



UNIVERSITY OF NOVI SAD
Technical Faculty "Mihajlo Pupin"
Zrenjanin, Republic of Serbia



PROCEEDINGS

of the XV International Conference on
**Industrial Engineering and
Environmental Protection
IIZS 2025**

Zrenjanin, Serbia, October 2-3, 2025.



University of Novi Sad
Technical Faculty "Mihajlo Pupin"
Zrenjanin, Republic of Serbia



PROCEEDINGS
of the XV International Conference on
**Industrial Engineering and
Environmental Protection
IIZS 2025**

Zrenjanin, October 2-3, 2025.

IN COOPERATION WITH PARTNERS:

	<p>UNIVERSITY POLITEHNICA TIMISOARA, FACULTY OF ENGINEERING, HUNEDOARA, ROMANIA</p>	
	<p>UNIVERSITY «St. KLIMENT OHRIDSKI», TECHNICAL FACULTY, BITOLA, MACEDONIA</p>	
	<p>„AUREL VLAICU” UNIVERSITY OF ARAD, FACULTY OF ENGINEERING, ARAD, ROMANIA</p>	
	<p>UNIVERSITY OF EAST SARAJEVO, FACULTY OF MECHANICAL ENGINEERING EAST SARAJEVO, REPUBLIC OF SRPSKA, B&H</p>	
	<p>UNIVERSITY OF GIRE SUN, FACULTY OF ENGINEERING, GIRE SUN, TURKEY</p>	

Proceedings of the XV International Conference - Industrial Engineering and Environmental Protection (IIZS 2025)

Conference organizer:

Technical Faculty "Mihajlo Pupin", Zrenjanin, University of Novi Sad, Republic of Serbia

Reviewers:

PhD Eleonora Desnica, Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia
PhD Bogdana Vujić, Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia
PhD Slavica Prvulović, Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia
PhD Ljiljana Radovanović, Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia
PhD Jasmina Pekez, Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia
PhD Višnja Mihajlović, Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia
PhD Snežana Filip, Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia
PhD Mića Đurđev, Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia
PhD Jasna Tolmač, Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia
PhD Mihalj Bakator, Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia
PhD Ivan Palinkaš, Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia
PhD Borivoj Novaković, Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia
PhD Una Marčeta, Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia
PhD Mila Kavalić, Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia

Publisher:

Technical Faculty "Mihajlo Pupin", Zrenjanin, University of Novi Sad, Đure Đakovića bb,
23101 Zrenjanin, Republic of Serbia

For publisher:

PhD Milan Nikolić, Dean of Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia

Technical preparation:

PhD Ivan Palinkaš, Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia
BSc Dejan Landup, Technical Faculty "Mihajlo Pupin", Zrenjanin, Republic of Serbia

CIP Classification:

CIP - Каталогизација у публикацији
Библиотеке Матице српске, Нови Сад

62:005.3(082)(0.034.4)
502/504(082)(0.034.4)

INTERNATIONAL Conference Industrial Engineering and Environmental Protection (15 ; 2025 ; Zrenjanin)

Proceedings [Elektronski izvor] / XV International Conference on Industrial Engineering and Environmental Protection (IIZS 2025), Zrenjanin, 2-3 October 2025 ; [organizer Technical Faculty "Mihajlo Pupin", Zrenjanin]. - Zrenjanin : Technical Faculty "Mihajlo Pupin", 2025. - 1 elektronski optički disk (CD-ROM) : tekst, ilustr. ; 12 cm

Nasl. sa naslovnog ekrana. - El. publikacija u formatu pdf opsega 483 str. - Bibliografija uz svaki rad.

ISBN 978-86-7672-393-5

a) Индустијско инжењерство -- Зборници b) Заштита животне средине -- Зборници

COBISS.SR-ID 183409673

SCIENTIFIC COMMITTEE - TECHNICAL FACULTY „MIHAJLO PUPIN“

PhD Slavica Prvulović, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Ljiljana Radovanović, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Bogdana Vujić, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Eleonora Desnica, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Jasmina Pekez, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Snežana Filip, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Višnja Mihajlović, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Jelena Stojanov, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Jasna Tolmač, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Mića Đurđev, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Una Marčeta, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Ivan Palinkaš, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Borivoj Novaković, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia

