of Biogeology and Environmental Geology, School of Environmental Studies, China University of Geosciences, Wuhan, PR China
[5] National Centre of Excellence in Geology, University of Peshawar, Peshawar, Pakistan,
[6] Aqua tim Ltd, Svetosavska 27, Glamočani, 78250 Laktaši, Republic of Srpska, Bosnia and Herzegovina
[7] University of Zagreb, Faculty of Food Technology and Biotechnology, Pierottijeva 6, Zagreb, Croatia,
[8] Pan-European University "APEIRON", Vojvode Pere Krece 13, Banja Luka, Republic of Srpska, Bosnia and Herzegovina
[9] EFT – Mine and TPP Stanari, Republic of Srpska, Bosnia and Herzegovina
[10] Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan
[11] MNS University of Agriculture, Multan, Pakistan
[12] College of New Energy and Environment, Jilin University, Changchun, China,
[13] Helmholtz Centre for Environmental Research - UFZ, Department of Environmental Engineering, Leipzig, Germany;
[14] School of Environmental Studies, China University of Geosciences, Wuhan, China;

predrag.ilic@institutzei.net

Abstract: This study investigates the environmental and public health implications of soil contamination in the Incel industrial zone, Banja Luka, Bosnia and Herzegovina, focusing on polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and heavy metals. Recognized as a significant threat due to their persistence, bioaccumulation potential, and toxic effects, these pollutants have been extensively analyzed in the Incel area, a former cellulose factory repurposed as an industrial complex. The comprehensive assessment revealed alarmingly high concentrations of PCBs, exceeding national and international safety thresholds, alongside PAHs and heavy metals, indicating a severe contamination level that poses risks to human health and the local ecosystem. The methodology encompassed quality assurance mechanisms, standard operation procedures, and environmental protection measures, with a detailed investigation conducted across identified hotspots. This investigation, aligned with the Stockholm Convention on Persistent Organic Pollutants' directives, underscores the urgent need for remediation strategies to address the identified contamination. The project highlights the necessity of international cooperation and regulation in tackling such environmental challenges, emphasizing the role of robust environmental governance in safeguarding public health and ecosystems. This endeavor represents a pioneering initiative in the Republic of Srpska, marking the first comprehensive effort to mitigate soil contamination by hazardous substances such as PCBs. Through this project, the Incel industrial zone serves as a critical case study, demonstrating the effective integration of scientific research with remediation practices to address industrial contamination legacy. The findings contribute significantly to the global discourse on industrial pollution management and environmental restoration, offering insights and models for future remediation projects.

Key words: PCB, Incel, Banja Luka, pollution, remediation

INTRODUCTION

Polychlorinated biphenyls (PCBs), a group of POPs represent a category of synthetic organic compounds previously utilized extensively as insulating materials, coolants, and lubricants within electrical apparatus. These compounds are notably persistent, toxic, and prone to bioaccumulation, indicating their ability to persist in the environment for extended periods and to progressively concentrate within the food chain. The presence of PCBs poses significant risks to both environmental health and human well-being, due to their adverse effects (Gašić et al., 2010; Ilić et al., 2020; Ilić et al., 2021c; Ilić et al., 2023). PCBs have been identified in urban atmospheres across cities in North America, Western

Europe, and former Yugoslavia, with variations in sources and concentrations suggesting localized urban inputs as significant contributors (Gašić et al., 2010; APOPSBAL, 2019).

Research conducted by Ilić et al. (2021a; 2021b; 2021c; 2021d) has provided insight into the source identification and ecological risk assessment of polycyclic aromatic hydrocarbons (PAHs) and PCBs in soils and groundwater within industrial zones. The contamination at the Incel industrial area in Banja Luka (Republic of Srpska, Bosnia and Herzegovina) presents a critical concern for both the environment and public health, as highlighted by research from Ilić et al., 2020 and Stojanović Bjelić et al., 2022. Located approximately 3 km from the city center of Banja Luka, Bosnia and Herzegovina's second-largest city, the Incel site (a former cellulose factory now repurposed as an industrial complex) exhibits extensive soil pollution. Investigations reveal varying concentrations of hazardous substances within the site's soil, including polycyclic aromatic hydrocarbons (PAHs), total petroleum hydrocarbons (TPHs), and heavy metals, confirming the area's high level of pollution (Ilić et al., 2020; Ilić et al., 2021a; Ilić et al., 2021b; Ilić et al., 2021c; Ilić et al., 2021d; Ilić et al., 2023). The presence of PCBs and other detrimental pollutants has significantly compromised the quality of the soil, water, and air in the area, thus endangering human health and the surrounding ecosystem. These studies emphasize the pervasive nature of these contaminants and their potential sources, including volatilization from soil as a significant pathway for organochlorine pesticides in urban environments (Lammel et al., 2011). The variability in PAH levels and their mass size distributions across small spatial and temporal scales further illustrates the complexity of urban and industrial pollution landscapes (Lammel et al., 2010a; 2010b).

These findings underscore the importance of targeted remediation strategies to mitigate urban PCB emissions effectively. Moreover, the critical role of air quality in maintaining biodiversity within urban and industrial settings is highlighted by Ilić and Maksimović (2021), pointing towards the intricate relationship between pollution and ecological health.

Addressing heavy metal contamination, (Ilić et al. (2020)) identify new 'hotspot' areas within industrial zones, underscoring the ongoing risk to environmental and human health (Stojanović Bjelić et al., 2022). The need for stringent regulation and remediation values for pollutants in soil is echoed in the Rulebook (2021), which sets a legal framework for environmental protection efforts.

The Stockholm Convention on Persistent Organic Pollutants (Lallas, 2001) provides an international legal basis for the global effort to eliminate or restrict the production and use of POPs, including PCBs and PAHs. This convention underlines the importance of international cooperation and regulation in addressing the challenges posed by these hazardous substances. The Stockholm Convention on Persistent Organic Pollutants (POPs) represents a global effort, established through an international agreement, to safeguard human health and the environment from the adverse effects of highly toxic and enduring chemicals like PCBs (Fiedler et al., 2019; Ilić and Maksimović, 2021). This issue of soil contamination by PCBs is intrinsically linked to the aims of the Stockholm Convention, considering that soil acts as a primary repository for these pollutants. The potential for contaminated soil to introduce PCBs into the food chain and their long-lasting presence in the environment underscores the risk they pose. The convention outlines a strategy for tackling soil contamination by POPs, including PCBs, advocating for risk assessments, the remediation of contaminated soils, and the prevention of pollution. The adoption of the convention's guidelines enables nations to mitigate the hazards associated with soil contamination by PCBs and other POPs, thereby ensuring the protection of human health and the ecological system (Lallas, 2001; Porta & Zumeta, 2002; Fiedler et al., 2019; Ilić and Maksimović, 2021). This framework is particularly relevant to remediation projects like that in the Incel industrial zone, where addressing soil contamination is critical to complying with international standards for environmental protection and public health safety. The remediation project for the Incel industrial zone not only aligns with the global environmental protection efforts as outlined by the Stockholm Convention on Persistent Organic Pollutants (POPs) but also represents a pioneering initiative in the Republic of Srpska. It stands as the first project of its kind within the region to comprehensively address soil contamination by hazardous substances such as PCBs. This groundbreaking endeavour sets a precedent for environmental remediation, emphasizing the importance of safeguarding human health and the ecosystem from the adverse effects of persistent pollutants. By undertaking such a significant project, the Republic of Srpska demonstrates a commitment to adhering to international environmental standards and contributes to the global effort to mitigate the risks associated with soil contamination by POPs. This initiative not only aims to remediate the contaminated soil in the Incel industrial zone but also serves as a model for future projects within the Republic and potentially beyond, highlighting the critical role of collaborative efforts in environmental protection and public health preservation.

Through the lens of these studies and regulations, our project in INCEL aims to adopt a comprehensive and informed approach to remediation, leveraging scientific research to guide our practices and policies. The integration of these findings into our project design is pivotal for the successful remediation of contaminated sites, ensuring a sustainable and healthy environment for future generations.

In the contemporary era, the intersection of urbanization and industrial activities has posed significant environmental challenges, notably in the form of persistent organic pollutants (POPs) and heavy metal contamination. The project of remediation and recultivation in INCEL, Banja Luka, stands as a testament to the urgent need for addressing these environmental concerns. This introduction aims to outline the research findings and methodologies that inform our approach to remediation, emphasizing the significance of understanding pollutant sources, distribution, and ecological risks.

MATERIAL AND METHODS

Macro-location

Banja Luka is the second largest city in Bosnia and Herzegovina. It is located in the north-western part of the country, and is the administrative centre of the Republika Srpska entity. It covers 1.238,91 km^2, with about 185.000 inhabitants. The town is situated on both banks of the Vrbas river, in a tectonic valley in the northeast-southwest direction, which is separated from Lijevce polje (Lijevce field) in Posavina by the Laktaska klisura. The city itself covers an area of 150 km2, and is located at 44°46' 'north latitude and 17°11' east longitude. The average altitude of the urban area of Banja Luka settlement is 164 meters. The position of the municipality of Banja Luka in relation to BiH, i.e. the location to which the subject of this project is given is given on Figure 1.

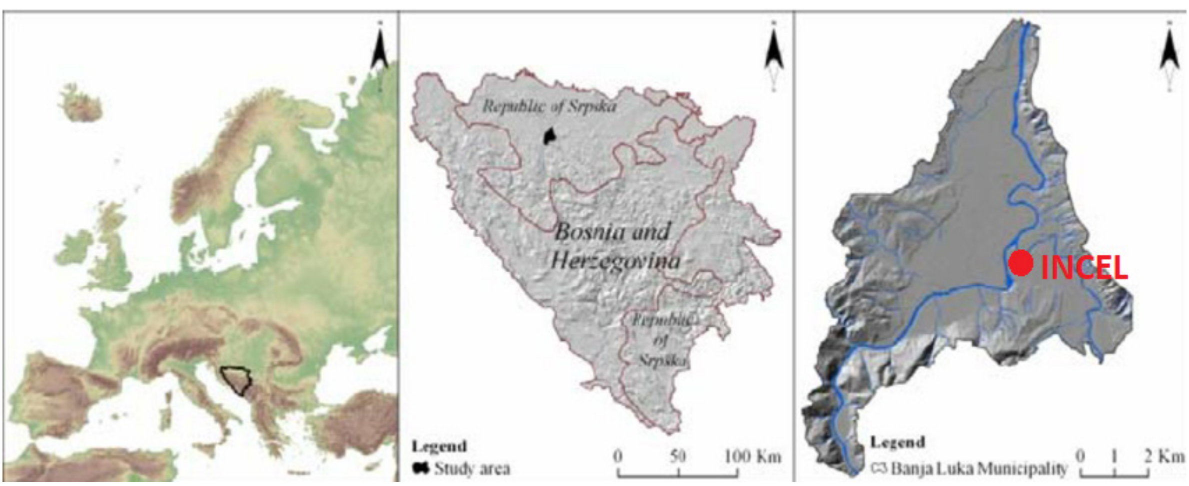


Figure 1 *Macro-location Banja Luka, "Business Zone" Incel*

Micro Location

The micro-location of this project is the „Business Zone" INCEL, which is located on the east bank of the Vrbas River, about 3 km from the center of Banja Luka, at 44°46'27" north latitude and 17°11'25" east longitude. The area of the location is approximately 65.65 ha, with an average altitude of approximately 155 m. The number of employees who perform daily activities and operations at the location is about 1,500, with about 1,500 visitors. This complex is located on the right bank of the river Vrbas in the alluvial plain. Its position in the city of Banja Luka is presented in Figure 2a. A detailed view of the entire micro-location, i.e., the „Business Zone" INCEL itself, is given in Figure 2b.

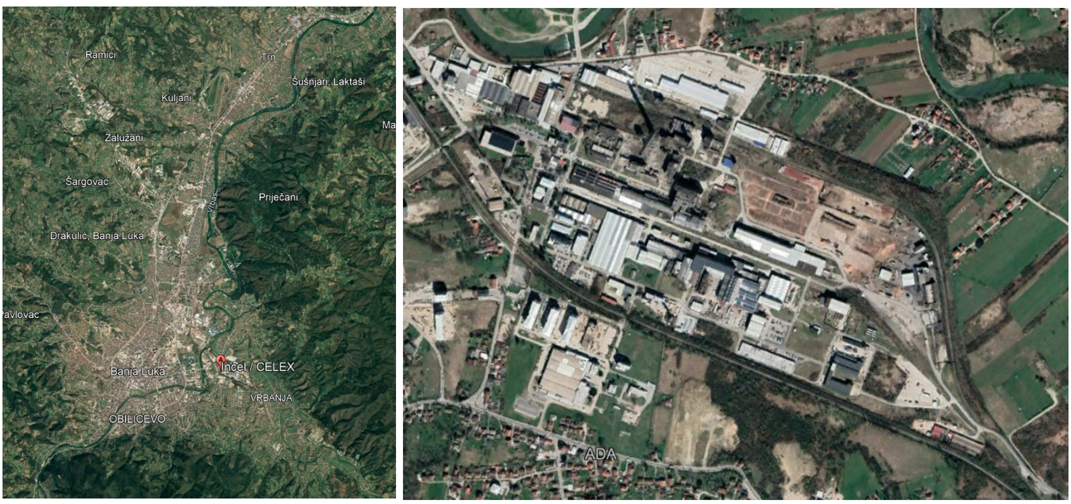


***Figure 2** a) Position of the location of the "Business Zone" INCEL about the city of Banja Luka; b) Micro-location Banja Luka, Incel*

Methodology for the remediation and recultivation

The methodology for the remediation and recultivation of the INCEL site in Banja Luka, includes a comprehensive approach emphasizing quality assurance, stakeholder engagement, and environmental protection. This methodology is implemented through a series of carefully planned activities, ensuring that the remediation process adheres to high standards of environmental safety and efficacy. Key aspects of this methodology include:

1. Quality Assurance Mechanisms: To ensure the remediation project's success, all processes are conducted under controlled conditions that align with the best international standards. This involves adhering to approved project documentation and employing proper methodologies

executed by qualified personnel, thus guaranteeing the final outputs' stable quality.

2. Standard Operation Procedures: The project emphasizes the importance of following Standard Operation Procedures for site sampling, analysis, monitoring, and investigation. This standardization ensures consistent quality and reliability of the remediation work.
3. Site Visits: Regular and non-regular site visits are proposed as part of the internal control measures to assess the progress of remediation works. These visits allow for real-time evaluation and adjustment of the project's execution to ensure alignment with the set objectives and standards.
4. Short-term Preventive Measures: Before the commencement of the actual remediation, short-term preventive measures are implemented to minimize human health risks at contaminated sites (hotspots). These measures are crucial for immediate risk mitigation until long-term and permanent remedial actions are executed.
5. Project Implementation: The project is segmented into specific activities, from preparatory works and site setup to final soil monitoring and backfilling. Each activity is detailed in subsequent chapters of the document, offering a clear technical description of the selected technologies and procedures involved.
6. Environmental Protection Measures: The methodology also includes a thorough evaluation of the environmental impacts of the remediation activities, with a detailed list of potential impacts and corresponding mitigation measures. This aspect underscores the project's commitment to minimizing its environmental footprint and protecting the surrounding ecosystem.
7. Waste Management: A significant focus is placed on the handling of waste generated during the project, including identification of waste types, treatment methods, and adherence to European Waste Codes. This ensures that all waste is managed in an environmentally sound manner, adhering to local and international regulations.
8. Professional Supervision and Monitoring: The methodology includes measures for professional supervision to oversee the remediation process. These measures emphasize the verification of milestones, monitoring and reporting accuracy, and the implementation of quality assurance. These measures are essential for maintaining the project's integrity and effectiveness.

This holistic approach, detailed in the Project/Design of Remediation and Recultivation for INCEL, Banja Luka (2021), combines rigorous quality assurance, environmental protection, and stakeholder engagement strategies, ensuring that the remediation and recultivation of the INCEL site are conducted to the highest standards.

RESULTS AND DISCUSSION

The Incel industrial zone in Banja Luka has been identified as a site with significant environmental and public health risks due to the high levels of PCBs found in the soil, alongside other pollutants like PAHs and heavy metals. These findings are concerning due to the well-documented risks PCBs pose to human health and their ability to remain in the environment for extended periods (Dorea, 2006; Srogi, 2008; EFSA et al., 2018). Industrial zones, particularly older ones such as Incel, are at a high risk for contaminating soil with these substances due to past practices before stricter chemical use regulations were established. Notably, PCBs, used in electrical equipment and other applications, were banned in the 1970s and 1980s, but their legacy remains a challenge (Gašić et al., 2010; Ilić et al., 2021c).

Recent assessments have revealed alarmingly high PCB concentrations at Incel, with levels reaching up to 400,000 ng/g (400 mg/kg) in dry soil samples, significantly surpassing levels at other sites (Apopsbal, 2019; Ilić et al., 2021c). These concentrations, alongside the presence of heavy metals and other hazardous materials, necessitate urgent remediation efforts. The total PCBs concentrations found ranged from 0.26 to 6,722 mg/kg in soil, vastly exceeding the national permissible value of 0.02 mg/kg, indicating a severe contamination issue (Ilić et al., 2021c; Rulebook, 2021).

This situation underscores the critical need for comprehensive cleanup measures and ongoing monitoring to mitigate the health risks and environmental impact. The case of Incel vividly illustrates the broader challenge of managing industrial pollution legacy and emphasizes the importance of robust environmental governance to protect public health and ecosystems.

In July and September 2021, a detailed field investigation of the previously verified seven hotspots in INCEL area and an analytical evaluation of the collected 595 samples of soil and construction debris were carried out. The results of the investigation are described in detail in the report "D2 - Report on Soil Sampling, Laboratory Analyses and Geodetic Survey" submitted to UNDP in October 2021. The results were used as a basis to propose the remediation design for the INCEL area, presented in detail in the previous chapters of the report (Project/Design, 2021).

The remediation and investigation of the INCEL site in Banja Luka has unveiled a significant level of polychlorinated biphenyls (PCBs) contamination across several hotspots. Through meticulous sampling and analysis, a detailed picture of the site's environmental challenge has been painted. Below are the key findings and discussions drawn from the investigative efforts:

1. Extent of PCB Contamination: The investigation identified PCB concentrations exceeding permissible limits in a substantial portion of the samples. Notably, some areas revealed PCB concentrations as high as 600 mg/kg, signaling severe contamination levels that necessitate immediate remedial action (Project/Design, 2021).
2. Soil and Groundwater Contamination: PCB contamination was predominantly found in the upper soil layers, with some locations also showing elevated concentrations at greater depths. This pattern of contamination suggests the potential for further environmental and health risks if not adequately addressed. Groundwater samples confirmed the presence of PCBs, adding another layer of complexity to the remediation efforts due to the potential for contaminant spread through groundwater flow toward the Vrbas River (Project/Design, 2021).
3. Impact on the Vrbas River Ecosystem: The investigation extended to the aquatic ecosystem of the Vrbas river, revealing the potential for contamination washout from INCEL hotspots to affect river sediment and, consequently, the benthic organisms, fish, and other higher organisms through bioaccumulation in the food chain (Project/Design, 2021).
4. Environmental Risk from Rainwater Sewage System: The environmental risk assessment highlighted the possibility of contaminants spreading through the rainwater sewage system. Sediment samples from the outlet of the sewage system, which discharges rainwater from the INCEL area into the Vrbas river, confirmed increased concentrations of PCBs and other contaminants, underscoring the need for comprehensive measures to prevent further environmental degradation (Project/Design, 2021).
5. Remediation Efforts: In response to the findings, short-term preventive measures were promptly implemented to mitigate immediate human health risks. These measures include informing local employees about potential risks, demarcating contaminated areas, and recommending personal protective equipment (PPE) use (Project/Design, 2021).

Additionally, the detailed analysis of contaminated materials facilitated the design of a targeted excavation plan, focusing on areas with the highest levels of contamination for prioritized remediation (Project/Design, 2021).

6. Recommendations for Future Action: Based on the analysis and the scale of contamination, a combination of excavation and ex situ disposal has been recommended as the most effective remediation strategy. This approach is supported by a multi-criteria screening of selected remediation technologies, weighing factors such as human health protection, efficiency, long-term effectiveness, compliance with environmental laws, and cost (Project/Design, 2021).

The hotspot with the highest amount of contaminated material is the Lukić hotspot (former power plant) with a total amount of material for excavation 4,281 m^3 (as summarized in the following table). The total amount of contaminated material in the Incel area intended for excavation and subsequent treatment is 4,890 m^3.

Table 1 *Average and maximum PCBs concentrations and volume of contaminated material to be excavated per each hotspot*

Hotspot	Average PCBs (mg/kg d.m.)	Maximum PCBs (mg/kg d.m.)	Volume proposed for excavation (m^3)
Univerzum AD	13.9	113	392
Lukić Invest (former power plant)	3.7 in soil 25.2 in construction debris	2,800 in soil 546 in construction debris	4,281
SHP CELEX AD	3.9	72.8	65
Business zone (electrolysis)	1.7	12	11
Top Metal	0.5	1.08	2
Business zone (in front of BC Metal)	1.8	15.2	102
Business zone (north)	0.22	<5.02	38
Total			**4,890**

The results of leaching tests show that none of the limit indicators for acceptance of waste to non-hazardous waste landfill (as defined by the European Council Directive 1999/31/EC on the landfill on waste) was exceeded. Thus, it can be stated that contaminated soil and construction debris with the content of PCBs below 50 mg/kg d.m. represented by the collected composite samples (Lukić Invest - former power plant, Business zone - in front of BC Metal and Business zone - Electrolysis) are potentially suitable for disposal at non-hazardous landfills. Nevertheless, the final parameters for waste disposal shall be assessed with regards to local legislation and conditions of the local landfills.

Two groups of contaminated materials are found in INCEL: (1) soil and construction debris with a PCB concentration ≥ 50 mg/kg d.m. and (2) soil and construction debris with a PCB concentration < 50 mg/kg d.m. of PCBs. For each group of contaminated materials, a multi-criteria screening of selected applicable remediation technologies/options has been performed using the following criteria: Protection of human health and the environment, Efficiency, Long-term effectiveness, Compliance with the current environmental laws and regulations, Implement ability, Time and Cost.

Although it is understood that Bosnia and Herzegovina currently do not possess the facilities to dispose of hazardous waste (PCBs ≥50 mg/kg d.m.), it is possible that such waste can be exported to a licensed facility abroad. For these reasons and, based on the above information and on the results of the evaluation and screening assessments of potential remedial options (Remediation Assessment Report, Dekonta, 2020), the most recommended option for remediation of contaminated areas at INCEL include excavation and ex situ disposal of contaminated soil and construction materials/debris.

Short-term preventive measures are proposed in the project. They are designed to immediately prevent contact of local employees, visitors and trespassers moving at the contaminated sites (hotspots) with contaminated soil and/or construction materials. The aim of the short-term preventive measures is to minimize human health risks until long-term and permanent remedial measures are implemented.

The remediation project at the INCEL site has highlighted the critical need for comprehensive environmental assessments and targeted remediation strategies to address industrial contamination. The findings underscore the importance of continued monitoring and adaptive management to mitigate the environmental and health risks associated with PCBs and other contaminants.

CONCLUSIONS

The Incel industrial zone in Banja Luka, Bosnia and Herzegovina, presents a notable case of environmental contamination, primarily due to the accumulation of polychlorinated biphenyls (PCBs) and other hazardous substances in the soil. Recognized as persistent organic pollutants, PCBs pose considerable risks to human health and ecological systems due to their environmental stability and potential for bioaccumulation. Classified as probable human carcinogens, PCBs are linked to numerous health issues, including disorders affecting development, reproduction, the immune system, and neurological functions. The migration of these substances into groundwater, surface water, and even the air through volatilization further exacerbates the risk, affecting the local ecosystem and the respiratory health of nearby populations. Remediation efforts in the Incel zone have been challenging, hindered by the contamination's complexity, high remediation costs, and legal disputes over pollution responsibility, slowing down the progress.

Concerns from various stakeholders, including residents, environmental organizations, and authorities, have led to calls for enhanced regulatory measures, better waste management, and more rigorous environmental monitoring to mitigate further contamination risks. In response, authorities have introduced stricter industrial controls and waste management improvements, yet significant challenges remain in fully addressing the pollution issues.

This situation underscores the critical need for sustainable industrial practices and responsible waste management to protect community health and the environment. It highlights the essential role of robust environmental regulations and enforcement to ensure industry practices do not compromise ecological and human health. Addressing the contamination at Incel requires a collaborative effort among government, industry, and community stakeholders to develop effective, long-lasting remediation strategies.The comprehensive investigation and remediation efforts at the INCEL site in Banja Luka reveal the profound impact of industrial activities on environmental health and underscore the critical importance of addressing legacy contamination issues. The findings from this project highlight the pervasive nature of PCBs and their potential to inflict significant harm on ecological systems and human health. They also demonstrate the effectiveness of targeted remediation strategies when underpinned by rigorous scientific analysis and a commitment to environmental stewardship. This endeavor stands as a testament to the necessity of integrating environmental science with practical remediation techniques to confront and mitigate the challenges posed by persistent pollutants. It underscores the importance of regulatory frameworks like the Stockholm Convention in guiding global efforts towards a healthier, more sustainable environment. Furthermore, the project exemplifies the potential for success in environmental restoration efforts, offering valuable lessons for similar projects worldwide.

As we move forward, it is imperative that the international community continues to prioritize the identification, assessment, and remediation of contaminated sites, leveraging both scientific advancements and collaborative efforts to safeguard public health and protect our natural world. The INCEL project not only contributes to the body of knowledge regarding PCB contamination and remediation but also serves as a beacon of hope and a model for future endeavors aiming to heal the scars left by industrial pollution.

REFERENCES:

APOPSBAL (2019). Assessment of the selected POPs in the atmosphere and water ecosystems from the waste materials generated by warfare in area of former Yugoslavia. Project. www.recetox.muni.cz/projekty/apopsbal/sources/final/scientific-report.pdf.

Dorea, J. G. Fish meal in animal feed and human exposure to persistent bioaccumulative and toxic substances. Journal of food protection, 2006; 69(11), 2777-2785.

EFSA Panel on Contaminants in the Food Chain (CONTAM), Knutsen, H. K., Alexander, J., Barregård, L., Bignami, M., Brüschweiler, B., ... & Hoogenboom, L. (2018). Risk for animal and human health related to the presence of dioxins and dioxin like PCBs in feed and food. Efsa Journal, 16(11), e05333. https://doi.org/10.2903/j.efsa.2018.5333

Fiedler, H., Kallenborn, R., Boer, J. D., & Sydnes, L. K. The Stockholm convention: a tool for the global regulation of persistent organic pollutants. Chemistry International, 2019; 41(2), 4-11.

Gašić, B., MacLeod, M., Klanova, J., Scheringer, M., Ilić, P., Lammel, G., ... & Hungerbühler, K. Quantification of sources of PCBs to the atmosphere in urban areas: A comparison of cities in North America, Western Europe and former Yugoslavia. Environmental Pollution, 2010; 158(10), 3230-3235.

Ilić P., Maksimović T. (2021) Air pollution and biodiversity, Pan-European University ''Apeiron'', Banja Luka.

Ilić, P., Ilić, S., Markić, D. N., Bjelić, L. S., Farooqi, Z. U. R., Sole, B., & Adimalla, N. Source identification and ecological risk of polycyclic aromatic hydrocarbons in soils and groundwater. Ecological Chemistry and Engineering, 2021a; 28(3), 355-363.

Ilić, P., Nešković Markić, D., Stojanović Bjelić, LJ., & Farooqi, Z. U. R. Polycyclic Aromatic Hydrocarbons in Different Layers of Soil and Groundwater-Evaluation of Levels of Pollution and Sources of Contamination. Polish Journal of Environmental Studies. 2021b; 30(2), 1191–1201. https://doi.org/10.15244/pjoes/125565

Ilić, P., Nešković Markić, D., Stojanović Bjelić, LJ., Mrazovac Kurilić, S., Farooqi, Z. U. R., Jat Baloch, M. Y., Mohamed, M. H., & Mohamed Ali, A. (2023). Polychlorinated Biphenyls Contamination Hotspot: A review of the Environmental Pollution at the Industrial Site. The third international conference on sustainable environment and technologies "Let's create a sustainable community" (Creating sustainable commUNiTy), Belgrade, Serbia.

Ilić, P., Nišić, T., Farooqi, Z. U. R. Occurrence of Specific Polychlorinated Biphenyls Congeners in an Industrial Zone. Polish Journal of Environmental Studies, 2021c; 30(1), 635-643

Ilić, P., Nišić, T., Farooqi, Z. U. R. Polycyclic Aromatic Hydrocarbons Contamination of Soil in an Industrial Zone and Evaluation of Pollution Sources. Polish Journal of Environmental Studies, 2021d; 30(1), 635–643.

Ilić, P., Nišić, T., Ilić, S., Stojanović Bjelić, LJ. Identifying New 'Hotspot' Heavy Metal Contamination in Industrial Zone Soil. Polish Journal of Environmental Studies, 2020; 29(4), 2987-2993.

Lallas, P. L. The Stockholm Convention on persistent organic pollutants. American Journal of International Law, 2001; 95(3), 692-708. https://doi.org/10.2307/2668517

Lammel, G., Klánová, J., Erić, L., Ilić, P., Kohoutek, J., & Kovacić, I. Sources of organochlorine pesticides in air in an urban Mediterranean environment: volatilisation from soil. Journal of Environmental Monitoring, 2011; 13(12), 3358-3364. https://doi.org/10.1039/C1EM10479A

Lammel, G., Klánová, J., Ilić, P., Kohoutek, J., Gašić, B., Kovacić, I., ... & Radić, R. Polycyclic aromatic hydrocarbons in air on small spatial and temporal scales–I. Levels and variabilities. Atmospheric Environment, 2010a; 44(38), 5015-5021.

Lammel, G., Klánová, J., Ilić, P., Kohoutek, J., Gašić, B., Kovacić, I., & Škrdlíková, L. Polycyclic aromatic hydrocarbons in air on small spatial and temporal scales–II. Mass size distributions and gas-particle partitioning. Atmospheric Environment, 2010b; 44(38), 5022-5027.

Project/Design of remediation and recultivation for INCEL, Banja Luka (2021). United Nations Development Programme, DEKONTA a.s., PSRI Institute for Protection and Ecology o the Republic of Srpska and Urbis center Ltd

Rulebook (2021) Rulebook on limit and remediation values of pollutants, harmful and dangerous substances in soil ("Official Gazette of the Republic of Srpska", No. 82/21)

Srogi, K. Levels and congener distributions of PCDDs, PCDFs and dioxin-like PCBs in environmental and human samples: a review. Environmental Chemistry Letters, 2008; 6, 1-28.

Stojanović Bjelić, LJ., Nešković Markić, D., Ilić, P., & Farooqi, Z. U. R. Polycyclic Aromatic Hydrocarbons in Soils in Industrial Areas: Concentration and Risks to Human Health. Polish Journal of Environmental Studies, 2022; 31(1), 595-608.

BUILDING MUTUAL UNDERSTANDING BETWEEN INDUSTRY AND LOCAL COMMUNITY – CASE STUDY: DRINKING WATER QUALITY ASSESSMENT ON MT. ROGOZNA

Rastko Petrović[1*], Nenad Marić[2], Predrag Matović[3]

[1] Tash Group, Kraljice Marije 9, Belgrade, Serbia

[2] University of Belgrade, Faculty of Forestry, Kneza Višeslava 1, Belgrade, Serbia

[3] Zlatna Reka Resources, Bulevar Kralja Aleksandra 24, Belgrade, Serbia

rastko@tashgroup.com

Abstract: In alignment with its Environmental Social Governance (ESG) program and commitment to the local community, Zlatna Reka Resources Ltd. (ZRR) conducted a water quality assessment following the detection of high heavy metals levels in the topsoil. Moreover, the hydrogeological settings of all investigated springs make them highly vulnerable to various sources of pollution. This study aimed to evaluate potential impacts on drinking water used by the local population on Mt. Rogozna. Analyses included chemical, physical, microbiological, and radiological parameters from eleven sampling locations. Most water samples were classified as bicarbonate-calcium type. Results showed that while some physical and chemical properties exceeded the maximum allowable concentrations (MAC), heavy metals or organic pollutants were not registered. However, a significant bacterial presence exceeding MAC was detected in almost all samples, indicating a potential health risk to the local population which uses this water for drinking.

Keywords: drinking water quality, heavy metals, pollution, local community commitment

INTRODUCTION

Zlatna Reka Resources Ltd. (ZRR) obtained a new exploration license (No 2385 - Shanac) on Rogozna Mountain (Novi Pazar, SW Serbia) in August 2020. Since then, ZRR has undertaken a series of exploration and evaluation campaigns to understand better the nature of the deposits investigated. Since the beginning of 2021, ZRR has initiated several environmental studies by engaging representative consulting entities. In addition, also several studies were prepared as an in-house activity. The ratio has been to achieve a better understanding between ZRR and local individuals or groups affected by the project. In other words, an environmental social governance (ESG) programme has been developed.

During the 2021 environmental sampling campaign, analysis of topsoil quality indicated high anomalous values of trace elements (heavy metals) in several locations. Such high values are predominantly geogenic but still pose a potential risk to human health and the environment (Prelević, 2022). Highly ranking the health of the local population but also following the idea of conscientious project management, ZRR recognized the necessity to assess whether abnormally high values of heavy metals impact drinking water quality. Not a single household had conducted any chemical analysis of the water before, making this campaign even more important.

Professional justification for this decision is that all households organized their water supply from gravity springs. Formed in a shallow fissured porous media within the base of weathering, the depth of this domestically used aquifer (DUA) is no greater than a few meters. Since the parent rock directly affects the quality of the topsoil and the presence of heavy metals above remediation values has been determined, the necessity to assess whether individual water supply systems are also affected by the parent rock was indicated.

The analyses' results were used to better understand the groundwater quality used for the local water supply. Much more importantly, the results pointed to an important fact: the necessity of more conscientious asset management, which refers to drinking water.

MATERIAL AND METHODS

The campaign consisted of water sampling from the faucet/tap in every residential household within the Shanac license area (9 households). In addition, samples were taken from the faucet in front of the local school in Rajetiće and from the local fountain „Česmalija". The ratio of sampling from the tap instead of directly from the tapping construction/reservoir was necessary to determine whether there was any quality deterioration within the pipeline (i.e., from the reservoir to the tap). As expected, the local community appreciated this assessment. The sampling was conducted from May 31 to June 09, 2021. The campaign was conducted as per the following standards: SRPS ISO 5667-1:2008, SRPS ISO 5667-3:2018, and SRPS ISO 5667-11:2019. Water samples were analyzed at the certified laboratory for the chemical and physical properties, major components, pollutants, organic matter, gas composition, microbiology, and radiology. The analyses were performed per Regulations on the quality of drinking water (Official Gazette of the FRY Nos. 42/98 and 44/99, and Official Gazette of the RS No. 28/2019; Official Gazette of RS" No. 36/2018).

RESULTS AND DISCUSSION

Results of the water quality characterization are summarized in Table 1.

Table 1 *Water quality characterization results – overview*

HOUSEHOLD	SAMPLING DATE	ANALYSES RESULTS	
		Physical & chemical properties	**Microbiological properties**
1	31.05.2022.	Above the MAC: ■ Suspended material ■ Turbidity	Identified presence of: ■ Total Coliform bacteria (**340**) ■ Faecal Streptococci (**70**)
2		Above the MAC: ■ Turbidity Below range: ■ pH	Identified presence of: ■ Total Coliform bacteria (**130**) ■ Faecal Coliform bacteria (**24**) ■ Faecal Streptococci (**24**)
3		Above the MAC: ■ Odor ■ Suspended material ■ Turbidity ■ Mn Below range: ■ pH	Identified presence of: ■ Total Coliform bacteria (**25**)
4		Above the MAC: ■ Turbidity	Identified presence of: ■ Aerobic mesophilic bacteria on 37 °C (**130**) ■ Total Coliform bacteria (**340**) ■ Faecal Streptococci (**47**)

5	01.06.2022.	Above the MAC: ■ Turbidity	Identified presence of: ■ Aerobic mesophilic bacteria on 37 ^{o}C (**1520**)
6		Above the MAC: ■ Suspended material ■ Turbidity	Identified presence of: ■ Aerobic mesophilic bacteria on 37 ^{o}C (**96**) ■ Total Coliform bacteria (**50**)
7		Above the MAC: ■ Suspended material ■ Turbidity	Identified presence of: ■ Aerobic mesophilic bacteria on 37 ^{o}C (**350**) ■ Total Coliform bacteria (**80**) ■ Faecal Streptococci (**10**)
8		Within the range	N/A
9	09.06.2022.	Above the MAC: ■ Odor ■ Suspended material ■ Turbidity	Identified presence of: ■ Aerobic mesophilic bacteria on 37 ^{o}C (**133**) ■ Total Coliform bacteria (**300**) ■ Faecal Streptococci (**21**)
Fountain "Česmalija"		Above the MAC: ■ Odor ■ Suspended material ■ Turbidity	Identified presence of: ■ Total Coliform bacteria (**180**) ■ Faecal Streptococci (**5**)
Local primary school	25.07.2022.	Within the range	Identified presence of: ■ Total Coliform bacteria (**36**)

As Table 1 shows, physical and chemical properties that exceeded the maximum allowable concentration (MAC) were most commonly odor, suspended material, and turbidity. These findings could have been expected since water supply systems are generally old and poorly maintained. The measured values of oxygen (O_2) and carbon dioxide (CO_2) were within the ranges typical for the gas composition of groundwater. On the other hand, the presence of hydrogen sulfide (H_2S) and ammonia (NH_3) was not detected.

Based on the content of significant components, analyzed samples were generally classified as a bicarbonate-calcium group (Alekin classification). Thus, the dominant cation is calcium (Ca^{2+}), while magnesium (Mg^{2+}), sodium (Na^{+}), and potassium (K^{+}) ions are considerably less abundant. The dominant anion is bicarbonate (HCO_3^-), while sulfate (SO_4^{2-}) and chloride (Cl^-) ions are significantly less present in the samples analyzed (Table 2; Figure 1).