INTERNATIONAL SCIENTIFIC COMMITTEE

PhD James G. Speight, CD&W Inc., Laramie, Wyoming, USA
PhD. dr Hosam E.A.F. Bayoumi Hamuda, Obuda University, Budapest, Hungary
PhD Svetlana Lilkova, University of Architecture, Civil Engineering and Geodesy (UACEG), Faculty of Hydraulic Engineering, Sofia, Bulgaria
PhD Dimitar G. Petrov, , Technical University Sofia, branch Plovdiv, Bulgaria
PhD Valentina Emilia Balas, „Aurel Vlaicu” University of Arad, Faculty of Engineering, Arad, Romania
PhD Imre Kiss, University Politehnica Timisoara, Faculty of engineering, Hunedoara, Romania
PhD Simona Dzitac, University of Oradea, Energy Engineering and Industrial Management Faculty, Oradea, Romania
PhD Francisc Popescu, University Politehnica Timisoara, Timisoara, Romania
PhD Mukrimin Şevket Guney, University of Giresun, Faculty of Engineering, Giresun, Turkey
PhD Muharrem Hilmi Aksoy, Selcuk University, Engineering Faculty, Konya, Turkey
PhD Alexander Salnikov, Ukhta State Technical University (USTU), Ukhta, Republic of Komi, Russia
PhD Hrvoje Glavaš, Josip Juraj Strossmayer University of Osijek, Faculty of Electrical Engineering, Computer Science and Information Technology, Osijek, Croatia
PhD Tomislav Barić, Josip Juraj Strossmayer University of Osijek, Faculty of Electrical Engineering, Computer Science and Information Technology, Osijek, Croatia
PhD Marijana Hadzima-Nyarko, Josip Juraj Strossmayer University of Osijek, Faculty of Civil Engineering, Osijek, Croatia
PhD Silva Lozančić, Josip Juraj Strossmayer University of Osijek, Faculty of Civil Engineering, Osijek, Croatia
PhD Mirko Karakašić, University of Slavonski Brod, Faculty of Mechanical Engineering Slavonski Brod, Slavonski Brod, Croatia
PhD Vangelce Mitrevski, University «sv. Kliment Ohridski», Technical Faculty, Bitola, Macedonia
PhD Milija Krašnik, University of East Sarajevo, Faculty of Mechanical Engineering, Republic of Srpska, Bosnia and Herzegovina
PhD Bratislav Blagojević, University of Niš, Faculty of Mechanical Engineering, Niš, Serbia
PhD Blaža Stojanović, University of Kragujevac, Faculty of Engineering, Kragujevac, Serbia
PhD Dragan D. Milanović, University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia
PhD Mijodrag Milošević, University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia

PhD Dejan Lukić, University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia
PhD Milan Rackov, University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia
PhD Jasmina Radosavljević, University of Niš, Faculty of Occupational Safety, Niš, Serbia
PhD Amelija Đorđević, University of Niš, Faculty of Occupational Safety, Niš, Serbia
PhD Snežana Dragičević, University of Kragujevac, Faculty of Technical Sciences, Čačak, Serbia
PhD Ivona Radović, University of Belgrade, Faculty of Technology and Metallurgy, Belgrade, Serbia
PhD Mirjana Kijevčanin, University of Belgrade, Faculty of Technology and Metallurgy, Belgrade, Serbia
PhD Aleksandra Sretenović, University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia
PhD Aleksandra Mihailović, University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia
PhD Nebojša Ralević, University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia
PhD Maja Petrović, University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia
PhD Zoran Čepić, University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia
PhD Aleksandar Ašonja, University Business Academy in Novi Sad, Faculty of Economics and Engineering Management in Novi Sad, Serbia
PhD Marina Milovanović, University “Union – Nikola Tesla“, Faculty for entrepreneurial business and real estate management, Belgrade, Serbia
PhD Jasmina Perišić, University “Union – Nikola Tesla“, Faculty for entrepreneurial business and real estate management, Belgrade, Serbia
PhD Jordana Ninkov, Senior Research Associate, Institute of Field and Vegetable Crops, Novi Sad, Serbia
PhD Marko Ristić, Research Associate, Institute Mihajlo Pupin, Belgrade, Serbia