Table 2 *Overview of the significant hydrochemistry components*

HOUSEHOLD	MAJOR COMPONENTS											
	Cation						Anion					
	Ca^{2+}		Mg^{2+}		$Na^{+}+K^{+}$		Cl^{-}		SO_4^{2-}		HCO_3^{-}	
	mg/l	%	mg/l	%	mg/l	%	mg/l	%	mg/l	%	mg/l	%
1	16.4	65.3	3.2	12.7	5.5	21.9	2.3	2.8	6.2	7.6	73.0	89.6
2	7.6	70.7	1.2	11.2	2.0	18.1	2.0	5.8	7.4	21.6	25.0	72.6
3	6.6	44.9	1.7	11.6	6.4	43.5	1.1	2.8	11.7	29.4	27.0	67.8
4	53.6	81.0	5.9	8.9	6.7	10.1	1.8	0.9	27.3	13.8	168.0	85.3
5	65.6	65.4	28.4	28.3	6.3	6.3	1.0	0.3	30.2	9.0	305.0	90.7
6	22.8	65.5	5.7	16.4	6.3	18.1	0.6	0.5	15.6	12.7	106.0	86.8
7	18.4	68.8	4.0	15.0	4.4	16.3	0.4	0.5	9.1	10.1	81.0	89.4
8	28.4	67.6	3.5	8.3	10.1	24.0	1.0	0.8	12.5	11.0	100.0	88.1
9	17.1	67.3	4.4	17.3	3.9	15.4	0.4	0.5	5.9	6.8	81.0	92.8
Fountain "Česmalija"	18.0	66.5	3.8	14.0	5.3	19.4	1.3	1.4	8.9	9.8	81.0	88.9
Local primary school	29.0	77.0	1.8	4.8	6.9	18.2	0.0	0.0	8.0	5.4	140.0	94.6

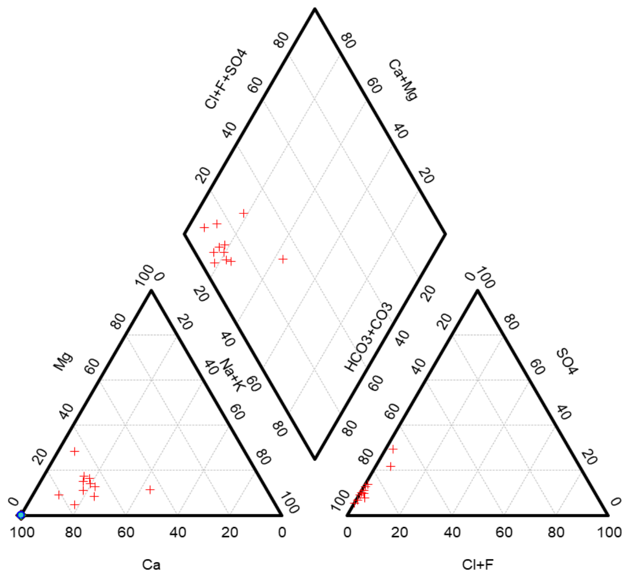


Figure . *Piper diagram of the significant hydrochemistry components*

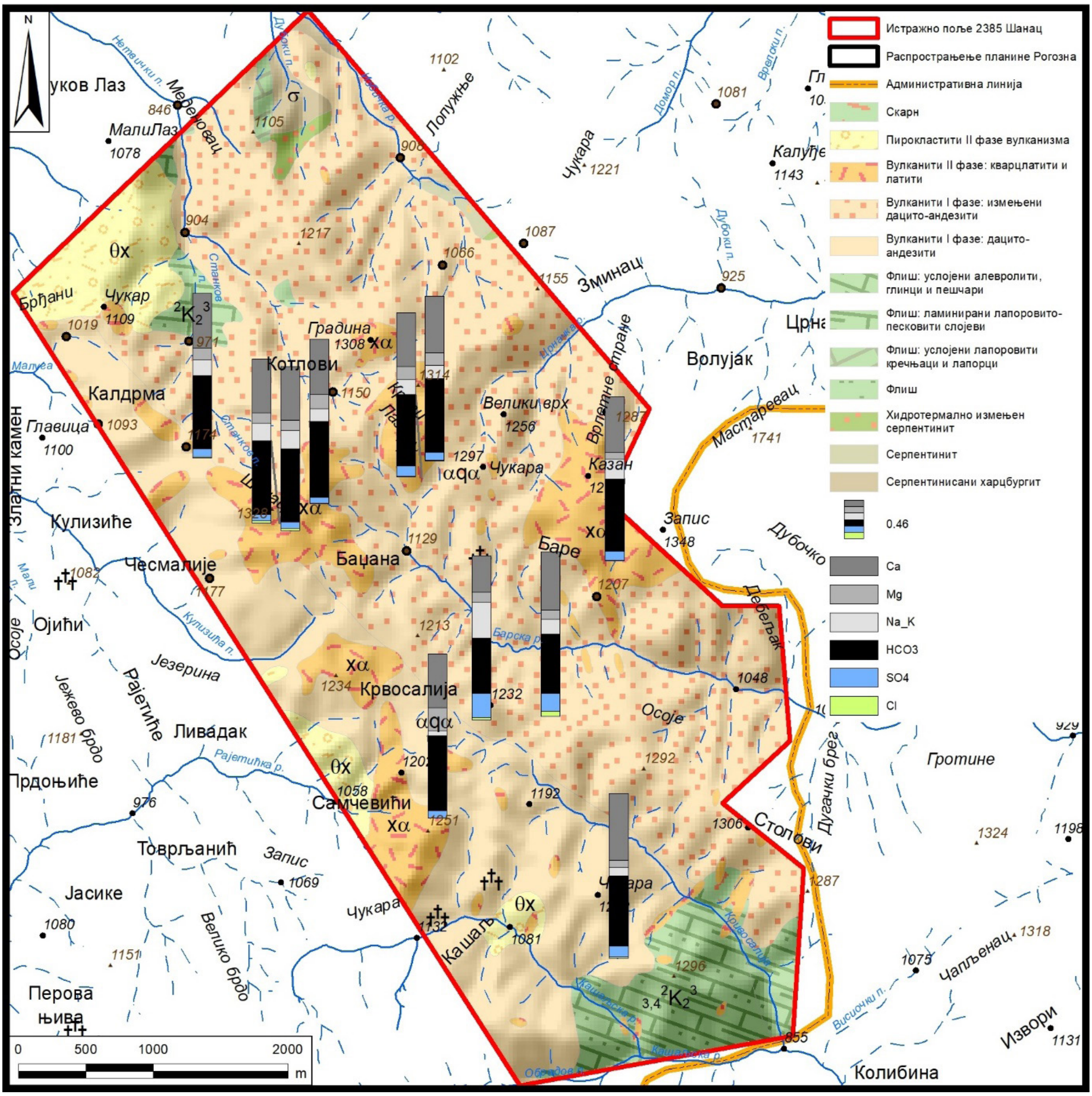


***Figure 2** A geologic map of the area with the significant hydrochemistry components of the samples analyzed*

The analysis indicated no micro component values exceeding the MAC relative to Regulations on drinking water quality. Thus, the study proved that no trace metals were present in the samples analyzed. Additionally, no organic pollutants were identified in any of the tested samples. Considering the living conditions of households and the lack of maintenance of water supply systems, these results presented a mild surprise. On the other hand, a significant presence of various bacteria was registered (exceeding the MAC) in almost all analyzed samples (Table 1). As mentioned above, these findings are not surprising due to these water supply systems' poor maintenance and status. In addition, if animal farming exists, it is organized without sanitary protection measures of water supply sources. The radiological analysis of groundwater indicated no parameter exceeding the MAC.

CONCLUSIONS

Hydrogeological settings of all investigated springs make them highly vulnerable to various sources of pollution. However, despite the anticipation, there were no trace metals of any kind that may originate from topsoil and generally parent rock in which the aquifers are formed. Also, analysis indicated no presence of pollutants/contaminants. On the other hand, the assessment identified microbiological parameters exceeding MAC. To be more precise, a considerable presence of various bacteria was registered in almost all samples, thus posing a potential health threat to these households.

lITERATURE:

ISO 5667-1:2008, Water quality - Sampling - Part 1: Guidance on the design of sampling programmes and sampling techniques, Belgrade, Serbia

ISO 5667-3:2018, Water quality - Sampling - Part 3: Preservation and handling of water samples

Prelević, D. (2022). Research Studies Report – Geochemistry of Topsoil. Exploration Field 2385 – Rogozna Mountain. Belgrade : Faculty of Mining and Geology, University of Belgrade

Regulations on the quality of drinking water (Official Gazette of the FRY Nos. 42/98 and 44/99; Official Gazette of the RS Nos. 28/2019 and 36/2018), Belgrade, Serbia

SRPS ISO 5667-11:2019, Water quality — Sampling — Part 11: Guidance on sampling of groundwaters (ISO 5667-11:2019), Belgrade, Serbia

CONTAMINATION AND HEALTH RISK ASSESSMENT OF HEAVY METALS IN PM_{10} IN CENTRAL SERBIA

Sanja Mrazovac Kurilić

Faculty of ecology and environmental protection, University "Union-Nikola Tesla", Cara Dušana 62-64, Belgrade 11000, Serbia

smrazovac@unionnikolatesla.edu.rs

Abstract: The study's objective was to investigate human health risks for heavy metals (As, Cd, Pb and Ni) in PM_{10} in central Serbia. Results showed that air in central Serbia does not contain significant heavy metal elements concentrations except in mining area (Bor). The contamination evaluation indicated that As, Cd, Ni and Pb in the air originated from anthropogenic sources. The non-cancer health risk assessment showed that ingestion was the primary exposure route for all metals in the air and that Pb, and As were the main contributors to non-cancer risks. HI values were calculated for children (HI=6.3E-07), indicating that children will likely experience higher health risks than adults (HI=7.1E-08). The non-cancer risks posed by all studied heavy metal elements and the cancer risks posed by As, Cd, and Ni to children and adults fell within the acceptable range.

Keywords: air; heavy metal elements; contamination assessment; health risk assessment; particulate matters PM_{10}

INTRODUCTION

The particulate matters (PM) not only influence the natural conditions and make climate change (Wang et al., 2014). They have critical effects on human health under the high levels due to their deposition in the respiratory system (Makkonen et al., 2010; Moreno et al., 2011). The trace elements within particulates are important components in the atmosphere. They are present in our surrounding and have a significant contribution to potential health on the lung under long-term environmental exposure owing to their high bioreactivity and toxicity (Moreno et al., 2011; Pan et al., 2015). According to the International Agency for Research on Cancer (IARC) of WHO (World Health Organization), the carcinogenic compounds are classified into five groups: Group 1 (carcinogenic to humans), Group 2A (probably carcinogenic to humans), Group 2B (possibly carcinogenic to humans), Group 3 (not classifiable as to its carcinogenicity to humans), and Group 4 (probably not carcinogenic to humans). In that study, As, Cd and Ni belong to Group 1, and Pb is included in Group 2A (Du et al., 2012; Tian et al., 2015). These toxic elements associated with particulate matter have potential threat to human health through air pollutants inhalation, dermal contact and ingestion in the human bodies (Zhang et al., 2015). Especially for children heavy metal adsorptions from the digestion system and hemoglobin sensitivity to these metals are both much higher than those for adults due to children's body at early ages and lower body weight (Kurt-Karakus, 2012). Therefore, trace elements in particulates are a serious concern for human health.

Young children might be exposed to dust bounded contaminants, including heavy metals, at elevated levels due to their behaviors increasing indirect ingestion by way of hand-to-mouth activities, touching and mouthing of various dust-contaminated objects. Moreover, lower body-weight of children would result ingestion of greater amounts of dust compared to adults (Beamer et al., 2008). Health risk is exceptionally high for children since their tolerance to toxins is lower (Acosta et al., 2009). Several studies reported exposure of children to contaminated soils, dust and air particulates by ingestion a significant amount of toxic elements through the hand-mouth pathway as well as other routes of exposure (Chirenje et al., 2006; Inyang and Bae, 2006)

Heavy metal elements in air (in PM_{10}) easily enter the human body through ingestion, inhalation, and dermal contact (Cook *et al*., 2005). The adverse effects on human health from exposure to heavy metal elements have been well-documented (Valko et al., 2006; Zheng et al., 2006; Sun et al., 2010).

Epidemiological studies have consistently shown an association between PM pollution and the number of deaths from cancer and cardiovascular and respiratory diseases (Pope et al., 2002). There is also evidence linking particulate air pollution and increases in hospital admissions for respiratory and cardiovascular diseases. In response to these adverse effects of air pollution, the EU Commission defined limit values for PM_{10} concentrations in ambient air (EU Directive 1999/30/EC).

Mining activities are notorious for their adverse impacts on the environment (Wang *et al*., 2008). Large quantities of dust laden with high levels of heavy metals can be released into the air due to mining operations including crushing, grinding, excavating, smelting, and refining (Csavina *et al*., 2012). Despite that, small regions affected by mining activities have received relatively limited attention. Thus, in comparison with mega-cities or capital cities, the environmental and human health risks in mining regions requires further investigation.

This study attempted to evaluate the above-mentioned issues by analyzing available PM_{10} data from 15 places in Serbia during 2017.

MATERIALS AND METHODS

Central Serbia also referred to as Serbia proper, is the part of Serbia lying outside the provinces of Vojvodina to the north and the territory of Kosovo to the south. Central Serbia takes up, roughly, the territory of Serbia between the natural borders consisting of the Danube and Sava (in the north), the Drina (in the west), and the „unnatural" border to the southwest with Montenegro, south with Kosovo and FYR Macedonia, and to the east with Bulgaria, with a small strip of the Danube with Romania in the northeast. The Danube and Sava divides central Serbia from the Serbian province of Vojvodina, while the Drina divides Serbia from Bosnia and Herzegovina. The Great Morava, a major river, goes through central Serbia. Extensions of three major mountain chains are located within Serbia proper: Dinaric Alps in the west and south, and the Carpathians and Balkan Mountains in the east.

Fig. 1 shows the geographical position of towns in central Serbia where the sites are placed.

Figure 1 *Map of the study area and sampling sites in Serbia*

The concentrations of pollutants were measured by monitoring the air quality in the national and local networks.

The urban stations monitor the influence of urban and suburban settlements on air quality. The monitoring area's radius varies between 1 and 5 km. Measurements of PM10 were performed by gravimetric analysis, and those of heavy metals (Pb, Cd, Ni) in PM10 were performed by atomic absorption spectrometry.

An ambient air sampler, Model LVS 3 Sven Leckel and Model MVS 6 Sven Leckel, Germany, samples suspended PM10 particles.

RESULTS AND DISCUSSION

The content of heavy metals Pb, As, Cd, and Ni in suspended PM10 particles was determined in 2023. Mean annual value measurements of heavy metals were used for analysis in 2023.

The concentrations of 4 metals varied widely in this region and followed Pb>Ni>As>Cd.

In 2023, the mean annual value of arsenic in PM_{10} in Bor exceeded the limit values at stations Bor1 and Bor2. These are the only stations where the values for the arsenic exceeded limit values. In contrast, the average annual value of indicative measurements did not exceed the limit value at other stations. The value of cadmium does not exceed the limit value at any station. The highest mean annual concentrations of cadmium were measured in Bor: at the stations Bor1 and Bor2. The content of nickel in PM_{10} during 2023 did not exceed the limit values. The maximum daily value was in Bor on station Bor1.

The HQ and HI for Ni, Pb, As, and Cd in PM_{10} samples in Serbia were calculated. The integrated HI values were 6.3E-07 for children and 7.1E-08 for adults living in Serbia, indicating children are likely to experience significantly higher non-cancer risks.

Among three different exposure pathways, the HQ_{ing} values were the highest. They contributed the most to HIs for both children and adults, indicating that ingestion of air appears to be the most threatening exposure way to human health in Serbia (Figure 2). The inhalation had the lowest contribution to health risks for children, and the HQ_{inh} values were 3–4 orders of magnitude lower compared with the other two pathways for children, indicating that the non-cancer risks posed by the inhalation might be negligible compared with ingestion and dermal contact. Similar results were obtained by previous studies (Ferreira-Baptista and De Miguel, 2005; Zheng *et al*., 2010a).

Additionally, children were found to experience higher health risks through ingestion compared with adults. The values of HQing for children were 9 times higher than those for adults and accounted for larger proportions (85% for children, 81% for adults) in integrated HI values. This result may be partially attributed to the special behavior patterns of children, particularly frequent hand-to-mouth contact (Figure 2).

The HIs for all studied metals were ranked in the order As>Pb> Cd> Ni for adults and children (Figure 3). Pb and As were the main contributors to health risks posed by PM_{10} exposure for children and adults and Ni had the smaller contribution.

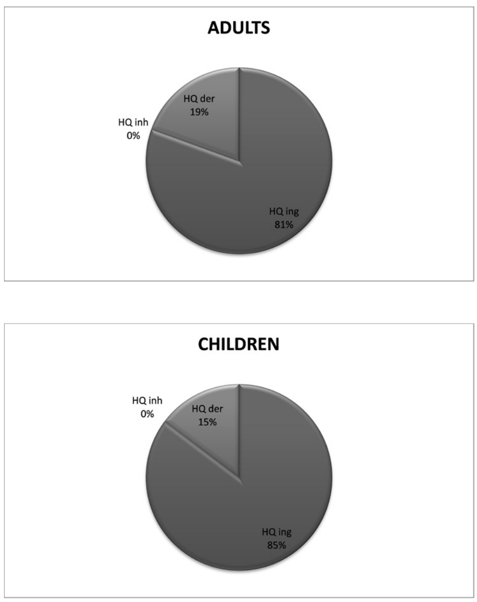
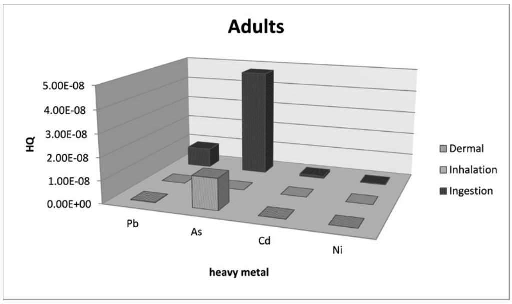


Figure 2 *Non-carcinogenic risk distribution of different exposure ways for children and adults in Serbia (2023)*



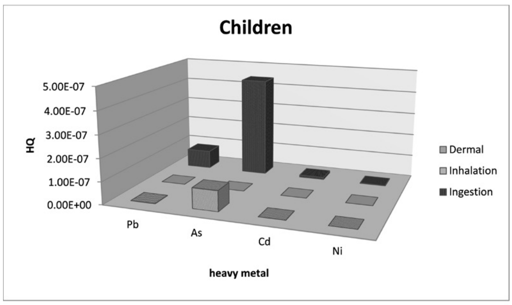


Figure 3 *The HQs of each heavy metal in the air in Serbia for adults (a) and children (b) (2023)*

The HI values for all metals tested in this study and the integrated HI values for children and adults, were within the safe level (<1), suggesting minimal non-carcinogenic risk to children and adults from exposure to PM_{10} metals.

The cancer risks according to inhalation exposure to Cd, Ni, and As showed that the overall cancer risk decreased in the order Ni>As> Cd. The leading heavy metal was Ni for which cancer risks were 1 order of magnitude higher than those for other metals. Overall, cancer risk values for all heavy metals in this study were within the acceptable range, implying negligible carcinogenic risk.

CONCLUSION

In 2023, 15 PM10 samples were collected from Serbia. The concentration and spatial distribution patterns of four potentially toxic heavy metal elements (As, Cd, Pb, and Ni) in PM_{10} were analyzed. Human health risks for each heavy metal element were assessed using a human exposure model.

Results showed that concentrations of Cd, Pb, Ni, and As were not higher than limit values. The spatial distribution of Cd, Pb, Ni, and As was all in accordance with the locations of industrial areas, indicating that these four heavy metals likely originated from industrial sources.

The health risks analysis showed that ingestion was the dominant exposure pathway for children and adults. The HI value for As accounted for nearly 86% of the integrated HI value for adults and 84% for children, indicating that this heavy metal was the most significant contributor to non-cancer risks. Among the 3 carcinogenic metals, Ni was the leading contributor to cancer risks, followed by As and Cd. Although both non-carcinogenic and carcinogenic risk for each metal fell within acceptable values, children were more susceptible than adults. They experienced higher non-carcinogenic risk from exposure to metals in air. The risks to children living in the central Serbia from exposure to heavy metal in air should receive greater attention.

Acknowledgements: This paper is the result of a project REINFORCING from The European Platform for Open and Responsible Research and Innovation practices (ORRI)

REFERENCES

Acosta JA, Cano AF, Arocena JM, Debela F, Martinez-Martinez S. Distribution of metals in soil particle size fractions and its implication to risk assessment of playground in Murcia City (Spain). Geoderma 2009;149:101–9.

Beamer P, Key ME, Ferguson AC, Canales RA, Auyeung W, Leckie JO. Quantified activity pattern data from 6 to 27 month-old farmworker children for use in exposure as- sessment. Environ Res 2008;108:239–46.

Chirenje T, Ma LQ, Lu L. Retention of Cd, cu, Pb, and Zn by wood ash, lime and fume dust. Water Air Soil Pollut 2006;171:301–14.

Cook A G, Weinstein P, Centeno J A, 2005. Health effects of natural dust. Biological Trace Element Research, 103(1): 1–15.

Csavina J, Field J, Taylor M P et al., 2012. A review on the importance of metals and metalloids in atmospheric dust and aerosol from mining operations. Science of the Total Environment, 433: 58–73.

Du, J., Zhang, Y., He, L., Huang, X., Mei, L., Lai, M., Luan, S., 2012. Pollution characteristics and health risk assessment of heavy metals in atmospheric PM2.5 in a region of Shenzhen. J. Environ. Health 29, 838–840.

Ferreira-Baptista L, De Miguel E, 2005. Geochemistry and risk assessment of street dust in Luanda, Angola: A tropical urban environment. Atmospheric Environment, 39(25): 4501–4512.

Inyang HI, Bae S. Impacts of dust on environmental systems and human health. J Hazard Mater 2006;132:5–6.

Kurt-Karakus, P.B., 2012. Determination of heavy metals in indoor dust from Istanbul, Turkey: estimation of the health risk. Environ. Int. 50, 47–55.

Makkonen, U., Hellen, H., Anttila, P., Ferm, M., 2010. Size distribution and chemical com- position of airborne particles in south-eastern Finland during different seasons and wildfire episodes in 2006. Sci. Total Environ. 408, 644–651.

Moreno, T., Querol, X., Alastuey, A., Reche, C., Cusack, M., Amato, F., Pandolfi, M., Pey, J., Richard, A., Prévôt, A.S.H., Furger, M., Gibbons, W., 2011. Variations in time and space of trace metal aerosol concentrations in urban areas and their surroundings. Atmos. Chem. Phys. 11, 9415–9430.

Pan, Y., Tian, S., Li, X., Sun, Y., Li, Y., Wentworth, G.R., Wang, Y., 2015. Trace elements in particulate matter from metropolitan regions of Northern China: sources, concentrations and size distributions. Sci. Total Environ. 537, 9–22.

Pope, C. A., Burnett, R. T., Thun, M. J., Calle, E. E., Krewski, D., Ito, K., & Thurston, G. D. (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. Journal American Medical Association, 287(9), 1132–1141.

Sun C, Bi C, Chen Z et al., 2010. Assessment on environmental quality of heavy metals in agricultural soils of Chongming Island, Shanghai City. Journal of Geographical Sciences, 20(1): 135–147.

Tian, H.Z., Zhu, C.Y., Gao, J.J., Cheng, K., Hao, J.M., Wang, K., Hua, S.B., Wang, Y., Zhou, J.R., 2015. Quantitative assessment of atmospheric emissions of toxic heavy metals from anthropogenic sources in China: historical trend, spatial variation distribution, uncertainties and control policies. Atmos. Chem. Phys. 15, 12107–12166.

Valko M, Rhodes C J, Moncol J et al., 2006. Free radicals, metals and antioxidants in oxidative stress-induced cancer. Chemico-biological Interactions, 160(1): 1–40.

Wang L, Guo Z, Xiao X et al., 2008. Heavy metal pollution of soils and vegetables in the midstream and down- stream of the Xiangjiang River, Hunan Province. Journal of Geographical Sciences, 18(3): 353–362.

Wang L, Liang T, Zhang Q et al., 2014. Rare earth element components in atmospheric particulates in the Bayan Obo mine region. Environmental Research, 131: 64–70.

Zhang, F., Wang, Z.W., Cheng, H.R., Lv, X.P., Gong, W., Wang, X.M., Zhang, G., 2015. Season- al variations and chemical characteristics of PM2.5 in Wuhan, central China. Sci. Total Environ. 518-519, 97–105.

Zheng G, Yue L, Li Z et al., 2006. Assessment on heavy metals pollution of agricultural soil in Guanzhong district.Journal of Geographical Sciences, 16(1): 105–113.

Zheng N, Liu J, Wang Q et al., 2010a. Health risk assessment of heavy metal exposure to street dust in the zinc smelting district, northeast of China. Science of the Total Environment, 408(4): 726–733.

POLYCYCLIC AROMATIC HYDROCARBONS (PAHS) IN SOIL AROUND THE COPPER MINING AND SMELTING COMPLEX BOR

Violeta Nikolić[1*], Vladanka Presburger-Ulniković[2], Novica Staletović[3] and Ivan Jovanović[4]

[1,2,3]Faculty of Ecology and Environmental Protection, University „Union-Nikola Tesla", Belgrade, Serbia
[4]Mining and Metallurgy Institute Bor, Bor, Serbia,

violetanikolic22@unionnikolatesla.edu.rs

Abstract: The presence of polycyclic aromatic hydrocarbons (PAHs) poses a significant risk to the environment due to their mutagenic and carcinogenic properties. In this paper a characterization of occurrence and levels of PAHs in 25 soils samples around Copper Mining and Smelting Complex Bor has been presented. Furthermore, the paper includes a characterization of source and carcinogenic potency of PAHs in analyzed soils. The diagnostic ratio of LPAHs/HPAHs was employed to differentiate between petrogenic and pyrogenic PAH sources. The results primarily indicated petrogenic PAH sources, with pyrogenic PAH sources identified at only three locations (with higher PAH concentrations). Overall, the PAH concentrations in these soils showed a low environmental risk, except at one location where the sum of 10PAH compounds exceeded the target value for hazardous and harmful contaminants.

Keywords: PAH, mining, environmental, carcinogenic risk

INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) are a group of organic pollutants of significant environmental and public health concern due to their toxic, genotoxic, mutagenic, and/or carcinogenic properties. PAHs are hydrophobic, semi-volatile organic contaminants comprising at least two fused aromatic rings made up of carbon and hydrogen arranged in various structural configurations, simple to complex, including linear, angular, or clustered arrangements (Aralu et al., 2022). PAHs exhibit varying physicochemical and toxicological characteristics depending on their molecular weight. PAHs with two or three aromatic rings, due to their lower molecular weight, are typically referred to as light PAHs

(LPAHs). In contrast, PAHs with four or more aromatic rings are known as heavy PAHs (HPAHs). Heavy PAHs are more stable and more toxic than the light PAHs.

Polycyclic aromatic hydrocarbons are widely distributed in soils, sediments, groundwater, and the atmosphere. They are present around the globe and have been found to contaminate the soil. They are hydrophobic with low water solubility, so they have a tendency to bind with organic matter present in the soil (Škrbić et al., 2021). PAHs are relatively stable contaminants showing a recalcitrant nature in soils, making them more challenging to degrade when compared to many other organic contaminants.

Both natural and anthropogenic activities contribute to the widespread environmental occurrence of PAHs. While natural phenomena such as accidental forest fires and volcanic eruptions are significant sources, most of the PAH contamination originates from anthropogenic sources. They are easily deposited onto soil surfaces and can persist in the soil for several decades. They are formed and released into the environment through the combustion of fossil fuels and biomass in industries, power plants, gas production sites, traffic, household activities, municipal activities, and the burning of agricultural waste (Škrbić et al., 2021). Besides being present in liquid and solid fossil fuels such as coal, crude oil, and refined petroleum, PAHs are also produced by high-temperature industries such as melting and metal processing. Heavy industries, including metal mining and smelting, are operated in resource-rich areas. One prominent example is the Copper Mining and Smelting Complex, located in the city of Bor in Eastern Serbia.

The aim of this study was to analyze the concentration and distribution of individual PAH compounds in soils around the Copper Mining and Smelting Complex Bor. The main objectives of this study were to: 1) Determine the distribution and levels of PAHs; 2) Identify the sources of PAHs; and 3) Determine the carcinogenic potency of PAHs in the analyzed soil samples.

MATERIALS AND METHODS

Description of the study site

The city of Bor (coordinates: 44°05'N, 22°06'E), located on the Balkan Peninsula, belongs to the Bor district and covers an area of 856 km^2. The copper deposit in Bor is one of the largest European copper deposits. The Mining and Smelting Complex Bor is the only manufacturer of copper in Serbia. Due to mining operations over the last century, the topography has changed significantly, characterized by large surface mines.

Soil sampling

To assess PAH concentration levels, soil samples were collected during April 2023. Figure 1 shows the geographical position of the soil sampling sites (25 measuring points - locations).

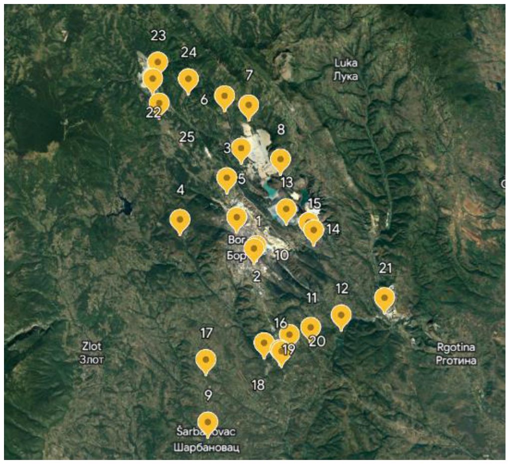


***Figure 1** The map of locations*

PAH analysis of samples was performed using a gas chromatograph with mass selective detector (GC/MS), according to ***EPA*** 8270D:2007, EPA 3540C:1996 and EPA 3630C:1996 methods. All GC/MS analyses were conducted by accredited chemical laboratory at the Mining and Metallurgy Institute Bor (Serbia).

RESULTS AND DISCUSSION

The descriptive statistical results (including abbreviations and the number of rings) of PAH compounds in soil samples are summarized in Table 1.

***Table 1** The concentration (μg/kg) of individual PAH compounds in soil samples*

PAH Compounds	Abbr.	Rings	Min	Max	Mean	SD
Naphthalene	Nap	2	20	46	31.2	6.1
Acenaphthylene	Acy	3	n.d.	n.d.	0.0	0.0

Acenaphthene	Ace	3	n.d.	21	7.4	5.0
Fluorene	Fl	3	11	34	17.9	4.5
Phenanthrene	Phe	3	30	393	57.3	70.4
Anthracene	Ant	3	n.d.	10	0.4	2.0
Fluoranthene	Flu	4	6	396	28.6	77.0
Pyrene	Pyr	4	23	304	43.8	54.7
Benzo(a)anthracene	BaA	4	n.d.	90	8.6	18.6
Chrysene	Chr	4	6	131	16.2	24.8
Benzo(b+k) fluoranthene	BbkF	5	n.d.	301	18.5	63.0
Benzo(a)pyrene	BaP	5	n.d.	68	6.7	15.3
Indeno(1,2,3-cd) pyrene	IcdP	6	n.d.	95	3.8	19.0
Dibenzo(a,h) anthracene	DahA	6	n.d.	62	3.0	12.4
Benzo(g,h,i)perylene	BghiP	6	n.d.	70	4.4	15.3

It is known that 16PAHs have been identified by the United States Environmental Protection Agency (USEPA) as priority contaminants due to their mutagenic, carcinogenic and teratogenic properties. Additionally, 7PAHs (benzo(a) anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a) pyrene, dibenzo(a,h)anthracene, benzo(g,h,i)perylene) are classified as carcinogenic compounds (Carc PAHs).

Serbia has established the Directive on systematic soil quality control program, indicators for soil degradation risk assessment and methodology for remediation programs (Directive 30/2018). This directive sets target and intervention values for regulating the occurrence of a sum of 10PAHs (i.e. sum of anthracene, benzo(a)anthracene, benzo(k)fluoranthene, benzo(a)pyrene, chrysene, phenanthrene, fluoranthene, indeno(1,2,3-c,d)pyrene, naphthalene and benzo(g,h,i)perylene) in soil. The Serbian Directive sets a target value of 1 mg/kg (1000 μg/kg) for 10PAHs, while the intervention value is 40 000 μg/kg. The concentration of total PAHs, the 10PAH and the carcinogenic 7PAH compounds at different locations are presented in Figure 2. The concentration of the 10PAHs is significantly below this target value at all locations except one - location 3 (Brezonik in the northern part of the Bor region). The high PAH concentrations at this location could be attributed to the nearby smelter, wich is surrounded by mining tailings, a quarry and underground pit exploitation.

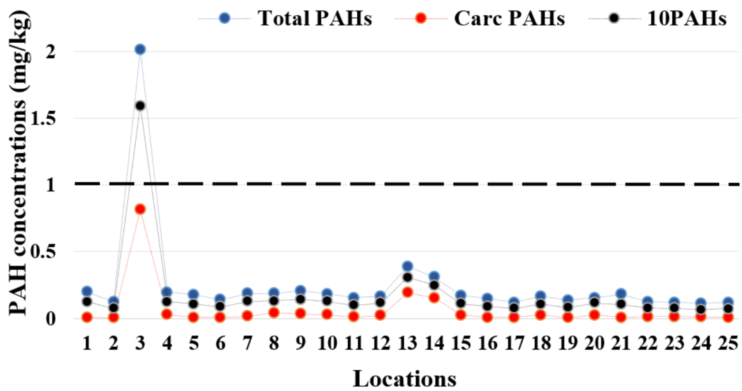


Figure 2 *PAH concentrations on different locations*

Based on the number of aromatic rings, 16 PAHs are categorized into 5 groups as: 2-rings PAHs, 3-rings PAHs, 4-rings PAHs, 5-rings PAHs and 6-rings PAHs. The distribution of PAHs in these soil samples indicates that 3-ring PAHs are the most dominant, followed by 4-ring PAHs and 2-ring PAHs (Figure 3).

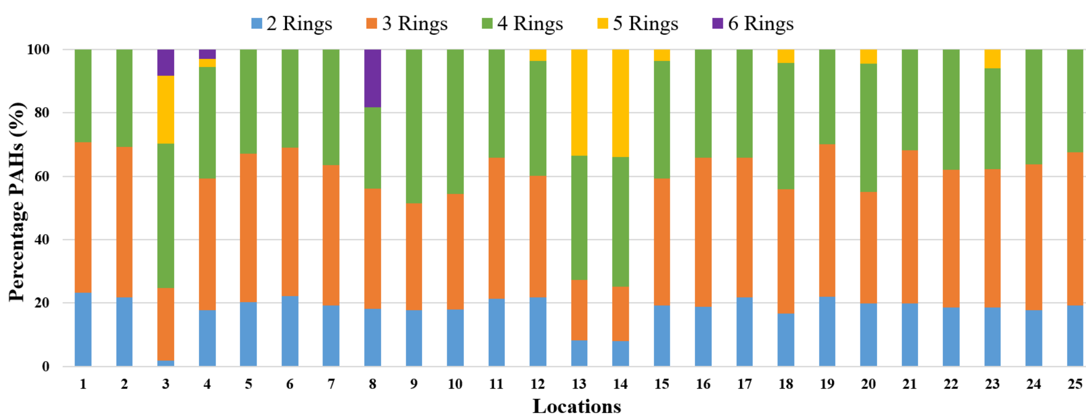


Figure 3 *Contribution of different ring numbers to the total PAHs depending on locations*

PAH source materials are generally classified as either petrogenic (derived from petroleum) or pyrogenic (derived from combustion). In order to characterize the sources of PAHs, the ratio of LPAHs/HPAHs was calculated. This ratio has been extensively used in literature to distinguish between petrogenic and pyrogenic PAH sources (Aralu et al., 2022). Generally, a LPAHs/HPAHs ratio greater than 1 indicates petrogenic sources, while a ratio less than 1 confirms pyrolytic PAH inputs. The results revealed that petrogenic source was dominant for most of the analyzed soil samples, while a pyrogenic source was confirmed for only three locations (Figure 4). It is interesting to note that these three locations with a dominant pyrogenic PAH source also have increased PAHs content. Petrogenic sources tend to be dominated by lower molecular weight LPAHs. Pyrogenic sources are associated with the incomplete combustion of organic matter. Some PAHs are characteristic for domestic heating or biomass burning (Flu, Pyr), while BghiP, BbF, IcdP were specific for car exhausts. The dominance of the LPAHs suggests a release of PAHs to the environment through the combustion of fossil fuels and their processing products. LPAHs are more biodegradable, less lipophilic and not to be sorbed as strongly as the HPAHs (Aralu et al., 2022). The increased PAHs content at location 3 could be attributed to the nearby smelter, as well as the operation of the mining machinery.

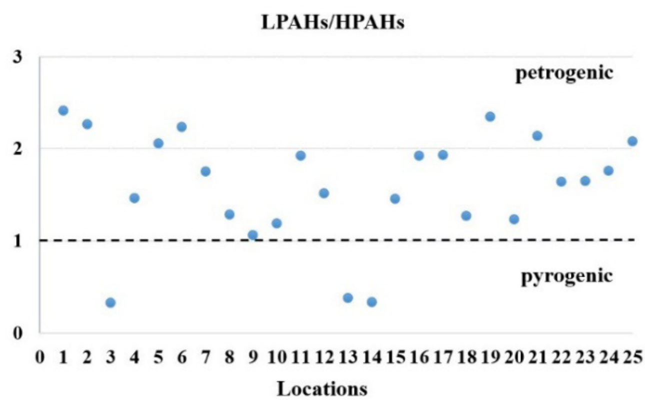


Figure 4 *Diagnostic ratio intended to identify PAHs sources in soils*

The PAH toxicities of soil samples were estimated using toxicity equivalency factors (TEF) as previously described (Škrbić et al., 2021). The TEF value indicates the toxicity and environmental risks of PAHs. As the most toxic PAH among 16 USEPA priority PAHs, benzo(a)pyrene BaP was used as the reference chemical with defined TEF value of 1. TEF values for other PAHs were assigned based on their carcinogenic level relative to that of BaP. The carcinogenic potency of each analysed soil sample was calculated as the toxicity equivalent quotient (TEQ) which is obtained as the sum of BaP equivalent concentrations (∑BaPeq) as follows:

$$TEQ = (\sum BaPeq) = \sum (TEF\ PAH_i \times PAH_i) \qquad (1)$$

where PAH_i represents the detected concentration of the *i*-PAH compound in analysed sample.

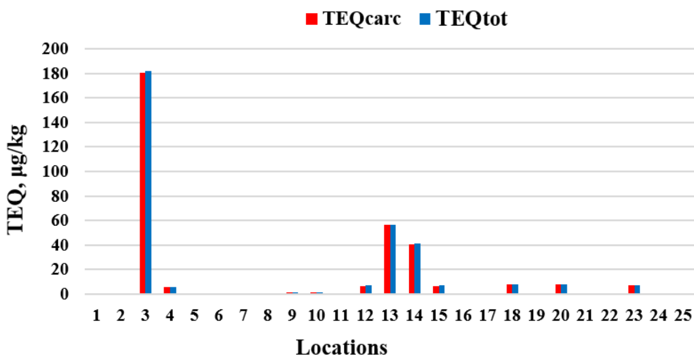


Figure 5 *The carcinogenic potency of analyzed soil samples*

The values of TEQ calculated for total PAHs (TEQtot) and carcinogenic PAHs (TEQcarc) were nearly identical (Figure 5). This implies that carcinogenic PAHs predominantly contributed to the total carcinogenic potency of the investigated soil samples. The risk from PAHs detected in soils was mainly affected by heavy compounds, i.e. PAHs with the highest TEF values (BaP and DahA with a TEF of 1; BaA, BbkF and IcdP with aTEF of 0.1).

TEQ values calculated for each location ranged from 0.02 µg/kg to 181 µg/kg. The carcinogenic potency of soil at the aforementioned three locations (especially location 3) was significantly higher compared to other locations. However, according to the Canadian soil quality guidelines for the protection of environmental and human health, TEQ values for these soil samples did not exceed the set value of ∑BaPeq of 600 µg/kg, which is considered a safe limit. Therefore, the concentration of PAHs in these soils might pose a low potential carcinogenic risk.

CONCLUSION

PAHs are a global concern for both environmental and human health. In this paper, PAH analysis was performed on 25 soil samples from around the Copper Mining and Smelting Complex Bor. The results showed that the examined area was not significantly affected by PAH contamination. Only at one location did the PAH concentration exceed the target value for the sum of 10 PAHs as prescribed by the Serbian Directive. Generally, the dominant PAHs detected in the soils were 3-ringed and 4-ringed PAHs. The diagnostic ratio of LPAHs/HPAHs was predominantly >1, indicating a mostly petrogenic PAH source in the study areas, while on only three locations this ratio was <1, which indicated a pyrogenic PAH source. TEQ values determined for all soil samples did not exceed the value of 600 µg/kg, which is considered a safe limit. This investigation provides valuable data on the PAHs presence in soils around the Copper Mining and Smelting Complex Bor and reveals a low environmental risk, except for one location.

REFERENCES

Aralu, C. C., Okoye, P. A. C., Akpomie, K. G., Chukwuemeka-Okorie, H. O., & Abugu, H. O. Polycyclic aromatic hydrocarbons in soil situated around solid waste dumpsite in Awka, Nigeria. Toxin Rev, 2022; 42(1);122–131.

Škrbić BD, Antić I, Živančev J, Vágvölgyi C. Comprehensive characterization of PAHs profile in Serbian soils for conventional and organic production: potential sources and risk assessment. Environ Geochem Health. 2021 Oct;43(10);4201-4218.

Canadian Soil Quality Guidelines (2010) Polycyclic aromatic hydrocarbons. Canadian soil quality guidelines for protection of environmental and human health.

Directive on systematic soil quality control program, indicators for soil degradation risk assessment and methodology for remediation programs, Directive 30/2018, Official Gazette of RS.

USEPA (Office of Research and Development, National Center for Environmental Assessment). (2011). Exposure Factors Handbook: 2011 Edition. EPA/600/R-090/052F. US. Environmental Protection Agency, Washington DC.