ORGANIZING COMMITTEE

PhD Ivan Palinkaš, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia, chairman
PhD Višnja Mihajlović, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Ljiljana Radovanović, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Slavica Prvulović, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Eleonora Desnica, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Bogdana Vujić, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Jasmina Pekez, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Snežana Filip, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Zoran Čepić, Faculty of Technical Sciences, Novi Sad, Republic of Serbia
PhD Mića Đurđev, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Una Marčeta, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Jasna Tolmač, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
PhD Borivoj Novaković, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
MSc Luka Đorđević, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
BSc Dejan Bajić, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
BSc Jovana Čugalj, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
BSc Vesna Drakulović, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
BSc Uroš Šarenac, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
BSc Branislava Radišić, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia
BSc Dejan Landup, Technical Faculty “Mihajlo Pupin”, Zrenjanin, Republic of Serbia

INTRODUCTION

The Department of Mechanical Engineering and the Department of Environmental Protection of the Technical Faculty “Mihajlo Pupin” in Zrenjanin organized the XV International Conference on Industrial Engineering and Environmental Protection – IIZS 2025.

The topics of this scientific conference cover the fields of Industrial Engineering and Environmental Protection, including: Mechanical Engineering, Energetics and Process Technique, Design and Maintenance, Oil and Gas Engineering, Health and Environmental Protection, Environmental Management, and Occupational Safety.

The main goals of the conference are: encouraging innovation and broadening knowledge among engineers in industry and environmental protection; supporting researchers in presenting their current scientific results; establishing new connections with leading national and international institutions and universities; promoting the Faculty and its leadership role in society and the local community in order to attract high-quality young people to study at the Faculty; strengthening cooperation with other organizations, public enterprises, and industry; initiating the collection of ideas aimed at solving specific practical problems; enabling networking and the establishment of business contacts; presenting the results of scientific and technical research to professional and business organizations; and exchanging scientific knowledge and experiences in the field of industrial engineering.

We would like to express our sincere gratitude to the partners of the XV International Conference “IIZS 2025” – Aurel Vlaicu University of Arad, Faculty of Engineering, Arad, Romania; University St. Kliment Ohridski, Technical Faculty, Bitola, North Macedonia; University Politehnica Timisoara, Faculty of Engineering, Hunedoara, Romania; University of East Sarajevo, Faculty of Mechanical Engineering, East Sarajevo, Bosnia and Herzegovina, Republic of Srpska; and University of Giresun, Faculty of Engineering, Giresun, Turkey – for their support in organizing this event. We are also grateful to all authors who contributed their papers.

The IIZS Conference has become a traditional annual gathering of researchers from around the world. We are open to and thankful for all constructive suggestions that could help make the next, XVI International Conference on Industrial Engineering and Environmental Protection, even better in terms of organization and program content.

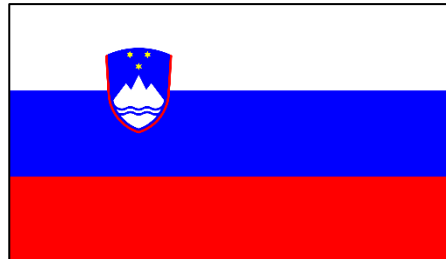
Chairman of the Organizing Committee
Asst. Prof. Ivan Palinkaš, PhD

Zrenjanin, October 2-3, 2025.

Conference participants are from the following countries:



Serbia



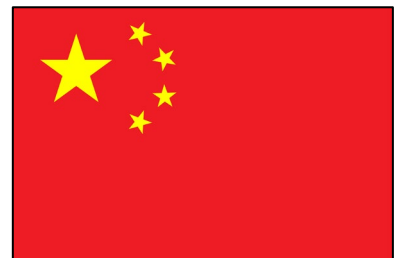
Slovenia



Romania



Bosnia and Herzegovina



China



North Macedonia



Bulgaria



Croatia



Turkey



Montenegro



Sweden



Finland



Germany



Hungary

CONTENTS

PLENARY SESSION

Silva Lozančić, Josip Radić, Držislav Vidaković, Marijana Hadzima-Nyarko: MITIGATING TECHNICAL AND OPERATIONAL FAILURES IN THE DESIGN AND MAINTENANCE OF BIOGAS PLANTS	2
---	---