STRUCTURAL OPTIMIZATION USING LIFE CYCLE ASSESSMENT

Milan Lujić[1], Irena Parović[2], Dejan Beljaković[2], Aleksandar Milajić[2]

[1]ML Bau GmbH, Wien, Austria

[2]Faculty of Construction Management, University "Union - Nikola Tesla", Belgrade

amilajic@unionnikolatesla.edu.rs

Abstract

Optimal design of an energy efficient building has to meet two confronted demands: to minimize total cost of construction, and to minimize environmental impact and energy consumption, which is usually obtained by implementation of expensive insulation materials and equipment. Therefore, optimisation task cannot be formulated by a single objective function, but with at least two functions. Consequently, there is no unique, i.e. the best solution, but a number of more or less acceptable ones among which designer chooses satisfying one considering given demands and limitations. This paper presents methodology for solving this problem using genetic algorithm.

Keywords: Green building, energy efficiency, genetic algorithm, optimization, sustainable development.

INTRODUCTION

Reduction of the energy consumption without compromising living standard has become very important issue in civil engineering and building industry. On the other hand, this problem includes numerous independent and often contradictory aspects because the design of an energy-efficient building usually includes more expensive insulation materials and better heating, ventilating and air-conditioning (HVAC) systems, which all can have significant impact on the total price of the construction. That indicates that a compromise between construction cost and energy efficiency should be found. Multi-objective genetic algorithms (GA) have been proven to be satisfying tools for solving similar problems (Grierson, 2002; Caldas, 2003), allowing a designer to make the most applicable or the most appropriate choice among several solutions that are optimal considering different objectives and thus not comparable between each other (Pareto optimum).

Further inconvenience in solving this problem is the fact that considering energy efficiency and using renewable energy sources a building cannot be observed independently of its natural environment and local meteorological data of a given region. Numerous authors have researched methods for maximizing energy efficiency and minimizing the cost and at the same time by optimizing type and of quality of windows and insulation materials (Diakaki, 2008), room shape and orientation, as well as the windows size and positioning (Caldas, 2008) or architectural and constructional aspects of the building and performances of the HVAC systems (Wright, 2002; Angelov, 2003).

Motivation for the study presented in this paper was to find the efficient way to fulfil the both demands using multi-objective optimization. Therefore, two objective functions were developed: one for minimizing total expenses, and another one for minimizing environmental impact. The nature of given problem and the combination of continuous and discrete variables indicated that the best tool for solving this task would be a multi-objective genetic algorithm. Developed genetic algorithm was successfully tested on numerous examples, one of which is presented in the paper. Obtained results indicate that the proposed methodology can be successfully used for optimal green building design which would satisfy both the energy efficiency demands on one side and economy aspects on the other.

FORMULATION OF THE OPTIMIZATION PROBLEM

Because of the complexity of the problem, the two objective functions to be minimized in this research were the life-cycle cost (C) and the life-cycle environmental impact (EI):

$$\text{Min: } C(X) = IC(X) + OC(X) \tag{1}$$

$$\text{Min: } EI(X) = EC(X) + EO(X) \tag{2}$$

where IC is the initial construction cost (€); OC is the present worth of life-cycle operating costs (€); EC is the environmental impact (MJ) due to building construction, and EO is the environmental impact (MJ) due to the building operation for heating, cooling, and lighting.

The environmental impact of a building is evaluated by the cumulative exergy consumption (Wang, 2005), where exergy is defined as "the amount of work obtainable when some matter is brought to a state of thermodynamic equilibrium with the common components of the natural surroundings by means of reversible processes, involving interaction only with the common components of nature" (Szargut, 1988). EC is represented by the embodied energy of all fuels consumed in pre-operation phase, while EO is expected total energy consumption during the life of a given building.

The variables considered in presented study are categorized into four groups: shape, structure, envelope configuration and overhang. Building shape is defined by the edge lengths and the angles between each edge and the true north axis. This representation is more useful than the traditional one (edge lengths and angles between edges) because it defines both the shape of the building and its orientation in the global coordinates. Therefore, shape-related variables are edge length (*m*) from a_1 to a_{n-2} (values a_{n-1} and a_n will be calculated according to the obtained angle values) and the edge bearing (angle between the true north axis and the corresponding edge) from α_1 to α_{n-1}. The building structural system has an impact on the envelope design by determining the applicable wall types. The structure-related variable defines different available alternatives for the building structural system (e.g., steel frame vs. concrete frame). Its purpose is to ensure the compatibility between walls, roofs, floors and overhangs. The building envelope system can be divided into opaque walls, floors, roofs, and windows. A wall can be decomposed into a number of successive layers such as cladding, insulation, and sheathing. The sequence and material types of wall layers depend on the wall type. In order to consider alternative wall constructions simultaneously, both wall type and wall layer are represented as related discrete variables. The same principle applies to roof type and roof layers, floor type and floor layers. In addition, this study considers window type and window ratio for each façade as variables. The overhang design is closely related to the window below it. In this study, the overhang width is the same as the window width, which is set equal to the length of the corresponding wall. The overhang-related variables are: overhang type (a discrete variable that indicates the possible overhang types for each façade, including the option of no overhang); overhang depth for each façade and overhang height for each façade.

MULTI-OBJECTIVE GENETIC ALGORITHM

Genetic algorithms (GA) are a special class of global optimization methods, based on the theory of evolution, able to minimize or maximize given objective function *G(x)*, where *x* represents a parameter vector, by searching the parameter space of *x* for the optimal solution. This means that GAs do not operate on a single trial solution, but on a group of solutions, called a population. A solution is a vector of all parameters which are to be optimized. After application of evolution inspired operators such as fitness, crossover and mutation, the best solutions are being transformed and saved, forming the next generation, which means that the whole population moves towards better solutions, and finally to the global optimum (Holland, 1992; Goldberg, 1989).

Optimization problem presented in this paper has two objective functions and both the continuous and discrete variables. Therefore, multi-objective GA is the appropriate method for finding the solution because its major advantage lies in its ability to locate multiple Pareto optimal solutions in a single run. A solution is said to be Pareto optimal if and only if it is not dominated by any other solution in the performance space. If one solution dominates another, it implies that the first one is non-inferior to the second one for all the considered performance criteria but it is better than the second one considering at least one criterion. Complexity of the given problem and its confronted objectives indicate exactly the same – that there is no unique, i.e. the best solution, but a number of more or less acceptable ones among which decision maker (designer or investor) should be able to choose satisfying one considering his/her demands and limitations.

CASE STUDY

The case study consists in the design of a single-story building located in Belgrade, Serbia. The building footprint takes the shape of a pentagon with floor area of 1000 m^2 and floor-to-floor height of 3.0 m. In the building energy simulation program (EnergyPlus), the heating season is from October 15th to March 15th, while the cooling season is from June 15th to August 31st. The indoor design temperatures are set to 23°C for both the heating and cooling, without night setback or setup. A period of 20 years is used in the life-cycle analysis for building performance.

For the pentagon floor, the interval of each edge length is set between 5 and 200 m and the interval of each edge angle is set between 15° and 345°. Shape-related variables are defined here as continuous variables. Six window types are available for each façade, as follows: double clear glazing; reflective double glazing; low-e double glazing with a coating with emissivity = 0.2 or 0.1 on the exterior of the inside pane and low-e double glazing with a coating with emissivity = 0.2 or 0.1 on the interior of the outside pane. The two alternative structural systems are steel frame and concrete frame. Both of them have the same two possible exterior wall types: concrete block wall and steel-stud wall.

However, they have different floor types: the steel deck on open web steel joist floor type is used for the steel frame while a cast-in-place concrete floor type is used for the concrete frame. Two wall types have been considered. The concrete block wall consists of cladding, rigid insulation, vapor barrier, concrete block, and finish, while the steel-stud wall consists of cladding, rigid insulation, air barrier, sheathing, steel-stud with cavity insulation, vapor barrier, and finish. Only the insulation layers are optimized because all other layers have minor impact on the two considered performance criteria. The rigid insulation layers can either be expanded poly-styrene (EPS) or extruded polystyrene (XPS) with different thicknesses. For the concrete block wall, the rigid insulation has the following eight alternatives: 76, 102, 127 and 152 mm for the both EPS and XPS. For the steel-stud wall, the rigid insulation has the following six alternatives: 25, 51 and 76 mm for the both EPS and XPS. Two possible values are defined for the overhang type: no overhang and aluminum overhang. The overhang depth varies between 0.1 and 1.2 m, while the overhang height is fixed to be 0.2 m. Following GA parameters are used: crossover probability 0.85, mutation probability 0.008, maximum number of generations 500, population size 50.

Obtained solutions are visibly grouped into two isolated regions – one with lower costs and larger environmental impacts (the best solution: $3.915 \cdot 10^5$€ and $2.745 \cdot 10^7$ MJ), and the other one, with lower environmental impacts but larger costs (the best solution: $4.450 \cdot 10^5$€ and $2.509 \cdot 10^7$ MJ). These two Pareto zones are directly connected with the allowed structural systems. The steel frame system has a lower cost but higher environmental impacts than the concrete frame system. The steel-stud wall is the optimal wall type for all solutions. For the steel-stud wall, the stud insulation has converged to 102 mm fiberglass in the stud cavity. The rigid insulation converged to 76 mm XPS for the first Pareto zone and 76 mm EPS for the second one.

As it was expected and logically assumed, the longest wall in all solutions (length ranging from 30 to 48 m) is south-oriented in order to take advantage of the passive solar heating. Since the building in this case study has a fixed floor area and height, the perimeter can be employed as a valuable indicator to measure the compactness of a building. It is found that the perimeter ranges between 122 m to 132 m and roughly 75 % of the solutions have a perimeter around 122.5 m. The general trend is that the perimeter increases with the life-cycle cost and that the LCC increases and the LCEI decreases as the perimeter of the pentagon and the length of its south edge increase. All solutions have the optimal window type as the double glazing with coating (emissivity = 0.2). Differences between two proposed types of glazing were negligible. The window ratio on the south façade varies while it has converged to the lower bound 0.2 for all other façades. If overhang is used, its depth takes the lower bound 0.1 m for most solutions. The largest overhang depth is 0.25 m for the solutions with the longest south wall and the largest window ratio. There should be no overhang on non-south façades because there is no direct sun on the north façade and the solar angle is low for the east and west façades.

CONCLUSION

The research presented in this paper has shown that choice of structural system and its elements can significantly influence the total price of a building as well its environmental impact. Since these two aspects are usually directly confronted, the decision-maker should be aware of all their advantages and disadvantages. Therefore, numerical analysis for exploring different possibilities should not be exclusive, i.e. not to provide only one solution, but to offer at least several solutions in order to enable decision-maker to get a good insight and to make the most appropriate choice considering given situation. The methodology presented in this paper, based on multi-objective genetic algorithm, has proven to be successful in solving this kind of problem.

ACKNOWLEDGEMENTS

Research presented in this paper was part of the project *Practical implementation of numerical optimization methods in structural design and construction process*, supported by the University "Union – Nikola Tesla" in Belgrade.

REFERENCES

Angelov, P., Zhang, Y., Wright, J., Hanby, V. and Buswell, R. (2003). Automatic design synthesis and optimization of component-based systems by evolutionary algorithms, Lecture Notes in Computer Science. 2724: 1938-1950. http://dx.doi.org/10.1007/3-540-45110-2_93

Caldas, L. (2008). Generation of energy-efficient architecture solutions applying gene arch: An evolution-based generative design system, Advanced Engineering Informatics. 22(1): 59–70. http://dx.doi.org/10.1016/j.aei.2007.08.012

Caldas, L.G. and Norford, L.K. (2003). Genetic algorithms for optimization of building envelopes and the design and control of HVAC systems, Journal of Solar Energy Engineering. 125 (3): 343–351. https://doi.org/10.1115/1.1591803

Diakaki, C., Grigoroudis, E. and Kolokotsa, D. (2008). Towards a multi-objective optimization approach for improving energy efficiency in buildings, Energy and Buildings. 40(9): 1747–1754. https://doi.org/10.1016/j.enbuild.2008.03.002

Goldberg, D. (1989). Genetic Algorithms in Search, Optimization and Machine Learning, Addison-Wesley, Reading, MA.

Grierson, D.E. and Khajehpour S. (2002). Method of conceptual design applied to office buildings, Journal of Computing in Civil Engineering. 16 (2): 83–103. https://doi.org/10.1061/(ASCE)0887-3801(2002)16:2(83)

Holland, J. (1992). Adaptation in Natural and Artificial Systems, MIT Press, Cambridge, MA.

Szargut, J., Morris, D.R. and Steward, F.R. (1988). Exergy Analysis of Thermal, Chemical, and Metallurgical Process. Hemisphere. New York.

Wang, W., Zmeureanu, R. and Rivard, H. (2005). Applying multi-objective genetic algorithms in green building design optimization, Building and Environment. 40 (11): 1512–1525. https://doi.org/10.1016/j.buildenv.2004.11.017

Wright, J., Loosemore, H. and Farmani, R. (2002). Optimization of building thermal design and control by multi-criterion genetic algorithm. Energy and Buildings, 34(9): 959 – 972. http://dx.doi.org/10.1016/S0378-7788(02)00071-3

INFLUENCE OF BIO-REINFORCED SOIL AND MASS OF VEGETATION ON THE STABILITY OF SLOPES

Mladen Marković [1*,2] , Stefan Koprivica [1], Gorjana Stanisavljević [1], Smiljana Kotur [1], Milica Raković [1]

[1]University UNION-Nikola Tesla, Faculty of Civil Engineering , Belgrade, Serbia

[2]The University of Belgrade, Faculty of Forestry, Belgrade, Serbia

mladenmarkovic88@gmail.com

Abstract: Vegetation has a multiple influence on the stability of slopes, which it achieves with its above-ground and underground parts. As the root system develops, it compacts the soil particles into one monolithic mass, which we call bio-reinforced soil, and thus contributes to increasing the soil's shear resistance. The type of vegetation, such as grasses and shrubs, will not affect the stability of the slopes with their mass, while the mass of the forest stand can represent an additional load on the slope. The resistance of vegetation to shear forces can decrease over time, especially after extreme events such as drought, fires or clear-cutting. In the paper for the prepared terrain model, the stability of the terrain was analyzed in two scenarios: 1) when the terrain model is bio-reinforced and loaded with vegetation 2) after clear-cutting. Geotechnical numerical modeling software GeoStudio 2024 was used for all analyzes of the stability of the terrain model. The results showed that by introducing the parameter of bio-reinforced soil and uniform load from the mass of vegetation into the stability calculation, the value is Fs=1.52, the terrain model is stable. Based on the obtained results, the impact of vegetation mass on the stability of the terrain model was discussed in particular. The presented results represent a contribution to the selection of parameters for the analysis of slope stability in hilly and mountainous areas, the importance of the biological component as a preventive measure in preventing the occurrence of unstable terrain, and the possibility of applying vegetation as one of the solutions for stabilizing slopes.

Keywords: slope stability, bio-reinforced soil, vegetation, modeling, software application

INTRODUCTION

Vegetation acts as a protective barrier between soil and agents that stimulate soil degradation processes. Regarding the influence on the stability of the slopes, the vegetation achieves its above-ground and underground parts. Plants increase the stability of slopes by influencing the physical properties of the soil, especially through the root-soil relationship (Figure 1). The root system that develops on slopes has the effect of increasing soil cohesion (Greenwood et al., 2006), thereby increasing slope stability. The branching and variety of branching angles of the root system increases the shear resistance of the soil (Abe and Ziemer 1991; Mickovski et al., 2007). The root system extends through the soil, compacting soil particles into one monolithic biologically reinforced mass (bio-reinforced soil). In addition to the positive effect on the stability of the slopes, the vegetation exerts an additional load that affects the increase of the resisting moments and the increase of the shear forces. Vegetation mass can have an impact on slope stability when trees with a breast diameter > 0.3 m (Norris et al., 2008). Trees with a height of 30 m and a breast diameter of 0.8 m weigh 100-150 kN (Coppin and Richards 1990). Due to its mass, it can reduce the stability by 10%, when the vegetation is located in the upper part of the slope (Coppin and Richards 1990). The resilience of the soil, on which the forest stand is located, can be increased by 50-70% or significantly reduced if clear-cutting is carried out on the slopes (Norris et al., 2008). In forest areas, there has been an increase in the number of unstable terrains, which were created as a result of clear-cutting (Swanson and Dyrness 1975). After clear cutting, the root system begins to rot and lose its function, thereby weakening the influence on the stability of the slope. Vegetation as a living system develops in time and space, and as such is prone to change. Procedures in the maintenance, care and monitoring of plant species on the slopes are very important. In the event that these procedures are absent, positive effects of vegetation cannot be expected, and thus the stability of the terrain will not be achieved. With newly formed vegetation on the slopes, the impact on stability will be negligible, it takes time for the vegetation to establish and develop. In such cases, appropriate technical measures should be applied that ensure stability in combination with biological measures.

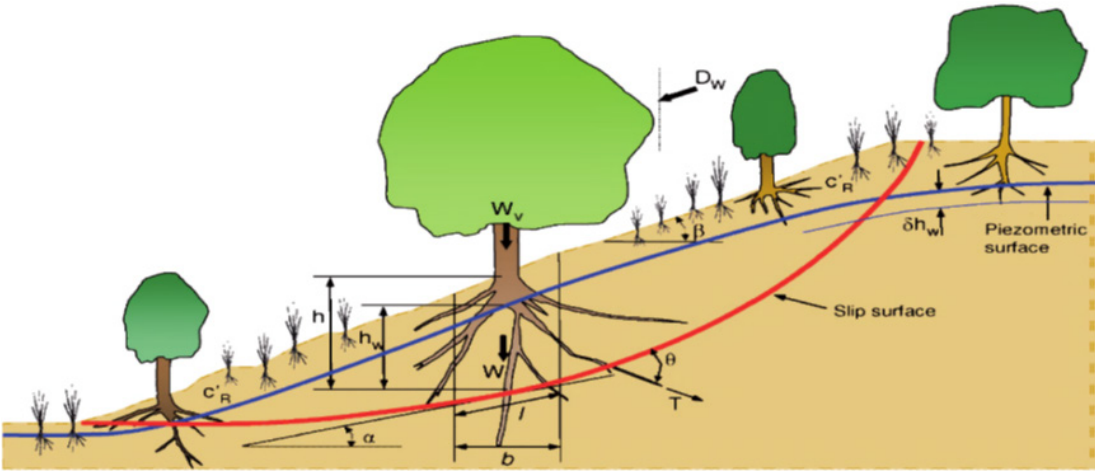


Figure 1. Forces exerted on a slope by vegetation (Greenwood et al. 2004). Parameters: α – angle of slip surface, β – slope angle; c'R – enhanced cohesion due to fine roots, D – wind force, b – width of slice, l – length of slice, h – height of slice above slip surface, hw – height of phreatic surface above slip surface, δhw – change in phreatic surface due to uptake of water by vegetation, W – total weight of soil slice, Wv – surcharge of vegetation, T – tensile force of roots acting on slip surface, θ – angle of roots to slip surface

Numerical modeling is a mathematical analysis of the simulation of real physical processes (National Research Council, 1990). The equations that describe the physical processes of soil mechanics can be very complex and do not have a simple analytical solution. Solving such complex equations requires the application of appropriate geotechnical software that enables the analysis of complex stability problems and the understanding of limit equilibrium. In the software, it is possible to analyze the stability of the terrain in different scenarios that simulate possible situations on the ground and the application of the optimal solution for stabilization. In most models, the influence of the root system on slope stability is shown as additional soil cohesion (Liu et al. 2021, Fata et al. 2023), which depends on the average tensile strength of the roots and the soil space occupied by the root system (Wu 1976, Waldron 1977). On terrain models, when calculating slope stability, the mass of vegetation acts as a uniform surface load (Hammond et al, 1992). The paper presents analyzes of the influence of vegetation on the stability of the slope model in two scenarios. GeoStudio 2024 software was used to analyze the stability of the slope model. The aim of the paper is to show the effects that vegetation can have on the stability of slopes.

The presented results provide information on the importance of the biological component in slope stabilization and the selection of parameters for the analysis of slope stability in hill-mountainous regions.

MATERIAL AND METHOD

For the defined terrain model, two scenarios of slope stability analysis are shown: 1) after clear felling of the forest stand (vegetation has no influence on slope stability), 2) the terrain model is bio-reinforced and loaded with vegetation mass (when vegetation has an influence on slope stability). In a study by Kim et al. (1999) analyzed the stability of slope models that had different dimensions. For the purposes of this paper, one such model of the slope was chosen, which is defined as follows: 1) it is formed by a layer of soil assigned physical-mechanical values γ = 18 kNm^3, c' = 20 kNm^3 and φ' = 15° 2) the dimensions of the terrain model are: D = 2m (soil depth at the base of the model), H = 10 m (total height of the model) and α = 45° (slope angle). GeoStudio 2024 software was used for terrain stability analyzes using the Slope/W tool included in the software package. The software is used for geotechnical modeling, it works according to the principles of the limit equilibrium method, taking into account all the given parameters (geometry of the terrain, soil material, etc.). The Morgenstern and Price (1965) method was used to calculate the terrain model safety factor. The method is based on the limit equilibrium of slopes, by establishing the balance of forces and moments acting on individual soil lamellae. When the value of the safety factor Fs ≥ 1.5, the ground stability condition is met. The software considers several potential sliding planes and displays the critical sliding plane with the smallest safety factor based on the slope stability calculation algorithm, according to the Morgenstern-Price method, with the following expression:

$$FS = \frac{\sum\{c * l + (N - ul)tan\varphi\}}{\sum Wsin\alpha}$$

Where: Fs- factor of safety, c- cohesion, N- normal forces, u- pore pressure, φ- angle of shear resistance, W sinα- shear (tangential) force, l- length of slice, α- angle of shear plane

When slopes under vegetation succumb to shearing forces, resistance is provided by elastic roots that move and increase shear resistance in addition to natural effective soil cohesion (Pollen and Simon 2005). It is assumed that the root system is directed to the sliding plane and that all parts of the root system achieve maximum tension at the same time. For the terrain model, the influence of the root system on the stability of the slope was analyzed by introducing a soil layer representing bio-reinforced soil. The influence of the root system shown as additional soil cohesion, which is expressed through the bio-reinforced soil cohesion (c_r), represented by Mohr-Coulomb - this shear stress equation (Wo, 2013)

$$\tau = c + c_r + (\sigma - u) * tan\varphi$$

Where: τ- tangential stress, c- soil cohesion, cr- cohesion of bio-reinforced soil, σ- normal stress, u- pore pressure, φ- angle of shear resistance

The values of c_r depending on the root-soil ratio, root tensile strength and plant species. For the purpose of the paper, the cohesion value of the bio-reinforced soil c_r=12.6 kPa was taken for the conifer forest (Wu, 1984). Bio-reinforced soil can have a significant impact on increasing stability in shallow landslides 2-3 m deep, while in deeper landslides, which are outside the zone of the root system, the impact is negligible (Norris et al., 2008). For the terrain model, the depth of the bio-reinforced layer of 2 m was adopted. In addition to the gravity load, the terrain model is uniformly loaded by the mass of vegetation (W). The load on the slope due to the forest stand with the height of trees from 30 to 60 m, is 0.5 - 1.5 kPa (Coppin and Richards 1990). For the terrain model, after clear felling of the forest stand, the value of W is 0, while the value of W = 1.5 kPa was taken in the case when vegetation is present on the slope model. In the paper, the stability of the terrain was additionally analyzed when the soil is bio-reinforced, but the parameter of uniform load from vegetation was not introduced.

RESULTS AND DISCUSSION

Based on the set parameters for the scenario after clear cutting, the analysis of the stability of the slope model showed that the safety factor Fs=1.18, which means that the condition of stability Fs ≥ 1.5 is not met (Figure 2 a), the terrain model is not stable. In the scenario by adding parameters when the vegetation has an influence on the slope, the value Fs=1.52 was obtained in the calculation of the stability of the terrain model (Figure 2 b). By comparing the obtained safety factors, it can be determined that in the case of scenarios in which vegetation affects the stability of the slope model, the safety factor increases. By introducing into the stability calculation the parameters of bio-reinforced soil and uniform load from the mass of vegetation, an increase in the safety factor by 0.34 (about 22%) is achieved. In the research on the influence of vegetation on the stability of slopes (Kokutse et al., 2016), similar results of increasing the safety factor were obtained.

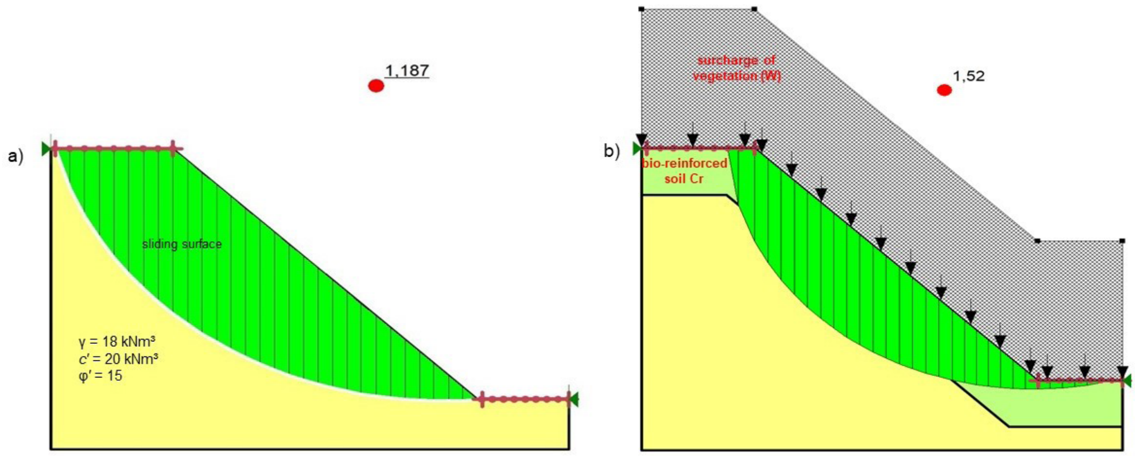


Figure 2: a) when the terrain model is bio-reinforced and loaded with vegetation, b) after clear cutting

In order to better understand the effect that vegetation has on the stability of slopes, the stability of the terrain was analyzed when the soil was bio-reinforced, but the parameter of uniform load from the vegetation was not introduced. After calculating the stability of the model, the value Fs=1.61 was obtained (Figure 3). A slight increase in the safety factor of 0.09 was found, compared to the safety factor of the slope model when it is bio-reinforced and loaded with vegetation. Greenway (1987) obtained similar results in research, where he found that the entire forest stand on a slope represents a relatively small load compared to the soil layer and other weighting factors. The total load from vegetation has no significant effect on slope stability (Greenwood et al. 2004). Taking into account the given geometry of the slope model and the assumption that the weight of the vegetation is zero, the root system can increase the safety factor by about 20%, while the safety factor will be reduced by the influence of the vegetation mass (Lotfalian et al. 2019).

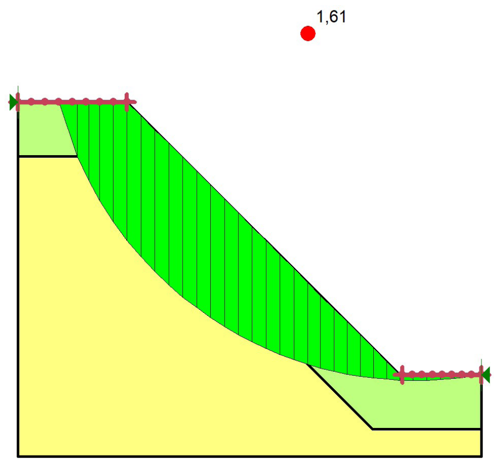


Figure 3: Stability of the terrain model when the soil is only bio-reinforced, without uniform load from the mass of vegetation

CONCLUSIONS

In this paper, the influence of vegetation on the stability of the slope model in two scenarios was analyzed using geotechnical modeling software. For the defined terrain model, the influence of the root system on the stability of the slope was analyzed as additional soil cohesion, which is expressed through the cohesion of the bio-reinforced soil. In the scenario where the terrain model is bio-reinforced and loaded with vegetation mass, the safety factor increases by about 22%, compared to the stability analysis scenario after clear cutting on the slope. For this terrain model, vegetation mass has no significant influence on slope stability. Further research can be improved by analyzing different shapes and depths of the root system (heart, tap and plate) and changes in the dimensions of the terrain model. Vegetation represents the best long-term measure for stabilizing slopes, but it should be borne in mind that on such terrains, the safety factor will increase in value over time, that is, permanent stability of the terrain will come over time. The presented results represent a contribution to the selection of parameters for the analysis of slope stability in hill-mountainous areas, the importance of the biological component in preventing the occurrence of unstable terrain and the possibility of applying vegetation as one of the solutions for stabilizing slopes.

REFERENCES

Abe K., Ziemer R.R. (1991): "Effect of Tree Roots on Shallow-Seate dLandslides", USDA Forest Service Gen. Tech. Rep. PSW-GTR-130.

Coppin N.J., Richards I.J. (1990): „Use of Vegetation in Civil Engineering", CIRIA, Butterworths, London.

Fata, Y.A., Hendrayanto, Erizal, Tarigan, S.D. and Katsumi, T. 2023. Modelling of mechanical roots on slope stability. Journal of Degraded and Mining Lands Management 10(4):4779-4790, doi:10.15243/jdmlm.2023.104.4779.

Greenway DR (1987) Vegetation and slope stability. In: Anderson MG, Richards KS (eds) Slope Stability. Wiley, Chichester, pp 187-230

Greenwood J.R., Norris J.E., Wint J. (2006): "Site investigation for the effects of vegetation on ground stability", Geotechnical and Geological Engineering, 24: p. 467–481, Springer, DOI 10.1007/s10706-005-4140-0

Greenwood JR, Norris JE, Wint J (2004) Assessing the contribution of vegetation to slope stability. J Geotech Eng 157:199-208

Hammond, C.; Hall, D.; Miller, S.; Swetik, P., 1992. „Level I stability analysis (LISA) documentation for version 2.0". USDA Forest Service Intermountain Research Station, Ogden, UT, General Technical Report INT-285. .

Kim J., Salgado R. and Yu H.S. (1999), Limit analysis of soil slopes subjected to pore-water pressures, Journal of Geotechnical Engineering, ASCE, 125(1), 49–58.

Kokutse, N.K., Temgouaa A.G.T, Kavazović, Z (2016): Slope stability and vegetation: Conceptual and numericalinvestigation of mechanical effects, Ecological Engineering 86 (2016) 146–153

Liu, C.; Bi, H.; Wang, D.; Li, X. Stability Reinforcement of Slopes Using Vegetation Considering the Existence of Soft Rock. Appl. Sci. 2021, 11, 9228. https://doi.org/10.3390/app11199228

Lotfalian, M., Nasiri, M., Modarres, A., & Wu, W. (2019). Slope stability analysis considering weight of trees and root reinforcement. Journal of Environmental Engineering and Landscape Management, 27(4), 201-208.

Mickovski S.B., Bengough AB, Bransby MF, Davies MCR, Hallett PD, Sonnenberg R (2007): „Material stiffness, branching pattern and soil matric potential affect the pullout resistanceof model root systems".

Morgenstern N.R., Price V.E. (1965): "The Analysis of the Stability of General Slip Surfaces", Géotechnique, 15(1), p 79–93. doi:10.1680/geot.1965.15.1.79

National Research Council, 1990. „Groundwater models: Scientific and regulatory applications". Water Science and Technology Board, Committee on Ground Water Modelling Assessment. Commission on Physical Sciences, Mathematics and Resources. National Research Council, National Academy Press, Washington, D.C.

Norris JE, Stokes A, Mickovski SB, Cammeraat E, Beek R, Nicoll BC, Achim A. (2008): „Slope stability and erosion control:Ecotechnological solution", Springer, The Nedherlands.

Pollen N, Simon A (2005) Estimating the mechanical effects of riparian vegetation on stream bank stability using a fiber bundle model, Water Resour Res 41:W07025, doi:10.1029/2004WR003801

Swanson F.J., andDyrness C.T. (1975): "Impact of clear-cutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon", Geology 3, p 393-396, doi: 10.1130/0091-7613

Waldron LJ (1977) The shear resistance of root permeated homogenous and stratified soil. J Soil Sci Soc Am 41:843-849

Wo T.H., (2013):"Root reinforcement of soil: review of analiytical models, test results, and applications to design",Can.Geotech. J. 50, p. 259–274 dx.doi.org/10.1139/cgj-2012-0160

Wu T.H., (1984) Soil movements on permafrost slopes near Fairbanks, Alaska. Can Geotech J 21:699-709

Wu, T. H., 1976. „Investigation of landslides on Prince of Wales Island, Alaska". Geotechnical Engineering Report (5). Ohio State University, Department of Civil Engineering.

HARNESSING GREEN INFRASTRUCTURE TO COMBAT URBAN AIR POLLUTION: CASE STUDIES

Aleksandra Milošević Pantović, Zlatomir Ignjatović, Vladimir Stevanović

University Union "Nikola Tesla", Cara Dušana 62-64, Belgrade, Serbia,
Faculty of Civil Engineering

aleksandramilosevic1992@gmail.com

Abstrakt:

This research paper explores the relationship between urban spatial planning and air quality through a case study of three locations within the municipality of Voždovac in Belgrade. The air quality measurements at these locations indicate the importance of green infrastructure arrangement in urban environments, particularly considering the impact of traffic on pollution. Emphasis is placed on the need for a systematic approach in designing architectural elements to achieve optimal results in realizing the goals of urban development, which encompass public health and a sustainable environment.

Keywords: air pollution, green infrastructure, urban planning, Belgrade.

INTRODUCTION

Cities are complex systems that are locally and regionally specific, yet they simultaneously have a significant impact on air quality at both local and regional levels. Conceptual insights from this research suggest the need for careful urban solutions, particularly concerning the location and positioning of architectural structures that may not necessarily be conducive to achieving urbanistic, economic, and health-related goals. „Air pollution is one of the greatest environmental risks to health" (World Health Organisation, 2016). According to (Abhijith, Kumar, & Gallagher, 2017, p. 72) green infrastructure in urban areas represents an important solution for improving air quality and the sustainability of cities. Vehicular traffic is often considered an indicator of air quality in cities and surrounding areas along roads. "Due to the significant impact of road traffic on pollution levels, vehicular traffic is commonly considered as an index for the air quality over the urban regions and the road neighbor areas (Logothetis, Antonopoulou, & Zisopoulos, 2023, p. 140)". "Road vehicles are one of the major sources of outdoor air pollution in cities (Kumar, Morawska, & Martani, 2015, p. 199)". In addition to numerous political, technological, and cultural changes, reductions in harmful emissions directly at the source are also necessary. "Numerous studies involving green infrastructure corroborate its cost effective multifunctionality by virtue of the variety of ecosystem services that may be achieved or enhanced, including ambient cooling and microclimate regulation (which bears additional gains in reducing local energy consumption and related emissions), storm water attenuation, improved mental and physical health, biodiversity support, and climate change mitigation and adaptation (Barwise & Kumar, 2020, p. 1)". In Serbia, the authorities are aware of the air pollution problem, and a plan (Skupština grada Beograda, 2021, pp. 165-184) has been adopted to address this issue. Author Marjanović (Marjanović, 2023, p. 24) emphasizes that the short-term action plan for reducing air pollution has not been implemented as planned, and a detailed operational plan for implementing measures has not been developed. "It has been estimated that as much as 70% of delivered energy is subject to the influence of land use planning" (Ligmann-Zielinska, Church, & Jankowski, 2006, p. 882). There is also concern that too many urban projects rely on traditional practices or adapt to investor demands. "It therefore remains an irony, if not a convenience, that evaluating the health and environmental impacts of alternative approaches to community design is deemed too costly of a luxury. At its most simplistic level, it is once again just a question of who wins and who loses (Frank & Kavage, 2008, p. 2018)".

MATERIALS AND METHODS

The research methods encompass empirical observation through fieldwork measuring air pollution. „In the Belgrade agglomeration, the air was of category III, excessively polluted, due to exceeding the limit values of suspended particles PM10 and PM2.5 for the year 2022"(Ministarstvo zaštite životne sredine, 2023, p. 7)", despite the implementation of the air quality plan[1]. "Exposure to ambient fine particulate matter (PM2.5) is a major global health concern" (Burnett, Chen, & Szyszkowicz, 2018, p. 9592). Changes in pressure can influence the movement and dispersion of pollutants, while air humidity can affect the stability and dispersion of pollutants. The IAQ parameter is useful for monitoring air pollution both indoors and outdoors. "Serbia ranked as Europe's 5th most polluted country, of a list of 37 European countries and regions, according to IQAir's 2019 World Air Quality Report, with an average PM2.5 concentration weighted by population of 23.3 µg/m3" (IQAir, 2022).

[1] Službeni list grada Beograda broj 46/21.

Research Location Details: The study was conducted through the analysis of urban plans and measurements of air pollution levels at three selected locations. The criteria for selecting locations or streets include traffic intensity, vegetation density, building height, street width, as well as a significant factor being their proximity to each other.

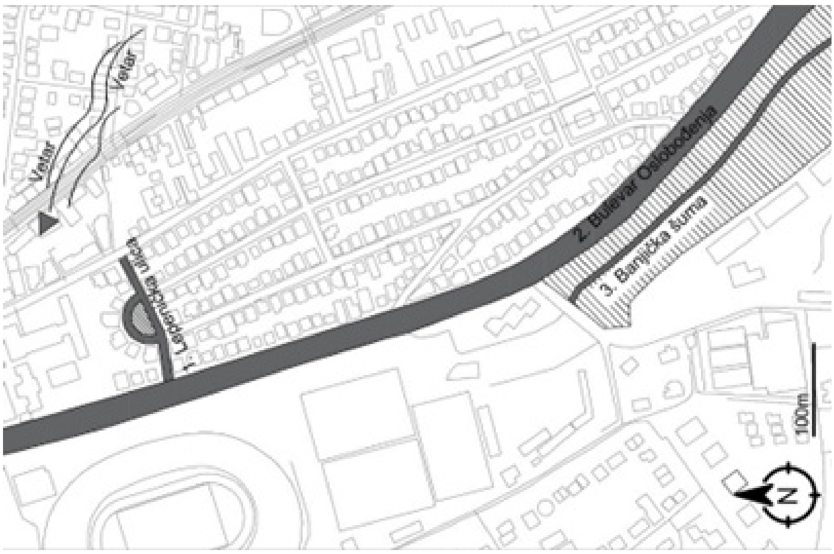


Figure 1 Location. Autors

Lepenička street- "street canyon" (Abhijith, Kumar, & Gallagher, 2017, p. 75) is a term used to describe a situation where buildings are placed along both sides of the street, creating a narrow corridor between them. This phenomenon can have a significant impact on the microclimate within the canyon, as it restricts air circulation and can lead to the accumulation of pollutants and increased heat effect. Bulevar Oslobođenja, with a width of 30 meters and the presence of residential and commercial buildings on one side and distant structures and forests on the other side, can be considered an open road (Abhijith, Kumar, & Gallagher, 2017, p. 78). Banjička Forest is a green area with a network of pedestrian paths that provide opportunities for recreation. Considering its proximity to traffic infrastructure, air pollution may be present in the forest.

RESULTS

The analysis has revealed a clear relationship between the urban characteristics of settlements and the levels of air pollution. Data analysis (Table 3) demonstrates significant differences in air pollution levels among three distinct locations. Measurements were conducted nine times, with only the mean values provided in the table.