Session 1: Mechanical Engineering

Svetlana Lilkova-Markova, Dimitar Lolov: DYNAMIC STABILITY OF A SLIGHTLY CURVED PIPE RESTING ON A WINKLER ELASTIC FOUNDATION	12
Borivoj Novaković, Luka Đorđević, Uroš Šarenac, Dejan Landup: THERMOGRAPHIC ASSESSMENT OF PRESSURE RELIEF VALVE OPERATION	18
Mirjana Misita, Neda Papic: ENHANCING DECISION SUPPORT SYSTEMS THROUGH AI-DRIVEN ADAPTIVE WEIGHTING METHODS	26
Zoran Karastojković, Jasmina Pekez, Nada Ratković-Kovačević: KINDS OF SHRINKAGE DURING MELTING AND SOLIDIFICATION OF A METAL	34
Sanja Simić, Mijodrag Milošević, Dejan Božić, Dejan Lukić: IDENTIFICATION OF KEY LEAN TOOLS IN THE AUTOMOTIVE INDUSTRY	41
Ratko Joksimović, Miroslav Milutinović: APPLICATION OF CAD TOOLS IN DESIGNING COMPLEX MECHANICAL ASSEMBLIES	49
Ersin Kaya, Sait Ali Uymaz, Ender Boz, Sevgi Alkan: INTELLIGENT 3D SPACE OPTIMIZATION FOR LOGISTICS OPERATIONS	56
Nemanja Tasic, Igor Vecstejn, Vuk Amizic, Tamara Milic: MODELS OF AI INTEGRATION IN ENGINEERING EDUCATION: A PRACTICAL FRAMEWORK FOR LEARNING OUTCOMES, RETENTION, AND ACADEMIC INTEGRITY	60
Mislav Benić, Hrvoje Glavaš: BRAILLE AS A PATH TO WRITTEN CONTENT	68
Dušan Jovanić, Ivana Vasović Maksimović, Eleonora Desnica: EXPERIMENTAL INVESTIGATION OF THE IMPACT TOUGHNESS OF POLYLACTIC ACID - PLA SPECIMENS FABRICATED BY FFF 3D PRINTING USING THE CHARPY METHOD	76

Aleksandar Rajić, Dušan Jovanić, Ljubica Lazić Vulićević: STRESS ANALYSIS OF WELDED JOINT BEHAVIOR UNDER TENSILE LOADING USING FEM	83
Milan Trifunović, Miloš Madić: ANALYSIS OF CO ₂ EMISSIONS IN SLOT MILLING OF C45E STEEL	91
Ivan Palinkaš, Aleksandar Rajić, Spasoje Erić, Eleonora Desnica, Dezsó Gergely: ENHANCING EDUCATIONAL QUALITY THROUGH VIRTUAL REALITY	98
Milana Ilić Mićunović, Borut Kosec, Boris Agarski, Zorica Miroslavljević, Slađana Jovanović, Zoran Čepić: GRAVIMETRIC ANALYSIS OF PARTICULATE MATTER EMISSIONS FROM MILLING PROCESSES	104

Session 2: Energetics and Process Technique

Slavica Prvulovic, Duska Jarcevic, Jasna Tolmac, Milos Josimovic: THE ROLE AND IMPORTANCE OF CONDENSATE PUMPS IN THE OPERATION OF A 110 MW COMBINED HEAT AND POWER PLANT	110
Srđan Kovačević, Ivana Mihajlović, Dušan Milovanović: BEST AVAILABLE TECHNOLOGIES AND PRACTICES TO TREAT THE THERMAL SPA WASTEWATER	118
Dimitrije S. Milovanović, Nikola B. Danković: APPLICATION OF PID CONTROLLER AND FUZZY LOGIC IN CONTROLLING A CIRCULATION PUMP	124
Stevo K. Jaćimovski, Jelena Lamovec, Dušan I. Ilić, Jovan P. Šetrajčić: ENERGY STATES OF ELECTRONS IN LAYERED GRAPHENE	130
Jasna Tolmac, Slavica Prvulovic, Marija Nedic, Uros Sarenac, Milan Markovic: OVERVIEW OF RENEWABLE ENERGY SOURCES IN SERBIA AND IN THE WORLD	137
Dejan Landup, Borivoj Novaković, Luka Đorđević, Dejan Bajić, Ognjen Krneta, Vesna Drakulović: ANALYSIS AND OPTIMIZATION OF THE WATER SUPPLY SYSTEM “BELO BLATO”	143
Stanko P. Stankov: WATER 4.0 - DIGITALISATION IN THE WATER SUPPLY AND SEWERAGE SECTOR	150
Stanko P. Stankov: WATER LOSSES IN THE WATER SUPPLY PROCESS – IDENTIFICATION AND CONTROL	158

Nadežda Ljubojev, Jasmina Pekez, Dalibor Dobrilović, Luka Đorđević, Ljubiša Malešev: SOLAR ENERGY IN THE REPUBLIC OF SERBIA: THE POTENTIAL AND LEGAL FRAMEWORK.....	167
--	-----

Anca-Adriana Petcut-Lasc, Valentina-Emilia Balas, Flavius-Maxim Petcut: COMPARATIVE ANALYSIS OF RESIDENTIAL PHOTOVOLTAIC SYSTEMS: IMPACT OF SHADING AND ORIENTATION ON ENERGY PRODUCTION	175
---	-----

Session 3: Designing and Maintenance

Tomislav Barić, Hrvoje Glavaš, Ljiljana Radovanović: HB9CV ANTENNA: THEORETICAL AND PRACTICAL ASPECTS	181
---	-----

Hristina Delibašić Marković, Violeta Petrović and Ivan Petrović: SIMULATED IoT SENSOR MONITORING AND ALERTING USING PYTHON AND WEB APIs	189
--	-----

Faruk Güner: DESIGN PRINCIPLES FOR A STANDARDIZED MUZZLE RISE TEST RIG.....	197
---	-----

Željana Kužet, Dejan Lukić, Vladimir Mučenski, Jovana Topalić, Mijodrag Milošević: CE COMPLIANCE FOR CRANES: LIFTING ACCESSORIES AND PROTECTIVE DEVICES AND EQUIPMENT.....	202
---	-----

Držislav Vidaković, Silva Lozančić, Josip Radić, Marijana Hadzima-Nyarko: REVIEW AND ANALYSIS OF REGULATIONS REDUCING MACHINERY SAFETY RISKS ON CONSTRUCTION SITES.....	208
--	-----

Mihalj Bakator, László Szabó, Nataša Đalić, Dragan Čočkalo, Sanja Stanisavljev: ICT APPLICATION FOR PREDICTIVE MAINTENANCE AND LOGISTICS EFFICIENCY IN INDUSTRIAL ENTERPRISES	216
--	-----

Zoltán Mikovity, Odry Péter, Zoltán Vizvári: IMPROVING MEASUREMENTS IN AUDIOLOGY USING ELECTROSTATIC TRANSDUCERS.....	224
--	-----

Uroš Šarenac, Borivoj Novaković, Slavica Prvulović, Jasna Tolmač, Vesna Drakulović: THE INFLUENCE OF FLUIDS ON THE OPTIMAL OPERATION OF THE HYDRAULIC SYSTEM	231
---	-----

Session 4: Oil and Gas Engineering

Milan Markovic, Marko Blažić, Katarina Vignjević, Jasna Tolmač: IMPACT OF GAS FLARING AND VENTING PROCESSES IN THE OIL INDUSTRY ON AIR QUALITY	237
Branislava Radišić, Sanja Stanisavljev, Verica Gluvakov, Slavica Prvulović, Mila Kavalić, Dragana Kovač: CORPORATE SOCIAL RESPONSIBILITY AND SWOT ANALYSIS: THE CASE OF NIS COMPANY	242
Jelena Kiurski-Milošević, Aleksandra Šučurović, Nikola Mahova: MODELING ISOBUTANE UNCONTROLLED RELEASE FROM A STORAGE TANK	249

Session 5: Environmental Management

Stefan Ugrinov, Đorđe Vučković, Sanja Stanisavljev, Verica Gluvakov, Mila Kavalić: CIRCULAR SUPPLY CHAIN PRACTICES AND THEIR CONTRIBUTION TO GREEN ECONOMY GOALS IN SERBIAN MANUFACTURING	255
Dragan Hristovski: QUALITY IN PROJECT MANAGEMENT AS A PIVOTAL PART IN THE CONSTRUCTION INDUSTRY	261
Dragan Ugrinov, Magdalena Nikolić: ENVIRONMENTAL AND ECONOMIC ADVANTAGES OF CIRCULAR GREEN WASTE MANAGEMENT	269
Srđan Kovačević, Višnja Mihajlović, Nemanja Stanisavljević, Marko Muhadinović, Xiaoming Wang: POTENTIAL FOR RDF PRODUCTION IN REPUBLIC OF SERBIA	279
Jovana Čugalj, Milana Čugalj, Saveta Bikić, Vesna Drakulović: PRACTICES AND PERSPECTIVES OF SUSTAINABLE MANAGEMENT OF ORGANIC KITCHEN WASTE	286
Milana Drašković, Danijele Jašin, Gelert Gligor: THE MICROBIOLOGICAL CONTROL OF DEMINERALIZED WATER	292
Maja Brborić, Branka Nakomčić Smaragdakis, Sonja Dmitrašinić, Borivoje Stepanov, Epari Ritesh Patro, Maja Turk Sekulić: UNSUPERVISED MACHINE LEARNING vs. CLASSICAL CLUSTERING: HOTSPOT IDENTIFICATION OF PBDEs IN DANUBE RIVER SEDIMENTS	300
Nikola Jovanov, Ivan Palinkaš, Eleonora Brtko, Vesna Makitan, Ema Brtko: A VISUAL APPROACH TO PROJECT MANAGEMENT USING REACT FLOW	306