Table 1Air pollution measurement results at locations. Authors

Location	PM<2.5 µq/m³	PM>2.5 µq/m³	∑PM µq/m³	Humidity %	Air Pressure	IAQ	CO2
Lepenička street	52	233.11	286.22	30.94	100185	79.99	608.89
Bulevar Oslobođenja	66.67	636.22	706.33	30.64	100186.78	82.72	613.31
Banjička forest	41.78	187.89	230	32.74	100094.89	30.69	509.95

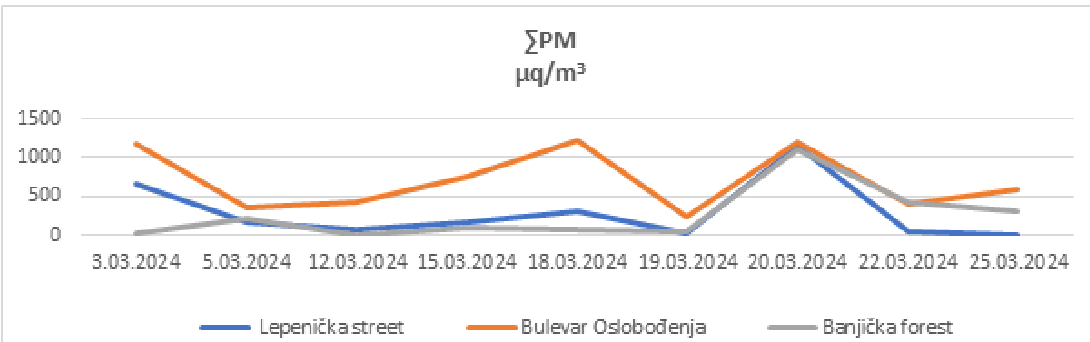


Figure 2 The diagram ∑ PM per day shows differences in values at the location. Authors

The research findings highlight an important factor often overlooked in urban environments - air pollution is not uniformly distributed along all streets. These findings are consistent with broader national studies (Agencija za zaštitu životne sredine, 2024) that also predicted similar differences in air quality at different locations. "Instead of determining the siting criteria to match all of the possible urban environments, more trust should be placed in local air quality expert analysis; in some cases, applying multiple sensors could be the way forward (Kuula, Timonen, & Niemi, 2022, p. 4806)".

DISCUSSION

According to (Greater London Authority, 2019, p. 3) properly placed vegetation can halve air pollution immediately behind the barrier at the local level, used to control the flow/distribution of pollutants by controlling their dispersion.

Lepenička street – "street canyon": Authors (Abhijith, Kumar, & Gallagher, 2017, p. 75) suggest that trees can reduce wind speed in the street canyon, leading to reduced air exchange and accumulation of pollutants. "Solid passive methods could provide lower pollutant exposure in both street canyon and open road conditions (Abhijith, Kumar, & Gallagher, 2017, p. 83)". In the case of Lepenička street, widening by 31 meters could be considered a potential solution to reduce the heat effect and provide an opportunity for a different layout, such as underground parking lots to reduce vehicle circulation and increase pedestrian areas.

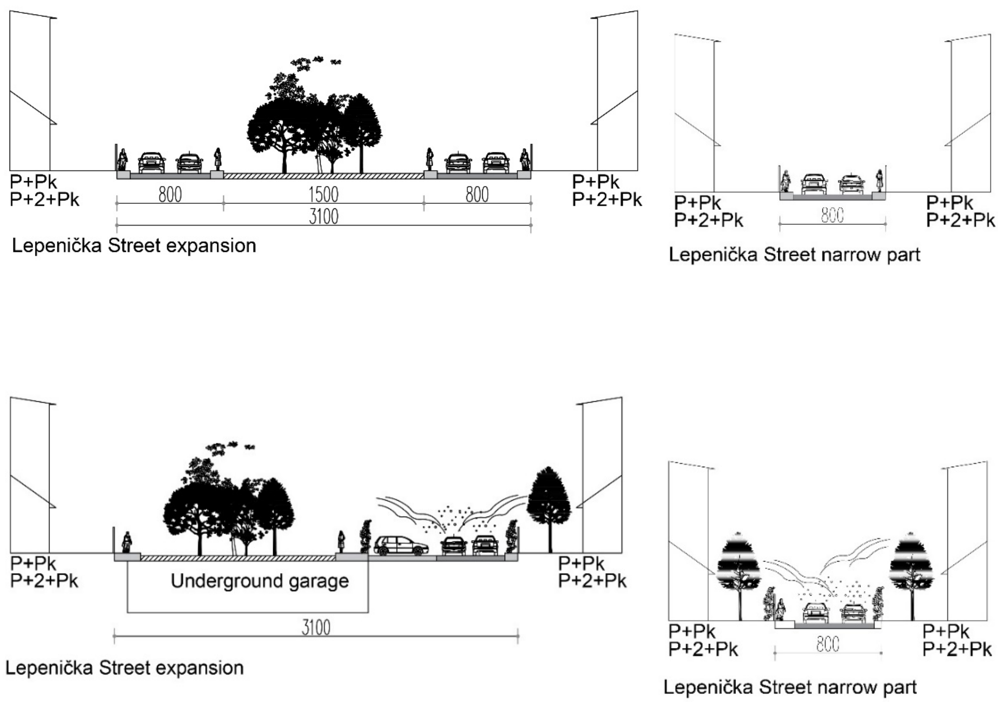


Figure 3 Current situation on site and proposed changes. Authors

Bulevar Oslobođenja- open road: According to (Abhijith, Kumar, & Gallagher, 2017, p. 83) "vegetation barriers have a positive impact on air quality with thick, dense and tall vegetation. In excess of a 50% reduction was observed with a 10 m thick green belt for numerous pollutants". Additionally, research (Barwise & Kumar, 2020, p. 15) suggests that vegetation barriers should be placed directly alongside the road edge, with a minimum height of about 2 meters. The proposed solution could involve organizing traffic lanes so that four traffic lanes are adjacent to each other, with parking along one side. Following that, space for pedestrians and cyclists is recommended.

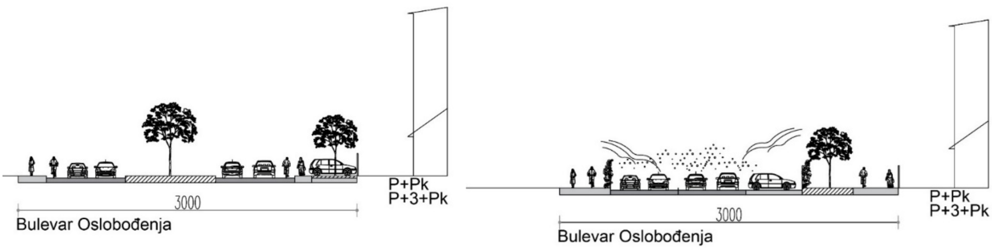


Figure 4 Current situation on site and proposed changes. Authors

Banjička šuma- green corridor: For Banjička forest, which already represents a well-preserved green area, we can consider additional interventions that would help in its preservation and enhancement. Considering its proximity to Bulevar Oslobođenja, where there is higher traffic and potential for pollution, one option would be to plant evergreen trees along the edge of Banjička forest bordering the boulevard. Evergreen trees have the advantage of retaining foliage throughout the year, enabling continuous filtration of pollutants from the air. Banjička forest serves as an example of well-preserved greenery and infrastructure that supports alternative modes of transportation such as cycling and walking paths.

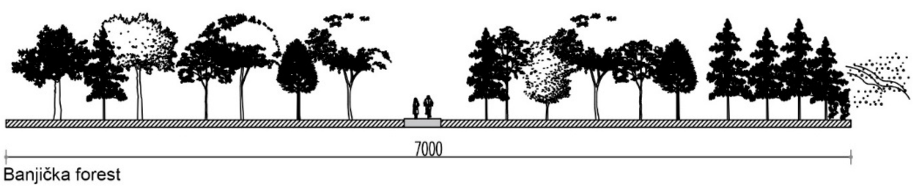


Figure 5 Current situation on site. Authors

"The planting of street trees and hedges can be challenging. Considerable space is needed to accommodate good cellular root systems, and space may be limited due to the routing of existing utilities underground and the preservation of safety-critical sight lines, vision splays" (Greater London Authority, 2019, p. 19). Additionally, vegetation requires maintenance. The financial burden of such projects can be significant for local municipalities and administrations as it often necessitates complete street reconstruction, which can limit the implementation of such initiatives.

CONCLUSION

Given the contemporary challenges regarding air pollution, there arises a question about the necessity of redefining the existing principles of urban space design, which have focused on aesthetics and practicality, in favor of designs that reduce pollution. Designing with the aim of reducing air pollution may involve a wide range of interventions such as more environmentally efficient transportation or incorporating a greater number of green spaces, building heights along streets aimed at reducing the „canyon effect," changing the orientation of residential streets perpendicular to the prevailing wind, and separating traffic streets in the direction of prevailing winds to prevent pollution from directly affecting settlements. "The current decision-making mechanisms recognize the importance of the nature-based solutions to embark on the path of shaping cities; however, urban green infrastructure as a concept has yet to be established in the legislation of the Republic of Serbia (Štrbac, Kašanin-Grubin, Pezo, & Stojić, 2023, p. 20)". Another important fact is that air pollution is not just a local problem but a global challenge that requires coordinated efforts at all levels - local, national, and global

.

ACKNOWLEDGEMENT

The work was written within the In-house project of the University Union "Nikola Tesla" in Belgrade under the title „Integrated Sustainable Practices in Architectural Design of Residential Buildings."

REFERENCES

Abhijith, K., Kumar, P., & Gallagher, J. (2017). Air pollution abatement performances of green infrastructure in open road and built-up street canyon environments – A review. *Atmospheric Environment, 162*, 71-86.

Agencija za zaštitu životne sredine. (2024). *Objedinjeni prikaz automatskog monitoringa kvaliteta vazduha u Republici Srbiji*. Retrieved March 21, 2024, from http://www.amskv.sepa.gov.rs/

Barwise, Y., & Kumar, P. (2020). Designing vegetation barriers for urban air pollution abatement: a practical review for appropriate plant species selection. *npj Climate and Atmospheric Science, 12*.

Burnett, R., Chen, H., & Szyszkowicz, M. (2018). Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. *PANS, 115*(38), 9592-9597.

Frank, L. D., & Kavage, S. (2008). Urban planning and public health: A story of separation and reconnection. *Journal of Public Health Management Practice, 14*(3), 214-220.

Greater London Authority. (2019). *Using green infrastructure to protect people from air pollution.* London: Greater London Authority.

IQAir. (2022). *Air quality in Serbia*. Retrieved March 17, 2024, from https://www.iqair.com/serbia

Kumar, P., Morawska, L., & Martani, C. (2015). The rise of low-cost sensing for managing air pollution in cities. *Environment International, 75*, 199-205.

Kuula, J., Timonen, H., & Niemi, J. V. (2022). Opinion: Insights into updating Ambient Air Quality Directive 2008/50/EC. *Atmospheric Chemistry and Physics, 22*(7), 4801-4808.

Ligmann-Zielinska, A., Church, R., & Jankowski, P. (2006). Development density-based optimization modeling of sustainable land use patterns. (pp. 881-896). Bolzano, Italija: 12th International Symposium on Spatial Data Handling.

Logothetis, I., Antonopoulou, C., & Zisopoulos, G. (2023). ACaseStudy of Air Quality and a Health Index over a Port, an Urban and a High-Traffic Location in Rhodes City. *Air, 1*, 139-158.

Marjanović, T. (2023). *Analiza primene plana kvaliteta vazduha za grad Beograd.* Belgrade: Renewables and Environmental Regulatory Institute.

Ministarstvo zaštite životne sredine. (2023). *Godišnji izveštaj o stanju kvaliteta vazduha u Republici Srbiji 2022. godine.* Retrieved March 16, 2024, from Sepa.gov.rs: http://www.sepa.gov.rs/download/Vazduh_2022.pdf

Skupština grada Beograda. (2021). *plan kvaliteta u aglomeraciji Beograd.* Belgrade: Skupština grada Beograda. Retrieved March 22, 2024, from https://www.beograd.rs/images/data/7a0a3b18c076a6bfb21688ca7d314015_4302538578.pdf

Štrbac, S., Kašanin-Grubin, M., Pezo, L., & Stojić, N. (2023). Green Infrastructure Designed through Nature-Based Solutions for Sustainable Urban Development. *International journal of environmental research and public health, 20*(1102), 1-22.

World Health Organisation. (2016). *Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease*. Retrieved March 17, 2024, from https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health?gad_source=1&gclid=Cj0KCQjwqdqvBhCPARIsANrmZhNLLnHvLDVupsl50xs_aouGt16Bc4I75D1lr1eRD4RKbVMmm9VZW-saAocPEALw_wcB

COHOUSING AS A MODEL FOR SUSTAINABLE COMMUNITIES: SOCIAL ASPECTS AND CURRENT SITUATION IN SERBIA

Aleksandra Milošević Pantović, Jelena Mitrović

University Union "Nikola Tesla", Cara Dušana 62-64, Belgrade, Serbia, Faculty of Civil Engineering, Department of Architecture and Urban Planning

aleksandramilosevic1992@gmail.com

Abstrakt: The paper explores the social background of the contemporary community housing model (cohousing), observed in relation to the crisis of the structural approach to apartment-related problems. This concept is considered a response to the contemporary lack of transparency in design experiences, bearing in mind that the self-sufficient nature of associations opposes the volatile trends dictated by the market. The paper interprets the concept of community in the contemporary circumstances of the crisis of public space and social practices, for which that space has been a stronghold. The thematic framework includes an analysis of historical forms of housing and their balance to highlight the psychological aspects of contemporary hybrid concepts. The cohousing model is reviewed in terms of its potential for a more open architectural approach and the establishment of sustainable alternative practices. The paper also includes a review of the current situation in Serbia, emphasizing the relevance of the concept from the perspective of potential users. Concluding considerations summarize the results of a previously conducted survey.

Keywords: cohousing, sustainable community, interaction, social contacts, Serbia

INTRODUCTION

Cohousing can be defined as a private initiative for the construction of a settlement with strong resident involvement at all stages, providing a supportive neighborhood environment with a sense of community. The characteristics of cohousing communities include "the rejection of set ideologies, the absence of social hierarchy, and the lack of a shared economy system" (Torres- Antonini, 2001, p. 12). Cohousing communities are becoming increasingly popular due to the desire for security and the avoidance of anonymity in urban environments.

"The increasingly mobile population has distanced many households from their extended families who have traditionally provided social and economic support. Things that people once took for granted, such as family, community and a sense of belonging must now be actively sought" (Medar & Čurčić, 2021, p. 81). The architectural design of the space corresponds to the principles of the community, with the aim of encouraging interaction and forming close relations between its members. In order to enable a balance between personal privacy and joint engagement, the number of housing units is limited between 20 and 40, and the spatial organization is such that it includes large common rooms whose capacities can be used by everyone, usually achieving economic savings in terms of additional life quality.

Transition process in Serbia, starting in the 1990s and still ongoing, has proven that the housing policy of post-war Yugoslavia paradoxically experienced the same fate as other political achievements of the socialist period. The disappearance of the party-state amidst crisis and civil wars resulted in radical resistance to any form of collectivism and growing segregation, best illustrated by the definition of the term balkanization in the global discourse. The processes leading to increasing social differences and divisions in Serbia in the last few decades are too complex to be the subject of this research. However, we can state that among the negative transitional phenomena, when it comes to the architectural profession, the loss of critical discourse about the city as a social entity and the divergence of architectural concepts from their urban dimension are at the forefront. It is difficult to speak in general terms about the spatial crisis given the complexity and ambiguity of urban situations. Each city is a characteristic and unique entity, where global processes affect in more or less mediated ways, but there is a general awareness of the dominance of markets over social interests which encourages unrestrained speculation threatening not only urban but also ecological disasters. Overlapping investments, a lack of communal services and areas, administrative sloppiness, and the inferior status of culture are some of the important indicators of the state in which the struggle for a city that is tolerable for life takes place every day in transitional cities in Serbia.

The fundamental question or thesis of the research relates to the possibility of identifying spatial conditions of open-type cohousing, i.e., a community that, while fulfilling its main function, has the capacity to engage with a broader space and act towards social integration. The goal is to examine the characteristics of cohousing as an urban-forming element. The expected survey results provide a foundation for the further development of the collaboration concept, where, depending on user groups and their participation, appropriate investment and upgrade models are conceptualized. The question of the accessibility of housing in relation to the changing needs of citizens arises, and new forms provide a framework for new experiences that adhere to the principles of construction flexibility.

THEORETICAL FRAMEWORK

Today, cohousing is the subject of a general housing reform movement whose followers are committed to the revitalization of value through the social alternative offered by the community (Wang and Hadjri, 2017). As the popularity of this concept in theory significantly exceeds the percentage of realization in practice, the question of its real capacities in experience remains open. Regardless of the crisis of public space, a crisis can be noted in the professional discourse on residential architecture. This discourse has been based on the research of the functional organization of a unit housing space in accordance with modern life, family structure and organization of time. Considering that communal living is a form of a private residential community, if the strategy and process of association are neglected, it does not differ in ownership structure from a gated community. The circumstances of desirable and undesirable social interactions, whose balance is articulated through the cohousing model, cannot be compared to the mere exclusion of those deemed not to belong. However, Jakobsen and Larsen (2019), authors of multiple studies on this topic, using examples from a country with a developed cohabitation practice like Denmark, warn of the risk of auto-segregation and a tendency towards social and ethnic homogeneity (Larsen, 2020). Emphasizing the necessity of a more careful interpretation in communal living projects, Chiodelli and Baglione (2013, p. 4) problematize „*introverted* spatial organizations," i.e., structures that, as described by Sørvoll and Bengtsson (2018, p. 21), function like „isolated island communities."

SUSTAINABLE PRACTICES IN COHOUSING

Each housing unit or family house has traditional amenities, households have independent incomes and private lives. Shared spaces typically include a communal kitchen and dining area, laundry facilities, and recreational areas. Shared outdoor spaces may include parking, walkways, open spaces, and gardens. Community activities include shared meals, parties, meetings, and workdays, with organized care for children and the elderly. "Cohousing residents typically share appliances, tools, and second automobiles. Sharing these items reduces the need for people to buy additional goods, which saves money, conserves resources and reduces waste. Many cohousers live in private units that are smaller than the traditional, homes take less energy and money to heat and maintain" (Siciliano, 2009, p. 3). Cohousing communities often encourage residents to actively care for their immediate environment and to conserve resources through sharing and joint use of goods. This not only reduces the community's ecological footprint but also raises members' awareness of the importance of sustainable practices and the preservation of natural resources. Additionally, by meeting most daily needs for recreation and socializing within the community, time and resources such as transportation are saved, contributing to reduced greenhouse gas emissions and an overall improvement in quality of life. Cohousing is particularly effective for maximizing the use of limited space in urban areas. Shared spaces such as gyms, workrooms, and kitchens are used by multiple people, resulting in reduced periods of vacancy. This increased utilization contributes to more efficient energy use for heating and cooling, as well as better economic returns through shared use of appliances and equipment. This approach optimizes the use of limited space and reduces overall energy costs, contributing to the sustainability of urban communities.

RESULTS

The research through a survey and questionnaire was designed and realized by Author in 2022. Instead of the term cohousing the Serbian word community was used for easier understanding of the term. The specifics of the community to which the questionnaire related (cohousing) were explained, but nevertheless the disadvantages emerged due to the lack of previous knowledge of the respondents in this area, which brought the answers to the imaginary situation. The aim of the survey is to connect individual information with general affinities for cohousing in order to gain insight into the fact which target group of residents is more closely interested in the development of communities in Serbia.

The questions in the questionnaire include age, gender, and occupation, with respondents remaining anonymous. The questionnaire consists of questions related to the affinity for living in a cohousing community, listing characteristics such as: 1) organizing care for children, elderly individuals, and shared transportation; 2) organizing communal meals, meetings, workdays, and entertainment; 3) reducing living costs, participating in construction; 4) the possibility of socializing and engaging in communal activities to the extent that suits members while owning a personal unit and maintaining a necessary degree of privacy. Respondents are then asked to choose the type of community based on the degree of urbanity they would prefer. All three categories – city, suburb and village – are presented with photographs based on selected characteristic examples that illustrate the prevailing type of open/closed space and communal activities. Respondents from the urban population group were selected based on probability (random sampling). The results were analyzed based on a group of 300 respondents. The survey results are presented in a diagram (Figure 1). Of the total number, 83% express a positive attitude towards living in some type of cohousing community. Within the group of interested respondents, 65% are female, and 80% have a high level of education. 50% express interest in urban cohousing, 37% are interested in the suburbs, and 13% are interested in village cohousing. The average number of household members among respondents who would like to live in the community is 3.2. while the average number of those who would not is 2.9.

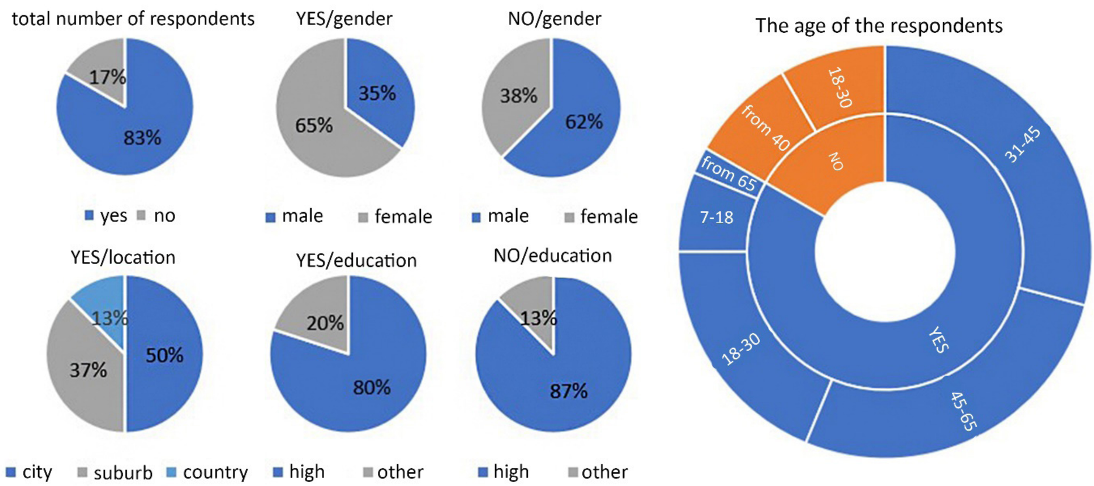


Figure 1 Diagrammatic representation of survey results at the level of a group of 300 respondents. Source: Author (2022)

The analysis of the age structure of respondents confirms that for the approximate age group between 18 and 30 years, cohabitation in the community provides the least benefits due to an independent lifestyle and freedom of choice, as well as interests and time spent outside the house. Co-living is a model that is much more suitable for this profile of users, as they connect and share housing with people of similar age and interests.

DISCUSSION

A large percentage of interested participants (over 80%) confirm the assumption that the benefits of living in a cohousing community are inversely related to the challenges of urban life, affected by negative phenomena such as overpopulation and unsystematic growth. These contribute to increasing inequality, stratification, and segregation of urban populations. Moreover, varying levels of investment in urban areas lead to stagnation, poor maintenance, inadequate commun al infrastructure, and unequal positioning in relation to transportation networks and public transit systems. Residents in cities across Serbia face dysfunctional transportation and impaired communication due to rising living costs and reduced available free time. The decline in strategic capacities and the quality of spaces affects the level of social sustainability, influencing ecological and economic attributes, as well as overall mood and declining perspectives. These phenomena, given the status, size, and number of inhabitants, are primarily considered in relation to Belgrade. For the largest percentage of the urban population, the living horizon progressively narrows without the possibility of significant influence through their own abilities and efforts. The described circumstances define a precondition for the general interest of citizens in the appropriate age group in the cohousing model. It is seen, on one hand, as an opportunity to improve individual chances through the division of responsibilities, including socializing (for which there is increasingly less time – most residents are aware of the absence of family and friendly gatherings as a form of forced isolation). On the other hand, it provides an opportunity to unite and gain a position for potential action. Although the results of the survey confirm the given assumptions, they do not provide insight into the actual possibilities of planning cohousing community. The lack of practical experience on one hand, and traditional frameworks on the other (which view family life and its spatial domain as nucleus of social structure), are factors that necessitate interpreting the research results in Serbia more as prevailing attitudes than genuine potential.

The concept of community as an attribute of the neighborhood is crucial for understanding the unique phenomenon against the background of different, increasingly popular hybrid residential concepts. In addition to cohousing (co-living) (Alfirević and Simonović Alfirević, 2020), there are condominiums and gated communities that formally gravitate to the same idea, but differ based on the main principle that enables and conditions cohabitation. In the first case, individuals and families are connected by joint activities and practices, and in the second and third cases, there are priorities of security and control, homogeneity of material status and class identity of users.

In this century, the community is offered as the last relic of modern utopias about a better society, symbolizing „what is left of the dreams of of a better life shared with better neighbors, all following better rules of cohabitation" (Bauman, 2000, p. 92). Given that the possibility of living in harmony with the environment has been reduced to the size of the immediate neighborhood, we should not be surprised that the active relationship between the individual and the collective is considered in the same spatial terms as the selling trump card that offers the comfort of a carefree life in a controlled all-inclusive environment. In both cases, the key word is territorial belonging as the basis of a common identity that provides a secure formula for intensifying desirable and eliminating undesirable encounters.

CONCLUSION

Cohousing, as a legal form implying ownership cooperatives, offers the possibility of implementation as a model for the reconstruction of the inherited housing stock, strategies for upgrading and improving the quality of these settlements if apartment owners, by joining forces, took over adjacent spaces, thus opening up possibilities for further investments. This form of cohousing would by its nature already be open and represent a step towards sustainable social development. The sustainable aspect of cohousing is also reflected in the shared responsibility and awareness of environmental impacts, encouraging residents to engage in eco-friendly practices and resource-sharing, thus fostering a culture of sustainability within the community. In conclusion, a tendency of connecting cohousing with a subset form of new urbanism is ever more present, both in theory and in practice, or at least in immagination of educators and professionals around the globe. In such conditions this study reveals that understanding the application of new design principles can lead to better cohousing design. Transferring the experience of communal living into urban development planning is possible way to enable deep spatial and social connectivity between neighborhoods. In addition to transferring design techniques from one space to another, there is the necessity of the involvement of all residents on a broader scale, almost in the original meaning of the political act. Achieving this goal entails not only revising the urban scale of these developments but also reconsidering the participation afforded to residents in shaping their physical community.

ACKNOWLEDGEMENT

The work was written within the In-house project of the University Union "Nikola Tesla" in Belgrade under the title „Integrated Sustainable Practices in Architectural Design of Residential Buildings."

REFERENCES

Bauman, Z. (2000). *Liquid Modernity*. Cambridge: Polity Press.

Chiodellia, F., Baglioneb, V. (2013). Living together privately: for a cautious reading of cohousing, *Urban Research & Practice,* Vol. 7, No. 1, pp. 3-15. http://dx.doi.org/10.1080/17535069.2013.827905

Jakobsen, P., Larsen, H. G. (2019). An alternative for whom? The evolution and socio-economy of Danish cohousing, *Urban Research & Practice*, Vol. 12, No. 4, pp. 414–430. https://doi.org/10.1080/17535069.2018.1465582

Larsen, H. G. (2020). Denmark: Anti-urbanism and segregation. In P. Hagbert, H. G. Larsen, H. Thörn, C. Wasshede (Ed.), *Contemporary Co-housing in Europe: Towards Sustainable Cities?*. London: Routledge, pp. 23-37.

Medar, K., & Čurčić, A. (2021). Cohousing and coliving - comparative analysis of two alternative housing typologies by reviewing contemporary trends. FACTA UNIVERSITATIS, 19(1), 81-92. doi:https://doi.org/10.2298/FUACE210329007M

Siciliano, J. M. (2009). The Process and Issues of Creating a Cohousing Development with Affordable Units in an Affluent Community: Stamford, Connecticut (Master's thesis,Graduate School of the University of Massachusetts, Amherst, Massachusetts). ScholarWorks@ UMass Amherst. https://scholarworks.umass.edu/cgi/viewcontent.cgi?article=1018&context=larp_ms_projects [Accessed: 07 May 2024].

Sørvoll, J., & Bengtsson, B. (2020). Mechanisms of Solidarity in Collaborative Housing – The Case of Co-operative Housing in Denmark 1980–2017. *Housing, Theory and Society*, Vol. 37, No. 1. pp. 65–81. DOI: 10.1080/14036096.2018.1467341

Torres-Antonini, M. (2001). *Our Common House: Using The Built Environment to Develop Supportive communities* (Doctoral dissertation, University Of Florida, Gainesville, FU). University of Florida ProQuest Dissertations Publishing, 2001. 3052380. https://www.proquest.com/openview/f3e551c5e25a6d70cadcb6f45b374d40/1?pq-origsite=gscholar&cbl=18750&diss=y [Accessed: 07 May 2024].

Wang, J., Hadjri, K. (2017). The Role of Co-housing in Building Sustainable Communities: Case studies from the UK. In M. Y. Abbas (Ed.) *Environment-Behaviour Proceedings Journal*. Annual Serial Landmark International, pp. 255-265. https://doi.org/10.21834/e-bpj.v2i6.946

POSSIBILITIES OF ENERGY RENOVATION OF RESIDENTIAL BUILDINGS BUILT DURING THE 1970s IN BELGRADE IN "IMS" SYSTEM OF PREFABRICATED CONSTRUCTION

Ana Rajković[1], Dragana Vasilski[2]

[1] Ministry of Defence RS
[2] Faculty of Construction Management, University "Union – Nikola Tesla"

rajkovic_ana@yahoo.com;

Abstract: The largest number of residential buildings in Belgrade were built in the period from the 60s to the 80s of the last century. Several systems of industrialized construction were used for these construction. Most of the completed buildings are in the "IMS" prefabricated construction system, which allowed designers freedom in designing and investors quick results. During those decades, several new laws, regulations and standards were formed that determined the way of applying the new construction system. After several decades of use of facilities built in the "IMS" system, certain shortcomings were observed, so this system was completely withdrawn from use.Current laws, regulations and standards require the reconstruction of these facilities. The goal of this research is to see what these shortcomings are, comparing the application of the legal regulations at that time with the current ones, to enable the reconstruction of residential buildings built in the "IMS" system of prefabricated construction and to achieve energy efficiency.

Key words: the "IMS" type of prefabricated construction, residential housing, legal regulations od 1970s, Belgrade, energy renovation.

INTRODUCTION

New technologies in the construction of buildings required new set of legal regulations. During the transition from a traditional construction system to an industrialized one, it was necessary to innovate legal regulations. Considering the fact that industrialized construction was applied in other European countries, there was an opportunity for mutual sharing of experiences when it comes to legal acts. This type of information sharing was not as present in traditional construction since the materialization and methods of construction were very specific to each country.

At the very beginning of the application of industrialized construction, Serbian legal acts were formed as a combination of European and domestic experiential laws, regulations and standards.

The innovative "IMS" system of prefabricated construction was designed for domestic area, which was later widely used in the world. The domestic legal regulation was formed so that, among others, it also corresponds to this system. After several decades of constructing buildings with the "IMS" system, Serbian legal regulations have continued to develop, using combination of European standards and domestic needs. Although the construction of buildings in this way is no longer in use, there is a large number of buildings that require reconstruction and sanitation. Given that the construction life of these buildings is still in progress, it is necessary to reconstruct them according to new legal acts so that they are suitable for further use.

LEGAL REGULATIONS IN THE FIELD OF RESIDENTIAL CONSTRUCTION IN BELGRADE

In Europe, legal regulations dealing with construction have been in use since the second half of the 19th century. In Germany, legal regulations have been developed in the field of fire protection and hygienic conditions for housing. Using some German legal regulations in the area of housing, numerous Serbian laws and standards were formed.

The formation of new regulations for the new system of constructing residential buildings in Belgrade

During the 70s of the last century, a large number of domestic legal acts were written that followed the development of the construction field in Yugoslavia. New materials and construction systems required development of specific legal regulations that include safe and high-quality application. Primarily, these acts cover the regulation of energy consumption for heating and cooling systems of buildings.

When equipping the facility for rational heat consumption, priority was given to traditional methods, and as a replacement, active heating and cooling systems were planned, which was regulated by specific legal regulations. This meant that buildings were designed using all available sources for achieving passive heating or cooling, in terms of the architectural design of the building, the internal organization of the rooms according to their purpose, the application of canopies or curtains, as was done during traditional construction. Only after that has been done, as a secondary measure, mechanically heating and cooling systems were designed, in accordance with the development of technology.

The first legal acts that dealt with the quality of construction and life in constructed living space, appeared at the end of the 1950s. The exact definition of the terms was given a little later, in 1961, through the Decision on amendments and replacaments to the Decision on rational design of residential buildings and apartments.

This legal act defined the rules for urban planning of spatial units in a sustainable and energy-efficient way with precisely defined parameters for cost-effective construction in terms of recommended floor space, population density, and etc.

The rulebook on minimum technical conditions for the construction of apartments written in 1967, in just a few pages, regulated the basic rules for the design of the necessary rooms in the apartment, the size of the apartment, then materialization, construction, types of necessary installations, and provided the minimum conditions for the protection of the building from the effects of moisture, heat, noise, fire and snow.

After this rulebook that defined the general construction rules, regulations that were based on individual topics soon followed, that is, separate regulations were written for sound and thermal protection of buildings and ventilation of residential premises in the building.

In 1970, in the SFRY, separate rules were published for the mentioned areas of building protection:

- Rulebook on technical measures and conditions for sound protection of buildings,
- Rulebook on technical measures and conditions for thermal energy of buildings and
- Rulebook on technical norms and conditions for ventilation in residential buildings.

The thing that enabled the good application of the regulations and decisions made regarding the multi-purpose protection of buildings, was the adoption of domestic regulations, standards and decisions that were a natural consequence of the previous adoption of legal acts in the form of regulations.

In 1980 began the official application of domestic standards in the field of thermal protection, and in 1982, in the field of building acoustics, that is, the sound protection of buildings.

After several years, amendments and additions to these standards were adopted. The standards for thermal protection were amended and supplemented in 1987, and the standards for sound protection of buildings in 1989.

The period of adaptation to European standards in the field of energy efficiency of residential buildings - from the 1990s to today

Since the 1990s, legal acts related to thermal and sound insulation of buildings have been innovated. Soon, the Rulebook on technical norms for the design and execution of finishing works in construction was formed and published, which provided instructions for the proper design and execution of 18 different construction works.

Since 2008, new regulations and standards have been adjusted according to European rules, which were not binding. In order to reverse this situation, efforts were made to syinchronize European and Serbian standards.

The result of this has been noticable since 2011, when the Rulebook on Energy Efficiency was formed, making the application of the standards binding. This regulation provided definitions of comfort and its importance in residential units. The progress in the application of the Rulebook on Energy Efficiency also brought stricter European standards in Serbian constructing field.

With the application of the Rulebook on the conditions, content and manner of issuing certificates on the energy properties of buildings from 2011, the issue of energy efficiency has become unavoidable in the construction of new and reconstruction of existing buildings.

After several amendments and additions to the Rulebook on energy efficiency, with all its accompanying decisions and additional rules in that area, finally in 2012 a separate rulebook for residential buildings was adopted - Rulebook on conditions and norms for the design of residential buildings and apartments.

After the Decision on conditions and technical norms for the design of residential buildings and apartments, from 1983, which only applied to the city of Belgrade, the one from 2012 was the first regulation adopted after so many years, which dealt with the conditions and norms for the design of residential buildings and housing units on the territory of the entire country. It represents an extremely important shift in construction legal acts and the way apartments are designed.

Since 2011, several amendments to the Rulebook on the conditions, content and method of issuing certificates on the energy properties of buildings have been adopted. Its content refers to the permitted values of the facility's energy consumption, which are further divided into specific categories. Recommendations for improving the building's energy efficiency are also included. By this Rulebook, buildings are divided according to purpose. This meant that a classification was made into residential, non-residential and other purpose buildings, and in accordance with this division, separate conditions were defined for improving the energy properties of such buildings.

Each time a amendment of the regulations in the construction field was made, it led to noticeable changes in the energy efficiency of residential buildings.

RESIDENTIAL BUILDINGS BUILT IN "IMS" TYPE OF PREFABRICATED CONSTRUCTION

Considering that the industrialized prefabricated construction system was applied, a large number of residential buildings in Belgrade were built during the 1970s. Two systems of prefabricated construction have been developed: the skeleton and the panel system.

The "IMS" type of prefabricated construction is in the skeletal system category , and is the most used among the constructed residential buildings in Belgrade. It is characterized by the use of prestressed concrete in structural elements. The joints of prefabricated slabs, beams and columns are achieved by prestressing concrete, which is why the entire structural assembly can withstand earthquakes of magnitude 9 on the Richter scale.

Disadvantages of the structural assembly of residential buildings in the "IMS" type of prefabricated construction

Damages to facade elements varies depending on type of finish applied on facade. The higher degree of damage is on buildings made of natural concrete, compared to buildings with certain finishing layers on the facade. In cases where concrete is directly exposed to atmospheric influences, crowning, corrosion, cracks and the appearance of microbiological corrosion (mold, algae, moss, etc.) occur.

Solving problems individually is not an effective solution. It is best to perform a complete analysis of the object, to see all the defects and problems that have happened, then to perform a classification according to the degree of damage and after that, proceed to a systematic solution.

In the Belgrade area, there is a large number of residential buildings built in the 1970s, which have a highly satisfactory construction in terms of structural statics. However, they are full of deficiencies as far as facade elements are concerned. Protection from external influences are very poor.

Some of possible problems that appear on prefabricated buildings are inadequate thermal insulation, damage to joints between elements caused by water penetration into the insulation layer, damage to the concrete protective layer of the reinforcement due to improper placement of bars during the production of elements, mesh cracks due to shrinkage of concrete, poor quality of concrete, etc.

Considering that it is a question of the moment when certain damages will appear on such residential buildings, repairs and maintenance imply continuous costs to which the tenants are exposed. That is why it is necessary to systematically look at the shortcomings, using modern technologies and to review the influence of moisture, heat and other relevant factors. Then gradually solve the problem in its entirety and continue with the analysis even after the repairs, i.e. reconstruction, in order to look at the overall quality of the facade envelope.

Possibilities of energy sanitation of buildings in the "IMS" type of prefabricated construction

Concrete is still among the most used construction materials, thanks to the fact that the cost of production is low, and the possibility of forming a wide variety of shapes. Also, it receives and transmits pressure forces well, and by installing steel reinforcement, it gains the ability to receive and transmit tension forces.

On the other hand, it has some disadvantage such as relatively short lifespan, depending on the surrounding conditions. It is very susceptible to atmospheric influences, therefore it is not the best choice for absolutely every constructing area.

If certain concrete performances were to be improved, the shortcomings of concrete could be overcome. New technologies provide the possibility to consider such an idea. By adding certain components to concrete, the characteristics of concrete can be significantly improved, with the fact that such additions should be adapted to the conditions in which the building is being built. On the other hand, it is necessary to approach the sanitation and protection of concrete on existing buildings in order to improve its performance.

By adding the mentioned components, several variations of concrete can be created, such as high and very high performance concrete, self-compacting concrete, etc.

High and very high performance concrete

High and very high performance concrete is characterized by high impermeability and strength, which makes it more durable than ordinary concrete. In order to obtain these characteristics, a superplasticizer is added to the concrete, which reduces the amount of water. Also, fine reactive silicon powder materials are added to it with a fineness greater than that of the cement, which improves the bond between the cement and the aggregate grains. In this way, the life of concrete is extended from 30-40 years to about 75 years.

For high-performance concrete, it is important to choose quality materials with high precision during production. While for very high-performance concrete, the choice of materials is even stricter, and it is necessary to use only fine aggregate.

Self-compacting concrete

In Japan, self-compacting concrete was invented for the first time, which works by adding a superplasticizer that allows this type of concrete to independently fill molds and formwork with the help of its own weight. During this process the air is released, without the need to apply vibration. Here too, the quality of the material used for mixing concrete is important. The amount of gravel is limited to up to 50%, and the optimal amount of sand is around 40%, which does not affect the overall cost of production, because the higher price for the material pays off later, considering that the cost of installation is reduced.

Sanitation and protection of concrete structures on existing buildings

In search of an efficient and economically accessible solution, it was designed that concrete can be protected by coating with waterproof material or by physical reinforcement. For impregnation, it is most effective to use a waterproof material based on silane or siloxane, which provides water repellency, but also allows a certain amount of vapor permeability so that the structure can "breathe".

When it comes to physical reinforcement, it is possible to apply carbon strips, which have eight times the tensile strength of steel, but the application is possible only when there is a satisfactory degree of adhesion between the concrete and the glue.