Kaan Taflanoğlu, Selim Ayaydın, Muhammed Murat Özbek, Gürol Sungun: HYBRID MODEL APPROACH FOR PRODUCT LEVEL DEMAND FORECASTING IN RETAIL.....	313
Emir Ramazan Yaşar, Selin Avcı, Muhammed Murat Özbek, Gürol Sungun: DIGITAL PROMOTION PLANNING AND OPTIMIZATION: AN AI-POWERED RETAIL APPLICATION.....	321
Dragana Kovač, Edit Terek Stojanović, Maja Gaborov: GREEN LEADERSHIP: AUTHENTIC SUSTAINABILITY OR GREENWASHING?	328
Gordana Rendulić Davidović, Nikola Radosavljević: THE IMPACT OF GREEN ORGANIZATIONAL CULTURE ON EMPLOYEE SATISFACTION IN SERBIA	334
Momcilo Ristic, Visnja Ognjenovic: THE FOUNDATION OF GREEN MINING – PRINCIPLES AND SUSTAINABILITY	342

Session 6: Health and Environmental Protection

Marija Perović, Tatjana Mitrović, Jelena Zarić Kovačević: IN SITU REHABILITATION OF AGING PUBLIC WATER SUPPLY WELLS	349
Marija Perović, Tatjana Mitrović, Jelena Zarić Kovačević: STRONTIUM IN GROUNDWATER AS AN INDICATOR OF DEEP AQUIFER MIXING	355
Edi Daruši: GREEN NEW DEAL FOR CLIMATE CHANGE	360
Verica Gluvakov, Mila Kavalić, Sanja Stanisavljev, Stefan Ugrinov, Snežana Mirković: A GREEN MODEL FOR BUSINESS IMPROVEMENT	366
Svetlana K. Belošević, Emin Memović, Saša Jovanović, Julijana Lekić, Jovana S. Belošević: CHEMICAL POLLUTANTS IN SOIL IN VRNJAČKA BANJA	372
Stevo K. Jaćimovski, Jelena Lamovec, Dušan I. Ilić, Jovan P. Šetrajčić: ANALYTICAL SOLUTION OF SPATIAL DISTRIBUTION OF AIR POLLUTION FROM POINT SOURCES	380
Vuk Amizic, Igor Vecstejn, Nemanja Tasic, Tamara Milic: SOFTWARE QUALITY MONITORING IN AGILE WORKING ENVIRONMENT	387
Milana Drašković, Danijele Jašin, Gelert Gligor: HYGIENIC CORRECTNESS OF DRINKING WATER OF ZRENJANIN	393

Jelena D. Nikolić, Ana M. Vujošević, Vladimir S. Topalović, Anja V. Antanasković, Veljko V. Savić, Marija S. Djošić, Zorica R. Lopičić: APPLICATION OF SUSTAINABLE FERTILIZERS: BIOCHAR AND PHOSPHATE GLASS EFFECTS AT ROSE FLOWERING	399
Maja Brborić, Jelena Radonić, Sonja Dmitrašinić, Ulrike Gayh, Vilmaurora Castillo, Maja Turk Sekulić: A MULTI-DIMENSIONAL APPROACH TO DANUBE RIVER PRESERVATION: COMBINING WATER QUALITY SCIENCE AND ACOUSTIC ART	405
Tijana Adamov, Mladenka Novaković, Ivana Mihajlović, Maja Petrović: READING BETWEEN THE WASTE: CORRELATION ANALYSIS OF INORGANIC POLLUTION IN LANDFILLS.....	412
Snežana Filip, Branislava Radišić: BIOPLASTICS AND THEIR BIODEGRADATION IN NATURAL ENVIRONMENTS.....	418
Milan Ivanović: ENERGY CRISIS AND GLOBAL WARMING - THE NECESSITY OF A PARADIGM CHANGE.....	424
Mădălina Ileana Zoț, Jovana Čugalj, Bogdana Vujić, Zoran Čepić, Francisc Popescu: EVALUATION OF SETTLEABLE PARTICULATE MATTER IN TIMISOARA AND ZRENJANIN. FIRST STEPS AND PERSPECTIVES.....	432
Zorica Lopičić, Anja Antanasković, Vladimir Adamović, Jelena Milojković, Tatjana Šoštarić: THE APPLICATION OF ENGINEERED PEACH STONE BIOCHAR IN REMOVING PHOSPHATES FROM AQUEOUS SOLUTION: KINETIC INSIGHTS	436