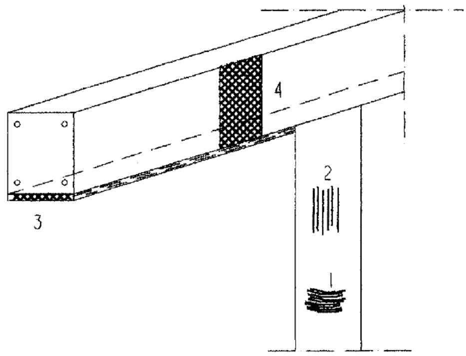


Figure 1. Graphic representation of various possibilities of strengthening concrete structures with high-strength strips: 1-spiral strengthening, 2-longitudinal bending and impact strengthening, 3-transverse bending and deformation strengthening, 4-shear strengthening (Source:Beslać, 2002, p.21)

Sanitation of the existing structure can also be achieved by using micro-reinforced concrete and mortar. Such materials have better physical-mechanical, technological and exploitation characteristics compared to the versions that do not have added fibers. Reinforcement is achieved by adding fibers to the mixture, which can be glass, steel or synthetic. Such fibers act as microreinforcements.

The disadvantage of micro-reinforced material is that it does not help with compressive strength. However, the advantages are numerous. The presence of fibers affects the reduction of water absorption, which means that the impact of cracking of the material due to frost is reduced. It also improves wear resistance, contributes to better binding of old and new concrete, reduces rheological deformations (shrinkage and flow of concrete), increases fire resistance, etc.

CONCLUSION

During the period of designing and constructing buildings using the prefabricated construction system, there were several general legal acts. They dealt with the minimum conditions for the protection of buildings from the effects of moisture, heat, noise, fire and snow.

Since 1970s, regulations on technical measures and conditions for sound and thermal protection and ventilation measures have been applied, which gave more detailed guidelines. But since the design and construction of buildings and the creation of regulations were done in parallel, many buildings were not affected by the newer regulations.

If we considere that since the 1980s the official application of domestic regulations and standards in the field of thermal protection and building acoustics began, and that a large number of buildings had already been built, it is clear that it is necessary to analyze and examine such buildings and then carry out the necessary reconstruction or sanitation of certain elements of the building. This method would bring a better quality of housing than before, with minimal investments.

Innovations are brought on almost a daily basis, when it comes to newly planned buildings as well as reconstruction or sanitation of existing buildings. The development of the information technology (IT) industry makes it possible to find out and understand the shortcomings of existing facilities in an easier way, but also to prevent problems during the construction of new facilities.

REFERENCE

Beslać J. (2002). „Beton u novom stoljeću" Građevinar 54 (1): 15-22,

Đukanović, Lj. 2015. Tipologija i valorizacija građevinske strukture stambenih zgrada Beograda sa stanovišta komfora stanovanja. Belgrade. Faculty of architecture. University of Belgrade.

Jevtić D. & Zakić D. (2006). „Mikroarmirani malteri i betoni – mogućnost poboljšanja fizičko-mehaničkih svojstava" Materijali i konstrukcije 49 (1-2): 35-44,

Laban M. (2006). „Kontrola kvaliteta prefabrikovanih betonskih fasadnih elemenata nakon višegodišnje eksploatacije"Materijali i konstrukcije 49 (1-2): 3-19,

THE IMPACT AND IMPORTANCE OF ECO-CREDITS IN THE WESTWRN BALKANS-SPECIAL REVIW OF NORTH MACEDONIA

Anita Chekredjieva, MSc

Personal banker, insurance and pension fund agent North Macedonia-Ohrid

a.cekredzieva@hotmail.com

Abstract: ECO credits are intended for investments in projects that have the effect of saving energy, increasing energy efficiency and reducing atmospheric pollution with CO2. ECO loans can be used by households and the business sector. Energy efficiency is the performance of the same or greater amount of activities with the same or less amount of consumed energy (thermal, electrical) and with less emission of carbon dioxide into the atmosphere.

Keywords: eco-credits, environmental, green-lending, benefits

Introduction

Environmental protection is a global problem and represents one of the biggest challenges of today.

The goals to which global policies strive are preservation, protection, restoration and improvement of the quality of the environment, protection of human life and health, as well as biological diversity, sustainable ecological development through rational and sustainable use of natural resources, the intelligent energy use and energy efficiency, the green economy through eco-innovations and the generation of business opportunities from environmental challenges.

Climate changes can affect price and financial stability, that is, the goals of central banks. From there, central banks, especially in the most developed economies, have been paying more and more attention to green finance in the past period.

It has been estimated that the economic damage from climate change amounts to about 25% of global GDP. The IMF estimates that natural disasters related to climate change reduce growth by

0.4 percentage points, on average, and even up to 0.7 percentage points in less developed economies. It is estimated that the negative effect in the coming period will be even greater, especially in the less developed economies, emphasizing the need to strengthen the activities of policy makers, but also of the international community.

Green investments in the Western Balkans

The EBRD Green Economy Financing Facility (GEFF) in Western Balkans provides finance for green economy investments in the residential sector as well as to businesses who provide energy efficiency and renewable energy products and services to households. GEFF in the Western Balkans is part of the international EBRD GEFF programme. The partnership with donors is central to promoting the high-performing green technologies and practices. Donors provide critical support to the GEFF projects which mitigate or build resilience to the effects of climate change and other environmental threats.

GEFF in the Western Balkans is implemented under the Regional Energy Efficiency Programme for the Western Balkans (REEP Plus).

EBRD GEFF in the Western Balkans is co-funded by the European Union through the Western Balkans Investment Framework, Austria, Japan, and Austria and Switzerland through the High- Impact Partnership on Climate Action (HIPCA). HIPCA is supported by Austria, Canada, Finland, Korea, the Netherlands, Switzerland, Spain, TaiwanICDF and the United Kingdom.

GEFF benefits:

Green economy investments are beneficial to the economy and the environment.

For households:

- reduced energy consumption through the installation of high-performing, energy-efficient technologies
- increased family budget through lower related costs
- better reliability of equipment
- more comfortable homes
- increased value of the real estate

For businesses:

- higher turnover
- larger sales/production of energy efficient and renewable energy technologies
- better availability of green technologies and solutions for the residential sector

For the environment

- conservation of precious natural resources
- reduction in pollution
- healthier surroundings

The EBRD has channelled over €6.6 billion to green projects via 206 financial institutions across 29 countries. This has enabled more than 236,000 green investments that collectively, together with funding from our co-financing partners, avoid almost 11 million tonnes of CO2 emissions per year.

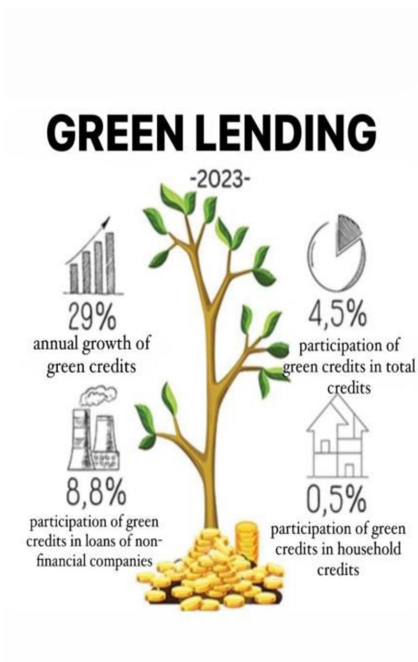
In less than seven years, more than 18,000 households in the Western Balkans (WB) have invested over €100 million in energy-saving technologies such as insulation, heat pumps, new windows or solar panels, thanks to the regional Western Balkans Green Economy Financing Facility (GEFF) programme, launched in the region in 2017.

Homeowners will be able to apply for loans for investments in insulation, windows, heat pumps, solar panels and other improvements, with a view to increasing the energy efficiency of their homes and reducing energy intensity. After successful implementation borrowers will be eligible for a grant of up to 20 per cent of the loan amount, funded by the government of Switzerland through High-Impact Partnership on Climate Action (HIPCA) and the government of Japan. GEFF programme is also co-financed by the EU, the Austrian Federal Ministry of Finance, and bilateral donors to the Western Balkans Investment Framework (WBIF).

North Macedonia-green finances

The Central Bank of Macedonia since March 2021, we have become part of the Green Finance Network in which central banks and supervisory bodies are members, thus we are already part of a platform through which we can follow them, but also actively engage in all new international initiatives in this field.

The National Bank has published the data on „green loans" for the fourth quarter of 2023, where growth is observed at the quarterly level of 5%, while on an annual basis of 29.1%. Compared to the end of 2019, when the data began to be collected, „green credits" are increasing by 2.8 times. We are talking about loans to people for projects that refer to sustainable, environmental goals, or goals that contribute to green technology in society, which is the development of new eco technology. According to the data of the National Bank, at the end of 2023, bank claims based on green credits amount to 19.9 billion dollars or about 325 million euros. For comparison, at the end of 2019 they amounted to 7.17 billion dollars. The growth of green lending is mostly due to loans from companies, while most green loans give large sizes. The share of greens in total loans is also growing, although it is still at a low level. From the end of 2019, concluded with 2023, the share of green in total credits has increased from 2.2% to 4.5%.



Source: National Bank of Macedonia (2024)

Зелени кредити и позајмувања на банките	**2019**	**2020**	**2021**	**2022**	**2023**
11. Зелени кредити на банките, по типови клиенти (во 000 MKD)	**7,176,453**	**8,865,235**	**10,548,784**	**15,389,336**	**19,863,692**
11.1 Домаќинства	1,160,476	**1,431,555**	**1,315,396**	**1,308,573**	**1,224,249**
11.2 Нефинансиски друштва	**6,015,977**	**7,433,680**	**9,233,388**	**14,080,763**	**18,639,443**
12. Зелени кредити на големите банки, по типови клиенти (во 000 MKD)	**3,204,864**	**3,792,980**	**5,234,006**	**9,725,750**	**13,254,288**
12.1 Домаќинства	**961,357**	**1,039,370**	**867,313**	**739,120**	**561,846**
12.2 Нефинансиски друштва	**2,243,507**	**2,753,610**	**4,366,693**	**8,986,630**	**12,692,442**
13. Зелени кредити на средните банки, по типови клиенти (во 000 MKD)	**3,872,702**	**4,971,305**	**5,229,129**	**5,581,871**	**6,387,155**
13.1 Домаќинства	**189,628**	**386,443**	**444,055**	**566,964**	**660,417**
13.2 Нефинансиски друштва	**3,683,074**	**4,584,863**	**4,785,074**	**5,014,907**	**5,726,738**
14. Зелени кредити на малите банки, по типови клиенти (во 000 MKD)	**98,887**	**100,950**	**85,649**	**81,716**	**222,249**
14.1 Домаќинства	**9,491**	**5,742**	**4,028**	**2,489**	**1,986**
14.2 Нефинансиски друштва	**89,396**	**95,208**	**81,621**	**79,227**	**220,263**

15. Учество на зелените кредити во вкупните кредити на банките (во проценти)	**2.2**	**2.5**	**2.7**	**3.6**	**4.5**

Source: https://www.nbrm.mk/ns-newsarticle-pregled-na-zeleni-pokazateli.nspx

The National Bank, recognizing the risks of climate change in the long term, took a proactive stance and set as one of its strategic goals the increased awareness of climate change and the contribution to a green sustainable economy. Through a series of activities, the central bank contributes to the encouragement of green financing, including monetary measures such as the decision to change the mandatory reserve instrument, which encourages lending to projects related to the domestic production of electricity from renewable sources. With this decision, the basis for setting aside a mandatory reserve in denars by banks is reduced by the amount of newly approved loans for financing projects for domestic production of electricity from renewable sources.

The National Bank prepared a Medium-term plan of activities in the field of managing risks related to climate change for the period 2023 - 2025, and recently, in order to improve the availability of data on climate change, it also published an overview of green indicators that will help in analyzes for further policy making .

Conclusion

The new ECO-loans offer will stimulate the improvement of energy efficiency, by taking advantage of the benefits provided by this credit line from the EBRD, with the ultimate goal of protecting the environment and encouraging investments in energy-efficient projects and products. The role of banks is not to be just a simple promoter of green credits they should also have social responsibility as the main supporters of the economy and be careful what type of businesses and investments they finance. I strongly believe that with the concept of green lending, we can have a positive and significant impact on the environment.

Literature

Narodna banka na Republika Severna Makedonija (2024), zeleno finansiranje, Skopje Green Economy Financing Facility (GEFF) for the Western Balkans https://kapital.mk/

https://ebrdgeff.com/macedonia/mk/ https://www.ebrd.com/home https://makfax.com.mk/

DESIGN OF SUSTAINABLE VISUAL EXPERIENCE: CASE STUDY OF *KATSURA RIKYU* GARDEN

Moto: 'The being what it is of anything is what is knowable and not the thing itself.'

Končarević Bojan

Architect, Ph.D. Assistant Professor: Faculty of Architecture, Union University

email: koncarevic.bojan@unionnikolatesla.edu.rs,
koncarevic.bojan@gmail.com

Abstract: Design method applied in artificial *Katsura Rikyu* garden promotes simultaneous visual and stepping experiences that develop in stepping stones' coordinates. This design method translates "is being" of human stepping presence into visual "being" of the garden four physical forms: stepping stones, landscape, greenery and tea ceremony pavilions.

Thus, research aim questions usual design methods rooted in architect vanities and material overuse in object oriented design ['*das Stoffliche'*]. O contrary, in case of *Katsura*, design method is discussed from bellow with bottom-up pragmatic relation with context of nature.

Thus, research analysis represents staged visual experience that extends on aesthetic agenda of New Bauhaus, whereas design is more about creating experience rather than object.

Key words: Experience, Optimal, Visual, Stepping, Relationship;

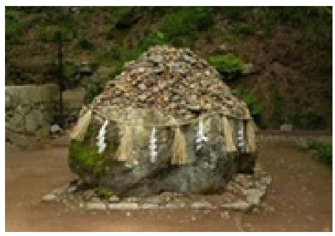
INTRODUCTION: FROM *NIWA* TO ARTIFICAL GARDEN

Katsura Rikyu represents 17th century garden consisting of artificially assembled artificial and natural physical forms. Natural forms are prolific greeneries, *s*ō group of naturally found stepping stones and landscapes. Artificial forms are *shin* group of artificially shaped stones, *gyō* group of semiformal stone units and tea ceremony pavilions positioned at ends of stepping paths. Hence, one has to grasp in basic notion of 'garden' in terms of Japanese religious and cultural discourses to understand this design intention.

It is presumed in Japanese culture that intact 'natural garden', namely *niwa*, differentiates into artificial state of being garden solely with human presence and influence. Differently *niwa* solely hosts kami, sacred spirits that singularly inhabit each natural physical form.

Masao Hayakawa claims that word *niwa* firstly appears in *Nihon Shoki* 'where it is used to refer to a place purified for the purpose of summoning deities, a point of contact and communication with the spiritual world' [Mitchell Bring and Wayembergh J., 1981, p.145]

Presently one can notice *yorishiro* sample of enclosed *niwa* within Shinto sacred sites [Fig.1]. They cannot be entered due to practice of enclosing these voids with *shimenawa* twisted rope.

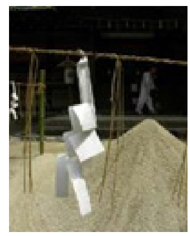


Figure 1: Yorishiro enclosed with shimenawa; Figure 2, Figure 3: Stone and wood inhabited with sacred spirits marked with rope and paper; Figure 4: Shimenawa white paper mark of other world;

RESEARCH HYPOTHESIS

Introduction to research objective

While creating garden one has to correlate with these sacred spirits [Fig.2, Fig.3] with *ji chin sai* prayers. This manner 'would seem to have been an attempt at mediation between cultural world of humans and supernatural world.' [Ibid, pp.92] [Fig.4]. 'In eleventh century *Sakutetiki* document [Manual of Garden Construction] about gardening principles in Japan was written [Ibid, p.93] that it is expected from designer 'to design each part of the garden tastefully, recalling one's memories of how nature presented itself for each feature' [Ibid, p.1]. Thus, design objective becomes to use natural forms without changing their inner scope.

From visual experience to high cognitive awareness

In Katsura Rikyu garden visual juxtaposition between garden natural forms is perceived from stepping stone path. 'Known as *roji*, this kind of *to-bi-shi* stone stepping path [Fig.6] is designed to help participants in tea ceremonies to prepare themselves psychologically as they approach tea house' [Teiji, 1973, p.69]. It resembles journey 'from mundane [Fig.5] to ritual' according to the anthropologist Dorinne Kondo, leading to Zen state of 'emptiness' [Kondo, 2010, pp.291-294]. This state should further result in '*zanshin*', heightened state of cognitive awareness before one engages tea ceremony in pavilions at stepping end of stone path [Fig.7].

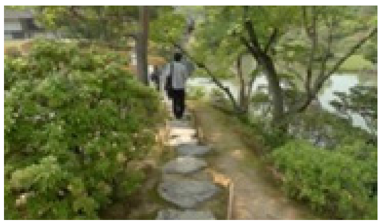
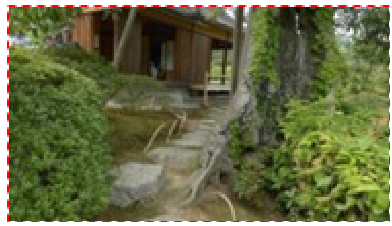




Figure 5: Mundane environment of Katsura garden; Figure 6: Garden stone stepping path leading to tea ceremony pavilion; Figure 7: Visual experience of tea ceremony pavilion at end of stepping path;

La question problematique: **Is there an object of garden design intention?**

Stone path pattern orchestrates development of field of view content of garden physical forms in relation how tea ceremony pavilion should appear in those stepping sequences [Fig.7]. Thus, garden design intention was not to design pavilion as an object, but rather its visual experience that further initiates visitor *'zanshin'* state of cognitive awareness.

That makes garden forms visual singularities to be in state of "fiction and a sickness" [Kuma, 2000, p.58] since they are perceptively dependent on visually succinct otherness [Fig.8].

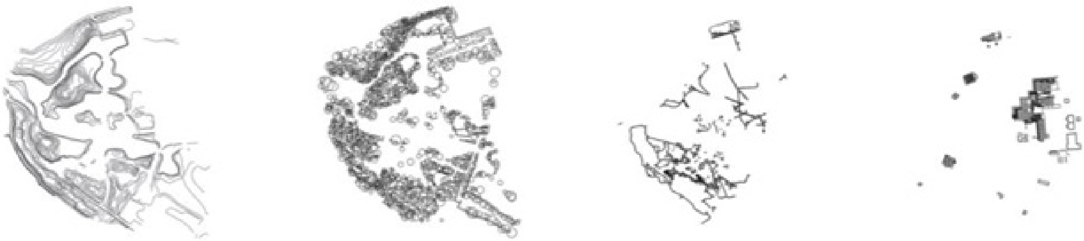


Figure 8: Layers of Katsura garden physical forms as perceptively dependent succinct otherness: landscape isolines, greenery trees disposition, stepping stone sub paths, pavilion units;

METHODS OF ANALYSIS

Perception of *Katsura Rikyu* artificial wilderness

'By stripping away matter and enabling it to articulate time, we can excite flow of time. The result will be emergence of something that is not so much architecture as landscape.' [Kuma, 2008, p.68]

Katsura garden environment 'is not a wilderness, yet not entirely artificial either' [Alexander, 1977, p.802]. Its wilderness is kept since its forms [greeneries, landscape, stepping stones] are integrated in their complete natural appearance. Their artificiality develops in visual content they mutually evoke. That becomes their artificial 'coming into the being' [Alexander, 1977. 802]. Hence, Heidegger stated: an object 'in its standing there, first it gives to things their look and to men outlook on themselves' [Heidegger, 1937, p.42-43].

'To give things their look' is meant for certain form to exist solely if it relates to other forms. This relation is finally perceived by men whom are given 'outlook on themselves' since one does not exist without perception of an environment. Thence, one can involve old-Greek word for notion of 'being': *aletheia* [forgottenness]. It defines an object to become 'forgotten' in its tangible physical form, but only remembered in intangible human perception of that form relationship with its belonging environment.

METHODS OF ANALYSIS

Selection of case study sub path

Tea ceremony pavilions are usual physical and visual endings of many sub paths that form complete garden circular path. Selected case study sub path consists of ten stepping stones [Fig.9] with both sides' landscapes and greeneries as dominant content of visual attention [Fig.10]. At the end of it protrudes tea ceremony waiting pavilion that characteristically visually 'appears' [Fig.11] while one advances along case study *tobi ishi* stone pattern.

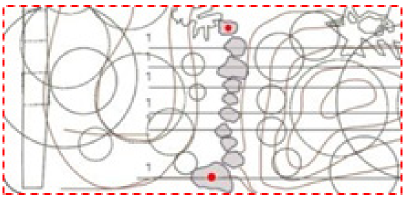
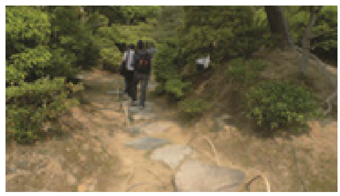
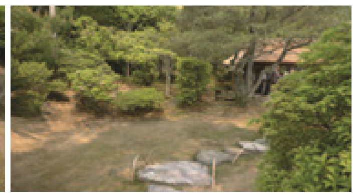




Figure 9: Sub path plan with first and tenth red circled stepping stones; Figure 10: View toward garden from first stepping stone; Figure 11: View from tenth stepping stone to appearing pavilion;

Presentation of four methods of analysis

Methods of analysis are applied in garden plan drawings and field of view sequences *in situ* acquired by author in stepping stone coordinates. Sub path drawings are retraced from original garden drawings and updated with site collected measures of physical forms. These novel drawings and site collected visual sequences are thoroughly applied in analysis.

Four methods of analysis are:

1. First method is analysis in plan drawings of *Katsura* garden sub path with selected forms;
2. Second method is analysis in section drawings of the garden sub path with selected forms;
3. Third method is applied on *tobi ishi* stepping stone *shin, gyo* or *so* group definition and analysis of attributions: stepping stone distances, their directionality and surfaces;
4. Fourth method is based on *in situ* collected field of view sequences material:

Greeneries are extracted in each sequence. They are further overlapped to decipher their progression with single diagram in order to understand their influence on visual experience.

RESULTS OF ANALYSIS

Analysis in plan drawings with comments on resulting graphs

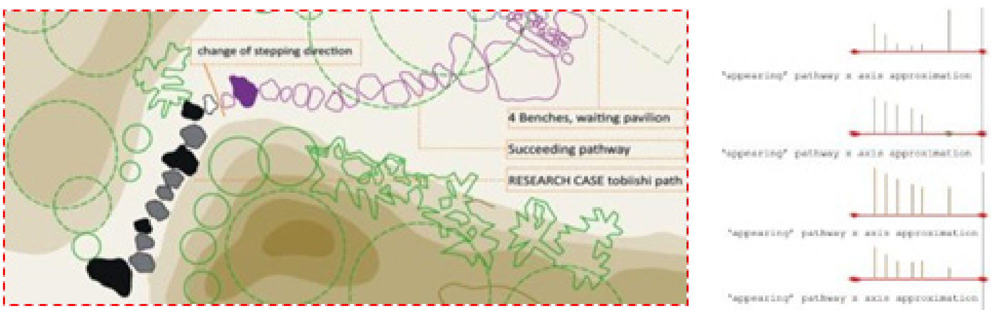


Figure 12: Tobi ishi plan with ten stepping stones, landscape, greeneries and pavilion;

Figure 13: From above graphs: [1st, 2nd] right and left side greenery distance from stepping points; [3rd,4th] right and left side distance from edge isoline to stepping points line;

Case study path plan [Fig.12] is used to measure progression of left and right distances of greeneries and landscape isolines to stepping coordinates. Right side greenery decreases and then gradually increases in second step in values of distances from stepping line [Fig.13: 1st graph]. Nonetheless, left side greenery constantly increases in steady values of distances [Fig.13: 2nd graph]. Concerning distances of right and left hillside to stepping points they gradually increase [Fig.13: 3rd graph, Fig.13: 4th graph] in rather higher values.

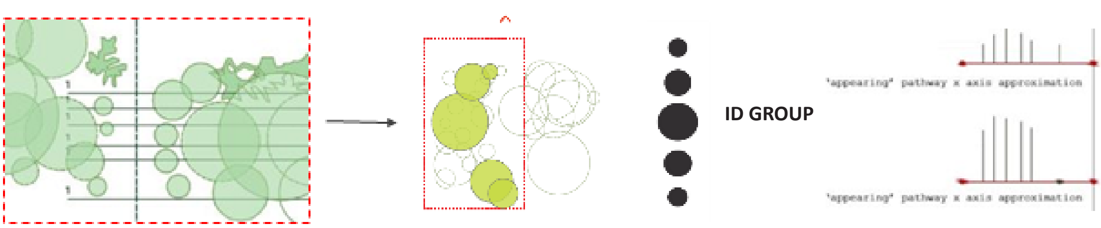
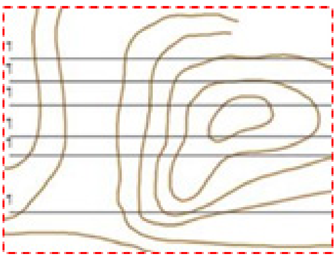
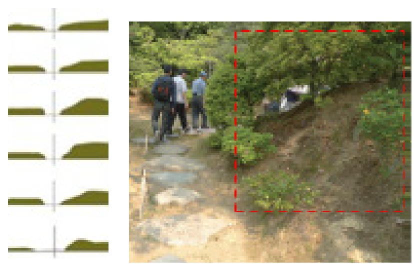


Figure 14: Path greenery plan; Figure 15: Diagram of type of greenery sizes progression; Figure 16: From above graphs: [1st and 2nd] greenery surface amount progression along stepping stone path;

Left and right side greeneries are extracted in plan and observed in their surface amounts [Fig.14]. Both sides belong to ID [increase-decrease] development [Fig.15] where they firstly gradually increase and in midpoint decrease in their amounts [Fig.16: 1st and 2nd graph].

Analysis in section drawings with comments on resulting graphs





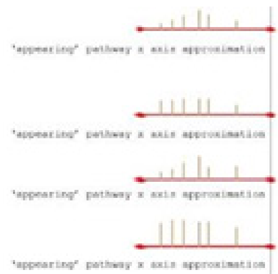


Figure 17: Sub path isolines plan; Figure 18: Landscape sections in stepping coordinates and photo sample with observed landscape encirclement; Figure 19: From above graphs: [1st, 2nd] right/left side development of landscape heights and [3rd, 4th] development of landscape slope angles;

Plan of landscape isolines and section [Fig.17, 18] are analyzed in their heights and angles against ground development. Right side landscape heights increase and then decrease from middle stepping point. Left side angles acquire higher value in second stepping coordinate and then stay rather equal. Both side landscape angles against ground level develop in increasing-decreasing tendency that again changes in middle stepping point.

Analysis in stepping stones attributions with comments on resulting graphs

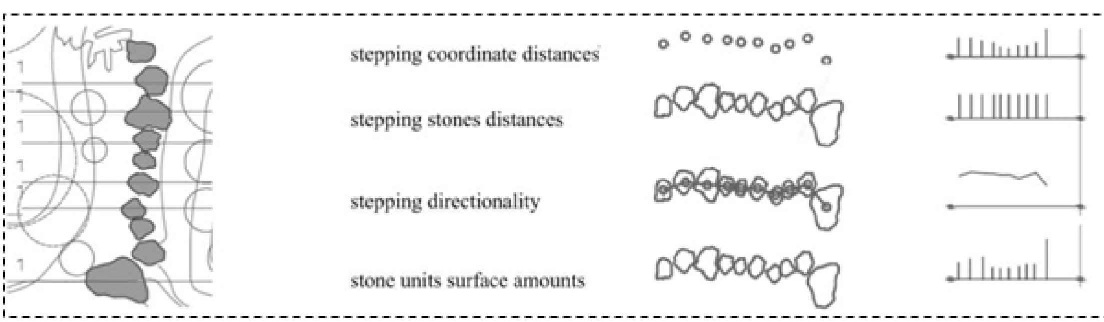


Figure 20: Tobi ishi stones plan; Figure 21: Tobi ishi four attributes; Figure 22: From

above graphs: [1st] Development of stepping points distances; [2nd] Development of stones distances; [3rd] Development of stones' directions; [4th] Development of stepping stones single surface amounts;

First graph presents development of stepping stones stepping coordinates mutual distances. They belong to DI group [decrease-increase] change in value that repeatedly occurs in middle point. Second graph presents rather equal values of all distances between stone units.

Stepping direction develops linearly. Succinctly it acquires left turn in seventh stepping point with first view to pavilion and then it turns to right to final stepping coordinate. [Fig.22]

Fourth graph presents development of stepping stone surface amounts. Highest value of first unit extensively decreases and acquires equal amount until seventh unit. In eighth unit it becomes again extensively higher and then again decreases in last two stepping stone units.

Analysis of visual progression of greeneries with comments on resulting diagrams

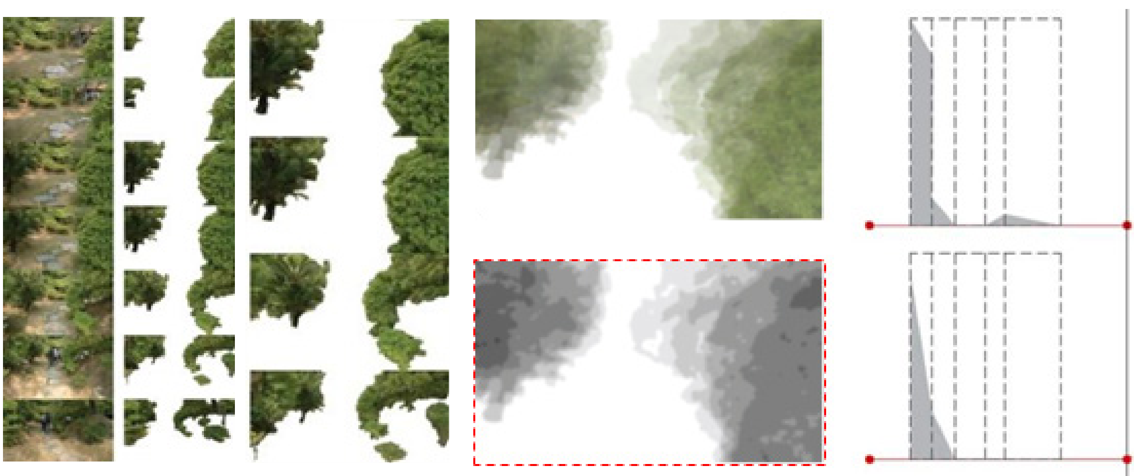


Figure 23: Extraction of greenery forms in field of view sequence; Figure 24: Overlapping diagram of extracted greeneries; Figure 25: From above graphs: [1st] Development of visibility of stepping stone pattern along path; [2nt] Development of visibility of stepping coordinates and pavilion;

Greeneries are singularly extracted in seven field of view sequences [Fig.23]. They are succinctly overlapped in single sequence that is transformed into black and white diagram. [Fig.24]. Progression of darker to lighter grey areas determines visual experience in terms of covering in relation to pavilion and stepping pattern.

That being so gray array diagram unarguably recovers how visibility of these two entities gradually reveals. Since darker grey is at outer outer edges and *vice versa,* visual experience of pavilion and stone pattern appears in path ending.

Pavilion visibility appears in seventh stepping stone and gradually develops until end [Fig.25: first graph], whereas visibility of stone pattern toward pavilion almost completely presents in second stepping half [Fig.25: second graph].

CONCLUSION

Discussion on research results versus research objective

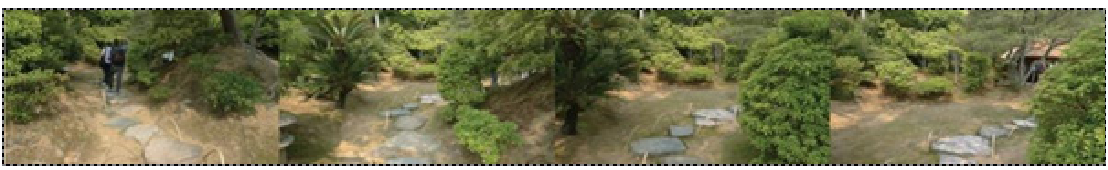


Figure 26: Mutually correlated development of garden forms in tobi ishi visual experiences;

Development of attributes of garden forms mutually change either in equal stepping stone coordinates, equal development of values or in mutually dependent manner [Fig.26].

Progression of left distances of greeneries to stepping coordinates decrease and increase and directs field of view orientation to right side in terms of content dominance. Right distances constantly increase and gradually open view to pavilion in eighth stepping stone coordinate. Distances of both landscape bottom edges to stepping line constantly increase and extensively open the view in eighth stepping stone. Hence, most importantly they retract at right side and open first glimpses to pavilion. Proportional tendency occurs in greenery surface amount development that increases and then decreases. It obviously follows hillside retraction with its start in middle stepping point and culmination in eighth coordinate.

Landscape heights and angles of hillsides against ground level develop both in increasing-decreasing tendency. It decreases most extensively at right side around sixth and seventh stepping stone. These values decline in equal positions as in previous attributes. They result in appearance of pavilion in field of view content repeatedly in eighth stepping stone.

Importantly to put forward is that all previously mentioned increasing developments along whole stepping path and decreasing tendencies from middle point visually reveal right side stepping stone pattern as well. It makes visitor visually aware about its stepping advancement and direction. Even though *tobi ishi* stone mutual distances stagnate, their stepping coordinates and stone surfaces firstly decrease and then increase in middle point. These tendencies make visitor to commit calm and short steps from seventh stone with continuous visual experience. Same tendency is supported by linear development of stepping direction that in seventh stone changes and put forward novel visual experience. Fourth method diagrams reveal visual experience of pavilion from middle coordinate to culmination in seventh and eighth coordinate. Superposition of garden forms therefore results in proportional changes in equal stepping coordinates with higher awareness before entering tea pavilion.

Conclusion on *Katsura* design intention

In order to become closer to Circular economy and New Bauhaus policies in terms of optimal, natural and recyclable usage of material to build certain space, one has to become closer and possibly materialize intangible principle of design. In *Katsura Rikyu* case study this principle is how to build temporal space that becomes according to rhythm of human stepping movement and continuous visual experience. Hence stepping stones determine measurable rhythm that makes space being time, 'which is to say an aspect of a movement or of a becoming' [Bergson, 2004, p.89]. It makes walking human to acquire 'the physical, the logical, and the perceptible [and thus the apprehensible]' [Kwinter, 2005, p.36] in time aspect of design intention. 'Insofar as artistic expression gives clear shape to our feelings, it expresses a depth of self not accessible to the activity of intellect. Truth values arise in judgment, and aesthetic values arise in imagination. Of the two, imagination is the deeper level and therefore the more fundamental' [Nishida, 1997, p.42].

Acknowledgments

Hereby I deeply confine my gratitude and friendship admittance to Ryan Cameron Moroney who have made me company on travels to Kyoto and helped me thoroughly during numerous *Katsura Rikyu* garden visits, material collecting and scientific discussions.

LITERATURE

Carter E Robert, Kitaro Nishida, (1997) The Nothingness Beyond God, An Introduction to the Philosophy of Kitaro Nishida, Second Edition, St. Paul: Paragon House,;

Christopher Alexander, (1967) Notes on the synthesis of form, Cambridge, Massachusetts: Harvard University Press,;

Heidegger Martin, (1937), The Origin of the Work of Art, Zurich,;

Henry Bergson, (2004), Matter and Memory, New York: Dover Publications,;

Mitchell Bring and Wayembergh J., 1981, Japanese Gardens: Design and Meaning, New York, McGraw-Hill,;

Sanford Kwinter, (2005), African genesis presentation, JSTOR: MIT Press,;

Teiji Itoh, (1973), Space & Illusion In The Japanese Garden, Tokyo, Hardcover: Kodansha,;

APPLICATION OF UNMANNED AIRCRAFT SYSTEMS IN PREVENTING ILLEGAL CONSTRUCTION: CASE STUDY OF THE CITY OF BELGRADE

Damir Ilić[1], Tatjana Ilić-Kosanović[2], Isidora Milošević[3]

[1]School of Engineering Management

[2]University „Union - Nikola Tesla"

[3]Technical Faculty in Bor, University of Belgrade
damir.ilic@fim.rs

Abstract: The application of unmanned aircraft systems (UAS) in various industries is reaching unprecedented proportions. This research deals with the possible application of the UAS with the aim of reducing the harmful impact on society as a whole that illegal construction brings with it in the city of Belgrade. In the research, the factors influencing the extent of their potential application were presented through the SWOT method, and through the TOWS analysis, strategies were defined that lead to their successful implementation in activities aimed at suppressing illegal construction. The research came to the conclusion that the UAS can be successfully used to suppress illegal construction as an effective tool for improving urban planning and planned controlled development of Belgrade.

Keywords: UAS, illegal construction, urban planning, SWOT, TOWS.

INTRODUCTION

Different dimensions of application of unmanned aircraft systems gain their dynamics. In addition to the military application, which with the bloody war in Ukraine reached almost unimagined proportions, somewhat shyly in the shadow of bombastic news and headlines, the field of their civilian application is expanding more and more every day. The field of application of UAS for civil use includes: Urban planning, Construction and infrastructure inspection, Utility inspecting, Agriculture and remote sensing, Disaster management, Geographic mapping, Real-time monitoring, Mining, Waste management, Law enforcement, Commercial photography, Wildlife conservation, Weather forecasting, etc. (Sivakumar & Malleswari, 2021). The fusion of the first three unknown application dimensions will be considered in this research.

At the same time as progress, there is a boom in cities whose borders are in continuous expansion. In Serbia, the so-called internal migration is pronounced, which is characterized by an increasing influx of people from villages to cities. According to the 2011 census, 45% of the population has taken part in migration movements and the capital of the Republic of Serbia, Belgrade, is emerging as a dominant destination for migrants from other areas within the Republic of Serbia. This was certainly influenced by the fact that the city of Belgrade represents the most economically developed part of the Republic of Serbia (Kokotović Kanazir, Filipović & Magdalenić, 2016).

MATERIALS AND METHODS

UAS construction inspection and city planning

Over the years of both military and civilian use, UAS technology has radically advanced and become incomparably more sophisticated, offering a wide range of applications in various fields. it is quite certain that future drones will be equipped with advanced automation and AI capabilities in order to carry out missions autonomously or with minimal human intervention. Unmanned aerial vehicles incorporated with artificial intelligence have the ability to move autonomously in a complex environment, identify and assess potential hazards and perform complex data analysis. Aircraft automation simplifies data collection, data processing and reporting, enabling civil engineers to make decisions more effectively. Advances in batteries and drone design result in greater range, i.e. drones gain the ability to cover large areas in one flight (Choi et al., 2023). When it comes to the Architecture, Engineering and Construction (AEC) industry, UAS, depending on the type of aircraft, are most often used for the following Fixed-Wing missions and hybrid vertical takeoff and landing (VTOL) (delivery), fixed wing (mapping and inspection of: roads, dam, landfill, railroads, irrigation systems landfill, pipeline, gas pipelines and transmission lines), Rotorcraft (LiDAR scanning, making photos and videos, inspection bridges, tunnels, roads, dams, railways, landfills, channel systems, irrigation systems, pipeline, and power line) (Nwaogu et al., 2023). UAS can be used extremely successfully throughout the entire life cycle of a construction project – starting from the early stages of pre-planning and design, moving through the construction phase, to the late stages of asset management, operations and management. During this third phase, which is the most interesting for research purposes, UAS can be used for different mapping, marketing, monitoring, and inspecting purposes (Hatoum & Nassereddine, 2022). During the complex process of urban development, from time to time cities are faced with the expansion of illegal construction. Traditional insight into the state of illegal objects requires a lot of human and material resources and often leads to work blockages and system overload. With the help of UAS and AI, high-resolution images of the observed area where the occurrence of illegal construction is suspected can be obtained in time and the process of automatic identification of illegal objects is realized. In this way, reliable information such as the location and shape of illegal objects can be obtained quickly and efficiently, which provides a basis for timely decision-making by the competent services (Autelpilot, 2023). The facade of the building represents its identity, one can say its architectural face, and it provides the opportunity to class building in terms of applied style. Let's take into account the possibility that part of the facade of an old building in the old part of the city is glazed or remodeled in some avant-garde way or in a way that does not suit the era when it was created. With the use of UAS and their sensors, we would be able to quickly detect such a change as illegal construction or an attempt to deface the city (Kaunas University of Technology, 2023).

The problem of illegal construction

Illegal construction occurs during the process of urbanization and rapid expansion of cities, such as construction which is carried out without precedent obtained building permit and authorized drawings, on a site that is not intended for construction and for the purpose of construction in existing plans of all levels. It is implemented in such a way that the person behind the construction of the illegal building can build quickly, without any previous time frames and expenses regarding the location of the building (Zegarac, 1999). Illegal construction is a phenomenon that by its nature is multidimensional and consists of legal, urban and social dimensions. The legal dimension is embodied in the violation of the law by the person who builds without a legal permit. The urban dimension refers to the fact that illegal construction is a major obstacle to the implementation of urban plans and greatly damages the infrastructure, efficiency and aesthetics of the city. The sociological dimension of illegal construction is the self-initiative of citizens with an unresolved housing issue who build to meet their housing needs due to the lack of any other legal approach to their problem (Grbović, 2006). Rapid, devoid of any planning, unregulated and completely uncontrolled expansion of urban areas without adequate supporting infrastructure has become a phenomenon that is present in all parts of the Republic of Serbia (Miladinović Bogavac & Lazić, 2022). Belgrade, the capital of the Republic of Serbia, is not exempt from this phenomenon. The problem of illegal construction is not new and it dates back to the era of socialism. The socialist leadership ignored the problem due to the inability to subsidize the solution of the housing issue for a large number of citizens who left the countryside and settled in the cities. At that time, some settlers from rural areas built summer cottages in the suburbs of Belgrade. There is another form of illegal construction that is defined as usurpation. This type of illegal construction does not necessarily occur in suburban settlements, but on land in public ownership and on public areas where commercial business facilities are built (this phenomenon was particularly pronounced in the 90s of the last century) (Grbović, 2006). Illegal construction has been present for many years in the history of Belgrade, as part of the urbanization process. The dimensions of this phenomenon were within somewhat acceptable limits until the early nineties, taking into account local circumstances, mentality and habits (Zegarac, 1999). It is precisely at the mentioned time that a new phenomenon appears where unfair construction is no longer a characteristic of the poorer sections of the population. At the end of the 90s of the last century, we are faced with the problem of the political elite who used their power and reputation to build and legalize their illegal facilities (Grbović, 2006). It should be pointed out that in Belgrade, as in the rest of Serbia, there are a large number of Roma settlements. What is characteristic is that most Roma settlements in Serbia are exceptional poor. In some settlements, the essential problem is the lack of infrastructure. A very poor standard is characteristic for a large number of settlements housing. Certain settlements are under constant threat of demolition because they are illegally built on municipal land. Mapping and enumeration of informal Roma settlements are therefore important in order to realize the different upgrading projects (Vuksanović-Macura, 2012). Urban renewal of the city is often driven by economic interests, while to a large extent the meaning and sentiment typical of a particular location is ignored. This encouraged a whole series of civil initiatives in Belgrade to to prevent further collapse of the built heritage and to clearly indicate the need for a stronger one inclusion of citizens in the processes of city development (Vukumirović & Nikolić, 2023).

SWOT and TOWS analysis

SWOT is an acronym for Strengths, Weaknesses, Opportunities and Threats. Strengths (S) and Weaknesses (W) represent internal factors, while Opportunities (O) and Threats (T) represent so-called external factors. Strengths are factors of the internal environment that give the project an advantage over some other projects. Weaknesses are characteristics of the internal environment that put the project at a disadvantage compared to others. Opportunities are elements of the external environment that a project could use to its advantage. Threats are elements of the external environment that can cause problems for the project (Huang & Wei, 2024). SWOT analysis is a useful tool used to determine the company's strategic positions, as well as to gain insight into the actual situation when deciding which strategy is more favorable to a company (Arsić et al., 2018). The TOWS matrix is a very useful analytical tool that combines each SWOT component with another to analyze four alternative strategies: SO, WO, ST and WT (Huang & Wei, 2024). By applying the SO strategy, it is possible to find ways to simultaneously maximize our strengths and opportunities; WO strategies, or so-called, „adaptive" strategies use existing opportunities with the aim of reducing weaknesses; ST strategies seek to use strengths in dealing with threats; WT strategies, or so-called „survival" strategies, aim to reduce weaknesses in order to reduce or neutralize threats (Baghernejad,, et al., 2023).

RESULTS

A careful analysis of the factors of the external and internal environment resulted in the SWOT matrix shown in Figure 1, which shows the strengths, weaknesses, opportunities and threats of application of unmanned aircraft in preventing illegal construction: case study of the city of Belgrade.

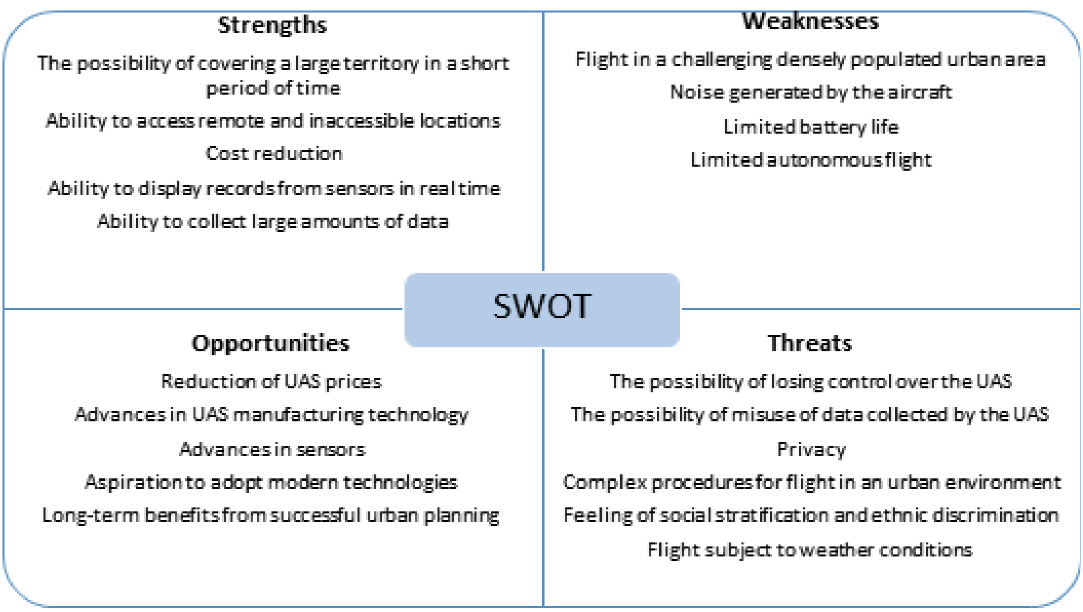


Figure 1. SWOT analysis of application of unmanned aircraft in preventing illegal construction: case study of the city of Belgrade

The factors identified by the SWOT analysis were then used to create a TOWS matrix through which four alternative strategies SO1, WO1, ST1 and WT1 were generated. which are shown in Figure 2 TOWS analysis of application of unmanned aircraft in preventing illegal construction: case study of the city of Belgrade

<table>
<tr><td colspan="2" rowspan="2">TOWS</td><td>Strengths</td><td>Weaknesses</td></tr>
<tr><td>S_1 The possibility of covering a large territory in a short period of time
S_2 Ability to access remote and inaccessible locations
S_3 Cost reduction
S_4 Ability to display records from sensors in real time
S_5 Ability to collect large amounts of data</td><td>W_1 Flight in a challenging densely populated urban areaW_2 Noise generated by the aircraftW_3 Limited battery life
W_4 Limited autonomous flight</td></tr>
<tr><td rowspan="2">Opportunities</td><td rowspan="2">O_1 Reduction of UAS prices
O_2 Advances in UAS manufacturing technology
O_3 Advances in sensors
O_4 Aspiration to adopt modern technologies
O5 Long-term benefits from successful urban planning</td><td>SO Strategy</td><td>WO Strategy</td></tr>
<tr><td>SO_1 Full integration of UAS technology into city management with strict compliance with laws and regulations</td><td>WO_1 Further development and implementation of safety systems in aircraft that perform missions in urban areas</td></tr>
<tr><td rowspan="2">Threats</td><td rowspan="2">T_1 The possibility of losing control over the UAS
T_2 The possibility of misuse of data collected by the UAS
T_3 Privacy
T_4 Complex procedures for flight in an urban environment
T_5 Feeling of social stratification and ethnic discrimination
T_6 Flight subject to weather conditions</td><td>ST Strategy</td><td>WT Strategy</td></tr>
<tr><td>ST_1 Better information of the population regarding the benefits of applying UAS technology in parallel with spreading awareness about the importance of urban planning</td><td>WT_1 Modern laws and regulations draconically punish all forms of illegal construction</td></tr>
</table>

Figure 2. TOWS analysis of application of unmanned aircraft in preventing illegal construction: case study of the city of Belgrade

DISCUSSION

Four strategies were created through the TOWS analysis: SO_1 Full integration of UAS technology into city management with strict compliance with laws and regulations, WO_1 Further development and implementation of safety systems in aircraft that perform missions in urban areas, ST_1 Better information of the population regarding the benefits of applying UAS technology in parallel with spreading awareness about the importance of urban planning and WT1 Modern laws and regulations draconically punish all forms of illegal construction . The first strategy arrived at through the analysis of SO1 Full integration of UAS technology into city management with strict compliance with laws and regulations implies greater integration of UAS technology into city functioning. Strict regulations, sometimes with good intentions, can have a negative effect on the spread of a certain technology that brings with it a whole series of benefits with relatively small risks for the population. UAS technology can contribute to the better functioning of Belgrade and provides the opportunity for the city administration to make much better decisions, especially those related to urban planning. The current situation, where there is a certain degree of urban planning rampage and where the building is first built and then entered into the legalization process, is not good for anyone. The essence is to provide management authorities with timely information so that they can react in a timely manner and prevent illegal construction. The second strategy WO1 Further development and implementation of safety systems in aircraft that perform missions in urban areas aims to make aircraft that perform their missions in a complex urban environment full of obstacles as safe as possible so that their presence does not cause fear and suspicion among citizens. In order for the UAS to function safely in an urban environment, it is necessary to create the supporting infrastructure, and all of this requires certain financial allocations. However, all this does not mean much if the struggle for a modern urban planning is followed from the ground by the views of citizens full of disbelief and fear. The third strategy ST1 Better information of the population regarding the benefits of applying UAS technology in parallel with spreading awareness about the importance of urban planning aims to create trust among citizens in the benefit of UAS technology on the one hand, and on the other hand to familiarize citizens with benefits brought by urban planning. If by following the procedure the city budget is filled and at the same time the devastation of the city's appearance is prevented, the benefits for the ordinary citizen are more than useful. A beautiful, urbanistically arranged city will attract far more foreign tourists who will contribute to the city's budget with a greater number of overnight stays. The fourth strategy Modern laws and regulations draconically punish all forms of illegal construction, although it is deeply repressive, in essence can bring a few benefits to the development of Belgrade. This includes new laws and regulations that would severely punish illegal construction, since now with the use of UAS technology, the city of Belgrade has at its disposal a powerful tool to detect it effectively. It is better to prevent illegal construction in time, than to engage in the sometimes complex and complicated procedure of removing an already built object. Another problem arises here, and it relates to land that is owned by an individual and construction has not started on it. By law, investors should be forced to turn the mentioned plots into landscaped green areas by the start of construction, and at the same time, they should be given a certain deadline for finalizing the buildings. UAs technologies will provide insight into compliance with all of the above.

CONCLUSION

The battle against urban sprawl embodied in illegal construction is a daily and continuous one. The city of Belgrade needs an effective tool to help it stand up to it. What is an agonizing fact is that the number of demolished illegal buildings during one year is incomparably lower than the number of illegal buildings built. The fight for an urbanistic Belgrade must start from building managers who would react in time if an individual want to influence the appearance of the building's facade and up to investor who are able to build an illegal multi-story building in just a few days.

More attention should also be paid to the fact that the old urban core must be maintained and preserved at all costs. Belgrade has been destroyed many times and has seen a large number of wars, but it seems that we ourselves deal the decisive death blow with our lack of understanding and strange understanding of what is good for the citizens and the city as a whole. Any demolition or inappropriate adaptation of buildings built before the Second World War should be absolutely prohibited. No matter how bad shape of the mentioned objects is, they must be preserved or restored to their original appearance. The interest of the investor must not be above the interest of the city and citizens. The result of this research leads us to the conclusion that UAS represents a very reliable, efficient and safe solution for the mentioned problem.

LIST OF REFERENCES

Arsić, S., Nikolić, D., Mihajlović, I., Fedajev, A., & Živković, Ž. (2018). A New Approach Within ANP-SWOT Framework for Prioritization of Ecosystem Management and Case Study of National Park Djerdap, Serbia. Ecological Economics, 146, 85–95. https://doi.org/10.1016/j.ecolecon.2017.10.006

Autelpilot (2023). Drones Help Smart City Planning and Construction. Autelpilot. Retrieved July 1 2024, from https://www.autelpilot.com/blogs/news/drones-help-smart-city-planning-and-construction.

Choi, H.-W., Kim, H.-J., Kim, S.-K., & Na, W. S. (2023). An Overview of Drone Applications in the Construction Industry. Drones, 7(8). https://doi.org/10.3390/drones7080515

Grbović, Lj. (2006). Belgrade in Transition: analysis of illegal building in a post-socialist city. London School of Economics and Political Science. PhD Thesis. Retrieved July 6 2024, from https://core.ac.uk/download/pdf/46518645.pdf.

Hatoum, M. B., & Nassereddine, H. (2022). The Use of Drones in the Construction Industry: Applications and Implementation. Proceedings of the International Symposium on Automation and Robotics in Construction, 2022–July, 542–549.

Jafar Baghernejad, Mohammad Sadegh Sabouri, Mohammad Shokati Amghani, & Abbas Norozi. (2023). Developing strategies for stabilizing the livelihood of smallholder farmers through non-farm activities: the application of the SWOT-AHP-TOWS analysis. Frontiers in Sustainable Food Systems, 7. https://doi.org/10.3389/fsufs.2023.1199368

Kaunas University of Technology (2023). Artificial intelligence to help prevent illegal construction. TechExplore. Retrieved July 5 2024, from https://techxplore.com/news/2023-01-artificial-intelligence-illegal.html

Kokotović-Kanazir, V., Filipović, M., & Magdalenić, I. (2016). Internal Mobility of Serbian Population in the Second Half of the 20th and the Beginning of the 21st Century. Glasnik Etnografskog instituta SANU = Bulletin of the Institute of Ethnography, 64 (3). pp. 553-567. ISSN 0350-0861 eISSN 2334-8259.

Miladinović Bogavac, Ž., & Lazić, D. (2022). Illegal occupation of land and building without a permit as an obstacle to the future development of tourism. The Future of Tourism (TISC 2022). 648–655. https://doi.org/10.52370/TISC22648ZM.

Nwaogu, J. M., Yang, Y., Chan, A. P. C., & Chi, H. (2023). Application of drones in the architecture, engineering, and construction (AEC) industry. Automation in Construction, 150. https://doi.org/10.1016/j.autcon.2023.104827.

Sivakumar, M., & Malleswari, N. (2021). A Literature Survey of Unmanned Aerial Vehicle Usage for Civil Applications. Journal of Aerospace Technology and Management, 13. https://doi.org/10.1590/jatm.v13.1233.

Vukmirović, M., & Nikolić, M. (2023). Industrial heritage preservation and the urban revitalisation process in Belgrade. Journal of Urban Affairs, 45(2), 191–216. https://doi.org/10.1080/07352166.2020.1851140

Vuksanović-Macura, Z. (2012). The mapping and enumeration of informal Roma settlements in Serbia. Environment and Urbanization, 24(2), 685–705. https://doi.org/10.1177/0956247812451809.

Zegarac, Z. (1999). Illegal construction in Belgrade and the prospects for urban development planning. CITIES -GUILDFORD-, 16(5), 365–370.

CIRCULAR ECONOMY IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

Ivana Stošić[1], Tatjana Kosić[2]

[1,2]Faculty of Construction Management, University Union Nikola Tesla, Belgrade

istosic@unionnikolatesla.edu.rs

Abstract

Sustainable development has become one of the most significant topics due to major climate problems and emerging need to address these challenges, so that negative impact of growth can be limited. With the aim to find solutions that reconcile need for development and need to preserve resources for future generations sustainable development searches for practices that can contribute to that goal. Circular economy is one of these actions. Circular economy is a model of production and consumption that tries to prolog the time in which one product or material is used. In that way, the life cycle of the product is longer and new resources and materials don't need to be used. The aim of this paper is to show how circular economy is perceived in the context of sustainable development. Main focus of the paper is to highlight all the benefits that circular economy can provide for sustainable development goals and the way these actions can be encouraged in the future.

Key words: *sustainable development, green goals, natural resources, circular economy.*

INTRODUCTION

Circular economy is one of the topics that are present in our discourse but is still very hard to define it. It is not rare to define circular economy in comparison with traditional economy model that is not connected with the environmental goals. One of the authors that defines circular economy that way is Ghufran et al. (2022). Circular economy is based on the notion that, in many cases, production does not require the acquisition of additional natural resources; rather, it is possible to maximize the use of already-existing resources while minimizing waste.

The challenge of sustainable development has become increasingly important due to the combination of increasing resource usage, climate change, and global resource scarcity (Knäble et al., 2022). In the scope of sustainable development, circular economy offers great potential that is further elaborated in this paper. In order to achieve sustainable development, the circular economy depends on sustainable consumption and production practices as well as resource efficiency.

It can be said that since 2000 when Sustainable Development Goals (SDGs) were established, sustainable development and circular economy are inseparable when it comes to the terms resource preservation and limitation of negative aspects of development (Ortiz-de-Montellano et al., 2023). So far, many research confirmed that circular economy is related to specific SDGs (Schroeder et al., 2018; Dantas et al., 2021). Having that in mind the paper would cover some main issues that connect these terms and try to establish clear explanation about their mutual impact.

ROLE OF CIRCULAR ECONOMY

The term circular economy is very complex and researching its role is of the great importance for determining all the ways in which progress can be made in the field of sustainable development by applying it.

Building on the economy's capacity for innovation and putting sustainable development into practice are the two main tenets of nearly every modern nation's strategic commitment. A lot of governments place a high priority on sustainable development because of the growing emphasis on this aim as a result of the globalization and integration of the world economy. The sustainability of the environment in particular has drawn attention (Marković et al., 2020). Globally, the circular economy is essential to sustainable economic systems. Relying on linear manufacturing is not feasible in the modern world due to resource scarcity and the pace of economic expansion. To make the most use of limited natural resources, materials utilized in both manufacturing and consumption must be recycled. It is becoming more and more necessary to transition from linear to circular economies, and to make developments in the circular economy (Binsuwadan et al., 2023).

Sharing, renewing, leasing, reusing, mending, dematerializing, upgrading, refurbishing, and recycling current resources and products for as long as possible are all part of the circular economy (CE) production and consumption paradigm.

Recently, CE has gained popularity across the globe for fostering harmonious societies and sustainable economic development (Mohajan, 2020).

Circular economy highlights resource efficiency by rethinking the conventional linear paradigm at a time when resources are becoming more scarce and material recycling and reuse are becoming essential. According to estimates, the widespread use of a circular economy might result in a sizable drop in CO2 emissions, assisting nations in meeting their climate change objectives. As a result, creating a circular economy is essential to combating climate change and attaining sustained economic growth. It enables nations to switch from linear to more resource-efficient and sustainable models. In addition to reducing the effects of climate change, the circular economy also opens up new avenues for economic expansion (Schroeder et al., 2018).

The three guiding concepts of the circular economy are: eliminating waste and pollution via design, maximizing the value of products and materials throughout usage, and restoring natural systems. The sources of value of the circular economy cascade down from:

i. renewable resources,
ii. reuse and sharing,
iii. repair and remanufacturing, and
iv. recycling when these three principles are upheld (Knäble et al., 2022).

With these actions, the need of new resources decreases and in the same time efficiency of the sources increases. The level of efficiency can vary depending on the circular activity that is selected.

All listed above is part of the role that circular economy has in the combine efforts to achieve the sustainable growth and to minimize negative effects of the growth.

REFLECTION OF MAIN PRINCIPLES OF CIRCUAL ECONOMY

To better understand the term circular economy, it is important to understand the main principles that are basis for its application. The three primary principles of the circular economy are:

i. designing for waste and pollution;
ii. protection of goods and materials while they're being used; and
iii. restoring the environment (EMF, 2019).

The first of these ideas has to do with how many resources people utilize and consume without giving them any thought. At the moment, just 9% of materials are recycled, and almost two thirds of resources end up as waste (EMF, 2019). It's crucial to note that circular economy aims for zero percent waste and pollution in relation to this notion. Additionally, circular economy identifies and eliminates harmful economic practices that negatively impact society or the environment. It directly contributes to the SDGs and the idea of sustainable development.

The goal of the second principle is to make materials and things last longer. Activities that conserve energy, labor, and materials are encouraged by this notion. This implies that long-lasting goods, components, and materials are kept in circulation in the economy through design for durability, reuse, remanufacturing, and recycling (EMF, 2019). Businesses that embrace the circular economy would be founded on this tenet. In order to reduce the consumption of materials, circular economy also promotes material recycling and reuse.

In addition to that, circular economy seeks to develop an industrial structure that can guarantee the regeneration of nature. Through restorative models, the system can attain net positivity by giving preference to renewable energy sources over non-renewable ones and getting rid of all waste. This implies that rather than taking resources out of the environment, economic activity will add to it.

Based upon role and principles on which circular economy relies on, the following benefits may be expected.

EXPECTED BENEFITS

The adoption of a circular economy might lessen reliance on conventional energy sources like gas and oil while also promoting economic diversity. The circular economy is closely related to sustainability and economic growth. It can increase economic efficacy, draw in investment, and spur expansion by encouraging resource efficiency and lowering waste generation. In addition, the circular economy promotes innovation and the growth of markets and technological advancements, creating chances for long-term, sustainable economic growth. The adoption of circular economy is essential for tackling environmental issues, advancing social development, and spurring economic expansion (Binsuwadan et al., 2023).

Product reuse and recycling would decrease the loss of biodiversity, lessen disturbance of the environment and habitats, and slow down the usage of natural resources.

Reduced annual greenhouse gas emissions are another advantage of the circular economy. The European Environment Agency reports that whilst waste management is responsible for 3.32% of greenhouse gas emissions in the EU, industrial processes and product consumption account for 9.10% of these emissions (European Parliament, 2023).

Reducing waste would need a switch to more dependable items that are repairable, upgradeable, and reusable. The problem of packaging is becoming more and more prevalent; the average European produces around 180 kg of packaging trash annually (European Parliament, 2023). Recycling raw materials reduces supply-side concerns such price volatility, availability, and reliance on imports. This is particularly true for the raw materials required to produce electric engines and batteries, two technologies that are vital to reaching climate targets (European Parliament, 2023).

These are only some of the expected benefits that indicate that further research of this topic is desirable and needed.

RESPONSE TO LIMITATONS

The social impact of the circular economy has gotten little, if any, analysis, despite the fact that its effects on the economy and environment have previously been examined. Some authors reflect even to this issue and state some of the benefits that might be associated with circular economy such as opening of new jobs. Still, this area is not analyzed enough. It is crucial to emphasize that, in the framework of sustainable development, the circular economy has drawn more and more attention recently as a tool for an integrated and interdisciplinary approach. It has emerged as a potential solution to some of the most pressing global concerns. Similar to this, the United Nations General Assembly established the 17 Sustainable Development Goals (SDGs) in 2015 with the intention of promoting world peace and acknowledging that the biggest global challenge is eradicating poverty in all its forms, including extreme poverty, and that doing so is a prerequisite for development (Aparecida et al., 2023). It indicates that this term evolves and progresses and aims to expand its positive impact on sustainable development.

CONNECTION BETWEEN SUSTAINABLE DEVELOPMENT AND CIRCULAR ECONOMY

The goals and processes of the circular economy and sustainable growth can be examined in order to demonstrate the theoretical relationship between them. The goal of the CE is to establish a regenerative economic system in which resources are continuously utilized during manufacturing. This calls for encouraging recycling habits, cutting waste, and making the most use of available resources. Sustainable growth, on the other hand, calls for economic development that prioritizes social progress, environmental preservation, and long-term growth. Businesses and industries can lessen their environmental effect and help to preserve natural resources by putting in place a circular economy. Thus, the likelihood of sustainable growth is increased. Moreover, resource efficiency and process innovation might result from circular economy initiatives. A move toward a circular economy can help economies become more sustainable and solve social and economic disparities in addition to environmental issues (Padilla-Rivera et al., 2020).

CONCLUSION

There is a significant and revolutionary relationship between the circular economy and sustainable development. The goal of sustainable development is to satisfy current needs without endangering the capacity of future generations to satisfy their own. This objective is enhanced by the circular economy, which encourages resource efficiency, waste reduction, and continuous resource usage. It can be dramatically lessen our influence on the environment, preserve natural resources, and promote inclusive and sustainable economic growth by switching from a linear to a circular economic model. The reach of the effects of the circular economy is changing every day and impact that it has on the goals of sustainable development are gradually increasing. With sustainable development becoming the priority, across different industries ways to support sustainable goals are searched for and many of the solutions are related to the circular economy. Circular economy becomes the common point of the joint efforts to change the ways resources are used and to contribute to the nature preservation.

Therefore, adopting the concepts of the circular economy is crucial to guaranteeing long-term sustainability and coordinating economic growth with social progress and environmental stewardship. Future research should focus on the concrete aspects such as specific goal or industry, and the influence that circular economy has within it.

REFERENCES

Aparecida, L., Cohen, M., Yamakawa, Y., Veiga Ávila, L., & Carolina, M. (2023). Circular economy and sustainable development goals: main research trends. *Journal of Management – ReA*, *16*(1), 1–30. https://doi.org/10.5902/1983465971448

Binsuwadan, J., Yousif, G., Abdulrahim, H., & Hind Alofaysan. (2023). The Role of the Circular Economy in Fostering Sustainable Economic Growth in the GCC. *Sustainability*, *15*(22), 15926–15926. https://doi.org/10.3390/su152215926

Dantas, T. E. T., de-Souza, E. D., Destro, I. R., Hammes, G., Rodriguez, C. M. T., & Soares, S. R. (2021). How the combination of Circular Economy and Industry 4.0 can contribute towards achieving the Sustainable Development Goals. *Sustainable Production and Consumption*, *26*, 213–227. https://doi.org/10.1016/j.spc.2020.10.005

Ghufran, M., Khan, K. I. A., Ullah, F., Nasir, A. R., Al Alahmadi, A. A., Alzaed, A. N., & Alwetaishi, M. (2022). Circular Economy in the Construction Industry: A Step towards Sustainable Development. *Buildings*, *12*(7), 1004. https://doi.org/10.3390/buildings12071004

EMF. (2019). *The circular economy in detail*. Ellenmacarthurfoundation.org. https://ellenmacarthurfoundation.org/the-circular-economy-in-detail-deep-dive

European Parliament (2023). Circular economy: definition, importance and benefits. https://www.europarl.europa.eu/topics/en/article/20151201STO05603/circular-economy-definition-importance-and-benefits#:~:text=Reusing%20and%20recycling%20products%20would,total%20annual%20greenhouse%20gas%20emissions.

Knäble, D., de Quevedo Puente, E., Pérez-Cornejo, C., & Baumgärtler, T. (2022). The impact of the circular economy on sustainable development: A European panel data approach. *Sustainable Production and Consumption*, *34*, 233–243. https://doi.org/10.1016/j.spc.2022.09.016

Marković, M., Krstić, B., & Rađenović, T. (2020). Circular economy and sustainable development. *Economics of Sustainable Development*, *4*(1), 1–9. https://doi.org/10.5937/esd2001001m

Mohajan, H. K. (2020). Circular Economy Can Provide a Sustainable Global Society. *Journal of Economic Development, Environment and People*, *9*(3), 38. https://doi.org/10.26458/jedep.v9i3.670

Ortiz-de-Montellano, C. G.-S., Samani, P., & Yvonne. (2023). How can the circular economy support the advancement of the sustainable development goals? A comprehensive analysis. *Sustainable Production and Consumption*, *40*, 352–362. https://doi.org/10.1016/j.spc.2023.07.003

Padilla-Rivera, A., Russo-Garrido, S., & Merveille, N. (2020). Addressing the Social Aspects of a Circular Economy: A Systematic Literature Review. *Sustainability*, *12*(19), 7912. https://doi.org/10.3390/su12197912

Schroeder, P., Anggraeni, K., & Weber, U. (2018). The Relevance of Circular Economy Practices to the Sustainable Development Goals. *Journal of Industrial Ecology*, *23*(1), 77–95. https://doi.org/10.1111/jiec.12732

BOTTLED WATER MARKET RESEARCH: CONSUMER BEHAVIOR AND BRANDS

Marijana R. Milunović[1], Marko M. Pavlović[2], Marija Perić[3]

[1] „Union-Nikola Tesla" University, Belgrade, Faculty of Economics and Finance

2,3 Academy of Technical Vocational Studies, Belgrade

mmilunovic@unionnikolatesla.edu.rs

Abstrakt: Bottled water represents a significant part of the global soft drink market and plays an important role in the daily life of consumers. Its popularity is growing due to a number of factors such as convenience, health awareness and increased availability. This paper aims to explore the bottled water market, analyze consumer behavior and highlight the importance of marketing and branding in creating brand awareness. In this paper, we have covered various thematic areas. The work presents an example of one of the most important waters of our region and its rise in this industry, as well as the reasons why it has become a leader in its region. The Rosa brand is an example of how remarketing strategies can contribute to creating and maintaining consumer awareness. In order to better understand the behavior of consumers and their preferences towards different brands of bottled water, a survey was conducted among the inhabitants of Serbia. The results of the survey provided valuable insights that were used for trend analysis and recommendations for further marketing activities.

Keywords: consumer behavior, bottled water, research, strategy and Serbia

INTRODUCTION

Although vessels for bottling and transporting water were part of the earliest human civilizations, water bottling began in the United Kingdom with the first bottling of water at the Holy Well in 1622. Demand for bottled water was largely fueled by the redevelopment of spa waters and water therapies among Europeans and American colonists in the 17th and 18th centuries. „Bristol Water" taken from the spa at Hotwells was one of the first drinking waters to be bottled and marketed widely. Daniel Defoe noted in 1724 that there were over

15 greenhouses in Bristol, more than in London, and a huge number of bottles were used to ship water from Hotwells not only across England but around the world. The first commercially distributed water in America was bottled and sold by Jackson's Spa in Boston in 1767. The first people who drank bottled spa water believed that the water at these mineral springs had therapeutic properties and that bathing or drinking the water could help cure many common ailments. Sparkling waters were developed to reproduce the natural effervescence of bottled spring water, and in 1809 Joseph Hawkins issued the first American patent for an „imitation" mineral water. Technological innovations in the 19th century led to cheaper glass and faster bottling. Thus, bottled water could be produced on a larger scale, and this led to an increase in the popularity of the product itself. Bottled water was considered by many to be safer than municipal water supplies, which could spread diseases such as cholera and typhus. Around 1850, one of America's most popular bottling plants, Saratoga Springs, produced more than 7 million bottles of water a year (Back et al.,1995). In the United States, the popularity of bottled water declined in the early 20th century, when the advent of water chlorination reduced public concern about waterborne diseases in municipal water supplies. However, it remained popular in Europe, where it spread to cafes and shops in the second half of the century. „Perrier" water had been bottled since the 19th century and was widely sold throughout the British Empire; „Perrier" was launched in the United States in 1977. Today, bottled water is the most popular commercial beverage in the United States, with an estimated 25% share of consumption compared to 18.7% for soft drinks (Chatelan et al., 2022). The first analysis of mineral waters from the Bukovica spring was carried out by Dr. Lindenmayer in 1836. The very next year, in 1837, Prince Miloš Obrenović issued a decree ordering the arrangement of the villages of Orašac and Vrbica. Twenty years later, in 1859, the prince ordered that the name of Vrbica be changed to Arandjelovac. With the first analysis of the quality of the mineral water from this source, the local population, and then the wider Bukovik area, began to recognize its importance and medicinal properties. After carrying out the first analysis of mineral waters, Dr. Emmerich Lindenmeier gave basic instructions for the use of these medicinal waters through daily newspapers, which can still be read today in Arandjelovac. The construction of the Aranđelovac-Mladenovac railway in 1904 greatly facilitated the distribution of water. Knjaz Miloš Pavilion, known as biveta, was the first mineral water bottling factory in Bukovik, built in 1907 on the site of the oldest spring. In the same year, the distribution of Knjaz Miloš mineral water abroad began, while the first prestigious awards for quality from exhibitions in Brussels and London were a real incentive for further development and progress. The source of thermal water was opened in

1935. At that time, around 3,000 bottles of mineral water were poured daily. 36 bottles each were packed in heavy wooden crates. The „Knjaz Miloš" source was recaptured in 1947. In the 1950s, the spa constantly recorded an increase in the number of visitors. Due to the high demand, an installation was installed at this source to add natural carbon dioxide gas to the water, the gas that was released from the hot spring for which a compressor station was built at the time. Thus, in 1956, more than a million liters of mineral water were produced for the first time in Serbia. Bukovička sour water is the only water in Serbia that was sold in 0.5 and 0.3 liter bottles. In 1964, advanced devices for industrial exploitation were installed. That was the moment when manual water bottling stopped. Within the company „Knjaz Miloš", non-carbonated bottled water „Aqua Viva" was launched in 1998, which became one of the leaders on the bottled water market in Serbia (https://knjaz.rs/o-kompaniji/). Other spas followed the great popularity of selling bottled water. One of the older companies that is still considered a popular choice is „Voda Vrnjci", which started bottling and marketing in 1970 (https://vodavrnjci.rs/istorijat/) as well as „MINAQUA" water, which began production in 1972 (https://bbminaqua.com/istorijat-kompanije/). In the eighties of the nineteenth century, the water „Mg Mivela" appeared on the market, while in the nineties, the water „Prolom voda" appeared, as well as the previously mentioned „Aqua Viva". While in the 2000s „Vlasinska Rosa" was rebranded and entered the market as „Rosa" (https://www.coca-cola.com/rs/sr/brands/rosa-vlasina/rosa-vlasina-i-priroda)

REMARKETING AND CREATING CONSUMER AWARENESS OF THE „ROSA" BRAND

Before „Vlasinska Rosa" was bought by the brand „Coca Cola" in 2009, it was one of the lesser known brands on the bottled water market. The complete redesign of the packaging itself, as well as the positioning of the brand itself in the eyes of consumers as an environmentally conscious and active brand, led to „Rosa" becoming the leader in the still water market. Considering that in that period „Coca Cola" realized the spread of the trend of socially responsible business, they invested their finances in the creation of one of the most famous campaigns of that time - the campaign to help premature babies. They successfully implemented their action and managed to open the first human milk bank in Serbia. After four months, new equipment and new incubators were purchased for the Institute of Neonatalology. Due to the educational character of this campaign, 21% more milk was collected compared to the beginning of the campaign itself. Continuing the trend of economic propaganda, „Rosa" gets a complete redesign of the packaging, which includes packaging that contains less plastic (Eco bottle). Due to the reduction of the colors on the label as well as the size of the cap, there is an increase in savings in the budget district. In order to achieve a competitive advantage, they decide to propagate the social responsibility of the brand with the activation of the media on the target consumers through advertising in the most effective places. Advertising on billboards, which at that time represented the most noticeable position in Serbia, health centers, municipalities and other media raised awareness of the brand as well as the needs that are of vital importance to society.

RESEARCH

The total number of respondents in this research is 520. The structure of the sample in relation to the gender of respondents, of the total number of respondents, 386 (74.2%) are female, while 134 (25.8%) are male. The structure of the sample in relation to the gender of the respondents refers to the determination of the objective age of the respondents. The largest number are respondents aged 26-45, whose number is 196 (37.7%), followed by respondents aged 46-65, whose number is 180 (34.6%). In this part, we can already conclude that the majority of our respondents are in their middle age, so we assume that they can independently decide on their financial spending. Next would be respondents aged 18-25 (98 respondents who make up 18.8% of the total) as well as respondents under 18 (28 respondents who make up 5.4% of the total). The smallest number of respondents were respondents aged 65+, of which there were only 18 (3.5%). Given that this survey was conducted online, it is expected that the least number of respondents will be in this age group solely due to the connection of the older population with digital media. This question referred to the place of residence, of which the largest number of respondents is concentrated in the region of Central Serbia with a total of 357 respondents (68%). Since this survey was shared via social networks, we can see that the largest number of respondents who shared and reacted to the same content were from this region. Next was the region of Belgrade and its surroundings, which consisted of 71 respondents (13.7%). After him, the regions of Western Serbia (28 respondents, 5.4%), Southern Serbia (22 respondents, 4.2%), as well as the regions of Vojvodina and Eastern Serbia, which were tied with 20 respondents each (3.8%). The smallest number of respondents is from the region of Kosovo and Metohija, which consisted of only 2 respondents (0.4%). In this question, we determine the amount of the respondent's monthly income. As we assumed, the percentage of employed respondents, which is 77.3%, closely matches the number of respondents in the age group of 26-65, which is 72.3%. Within this question, we can see that the largest number of respondents have an average salary of 60,000 to 120,000 dinars, and they comprise 209 respondents (40.2%). They are followed by 146 (28.1%) respondents with a salary of less than 60,000 dinars, and 118 (22.7%) unemployed residents. The smallest number of respondents had a salary higher than 120,000 dinars, and they were 47 respondents (9%). After the first four demographic questions, this is the first question related to the research product itself. In this question, we examine the habit of drinking water and buying bottled water in Serbia. As the water from the municipal waterworks is safe for consumption in our country, it is not surprising that the majority of respondents (297 respondents who make up 57.1% of the total) answered with the attitude that sometimes they use bottled water and sometimes they use tap water. Also, this issue sets a strict requirement for everyday application that most of our population cannot get used to. Regarding the strict consumption of only bottled or tap water, the opinions of the respondents were divided, where 112 respondents (21.5%) use only bottled water, while 111 respondents consume only tap water (21.3%). Starting with the assumption that the majority of the population of Serbia does not have a constant habit of buying bottled water, we wanted to examine how much it is actually represented in the daily life of consumers. This scale went from never (marked with the number 1) to very often (marked with the number 5) where the largest number of residents was again neutral where 182 respondents (35%) chose option number 3. The second place is occupied by option 5 with 144 (27.7 %) of respondents. After that, there are options number 2 with 97 respondents (18.7%) and option 4 with 61 respondents (11.7%). 36 respondents (6.9%) had the least option 1, which represents never. With this, we can determine that although the habit is not everyday, the majority of the population would rather buy bottled water than exclusively drink water from the tap. In this question, we examine consumer brand loyalty. In the territory of Serbia, the majority of consumers have a strong sense of loyalty to bottled water brands, either because of the health benefits or environmental propaganda that the brand spreads. We can see this from the answers to this question, where the majority of respondents, consisting of 323 respondents (62.1%) answered with the option „Yes", while 197 respondents (37.9%) answered with the option „No". We assume that a large number of respondents who answered with the option „No" are respondents who mostly do not buy bottled water. We can thus conclude that, as we stated a little while ago, the majority of regular consumers generally remain loyal. To the question How inclined are you to experiment with different brands of bottled water: This question was asked for formal reasons in order to determine the percentage of honesty in answering the respondents. It is very similar to question number 7, only it is formulated and presented in a different way. The number 1 in this context means „Not at all" while the number 5 means „Very much". In this question, we can conclude that 48.1% of respondents (248) will be very weak or would not experiment at all with the brand they buy, 32% (165) of respondents will be neutral and 20% (103) of respondents will be more inclined to experiment. When we compare this with question number 7 where the answer was strictly „Yes" or „No" we can see that a large number of respondents who answered with the option „Yes" have now become neutral. Regarding the no option, it is not surprising that a certain number of respondents switched to the neutral option due to their indifference towards the product itself. Here we cover which features most attract consumers to a particular product. The largest number of respondents opted for quality (332 respondents (63.8%)), while the second option was price with 111 respondents (21.3%). It is followed by the size of the bottle (46 respondents (8.8%)) and the one with the least affiliation from the offered options is the packaging design with 15 respondents (2.9%). The rest of the answers were offered to the respondents' free input and mainly consist of the taste of the water (6 respondents) as well as a combination of the already mentioned options (price-quality ratio) as well as the indifference of the respondents according to the fact that they do not consume bottled water. Not surprisingly, the most popular answer in this question was the quality option due to the very positioning of bottled water as a healthier option compared to tap water. In this question, we determine what respondents gravitate towards, carbonated or still water. 411 respondents chose the still water option, which is 79%, while 21% of the respondents chose the carbonated water option (109 respondents). Due to the daily use and intake of still water, this is an obvious choice. When we compare this question with the results of the eighth question, we can see why the first leading places are occupied by non-carbonated water brands such as „Rosa", „Aqua Viva", „Voda Voda", while the two leaders of carbonated water had significantly lower numerical results. Here we can also understand the significant difference in the placement of water „Aqua Viva" and „Knjaz Miloš" which are under the same company. This question examines which type of bottled water the respondents consume most often. The largest number of respondents opted for spring water (217 respondents (41.7%)), which we can relate to the health benefits that the consumption of this water should achieve, as well as the consumption of water that is collected on the domestic market. The second option was I don't care, which was chosen by 160 respondents (30.8%), which is mostly the indifferent side of the examiner who either does not consume or rarely consumes and is therefore not informed or interested in the differences. They are followed by the option of mineral water with 119 respondents (22.9%) and the smallest number of respondents prefer filtered water (24(4.6%)). Here we are already getting into the process of product innovation and how our respondents would feel about it. By researching such innovations, companies can determine whether it is wise to invest in creating a new product. 223 respondents (42.9%) answered this question with the „Yes" option, while 297 (57.1%) respondents answered with the „No" option. Whether this would be a good marketing move for some companies cannot be determined precisely, specific research would have to be done for the specific company and their target group. As we saw previously in the example of remarketing „Rosa" water using propaganda for economic acceptability this can be a key point to improve the brand image in the eyes of consumers. As it was 10 years ago and today, environmental friendliness is one of the most important characteristics of the brand that consumers follow. 393 respondents (75.6%) answered with the option „Yes", while 127(24.4%) answered with „No". We conducted this question for the purpose of market research and which of the mentioned marketing channels has the highest response can be the most profitable. Given that the largest number of respondents was a middle-aged population, the largest number of respondents answered this question with the option of advertising through television media with 219 respondents (42.1%), while 97 respondents (18.7%) answered with the social network option. 61 respondents (11.7%) answered with the option of billboards, posters or moving advertisements, while the option of influencer with 22 respondents (4.2%) was in last place among the already offered answers. Within this question, the respondents had the option to enter their answers independently, which was chosen by 23.3% of the respondents. The most popular option for self-answering was none/none. I believe that in this sense, people are not aware of the impact that marketing strategies have on the consumer's perception of the brand, because if a certain company did not have a well-developed marketing strategy, it would not even exist on the market as such. The rest were word-of-mouth marketing (recommendations from friends and acquaintances) as well as invalid responses. The results of this question were expected due to the reference in the tenth question, where the majority of respondents answered with the attitude that quality is the most important to them. Accordingly, it is not surprising that 359 respondents answered with the health claim option, which is 68.5% of the respondents. The second most popular option was packaging aesthetics with 140 respondents (26.9%) and last was the sustainability message with 78 respondents (15%).

CONCLUSION

Research on the bottled water market in Serbia reveals significant insights into consumer behavior and the role of brands in this sector. By analyzing the various factors that influence the choice of a brand, as well as the specifics of the market itself, we can better understand the dynamics and trends that shape this industry. The behavior of consumers when buying bottled water shows that the main factors influencing the choice of brand are price, quality and taste, as well as packaging and environmental awareness. Consumers are increasingly oriented towards healthy and environmentally friendly products, which affects their purchasing decisions. Research shows that a large number of consumers are willing to pay more for products that meet these criteria. Brands play a key role in shaping the bottled water market. Well-known brands such as „Knjaz Miloš" and „ROSA" have managed to build strong recognition and loyalty among consumers. The success of these brands is based on consistent product quality, effective marketing strategies and adaptation to trends and consumer needs. Also, environmental responsibility and innovation in packaging are becoming increasingly important factors in differentiating brands on the market. The market of bottled water in Serbia is characterized by growing competition and increasing consumer expectations. Brands must continue to invest in research and development to remain competitive and meet changing consumer needs. In addition, sustainability and environmental responsibility will be key factors for future success. It is recommended that companies continuously monitor market trends, adjust their products and marketing strategies, and invest in educating consumers about the importance of water quality and environmental protection. Overall, the research on the bottled water market in Serbia shows that consumers are increasingly aware of the importance of quality and environmental responsibility. Brands that manage to meet these criteria will have a better position in the market and greater consumer trust. Continuous monitoring of trends and innovation remain key to maintaining competitiveness and growth in this dynamic market.

LITERATURE

Back, W., Landa, E. R., & Meeks, L. (1995). Bottled Water, Spas, and Early Years of Water Chemistry". *Groundwater*, *33*(4), 605-614.

Chatelan, A., Lebacq, T., Rouche, M., Kelly, C., Fismen, A. S., Kalman, M., ... & Castetbon, K. (2022). Long-term trends in the consumption of sugary and diet soft drinks among adolescents: a cross-national survey in 21 European countries. *European journal of nutrition*, *61*(5), 2799-2813.

https://knjaz.rs/o-kompaniji/

https://vodavrnjci.rs/istorijat/

https://bbminaqua.com/istorijatkompanije/#:~:text=Prve%20analize%20ove%20vode%20ura%C4%91ene,i%20bikarbonata%20nego%20morska%20voda

https://www.coca-cola.com/rs/sr/brands/rosa-vlasina/rosa-vlasina-i-priroda 10.08.2024

MACROECONOMIC ENVIRONMENT AND FINANCIAL PERFORMANCE OF COMPANIES IN SERBIA

Olgica Nestorović [1] ,Dušan Aničić [2] ,Ana Anufrijev [3] ,Gordana Bejatović [4] ,Jugoslav Aničić [5]

[1] JKP "Kruševac",Kruševac, Srbija,
[2,3,4,5] Fakultet za ekonomiju i finansije, Univerzitet Union – Nikola Tesla, Beograd, Srbija

olgica.n@yahoo.com

Abstract: Companies in the Republic of Serbia have been operating in an unfavorable macroeconomic environment for many years, including geopolitical tensions, energy crises, inflationary pressures and others. During the transitional period, companies have failed to significantly increase their competitiveness at the international level, resulting in the country still having a high trade deficit, large disparities in regional developmentand unfavorable migration of young, educated populations to urban centers or abroad. Economic policy must correct the mistakes of transitional period, focusing primarily on neglected development of the real sector, particularly industry and agriculture. This can be achieved through an adequate developmental investment policy, in which both domestic and foreign investments, both public and private, would participate on equal terms.

Keywords: business environment, financial results, investments, economic enterprises

INTRODUCTION

Economic development of Serbia, during transitional period, was based on a neoliberal development concept and inefficient privatization, which led to a negative change in the country's economic structure. After the year 2000, there were periods of relatively high GDP growth rates, but with a neglect of industrial development: the highest growth was achieved in service activities closely related to large, economically unjustified imports, while the development of the real sector of economy lagged behind. The consequences of such economic policies include low competitiveness of the economy in international contexts, a negative trade balance, neglected regional development, unfavorable migration trends accompanied by the departure of young population abroad, low living standard of population and so on.

MACROECONOMIC ENVIRONMENT

Competitiveness of the Serbian economy, when viewed on a global scale, has been low throughout the entire transition period, largely due to flawed economic policies implemented since the year 2000. Key mistakes stem from relying on the development of non-tradable sectors, while the development of manufacturing industry, agriculture and other branches of the real sector remained neglected. Undeniable is the negative impact of the inefficient and, to a large extent, corrupt privatization process, which led to the closure of manufacturing enterprises in the industrial sector, uncontrolled imports, trade deficits and more.

Macroeconomic trends in the Republic of Serbia over the past few years have been strongly influenced by adverse effects from the environment caused by geopolitical tensions, as well as the intensification of the global energy crisis, resulting in a slowdown in economic growth and increased inflationary pressure. However, thanks to achieved financial stability and the growth momentum from previous years, as well as significant inflows of foreign investments, a stable exchange rate has been maintained and the number of employees is experiencing a slight increase.

We will analyze the state of the economy in the Republic of Serbia through the achieved results in 2022 and previous years, based on the reports of the Business Registers Agency, formed on the basis of submitted financial reports of economic enterprises during that period.

Economic activity in the Republic of Serbia, measured by Gross Domestic Product (GDP), increased by 2,3% in 2022, according to data from the Statistical Office of the Republic of Serbia and the National Bank of Serbia (Table 1). Industrial production grew at a rate of 1,7%, which is considerably slower compared to the previous year, 2021. The existing economic trends have impacted international trade. Exports increased by 26,3% compared to the previous year, but imports grew faster - by 34,8%, leading to a further increase in the trade deficit.

The rise in energy prices globally, as well as agricultural and industrial raw materials, has stimulated inflationary pressures in the domestic economy, resulting in an inflation rate of 15,1% at the end of 2022, compared to 7,9% in the previous year. The exchange rate remained relatively stable and the number of employed persons increased by 1,8% compared to the previous year.

Table 1: Basic macroeconomic indicators

DESCRIPTION	Year	
	2022	2021
Gross domestic product (in millions of dinars - current prices)	7.090.743,9	6.270.097,0
Gross domestic product - growth rate	2,3	7,5
Industrial production	101,4	106,3
Annual inflation rate (consumer price index)	15,1	7,9
Exports (in millions of euros)	27.604,7	21.858,0
Imports (in millions of euros)	39.008,7	28.935,3
Foreign trade deficit (in millions of euros)	11.404,0	7.077,3
Number of employees (in thousands)	2.253	2.213
Exchange rate of dinar to the euro (as of December 31)	117,32	117,58

Source: Republic Institute of Statistics of Serbia (2023), National Bank of Serbia (2023)

At the end of 2022, there were 135.490 economic enterprises operating in the Republic of Serbia, employing 1.281.412 workers, representing an increase of 5.375 employees compared to the end of the previous year. Looking at the sectors, non-tradable sectors were more prevalent in the economy - there were 86.095 (79,1%) economic enterprises operating in these sectors, employing 748.604 workers (58,4%). In terms of specific sectors, the highest number of economic enterprises operated in the sectors of Wholesale and Retail Trade, Manufacturing Industry, Construction, Information and Communication, Transport, Professional, Scientific, Information and Technical Activities.

The largest number of employees were in the Manufacturing Industry sector (31,4%), followed by the Wholesale and Retail Trade sector (18,3%) and Transport and Storage sector (8,1%). The increase in the number of employees compared to the previous year was highest in the Information and Communication sector, followed by the Professional, Scientific, Innovative and Technical Activities sector.

In the structure of Serbian economy, when observed by the size of enterprises, micro-enterprises predominate, accounting for 93.064 (85,5%) of them. On the other hand, there were 528 large enterprises, employing the highest number of workers – 450.049 or 35,1% of employees. The number of small enterprises was 13.172 with 333.356 employees, while there were 2.092 medium-sized enterprises with 270.770 employees. The division into micro, small, medium and large enterprises was carried out in accordance with the Accounting Law (Official Gazette of RS, No. 73/2019 and 44/2021-other law), based on criteria such as the number of employees, generated revenues and the value of business assets.

A significant number of enterprises operated without any employees, numbering 32.139 or 29,5%. Micro-enterprises dominate their structure, followed by 303 small, 25 medium-sized, and 7 large enterprises. An analysis from the perspective of the number of employees shows that after enterprises without employees, the majority were those employing between 2 to 5 workers, followed by enterprises with a single employee. Over 250 employees were employed by 614 enterprises, which accounted for 43,4% of the workforce.

FINANCIAL PERFORMANCE OF COMPANIES

Analysis of the achieved business results of companies in 2022 was conducted based on the data from the Business Registers Agency (BRA), which were obtained by systematizing the submitted financial reports by the companies.

Financial statements represent a direct product of the accounting reporting system which, by its essence and purpose, reflect the performance (achievements) of a company for a specific period, its financial-structural position, as well as its liquidity position on a chosen balance sheet date. Primary purpose of their preparation lies in providing information to various stakeholder groups who rely on them in the process of making business decisions. Financial reporting supplies important information to all existing and potential participants in the financial market, affirming itself as a significant factor that enhances its functioning (Ćeha, et. all. 2023) .

Financial reporting connects top management and executive activities of the company, providing essential information to both internal and external users. Therefore, there needs to be a strong link between financial reporting, the efficiency of financial markets and the development of market economy (Gajić, Medved, 2014).

In 2022, companies in the Republic of Serbia operated under the influence of growing global instability and increased risks caused by numerous international conflicts, energy crises and strong inflationary pressures. Despite these challenges, companies demonstrated resilience to external shocks and continued the trend of successful operation from the previous period.

According to the data from Table 2, the total revenues generated at the level of the economy amounted to 17.772.856 million dinars, representing an increase of 19,2% compared to the previous year. The majority of the total revenues were generated by economic enterprises through their primary activities. At the same time, total expenses amounted to 16.721.985 million dinars, representing an increase of 18,8% compared to the previous year.

Revenues from financing increased by 61% compared to the previous year, while financial expenses increased by 30%, resulting in an improvement in the overall financing result. As a result, economic enterprises in the financing sub-balance recorded a loss that was 28% lower compared to the previous year. All of this resulted in a positive net result at the level of the economy amounting to 864.190 million dinars, representing an increase of 26.3% compared to the previous year.

Table 2: Structure of income, expenses and results of business companies (in millions of dinars)

DESCRIPTION	**Year**		**Index**
	2022	**2021**	
Business income	17.285.581	14.490.569	119,3
Business expenses	16.143.910	13.583.118	118,9
I Business result	**1.141.671**	**907.451**	**125,8**
Financial income	195.673	121.550	161,0
Financial expenses	242.335	186.389	130,0
II Funding result	**-46.661**	**-64.839**	**72,0**
III Result from other activities	**-44.138**	**-9.050**	**487,7**
IV Result before tax	**1.044.209**	**827.738**	**126,2**
VNet result	**864.190**	**683.976**	**126,3**

Source: Agency for Business Registers, 2023.

Positive performance of the economy, for the eighth consecutive year, has been achieved through conducting business activities. Additionally, there has been an increase in the yield on sales revenue, which has impacted the rate of operating and net profit. Moreover, rates of return on total assets and equity have also experienced growth. Furthermore, economic enterprises have managed to finance interest expenses from the achieved results, leading to an increase in the interest coverage ratio - as shown in Table 3.

Table 3: Profitability indicators at the economy level

DESCRIPTION	Year	
	2022	2021
1. Rate of return on equity (after taxes)	11,4	9,9
2. Rate of return on total assets (after tax)	4,8	4,3
3. Rate of business profit	6,9	6,6
4. Net profit rate	5,2	5,0
5. Interest coverage ratio	11,25	10,65

Source: Agency for Business Registers, 2023.

Serbia's economy needs a new development strategy based on increasing investments, providing greater support to export-oriented enterprises and investing in infrastructure. This will create the foundation for long-term, sustainable economic development and enable a larger participation of SMEs (Small and Medium-sized Enterprises) in overall economic activities. This would imply a correction of the current economic policy, which relies on indiscriminate imports and foreign investments and a shift towards a developmental economic policy where domestic investments and industrial production take precedence.

CONCLUSION

Creators of economic policy should learn from the negative outcomes of implementing the neoliberal model of economic development during the transitional period and shift towards a developmental policy where infrastructure development, private and public investments – both domestic and foreign – as well as increasing industrial production, are prioritized. By leveraging the positive effects offered by the EU accession process through economic policy, a more significant role for the small and medium-sized enterprises (SMEs) sector and entrepreneurship in economic and overall social development can be expected. Institutions responsible for economic development must address numerous obstacles and limitations still present to facilitate economic growth and enable competitive performance of economic entities in the developed international market.

On their part, companies must address internal weaknesses and maximize the use of internal reserves because relying solely on external sources of financing creates an unfavorable financial structure for the company, which is unsustainable in the long run. Economic recovery will be challenging due to the prolonged impact of the economic crisis, so it is necessary to redirect investments into companies engaged in manufacturing and exporting products with a higher degree of processing, focusing on strategic sectors that will contribute most to stable and dynamic economic development and achieving the country's economic and development policy goals.

LITERATURE

Agencija za privredne registre (2023), Godišnji izveštaj o poslovanju privrede 2022., Beograd

Besley, S., Brigham, E., (2015), Corporate finance, DATA STATUS, Beograd

Ćeha, N., Aničić, J., Aničić, D., Ćeha, M., Nestorović, O., (2023), High quality financial reporting in the function of company growth in Serbia, The European Journal of Applied Economics, 20(2), 111-130.

Gajić, Lj, Medved, I., (2014) Upravljačko računovodstvo u funkciji postizanja konkurentske prednosti, Anali Ekonomskog fakulteta u Subotici, br. 32, Subotica, str. 400.

Leković, M., Arsenović, S., (2013), Uloga i značaj kvalitetnog finansijskog izveštavanja, Bankarstvo, br. 4, str. 79-93).

Malinić, D., (2014) Merenje kvaliteta finansijskih izveštaja,. Računovodstvo i Menadžment Privatnog i Javnog Sektora, Savez Računovođa i Revizora Srbije, 7–32.

Narodna banka Srbije (2023), Osnovni makroekonomski pokazatelji, Beograd

Republički zavod za statistiku (2023), Anketa o radnoj snazi za 2022. godinu, Beograd

Stevanović, N., (2011) Finansijsko - izveštajna odgovornost u kontekstu EU, medjunarodnog i novog domaćeg regulatornog okvira, Ekonomika preduzeća, br. 5-6, str. 227-242.

POSSIBILITIES OF IMPLEMENTATION OF SOLAR POWER PLANTS IN URBAN AREAS ON THE MODEL EXAMPLE OF THE ENERGOPROJEKT'S OFFICE BUILDING IN BELGRADE

Rista Popović[1], Dragana Vasilski[2] , Vladimir Stevanović[2]

[1]Union Nikola Tesla Univesrity, *Energoprojekt Industrija*, Belgrade,
[2]Union Nikola Tesla University, Department of Architecture and Urbanism, Belgrade

popovicrista2@gmail.com

Abstract Urban areas, responsible for 80% of global energy consumption and 60% of CO2 emissions, face a significant challenge in achieving the net-zero emissions goal set by the Climate Protection Act for 2050. With the continuous growth of cities and increasing energy demands, it's crucial to explore local power generation options to meet infrastructure needs and reduce reliance on external energy sources. This study focuses on the potential of solar energy, as the most widely accessible renewable source, for urban areas applications. Using Energoprojekt's business building in Belgrade, as a case study, we research the feasibility and performance of implementing solar power systems within the urban landscape. Derived recommendations provide insights into how solar technology can be effectively integrated with other urban locations. By researching this case study's technical, economic, and environmental aspects, we aim to contribute valuable knowledge to the broader discussion of sustainable urban energy solutions.

Key words: *Energoprojekt*, solar power plants, renewable energy sources, solar energy, cities (urban areas).

INTRODUCTION

Integration

Integration of solar energy in urban areas is a key strategy for achieving sustainable energy and mitigating environmental impacts (Etukudoh, et al., 2024). Despite the challenges posed by limited space, shadows from high-rise buildings, and legal obstacles, integrating solar energy into urban areas is crucial to unlock the vast potential for clean energy production within urban areas.

Benefits

The benefits of using solar energy in urban areas are numerous. It's quiet, clean, and a reliable source of energy. Most of the investments in renewable energy sources consume less material and labour in their construction, as well as less investment in their construction and maintenance. As fossil fuel reserves continue to dwindle, it is clear that their prices will continue to rise, which gives room for the development of renewable energy sources (Vujovic, 2019). The relentless search for sustainable energy solutions has led to Solar energy being at the forefront of global discussions on clean and renewable energy sources. Solar rooftop plants (solar power plants), which offer a decentralized approach to energy production, attracted a lot of attention because of their potential to revolutionize the production of electric energy (Singh & Agrawal, 2023). Some of the main benefits of applying solar power plants on the roofs of buildings in urban areas:

- **Simplicity and ease of installation:**Solar roof mounts are straightforward in design and require a few components, allowing for quick implementation in urban environments. They do not require additional land and infrastructure.
- **State subsidies:** In the Republic of Serbia, with the plan for 2023/2024, 131 municipalities are awarding subsidies in the form of financing 50% of the project value, up to a maximum of 420,000.00 RSD. Also, under certain conditions, there is a possibility of acquiring the status of a „privileged producer" and the production and sale of electricity to „EPS" at an incentive purchase price (feed-in tariff).
- **Easy maintenance:**Maintaining solar panels is simple. They require cleaning several times annually with plain clean water to maintain the best performance and efficiency.
- **Low aesthetic impact on the building:** Integrating this type of solar power plant directly into the roof of the buildings, roof minimizes its visual impact, depending on the roof type.
-

Quality of Architectual Integration

The low prevalence of solar power plants can be partly attributed to the generally poor quality of their architectural integration (Probst, 2008).Research suggests that improving the architectural quality of integrated solar systems may be even more impactful than just reducing costs or refining technology.Thus by incorporating solar technology into the design of new buildings from the very beginning, significant cost savings can be achieved (Puroar et al., 2009).This approach signals that all new buildings should be designed with the potential for future solar integration - in anticipation of rising fossil fuel costs and decreasing solar technology costs.

Global solutions - Integration of Solar Power Plants on Roofs

A good example of the integration of solar power plants in an urban area can be taken from „Queens Bridge Houses", a public housing complex with 96 buildings in the Long Island City neighbourhood of Queens, New York, USA (New York City Housing Authority [NYCHA], 2021). Solar photovoltaic panels installed on the roofs of 27 buildings across the complex produce 1.8MW of clean energy, allowing this group of residents to benefit from lower electricity costs.

„La Seine Musicale", a centre for music and performing arts on the Seine Island in the western suburbs of Paris, France, exemplifies the integration of solar panels in an unconventional yet aesthetically pleasing manner. The egg-shaped structure's energy needs are primarily met by a large mobile solar sail, comprised of 470 individual panels, that rotates around the building every 15 minutes, mimicking the sun's path to maximize sunlight capture (Volpicelli, 2017).

Dallas, North Texas, boasts one of U.S. history's largest urban solar integrations (Seeley, 2022). The Solar Company is installing a massive 15MW system – 40,000 solar panels! – across the rooftops of 16 multi-family housing estates, totalling 3,600 apartments. However, not all the complexes had suitable rooftops. For 9 of the 16, The Solar Company got creative with solar carports. This not only provided residents with roughly 2,000 covered parking spaces but also generated clean energy and further reduced energy costs.

CASE STUDY: Solar Power Plant on the Roof of the Energoprojekt's Office Building in Belgrade

The Idea of Construction and Legal Regulations

Following European trends related to environmental protection and the use of renewable energy sources, on 27 September 2001, Serbia accepted the obligation to adopt and implement a plan for Directive 2001/77/EC on actively promoting electricity production from renewable energy sources. This resulted in the Ministry of Urban Planning, Spatial Planning, Mining and Energy adopting appropriate legislation and regulations regulating the installation, and connection of renewable energy sources to the electricity grid of Serbia, as well as the decision on the subsidized price of electricity (feed-in tariff) for users who want to install photovoltaic systems and thus relieve the energy system, where they can obtain the status of a privileged producer (Grujić, Zanoškar, Miletić, 2012).

Energoprojekt-ENTEL is committed to the development and application of renewable energy sources and has therefore taken a leading role by installing a 120 kW solar power plant (consisting of 492 solar panels) atop its New Belgrade office building. This project positions them as one of the first independent electricity producers in Serbia, demonstrating the potential of solar power for a broader range of users beyond the „privileged producer" category. Many private investors are also embracing solar power, either for their own energy needs or for selling electricity to traders (Obnovljivi izvori energije [OIE], 2021).

Architectual Solution

The *Energoprojekt's* building has four separate units, labelled A, B, C, and D. The roof surfaces are marked with the same letters. This project's feasibility was further bolstered by the architectural solution of the roof itself, which proved to be extremely suitable for implementing a solar power plant. The installation of equipment and solar panels utilized the walkable sections of the roof on units A, B, C, and D. These walkable sections are designed with a two-slope symmetrical slope of 0.5% from the centre of the plane (helmet) to the circumferential gutters. These gutters stand on the inclination towards the gutter verticals. The final layer structure of the existing passable part of the roof consists of thermalization laid over a vapour barrier on reinforced concrete supports, waterproofing over a perlite drop layer, and finally, rectangular concrete cover plates 30 mm thick laid over sand. The existing roof domes (skylights) arranged between the passable roof planes are polycarbonate in an aluminium frame.

Figure 1. Appearance of the Roof - Energoprojekt's Office Building, New Belgrade (Energoprojekt Archive, Bulevar Mihajla Pupina 12, New Belgrade)

The solar panels are arranged in six-panel groups to the left and right of the gable roof's ridge, positioned optimally for the sun's daily cycle. A 2.0 meter (m) space is provided between the groups for maintenance access. Two existing equipment towers are located at the ends of the slats, offering access to the roof planes via vertical metal stairs. The Energoprojekt office roof features a lightning protection system that covers the entire surface. Since the position of the solar panels and their associated equipment falls within the existing lightning protection zone, no additional work on the system was necessary.

Structural Design and Considerations

The photovoltaic panels, measuring 1652 x 1000 mm, are supported by an aluminium frame. To preserve the existing waterproofing layer as per the project requirements, a modified solution with a ballast beam was chosen. This design ensures unobstructed water drainage on the sloping roof surface while securing the panels. Concrete beams with an inverted „T“ cross-section, measuring 500x250x2000mm, were installed to anchor the aluminium frame. These beams are specifically designed to withstand the wind loads acting on the panels and the supporting structure. Due to the unique shape of the panels and the supporting frame, wind loads were a primary concern. Therefore, thorough calculations and analyses were conducted to assess the additional roof loads and ensure the safety of the entire system.

Electrical Part - Calculation of Solar Panel Power

To achieve the greatest possible absorption of solar radiation, the panels will be strategically positioned with the ability to choose between two tilt angles relative to the horizontal plane: 20 degrees (20°) and 45 degrees (45°). The intensity of solar radiation reaching the Earth's surface can be calculated using the following formula:

$$I_d = C \cdot I_0 \cdot e^{-k \cdot m} \cdot F \quad (1)$$

Where:

I_0 - stands for extraterrestrial radiation intensity (W/m^2)

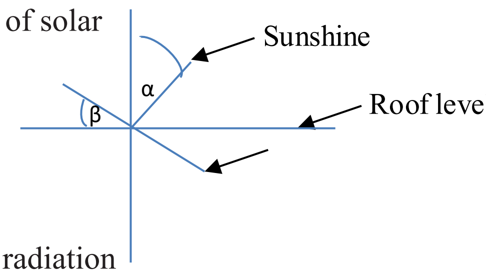
k -stands for the coefficient of attenuation of solar radiation in the Earth's Atmosphere

C -stands for the diffuse radiation factor

m -stands for the optical air mass

F -stands for the angle factor

I_d -stands for the intensity of diffuse solar radiation



α - stands for the angle between the solar radiation and the vertical plane

β **-** stands for the angle between the panel and the horizontal plane

$$F = \frac{1}{2}(1 + \cos\beta) \quad (2) \qquad m = \frac{1}{\cos\alpha} \quad (3)$$

Month	Jan	Feb	Mar	Apr	May	June	July	Avg	Sept	Oct	Nov	Dec
Daylight Hours	8:50	10:30	12:00	13:40	14:40	15:00	14:40	13:40	12:00	10:30	8:50	8:20
Angle of the sun (α^0)												
8h	4	12	22	28	34	36	34	28	22	12	4	2
10h	18	27	37	47	54	56	54	47	37	27	18	15
12h	24	33	45	56	64	68	64	56	45	33	24	20
14h	18	27	38	48	55	58	55	48	38	27	18	16
16h	5	13	22	29	34	37	34	29	22	13	5	3
18h				8	14	17	14	8				

Table 1: Monthly Variations in Daylight Hours and Solar Angle (Energoprojekt Archive, Bulevar Mihajla Pupina 12, New Belgrade: Grujić J, Zanoškar I, Miletić N. (2012) Ugradnja solarnih panela na delu krova poslovne zgrade Enegoprojekta - Glavni projekat)

The panels are strategically tilted to maximize the amount of sunlight absorption. This adjustable approach yields an estimated 3% increase in total radiated energy compared to fixing the panels at a single angle. The chosen solution utilizes a 20-degree tilt relative to the horizontal plane from April to August. This angle optimizes sunlight absorption during these peak sun months; the panels will be adjusted to a 45-degree tilt to ensure optimal energy production for the rest of the year.

Lamela	Maximum power per panel	Number of solar panels	Maximum power per area
	Wp		kWp
A	240	132	31,680
B	240	156	37,440
C	240	132	31,680
D	240	84	20,160
Maximum installed power per panel			120,96

Table 2: Total number of maximal installed solar panel power per unit (Energoprojetk Archive, Bulevar Mihajla Pupina 12, New Belgrade: Grujić J, Zanoškar I, Miletić N. (2012) Ugradnja solarnih panela na delu krova poslovne zgrade Enegoprojekta - Glavni projekat)

The Budget Results

The total calculated annual electricity production from solar panels installed on the Energoprojekt building is **270,127kWh**.

Financial Viability

Considering the preliminary estimates for construction, equipment (including solar panels, cables, and inverters), and architectural design, we determined this project to be economically viable. The initial investment recovered in approximately 4.82 years. Since the Republic of Serbia guarantees a buyback rate (feed-in tariff) for 12 years, there are still 7.18 years left to sell electricity to the Electric Power Company of Serbia (EPS) at this subsidized price.

Ecologic Aspect

The environmental benefits of this project are significant. Although the installation caused temporary disruptions, noise and emissions from delivery trucks and construction machinery, they were minor compared to the lasting advantages power plants provide.Once operational, it generates emission-free energy but eliminates the production of hazardous waste and the need for fuel transportation - both significant contributors to environmental pollution. These advantages position solar energy as essential in reducing environmental pollution and mitigating climate change.

DISCUSSION AND CONCLUDING REMARKS

Solar power plants for building roofs research of technical, economic, and environmental aspects provides valuable insights into harnessing solar energy. The introductory part of this paper demonstrated that solar technology can be easily integrated with all building types, regardless of function (residential, public, commercial). However, the quality of architectural integration significantly limits the potential for solar energy use. Improving the architectural design during construction can dramatically increase solar adoption.

A review of the current subsidy plan in the Republic of Serbia for financing such projects reveals that the subsidies are negligible and do not provide sufficient incentive for the widespread adoption of renewable energy sources - implementation of robust subsidy programs might boost the national adoption of renewables.Drawing on our analysis of the *Energoprojekt's* office building's solar power plant project in New Belgrade, which examined the technical, economic, and environmental aspects involved, we have formulated several key recommendations to facilitate the more efficient integration of these systems in other urban locations.

Recommendation One: Prioritize a comprehensive on-site feasibility assessment. Empty rooftops across buildings offer significant potential for solar power integration. Although initial implementation may appear straightforward, unforeseen contingencies can often arise during the realization phase - a thorough site feasibility assessment is critical to mitigate these risks. This evaluation comprehensively examines all potential challenges, ensuring the most optimal and efficient path to a successful solar power plant project. Fortunately, many software tools and design aids are currently available, facilitating the identification of the most suitable solution for each unique location.

Recommendation Two: Economic Considerations and Project Viability. Beyond environmental benefits, economic factors are a primary motivator for individuals and investors considering rooftop solar installations. Comprehensive financial evaluation requires investigating current subsidies and feed-in tariff rates. Additionally, research into grid interconnection costs and the availability of qualified contractors within the designated area is essential. Finally, the project's total economic feasibility factors in the acquisition and installation costs of the requisite equipment.

Recommendation Three: Legislative Framework and Regulatory Compliance: The Serbian legal framework governing the utilization of renewable energy sources presents a web of complexity that defies easy explanation. A thorough investigation into this domain is imperative to mitigate potential adverse consequences, such as the revocation of privileged producer status or, in extreme cases, the state's removal of the power plant if the producer fails to fulfil their obligations as mandated by the legislation.

This research has shown that implementing solar power plants in urban areas significantly impacts the environment at both micro and macro levels. It influences people's awareness of the ability to participate in modern life cycles, fulfilling a sense of purpose, and contributing to their immediate environment at the micro level. At the macro level, solar power plants contribute to the fight for environmental preservation by tackling the challenges posed by climate change. They represent a small but crucial step towards achieving the global goal of zero carbon dioxide emissions by 2050.

ACKNOWLEDGEMENTS

The paper is a part of the research done within the In-house project Energoprojekt's influence on the formation of Industry standards in the period from 1980. to the present day. The authors would like to thank to the Union Nikola Tesla University in Belgrade, which financed this project.

REFERENCES

Etukudoh E, Nwokediegwu Z, Umoh A, Ibekew K, Ilojianya V, Adefemi A (2024): Solar power integration in urban areas: A reviev of design innovations and efficiency enhancements: World Journal of Advenced Research and Revievs (WJARR), p. 2

Grujić J, Zanoškar I, Miletić N. (2012) Ugradnja solarnih panela na delu krova poslovne zgrade Enegoprojekta - Glavni projekat: Arhiva Energoprojekta

New York City Housing Authority [NYCHA] (2021): Announces Completion of Solar Installations at Queensbridge Houses: Bright Power News & Reports, New York, NY. Retrived April 22, 2024, from https://www.brightpower.com/nycha-announces-completion-of-solar-installations-at-queensbridge-houses/

Probst M. (2008) Architectual Integration and Design od Solar Thermal Systems : *École* Polytechnique Fédérale de Lausanne, Vaud, Switzerland, p. 5

Puoar M, Riznić M, Simonović S, Nikolić D (2009) Mogućnost primene foto-naponskih sistema u urbanim sredinama-studija slučaja: Energija, ekonomija, ekologija, Beograd, p.105

SeeleyD. (2022) The Largest Multifamily Solar Instalation in the U.S. is Going Up Now in North Texas: Dallas Inovates, Dallas, Texas. Retrived April 22, 2024, fromhttps://dallasinnovates.com/the-largest-multifamily-solar-installation-in-the-u-s-is-going-up-now-in-north-texas/

Singh P, Agrawal A. (2023) A Reviev of Solar Roof plant with or withouth reflectors: International Journal for Research in Applied Science & Engineering Technology (IJRASET), p.1

Sunce: Obnovljivi izvori energije[OIE] SRBIJA (2021), *Đorđa* Stanojevića 12, Novi Beograd. Retrived May 01, 2024, from https://oie.rs/oie/

Volpicelli G. (2017) La Siene Musicale is a building that's a boat that's an island: WIRED, San Francisco, California. Retrived April 22, 2024, from https://www.wired.com/story/la-seine-musicale-paris-river-architecture-design/

VujovićO. (2019) Korišćenje aktivnih solarnih sistema za uvećanje energetske efikasnosti objekata i drugi aspekti primene solarnih sistema na stambenim zgradama ili drugim objektima u komercijalne svrhe: Univerzitet Metropoliten Beograd, Futura Fakultet za primenjenu ekologiju, p.6

INVESTMENT IN RESEARCH AND DEVELOPMENT-CONTRIBUTION TO THE INNOVATIVE DEVEOPMNET

Stoimenov Suzana[1)] Gračanac Aleksandar[2)]

[1)]Univerzitet Union Nikola Tesla, Fakultet za preduzetnički biznis i menadžment nekretnina Beograd, JKP „Naissus" Niš

[2)]Univerzitet Union Nikola Tesla, Fakultet za preduzetnički biznis i menadžment nekretnina, Beograd

stoimenovsuzana@gmail.com

Abstract: The paper analyzes the investment in research and development, in the light of the innovative development of the country, and viewed through the approach to the defined goals of the strategies and the achieved number of patents.

The subject of the paper can be presented with the following questions: To what extent is investment in research and development carried out? What is the achieved level of realization of the goals determined in the strategies? Whether and to what extent investments in research and development contribute to the generation of patents or Is there a proportional relationship between the amount of investment in research and development and the number of patents? The aim of the paper is to present whether the investment of the analyzed countries over the period in research and development is aligned with the defined strategic goals, as well as to determine if investments in research and development are proportional to the indicator of the number of patents, without going into the issue of patent quality.

The contribution of this work is reflected in the application of the methodology of comparing the achieved level of realization of the set goal, which is related to the investment in research and development and the number of patents.

Research and development contributes to solving problems, developing innovation and competitiveness, but also sustainable development. Without investment in scientific research, there is no economic, social and environmental progress.

Key words: research and development, innovation, strategies

INTRODUCTION

Research and development is an important instrument in the development of innovation, and innovation is the basis of a country's competitive advantage. „Research and development (R&D) and innovation are key to providing the scientific and technical solutions needed to face global societal challenges such as climate change or active and healthy ageing." (Eurostat, 2024, p.55). Without investment in research and development, sustainable development cannot be ensured.

The paper is divided into thematic sections. In addition to outlining the goals of strategies that foresee investment in research and development, an analysis of R&D investments in selected countries for the period 2010-2022 has been conducted. The paper further presents a comparison between R&D investments and the number of patents to create a comprehensive picture of a country's achievements. The comparison between R&D investments and the number of patents helps in forming an image of a country's progress and accomplishments. The existence of strategies defining investment in research and development obliges countries to act in accordance with these strategies (Lisbon Strategy, Europe 2020 Strategy and Europe 2030). According to OECD (2023), investments in innovation and R&D can be a crucial part of business operations.

MATERIALS AND METHODS

The research method applied in this paper includes:

- Collection and systematic analysis of available data on investments in research and development, as well as the number of patents.
- An analytical approach to the significance of investments in research and development through the lens of patent numbers.
- Examination and analysis of data, extraction, and integration of data to address the topic of investment in research and development and its contribution to innovative development

RESULTS AND DISCUSSION

Strategies – Investment in Research and Development (% of GDP) – Patents

The Lisbon Strategy of 2000 set ambitious goals, one of which was for investment in research and development (R&D) to reach 3% of Gross Domestic Product (GDP) by 2010, with two-thirds of this funding to come from the private sector. The aim of the Lisbon Strategy was for the EU to become the most competitive knowledge-based economy in the world by 2010, capable of achieving sustainable economic growth. The indicator of investment in R&D as a percentage of GDP is a significant measure of a country's commitment to innovation.

The successor to the Lisbon Strategy, the new strategic framework for development until 2020, is the Europe 2020 Strategy. Adopted by Europe in March 2010, this strategy addresses the period following 2010. One of its main objectives is also to maintain the investment in research and development (R&D) at 3% of GDP. The period from 2020 onwards represents a new phase for research and innovation, and the European Commission has reaffirmed the goal that investment in research and innovation should remain at 3% of GDP.

The number of patents can be considered an indicator of technological progress related to research and development, as patents are a significant measure of how productive a country's investment in R&D has been. „Investing in research and development is regarded as a reliable measure of innovative potential" (Janjić, Jovanović, Simonović, 2021, p. 21). Additionally, as Eurostat notes: „Science and technology are part of almost every aspect of our daily lives and, along with innovation, can help address some of the major challenges facing society" (Eurostat, 2023, p. 9).

Investment in Research and Development by Country for the Period 2010-2022

Data on investment in research and development (% of GDP) has been sourced from the Eurostat database for the period 2010-2022. An analysis of the available data has been conducted, and the data and statistics are crucial indicators for monitoring societal reforms.

The analysis involves comparing countries based on their level of investment in research and development as a percentage of GDP. Below is a tabular representation (Table 1) of the R&D investments for the analyzed countries from 2010 to 2022, according to Eurostat data.

Table 1: Investment in Research and Development (% of GDP) for Analyzed Countries, 2010-2022

		R& D (%GDP)											
REGION/ TIME	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
European Union - 27 countries (from 2020)	1.97	2.02	2.08	2.1	2.11	2.12	2.12	2.15	2.18	2.22	2.3	2.27	2.24
Euro area – 20 countries (from 2023)	1.99	2.04	2.09	2.11	2.13	2.13	2.14	2.18	2.21	2.25	2.33	2.3	2.27
Euro area - 19 countries (2015-2022)	2.0	2.04	2.1	2.12	2.14	2.14	2.14	2.18	2.21	2.26	2.33	2.31	2.28
Belgium	2.06	2.17	2.28	2.33	2.37	2.43	2.52	2.67	2.86	3.16	3.4	3.43	3.43
Bulgaria	0.56	0.53	0.6	0.63	0.79	0.95	0.77	0.74	0.75	0.83	0.85	0.77	0.77
Czechia	1.33	1.54	1.77	1.88	1.96	1.92	1.67	1.77	1.9	1.93	1.99	2	1.96
Denmark	2.92	2.94	2.98	2.97	2.91	3.05	3.09	2.93	2.97	2.94	2.97	2.76	2.89
Germany	2.73	2.81	2.88	2.84	2.88	2.93	2.94	3.05	3.11	3.17	3.13	3.13	3.13
Estonia	1.58	2.31	2.12	1.72	1.43	1.47	1.24	1.28	1.41	1.62	1.75	1.77	1.78
Ireland	1.59	1.55	1.56	1.57	1.52	1.18	1.18	1.25	1.11	1.16	1.15	1.11	0.96
Greece	0.6	0.68	0.71	0.81	0.84	0.97	1.01	1.15	1.21	1.27	1.51	1.46	1.48
Spain	1.36	1.33	1.3	1.27	1.24	1.22	1.19	1.21	1.24	1.25	1.41	1.41	1.44
France	2.18	2.19	2,23	2.24	2.23	2.23	2.22	2.2	2.2	2.19	2.27	2.22	2.18
Croatia	0.73	0.74	0.74	0.8	0.77	0,83	0.85	0.85	0.95	1.08	1.24	1.24	1.43
Italy	1.22	1.2	1.26	1.3	1.34	1.34	1.37	1.37	1.42	1.46	1.51	1.43	1.33
Cyprus	0.44	0.45	0.44	0.48	0.51	0.48	0.52	0.54	0.61	0.71	0.84	0.8	0.77
Latvia	0.61	0.72	0.66	0.61	0.69	0.62	0.44	0.51	0.64	0.64	0.73	0.75	0.75
Lithuania	0.78	0.9	0.89	0.95	1.03	1.04	0.84	0.9	0.94	0.99	1.13	1.1	1.02
Luxembourg	1.42	1.42	1.21	1.23	1.22	1.25	1.27	1.24	1.17	1.18	1.1	1.04	0.98
Hungary	1.13	1.18	1.25	1.38	1.34	1.34	1.18	1.32	1.51	1.47	1.59	1.64	1.39
Malta	0.59	0.67	0.8	0.74	0.69	0.72	0.56	0.55	0.57	0.56	0.65	0.65	0.69
Netherlands	1.7	1.88	1.92	2.16	2,17	2.15	2.15	2.18	2.14	2.18	2.32	2.27	2.3
Austria	2.73	2.67	2.91	2.95	3.08	3.05	3.12	3.06	3.09	3.13	3.2	3.26	3.2
Poland	0.72	0.75	0.89	0.88	0.95	1	0.97	1.04	1.21	1.32	1.39	1.43	1.46
Portugal	1.54	1.46	1.38	1.32	1.29	1.24	1.28	1.32	1.35	1.4	1.61	1.67	1.7
Romania	0.45	0.47	0.46	0.39	0.38	0.49	0.49	0.51	0.5	0.48	0.47	0.47	0.46

Slovenia	2.05	2.41	2.56	2.56	2.37	2.2	2.01	1.87	1.95	2.04	2.14	2.13	2.11
Slovakia	0.61	0.65	0.79	0.82	0.88	1.16	0.79	0.88	0.84	0.82	0.9	0.92	0.98
Finland	3.71	3.62	3.4	3.27	3.15	2.87	2.72	2.73	2.76	2.8	2.91	2.99	2.95
Sweden	3.17	3.19	3.23	3.26	3.1	3.22	3.25	3.36	3.32	3.39	3.49	3.4	3.4
Iceland	:	2.4	:	1.69	1.94	2.18	2.11	2.08	2	2.34	2.49	2.8	2.66
Liechtenstein	:	:	:	:	:	:	:	:	:	:	:	:	:
Norway	1.64	1.62	1.61	1.64	1.7	1.92	2.03	2.08	2.03	2.14	2.24	1.94	1.6
Switzerland	:	:	2.87	:	:	3.08	:	3.08	:	3.2	:	3.31	:
United Kingdom	1.64	1.65	1.58	1.62	1.64	1.65	1.66	1.68	1.73	1.76	:	:	:
Bosnia and Herzegovina	0.79	:	0.27	0.32	0.26	:	:	:	:	0.19	0.2	0.19	:
Montenegro		0.31	:	0.37	0.36	0.37	0.32	0.35	0.5	:	:	:	:
North Macedonia		:	:	:	:	0.44	0.44	0.35	0.36	0.37	0.37	:	0.38
Albania		:	:	:	:	:	:	:	:	:	:	:	:
Serbia		0.68	0.85	0.68	0.72	0.81	0.84	0.87	0.92	0.89	0.91	0.99	0.97
Türkiye		0.79	0.83	0.81	0.86	0.97	1.12	1.18	1.27	1.32	1.37	1.4	1.32

Source:Eurostat, https://ec.europa.eu/eurostat/databrowser/view/tsc00001/default/table?lang=en&category=t_scitech.t_rd

As the goal of the Lisbon Strategy is investment in research and development of 3% (GDP) by 2010, the tabular presentation refers to the period 2010-2022. Data on investment in research and development as a % of GDP, as an indicator of the intensity of research and development, are relatively low compared to the defined goal of 3%. Although some countries have made significant progress in the field of investment in research and development, it can be seen that only a few countries achieved this goal in 2010, namely: Sweden's investment percentage was 3.17%. and Finland with an investment percentage of 3.71% of GDP. This percentage exceeds the goal set by the Lisbon Strategy of 3% and puts Finland at the very top in Europe, with Sweden positioned right behind it.

For the period following 2010, a new strategy was defined to continue development—the successor to the Lisbon Strategy, „Europe 2020"—a strategy for smart, sustainable, and inclusive growth. One of its main goals is also to achieve an R&D investment level of 3% of GDP. The Europe 2020 Strategy is not only relevant within the EU but also offers significant potential for candidate countries.

Germany stands out for its higher investment in research and development compared to other countries. However, it only achieved the 3% GDP target in 2017. In 2011, Germany's investment was 2.81%, which was still higher than the EU average of 2.02%

It is observed that countries which have significantly invested in research and development, besides Finland and Sweden, include Denmark, Austria, Slovenia, and France. Although Denmark invested significantly throughout the entire period, consistently more than the EU average, it managed to achieve R&D investment close to 3%—near the target set by the Lisbon Strategy—in 2015 and 2016. Some countries, such as Bulgaria, Latvia, Malta, and Romania, invested less than 1% during the period. While there has been notable progress towards achieving the targets between 2010 and 2020, investments in research and development still generally fall short of the goals set by the Europe 2020 Strategy.

In 2011, Finland achieved the highest R&D investment value at 3.62%, while Cyprus recorded the lowest at 0.45%. The difference between the maximum and minimum R&D investment values was 3.17%. The national targets set by member states for R&D investment were 4% of GDP for Finland and Sweden, while the lowest targets were set for Cyprus (0.5%) and Greece (0.67%).

Number of Patents as an Indicator of R&D Investment (% GDP)

In order to evaluate the process of investment in research and development of the state, the number of patents was observed in the continuation of the paper. The number of patents indicator can be expressed as the total number of patents or the number of patents per million inhabitants. The total number of patents was taken into consideration (Patents for climate change mitigation technologies related to wastewater treatment or waste management). The mentioned sub-indicator was also chosen for the reason that investment in research and development is crucial in order to achieve climate neutrality. In the continuation of the work, table 2 shows the number of patents for the analyzed countries for the period 2010-2020. Years, according to Eurostat data. It is about an indicator that is standardized for all countries (predicted by the monitoring of the European Commission), so it represents a good basis for comparison between countries. Analysis by parameter number of patents with public indications of which countries are leaders in the number of patents can be very useful for other countries to apply the principles of commitment.

Table 2: Table display - number of patents for the period 2010-2020.

REGION/ TIME	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
European Union - 27 countries (from 2020)	307.86	324.62	339.79	321.47	337.33	357.28	325.76	309.21	316.13	385.71	206.55
Belgium	14.03	8.37	8.92	15.41	12.15	19.26	16.26	19.35	16.08	15.58	5.49
Bulgaria	1	1	0	0	1.5	0.5	0.33	0.22	0.5	0	0
Czechia	7.65	4.46	7.32	7	4.33	2.66	1.84	6.4	4.67	9.49	7.16
Denmark	0.31	4.99	4.3	6.94	10.04	5.75	7.18	6.34	5.63	8.4	2.83
Germany	92.02	110.25	91.62	86.41	89.86	89.46	82.62	71.18	84.57	103.78	45.67
Estonia	0.25	0	0.25	0	3	0	1	0	0	0	0
Ireland	2.09	3.75	1.4	2.46	3.86	1.45	4.93	3.75	1.87	5.42	3.83
Greece	1.29	0	0	0	1	3.5	1	2.25	0	0.3	0.5
Spain	17.72	17.66	18.37	29.64	21.94	18.21	27.31	15.34	18.45	17.68	21.34
France	47.28	37.54	52.12	39.61	69.07	39.34	36.88	38.46	37.16	52.41	27.09
Croatia	1	0.67	0.17	0	0	0	2.16	0	0	0	0
Italy	28.7	29.45	33.59	27.22	18.71	20.82	29.34	28.61	23.39	48.51	21.51
Cyprus	0	1.8	0	0	0	1	0	0	0	0	0
Latvia	1.5	0	2.33	4	0.08	2.3	1	1	0	0	0.5
Lithuania	2	1.5	1.14	1	0	0	0	0	0	1.5	0
Luxembourg	1.8	1.67	2.81	3.53	6.62	3.54	2.7	5.74	2.33	2	2.5
Hungary	6.32	4.57	3.4	1.25	2.9	2.33	3.16	1	2	3	0
Malta	0	0	0	0	0.75	1	0	0	0	0	0
Netherlands	11.38	18.52	18.57	17.86	22.18	23.93	24.25	24.47	33.46	33.52	13.25
Austria	10.31	15.95	11.44	10.44	10.37	10.6	7.71	5.33	13.01	17.53	6.49
Poland	34.67	36.9	55.67	36.71	28.22	69.61	44.35	34.27	22.21	20.23	17.25
Portugal	2.5	5.25	2.83	3	0	5	1	1	2	3	5.42
Romania	4.97	5	4.99	2.33	5	4.5	5.71	8.49	9.5	7.9	5
Slovenia	0	0.2	0	2	2.25	0	0	0.99	0	1	1
Slovakia	0	0	2.23	1	1.33	4.25	0	2.27	1.5	3.67	0
Finland	15.06	7.79	11.73	14.95	15.37	18.47	18.96	18.78	18.63	16.38	15
Sweden	4.01	7.33	4.59	8.71	6.8	9.8	6.07	13.98	19.17	14.41	4.72
United Kingdom	27.21	27.09	32.15	26.78	24.37	23.36	31.51	23.89	24.26	34.38	14.12

Source:Eurostat ,https://ec.europa.eu/eurostat/databrowser/view/CEI_CIE020__custom_6107747/bookmark/table?lang=en&bookmarkId=97a2d688-b1ac-4b66-a9ae-0bc787460db7

The leader is Germany, and the number of patents is increasing every year. Right behind Germany are France and Poland. Germany is a highly developed industrial country with a highly efficient scientific system. This has really contributed to Germany being a leader in innovation among many other countries. An example of high investment in research and development (R&D) in Germany can be seen through the activities of large German companies that are at the forefront of global innovation. Some examples in Germany are: (Volkswagen Group, Bosch, Siemens, Bayer). Finland and Sweden, as two countries with high investments in research and development, are far below Germany in terms of the number of patents. While the average number of patents/year (period 2010-2021) for Germany is 86, in Sweden that number is around 9 and in Finland 16 patents/year for the mentioned period. The countries with the largest number of patents are: Germany, France, Poland, Italy, the Netherlands, Great Britain).

CONCLUSION

It is very important that the countries set their national pipelines, as well as that the national goals of the member states are fulfilled, so that it is possible to reach the goals of the EU strategies. data presented in the paper. A significant factor is the efficiency of research processes, the quality of the workforce, the size and structure of the economy. The size of the investments alone does not automatically guarantee a high number of patents.

REFERENCES

European Commission – EC (2020). „Communication from the commission to the European Parliament, the council, the European Economic and social committee and the committee of the regions",COM/2020/628. Retrieved January 12,2024, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0628

European Commission – EC (2021). „Communication from the commission to the European Parliament, the council, the European Economic and social committee and the committee of the regions",COM/2021/252. Retrieved January 15,2024, from

Eurostat. (2024). „Key figures on Europe – 2024 edition", Flagship publications. Retrieved Jun 20, 2024, from

Eurostat.(2023). „European Business Statistics Methodological Manual for R&D statistics- 2023 edition", Manuals and Guidelines.Retrieved Jun 20,2024,from https://ec.europa.eu/eurostat/documents/3859598/18171553/KS-GQ-23-

015-EN-N.pdf/0b833957-f02e-c3cd-fc43-e86d771926f4?version=1.0 &t=1702890320670 , p.9

Eurostat.(2023)."Patents related to recycling and secondary raw materials", Data browser. Retrieved Jun, 2, 2024 from

Eurostat.(2024). „Research and development expenditure, by sectors of performance", Data browser. Retrieved Jun, 2, 2024 from

https://ec.europa.eu/eurostat/databrowser/view/cei_cie020/default/table?lang=en

https://ec.europa.eu/eurostat/databrowser/view/tsc00001/default/table?lang=en&category=t_scitech.t_rd

https://ec.europa.eu/eurostat/documents/15216629/19559843/KS-EI-24-001-EN-N.pdf/4aa75d55-c529-414b-5dc2-e4be3df1b199?version=3.0 &t=1722243547613, p.55

https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0252

https://www.oecd-ilibrary.org/docserver/4b829cf6-en.pdf?expires=1724757411&id =id&accname=guest&checksum=565FD2DFA7880F955B9A48CE4A279E4D

Janić, I., Jovanović, M & Simonović, Z.(2021). „The importance of research and development for innovative activity: the overview of the top countries in Europe and worldwide,the overview of the countries in Europe and worldwide." Economics of sustainable developmnet 5(2): p.21. DOI: 10.5937/ESD2102019J

Kronja, J.(2015). „Strategija Evropa 2020 - 4 godine kasnije vodič. Evropski pokret u Srbiji" Retrieved Jun, 15, 2024 from https://europa.rs/images/publikacije/29-Evropa_2020.pdf

Organisation for Economic Co-operation and Development – OECD. (2023). „Competition in the Circular Economy" OECD Competition Policy Roundtble", OECD publishing. Retrieved Jun, 12, 2024 from

ECO INNOVATIONS AND EMPLOYEE KNOWLEDGE, SKILLS, AND ABILITIES

Tatjana Ilić-Kosanović[1] Damir Ilić[2]

[1]University „Union - Nikola Tesla"

[2]School of Engineering Management

tilickosanovic@unionnikolatesla.edu.rs

Abstract:

Technological, social, and environmental changes are reshaping the business landscape, influenced by the rise of new economic powers, advancements in Industry 4.0, and the emphasis on environmental protection. The adaptation of both local and global businesses to these changes will significantly impact long-term economic effectiveness, sustainability, social relationships, and environmental protection. Eco-innovations, encompassing innovative manufacturing processes, products, services, and business strategies, aim to prevent or reduce environmental risks and pollution throughout a product's lifecycle. Promoting workplace innovations, where employees generate new ideas to enhance performance, product quality, and customer satisfaction, is a key method of adaptation. Employee-led eco-innovations can improve job satisfaction, organizational performance, and contribute to economic and social growth, recognized increasingly by European governments as a strategic advantage. EU programs support eco-innovations by fostering sustainable production and consumption strategies, advancing new technologies, creating jobs, and enhancing economic competitiveness, with a focus on areas such as materials reutilization, sustainable construction, food industry, water resource management, and environmentally friendly business models.

Eco-innovation training programs are essential for equipping employees with the skills needed to develop, implement, and support sustainable practices within their organizations. These programs encompass several key components, including foundational knowledge of sustainability, compliance with relevant legislation, technical training in renewable energy and green technologies, methodologies like Life Cycle Analysis (LCA) and eco-design, practical project management skills, and fostering creative thinking and continuous learning.

Through specialized workshops, online courses, field training, internal development programs, academic partnerships, certification opportunities, simulation games, and industry-specific modules, these trainings can be tailored to the diverse needs of various sectors. The significance of these programs lies in their ability to enhance organizational efficiency, reduce ecological footprints, boost competitiveness, ensure regulatory compliance, and stimulate innovation and growth. By integrating these comprehensive and adaptable approaches, eco-innovation training not only advances sustainable development but also prepares organizations to meet future challenges effectively.

Keywords: Eco-innovations, employee skills, training.

INTRODUCTION

Technological, social, and environmental changes are altering business landscape for various industries, compelled by factors such as the emergence of new economic powers; technological advancements and implementation of Industry 4.0 modifying manufacturing and business practices; and the understanding of the importance for focusing on environmental protection. How both local and global businesses adjust to these changes will considerably influence long-term economic effectiveness and sustainability, social relationships, and environmental protection (Ortega-Lapiedra, Marco-Fondevila, Scarpellini, Llena-Macarulla, 2019; Huang, Lu, Chau, Zeng, 2020; Peyravi, Jakubavičius, 2022; Novita, Hidayatulloh, Renwarin, Santoso, Mardikaningsih, 2022; Piwowar-Sulej, Iqbal, Dagar, Singh, 2024).

Eco-innovations consist of innovative manufacturing processes, products, services, and business management strategies that focus on preventing or considerably reducing environmental risks, pollution, and other destructive influences related to linear economy and usage of resources throughout a product's entire life cycle (Arundel, Kemp, 2009; Pereira, Vence, 2012; Peyravi, Jakubavičius 2022; Cisneros Chavira, Shamsuzzoha, Kuusniemi, Jovanovski, 2023; Miao, Iqbal, Ayub, 2023). One method of adaptation is through promoting workplace innovations, where employees are motivated to cultivate and propose new ideas in order to enhance organizational performance, products or services quality, and customer satisfaction (Weigt-Rohrbeck, Linneberg, 2019; Peyravi, Jakubavičius, 2022; Piwowar-Sulej, Iqbal, Dagar, Singh, 2024).

Various implemented eco-innovations models demonstrate that eco-initiatives proposed and implemented by employees can improve job satisfaction and commitment, and organizational performance, contributing to economic and social growth (Klewitz, Zeyen, Hansen, 2012; Rashid, Jabar, Yahya, Shami, 2015; Peyravi, Jakubavičius, 2022; Jovanović-Vujatović, Ognjanović, Popović, 2022; Falchi, Grolleau, Mzoughi, Pekovic, 2023). European governments are increasingly identifying employee-led workplace innovation as a main strategic competitive advantage at turbulent and competitive markets.

EU programs for entrepreneurship and innovation support eco-innovations by promoting new products, processes, and services that have a reduced environmental impact throughout their life cycle. The European Commission aims to encourage market diffusion of these eco-innovations, which fosters sustainable production and consumption strategies, advances new technologies, generates jobs, and enhances economic growth and competitiveness. Funding opportunities predominantly target small businesses needing support to overcome barriers to successfully bringing best eco-innovative projects to the European market (European Commission, n.d.). Most of the programs for entrepreneurship and innovation focus on the following areas (European Commission, n.d.):

- Materials reutilizing and recycling good practices;
- Sustainable construction;
- Food industry;
- Competent consumption, management, and distribution of water resources;
- Environmentally friendly business models.

MATERIALS AND METHODS

Eco innovations

Eco-innovations, also known as environmental innovations or green innovations, refer to new products, processes, or practices that reduce environmental impacts, enhance resource efficiency, and contribute to sustainable development (Kiefer, Del Río González, Carrillo-Hermosilla, 2019; Sehnem, Lazzarotti, Bencke, 2016; Triguero, Cuerva, Sáez-Martínez, 2022). These innovations aim to minimize the negative effects on the environment, promote the use of renewable resources, and improve the quality of life for current and future generations (Pereira, Vence, 2012; Kesidou, Demirel, 2012; Rashid, Jabar, Yahya, Shami, 2015). Some key aspects and examples of eco-innovations are:

- Resource efficiency: Innovations that optimize the use of natural resources, reducing waste and energy consumption. Examples include energy-efficient appliances, water-saving technologies, and materials recycling processes.

- Renewable energy: Development and deployment of technologies that harness renewable energy sources, such as solar, wind, hydro, and geothermal energy. These innovations help reduce dependence on fossil fuels and lower greenhouse gas emissions.
- Sustainable agriculture: Practices and technologies that promote sustainable farming, such as precision agriculture, organic farming, and agroforestry. These methods aim to maintain soil health, reduce chemical inputs, and enhance biodiversity.
- Green transportation: Innovations in transportation that reduce emissions and improve fuel efficiency. Examples include electric vehicles, hybrid cars, public transportation systems, and bike-sharing programs.
- Circular economy: Business models and processes that promote the reuse, refurbishment, and recycling of products and materials. This approach minimizes waste and maximizes the lifecycle of resources.
- Eco-friendly materials: Development of sustainable materials that have a lower environmental impact. Examples include biodegradable plastics, recycled materials, and non-toxic chemicals.
- Waste management: Technologies and practices that improve waste collection, sorting, recycling, and disposal. Innovations in this area help reduce landfill usage and promote the recovery of valuable materials.
- Water management: Solutions that enhance water conservation, purification, and distribution. Examples include advanced irrigation systems, water recycling technologies, and desalination plants.

The most known examples of eco-innovations are:

- Solar panels: Devices that convert sunlight into electricity, providing a clean and renewable source of energy.
- Electric vehicles (EVs): Cars powered by electricity, which produce zero emissions and reduce reliance on fossil fuels.
- Smart thermostats: Devices that optimize heating and cooling in buildings, reducing energy consumption and costs.
- Vertical farming: Growing crops in vertically stacked layers, often in urban environments, to maximize space and resource efficiency.
- Biodegradable packaging: Packaging materials that decompose naturally, reducing plastic waste and pollution.
- Rainwater harvesting systems: Technologies that collect and store rainwater for reuse in irrigation, flushing toilets, and other non-potable applications.

Importance of Eco-Innovations

Eco-innovations are crucial for addressing global environmental challenges such as climate change, resource depletion, and pollution (Sehnem, Lazzarotti, Bencke, 2016; Triguero, Cuerva, Sáez-Martínez, 2022; Passaro, Quinto, Scandurra, Thomas, 2023). They help to:

- Reduce environmental footprint: By minimizing emissions, waste, and resource consumption.
- Promote sustainability: Supporting the transition to a more sustainable and resilient economy.
- Enhance quality of life: Providing cleaner air, water, and healthier living conditions.
- Create economic opportunities: Generating new markets, jobs, and business models focused on sustainability.

Overall, eco-innovations are vital for achieving a balance between economic growth and environmental stewardship, ensuring a sustainable future for all (Ortega-Lapiedra, Marco-Fondevila, Scarpellini, Llena-Macarulla, 2019; Novita, Hidayatulloh, Renwarin, Santoso, Mardikaningsih, 2022; Triguero, Cuerva, Sáez-Martínez, 2022).

Eco-innovations and employee skills

Eco-innovations and employee skills are closely entangled, as the successful development and implementation of eco-innovations depend on a workforce equipped with the necessary knowledge, skills, and abilities (Horbach, Jacob, 2018; Ortega-Lapiedra, Marco-Fondevila, Scarpellini, Llena-Macarulla, 2019; Shamzzuzoha, Chavira, Kekäle, Kuusniemi, Jovanovski, 2022). It is important to analyze how employee skills contribute to eco-innovations and the types of skills that are particularly relevant. Importance of employee skills for eco-innovations include (Sehnem, Lazzarotti, Bencke, 2016; Novita, Hidayatulloh, Renwarin, Santoso, Mardikaningsih, 2022; Shamzzuzoha, Chavira, Kekäle, Kuusniemi, Jovanovski, 2022):

- Innovation and creativity: Employees with creative thinking and problem-solving skills can develop new ideas and solutions that drive eco-innovations. They can envision novel approaches to reduce environmental impacts and enhance sustainability.

- Technical expertise: specialized knowledge in fields such as engineering, environmental science, and information technology is crucial for developing and implementing eco-friendly technologies and processes.
- Interdisciplinary knowledge: Eco-innovations often require a holistic understanding of various disciplines. Employees who can integrate knowledge from multiple fields, such as biology, chemistry, economics, and social sciences, can create more effective and comprehensive solutions.
- Project management: Effective management skills ensure that eco-innovation projects are planned, executed, and evaluated efficiently. This includes skills in resource allocation, time management, and stakeholder coordination.
- Communication and collaboration: Clear communication and the ability to work collaboratively across different teams and departments are essential for the successful adoption of eco-innovations. Employees must be able to convey the benefits and processes of eco-innovations to stakeholders.
- Adaptability and learning agility: The field of eco-innovation is dynamic, with constant advancements and changes. Employees who can quickly adapt to new technologies and methodologies and who are committed to continuous learning are valuable assets.

The most important specific skills for eco-innovations include:

- Environmental management: Understanding of environmental regulations, sustainability practices, and ecological principles.
- Renewable energy technologies: Knowledge of solar, wind, hydro, and other renewable energy systems, including their design, installation, and maintenance.
- Sustainable design and architecture: Skills in designing buildings and products that are energy-efficient, use sustainable materials, and have a minimal environmental footprint.
- Data analysis and modeling: Ability to analyze environmental data, model ecological impacts, and assess the effectiveness of eco-innovations.
- Life cycle assessment (LCA): Expertise in evaluating the environmental impacts of products and processes throughout their entire lifecycle.
- Green chemistry: Knowledge of chemical processes and products that reduce or eliminate the use of hazardous substances.
- Circular economy practices: Skills in designing and implementing processes that promote recycling, reuse, and waste reduction.

- Energy management: Ability to optimize energy use in industrial processes, buildings, and transportation systems.

Brainstorming Session

A brainstorming session on eco-innovation and employee skills as an imaginative method intended to implement scientific qualitative analysis and to produce inventive concepts and explanations that contribute to improving sustainability and environmental performance within the organizations. In the case of researching for this particular article, a session focused on leveraging the skills and knowledge of employees to develop practical and impactful eco-innovations is organized. Participants were scientists involved in research on sustainability, environmental protection, green organizational approaches, human resources management and development.

According the literature research, participants were given the foundations for the discussion: identifying training needs for eco-innovation skills, participation of employees in generating new product ideas, improving existing processes, improving energy efficiency, waste reduction, or sustainable sourcing. Brainstorming session was organized on June 8, 2024. Main discussion focused on training or development programs required to equip employees with these skills.

Main talking points of the brainstorming session build a base for enhancing employee skills for eco-innovations that includes:

- Training and development programs: Organizations can invest in training programs to equip employees with the latest knowledge and skills in sustainability and eco-innovation.
- Cross-functional teams: Encouraging collaboration across different departments can foster the exchange of ideas and knowledge, leading to more holistic and effective eco-innovations.
- Partnerships with educational institutions: Collaborating with universities and research institutions can provide access to cutting-edge research and emerging talent in the field of eco-innovation.
- Continuous learning opportunities: Offering opportunities for continuous learning, such as workshops, seminars, and online courses, can help employees stay updated with the latest trends and technologies.
- Encouraging a culture of innovation: Creating an organizational culture that values and rewards innovation and sustainability can motivate employees to pursue eco-innovative ideas and solutions.

Brainstorming session participants agreed that by focusing on these areas, organizations can ensure that their workforce is well-prepared to drive and support eco-innovations, contributing to a more sustainable and environmentally friendly future.

RESULTS

Discussion group members agreed that eco-innovation trainings are key to empowering employees to develop, implement and support innovative and sustainable practices in their organizations in line with previous research (Valdez-Juárez, Castillo-Vergara, 2021; Zappalà, Radassao, Toscano, 2023). The group created outline of what eco-innovation trainings may look like, what components would they comprise of, what is their significance:

1. Components of training for eco innovations
   - Theoretical basis and awareness of sustainability.
   - Basic terms and principles: Getting to know the basics of sustainable development, eco-innovation and circular economy.
   - Legislation and standards: Understanding of local and international regulations, standards and guidelines related to environmental protection and sustainability.
2. Technical training
   - Renewable energy: Education on solar, wind, hydro and geothermal technologies, including design, installation and maintenance.
   - Green technologies: Training on energy efficient technologies, waste management systems, recycling and reuse of materials.
3. Methodologies and tools
   - Life cycle analysis (LCA): Training on tools and methodologies for assessing the environmental impacts of products throughout their life cycle.
   - Eco-design and sustainable design: Principles of designing products and systems that reduce the negative impact on the environment.
4. Practical skills
   - Project management: Techniques of planning, implementation and evaluation of eco-innovation projects.
   - Communication and collaboration: Developing skills for effective communication and collaboration with diverse teams and stakeholders.

5. Creative thinking and innovation
    - Creative thinking techniques: Training for the development of creativity and innovative thinking that can lead to new and more efficient eco-solutions.

- Idea generation workshops: Hands-on sessions to identify problems and find innovative solutions.

6. Continuous learning and improvement
    - Seminars and workshops: Regular events to refresh your knowledge and familiarize yourself with the latest trends and technologies.
    - Online courses and webinars: Flexible learning options that allow employees to follow the course at their own pace.

Some of the trainings, discussion group agreed, may include: trainings for energy efficiency (energy saving techniques); waste management training (advanced systems for recycling, reuse and waste reduction); training for sustainable agriculture (principles of organic agriculture, the use of new technologies), etc.

DISCUSSION

Significance of training for eco innovations is acknowledged by many authors researching the topic of eco innovations (Shamzzuzoha, Chavira, Kekäle, Kuusniemi, Jovanovski, 2022; Passaro, Quinto, Scandurra, Thomas, 2023), some of the outcomes may be:

- Increased efficiency and productivity: Training enables employees to use resources more efficiently and reduce operating costs.
- Reducing the ecological footprint: Educated employees can implement practices that reduce the negative impact on the environment.
- Increased competitiveness: organizations with a focus on eco-innovation can become market leaders and attract customers and investors who value sustainability.
- Improved regulatory compliance: understanding and complying with environmental regulations and standards can reduce legal risks and improve a company's reputation.
- Encouraging innovation and growth: continuous training of employees boosts innovative thinking and can lead to the development of new products and services.

Through these modules and approaches, eco-innovation training can considerably contribute to the sustainable development of organizations and their capability to adjust to the challenges of the future (Sehnem, Lazzarotti, Bencke, 2016; Passaro, Quinto, Scandurra, Thomas, 2023;). Eco-innovation training can be diverse and modified to the particular needs of different industries and organizations (Shamzzuzoha, Chavira, Kekäle, Kuusniemi, Jovanovski, 2022). Here are a few different approaches and training formats that can be useful for improving the skills of employees in the field of eco-innovation:

1. Specialized workshops
   - Intensive courses: through short, intensive courses, employees can quickly acquire specific skills and knowledge. For example, a two-day workshop on the introduction of solar panels or recycling systems.
   - Practical exercises: workshops that include practical exercises, such as the installation of energy-efficient devices or life cycle assessment (LCA) simulation.
2. Online trainings and webinars
   - Flexible learning: online courses allow employees to learn at their own pace.
   - Specialized webinars: regular webinars with industry experts providing the latest information and trends in the field of eco-innovation.
3. Field training and visits
   - Study visits: organizing visits to companies or plants that have implemented successful eco-innovations, where employees can see examples of good practice.
   - Field work: practical training in the field, such as sustainable agriculture programs or renewable energy installations.
4. Internal development programs
   - Mentoring and coaching: Experienced sustainability experts mentor younger or less experienced employees, helping them develop specific skills.
   - Job rotation: employees are rotated between different departments in order to gain a broad knowledge and understanding of eco-innovations in different contexts.
5. Cooperation between Academia and Industry
   - Partnerships with universities: Organizational cooperation with universities to develop specific training programs, including joint research projects and professional courses.

- Practical teaching: inclusion of practical teaching modules in academic courses, where students work on real industrial projects.

6. Certification programs
   - Professional certifications: Programs offering internationally recognized certifications, such as ISO 14001 (Environmental Management).
   - Specialized trainings: trainings that end with a recognized certificate, such as certificates for energy managers or certificates for sustainable resource management.
7. Simulations and games
   - Simulation games: using simulation games to learn about resource management, energy planning or circular economy.
   - Interactive platforms: online platforms that use interactive training approaches, such as gamification and virtual realities.
8. Customized programs for specific industries
   - Industry specific training: programs adapted to the specific needs of certain industries, such as construction, agriculture, manufacturing or IT.
   - Flexible approach: trainings consisting of different modules, where organizations can choose the ones most relevant to their needs.

The researchers agree on the advantages of different approaches that include:

- Flexibility and adaptability: different training formats allow organizations to choose approaches that best suit their needs and resources.
- Practical application: the combination of theory and practice ensures that employees not only acquire knowledge, but also apply it in real situations.
- Continuous learning: opportunities for continuous learning and improvement ensure that employees stay up to date with the latest trends and technologies.
- Motivation and engagement: varied and interactive training methods can increase employee engagement and motivation to learn.

CONCLUSION

Eco-innovation trainings are key to empowering employees to contribute to sustainability and innovation in their organizations. The diversity of training methods and designs allows organizations to fit programs to their specific needs and resources, in that way increasing the effectiveness and impact of these initiatives. Furthermore, it is imperative to include eco-innovation into the organizational culture and to develop organizational behavior outlines and patterns for embedding eco-innovations awareness and compliance into the organizational culture.

REFERENCES

Arundel, A. V., & Kemp, R. (2009). Measuring eco-innovation. MERIT Working Papers from United Nations University - Maastricht Economic and Social Research Institute on Innovation and Technology (MERIT). Retrieved on June 24, 2024 from https://unu-merit.nl/publications/wppdf/2009/wp2009-017.pdf

Cisneros Chavira, P., Shamsuzzoha, A., Kuusniemi, H., & Jovanovski, B. (2023). Defining green innovation, its impact, and cycle – A literature analysis. Cleaner Engineering and Technology, 17. https://doi.org/10.1016/j.clet.2023.100693

European Commission. (n.d.). Sustainable Product Policy. Retrieved on June 28, 2024 from https://joint-research-centre.ec.europa.eu/scientific-activities-z/sustainable-product-policy_en

Falchi, A., Grolleau, G., Mzoughi, N. & Pekovic, S. (2023). Eco-innovations and Job Satisfaction: A Moderated Mediation Approach. Journal of Innovation Economics & Management, 42, 185-199. https://doi.org/10.3917/jie.pr1.0142

Horbach, J., & Jacob, J. (2018). The relevance of personal characteristics and gender diversity for (eco-) innovation activities at the firm-level: Results from a linked employer–employee database in Germany. Business Strategy and the Environment, 27(7), 924-934.

Huang, S. Z., Lu, J. Y., Chau, K. Y., & Zeng, H. L. (2020). Influence of ambidextrous learning on eco-innovation performance of startups: Moderating effect of top management's environmental awareness. Frontiers in Psychology, 11, 1976.

Jovanović-Vujatović, M., Ognjanović, J., & Popović, S. (2022). The role of eco-innovation in sustainable intellectual capital of the company. Economics of Sustainable Development, 6(2), 43-51. https://doi.org/10.5937/ESD2202043J

Kesidou, E., & Demirel, P. (2012). On the drivers of eco-innovations: Empirical evidence from the UK. Research policy, 41(5), 862-870.

Kiefer, C. P., Del Río González, P., & Carrillo-Hermosilla, J. (2019). Drivers and barriers of eco-innovation types for sustainable transitions: A quantitative perspective. Business Strategy and the Environment, 28(1), 155-172.

Klewitz, J., Zeyen, A., & Hansen, E. G. (2012). Intermediaries driving eco-innovation in SMEs: A qualitative investigation. European Journal of Innovation Management, 15(4), 442-467.

Miao, Y., Iqbal, S., & Ayub, A. (2023). The road to eco-excellence: How does eco-friendly deliberate practice foster eco-innovation performance through creative self-efficacy and perceived eco-innovation importance? Sustainability, 15(4), 3481.

Novita, D., Hidayatulloh, A. N., Renwarin, J. M., Santoso, R., & Mardikaningsih, R. (2022). Relationship Between Eco Transformational Leadership, Eco Training, and Employee Eco Behavior on Sustainable Corporate Performance of SMEs. Frontiers in Psychology, 13, 900787.

Ortega-Lapiedra, R., Marco-Fondevila, M., Scarpellini, S., & Llena-Macarulla, F. (2019). Measurement of the human capital applied to the business eco-innovation. Sustainability, 11(12), 3263.

Passaro, R., Quinto, I., Scandurra, G., & Thomas, A. (2023). The drivers of eco-innovations in small and medium-sized enterprises: A systematic literature review and research directions. Business Strategy and the Environment, 32(4), 1432-1450.

Pereira, Á., & Vence, X. (2012). Key business factors for eco-innovation: An overview of recent firm-level empirical studies. Cuadernos de Gestion, 12, 73-103.Pichlak, M. (2021). The drivers of technological eco-innovation—Dynamic capabilities and leadership. Sustainability, 13(10), 5354.

Peyravi B, Jakubavičius A. (2022). Drivers in the Eco-Innovation Road to the Circular Economy: Organiational Capabilities and Exploitative Strategies. *Sustainability*. 2022; 14(17):10748. https://doi.org/10.3390/su141710748

Piwowar-Sulej, K., Iqbal, Q., Dagar, V., & Singh, S. (2024). Employees' eco-friendly innovative behaviors: Examining the role of individual and situational factors. European Management Journal. https://doi.org/10.1016/j.emj.2024.04.005

Rashid, N., Jabar, J., Yahya, S., & Shami, S. (2015). Dynamic eco innovation practices: A systematic review of state of the art and future direction for eco innovation study. Asian Social Science, 11(1), 8.

Sehnem, S., Lazzarotti, F., & Bencke, F. F. (2016). Sustainable practices and eco-innovations adopted by industrial companies. International Journal of Innovation, 4(2), 42-58.

Shamzzuzoha, A., Chavira, P. C., Kekäle, T., Kuusniemi, H., & Jovanovski, B. (2022). Identified necessary skills to establish a center of excellence in vocational education for green innovation. Cleaner Environmental Systems, 7, 100100.

Triguero, Á., Cuerva, M. C., & Sáez-Martínez, F. J. (2022). Closing the loop through eco-innovation by European firms: Circular economy for sustainable development. Business Strategy and the Environment, 31(5), 2337–2350. https://doi.org/10.1002/bse.3024

Valdez-Juárez, L. E., & Castillo-Vergara, M. (2021). Technological capabilities, open innovation, and eco-innovation: Dynamic capabilities to increase corporate performance of SMEs. Journal of Open Innovation: Technology, Market, and Complexity, 7(1), 8.

Weigt-Rohrbeck, J., & Linneberg, M. S. (2019). Democratizing innovation processes: personal initiative in bottom-up eco-innovation. European Journal of Innovation Management, 22(5), 821-844.

Zappalà, S., Radassao, L., & Toscano, F. (2023). Greening Organizations: The Relationship between Employee Environmental Concern, Perception of Advantages of Eco-Innovations, and Support for Innovation. Sustainability, 15(24), 16718.

CIP - Каталогизација у публикацији Народна библиотека Србије, Београд

502/504(082)

INTERNATIONAL Conference on Sustainable Environment and Technologies „Creating sustainable commUNiTy" (4 ; 2024 ; Beograd)
Proceedings / The Fourth International Conference on Sustainable Environment and Technologies [„Creating sustainable commUNiTy"], 27-28 September 2024, Belgrade, Serbia ; [editors Ljiljana Nikolić Bujanović, Sanja Mrazovac Kurilić] ; [organizer University „Union Nikola Tesla", Belgrad, Serbia]. - Beograd : University „Union Nikola Tesla", 2024 (Belgrade : Dobrotoljublje). - 396 str. : ilustr. ; 26 cm

Tiraž 60. - Napomene i bibliografske reference uz radove. - Bibliografija uz svaki rad.

ISBN 978-86-89529-46-3

а) Животна средина -- Зборници

COBISS.SR-ID 152377097