Session 7: Occupational Safety

Dejan Bogdanović: MULTICRITERIA ANALYSIS OF OCCUPATIONAL HAZARDS IN UNDERGROUND MINING	442
Nikola Petrović, Ermina Ćosović, Uglješa Bugarić: OCCUPATIONAL HEALTH AND SAFETY RISK EVALUATION OF PM2.5 AIR POLLUTION DURING THE HEATING SEASON IN BELGRADE, SERBIA	450
Adrian-Flavius Craioveanu, Adrian-Eugen Cioablă, Luisa – Izabel Dungan, Una Marčeta: OPTIMIZING NOISE LEVELS IN A VEHICLE – CASE STUDY.....	459
Dunja Istrat, Mladenka Novaković, Ljubica Duđak, Maja Petrović: HEALTH AND SAFETY OF EMPLOYEES IN HYBRID WORKING CONDITIONS	467

Aleksandra Mihailović, Nada Marković, Robert Lakatoš, Selena Samardžić Cvijanović, Savka Adamović: EVALUATION OF NOISE EXPOSURE FROM PRINTING MACHINES IN A DIGITAL PRINTING LABORATORY	475
Aleksandar Kupusinac, Mladen Radišić, Dragica Kupusinac, Maja Radišić, Dušan Pevac: MOBILE APPLICATIONS FOR A HEALTHY AND BALANCED DIET: A REVIEW AND COMPARISON	480

DOI:10.5937/IIZS25355P

STRONTIUM IN GROUNDWATER AS AN INDICATOR OF DEEP AQUIFER MIXING

Marija Perović¹, Tatjana Mitrović², Jelena Zarić Kovačević³

¹Jaroslav Černi Water Institute, Belgrade, Serbia,

²Institute of Physics Belgrade, University of Belgrade, Serbia

³Mining Institute Ltd. Belgrade, Serbia

e-mail: marija.perovic@jcerni.rs

Abstract: Strontium (Sr) is a naturally present trace element in groundwater, and its concentration can vary widely depending on geology, hydrochemistry, and climate. This study integrates the geochemical behaviour of Sr in groundwater environment, emphasizing its sources, mobility, and potential as a tracer of deep groundwater mixing. Sr usually originates from the dissolution of carbonate, sulphate, and silicate minerals, with carbonate aquifers often contributing the highest concentrations. Its mobility is governed by pH, competing ions, ionic strength, and residence time, while redox conditions exert only indirect effects through mineral solubility. Typical concentrations range from <1 mg/L in shallow fresh recharge zones to >10 mg/L in deep, mineralized, or saline systems. High Sr levels in shallow aquifers may indicate deep groundwater input, particularly when accompanied by elevated total dissolved solids or other tracers. The research highlights Sr's utility as a conservative tracer when a significant geological difference exists between shallow and deep aquifers. Understanding the concentration data requires considering local geochemical processes, co-precipitation and evaporation. When used in combination with other hydrochemical indicators, Sr concentration can present a valuable tool for identifying groundwater mixing and tracing water-rock interactions over varying spatial and temporal scales.

Key words: groundwater mixing, strontium, tracer

INTRODUCTION

Sr is an alkaline earth metal (Group 2) that commonly occurs as a trace element in rocks, soils, and natural waters [1]. Strontium is a widespread constituent in groundwater, as evidenced by a comprehensive survey of U.S. aquifers that detected its presence in 99.8% of analysed samples [1]. It is typically present as the divalent cation Sr^{2+} in solution, and its concentration depends on water-rock interactions. The primary sources of Sr in groundwater are the dissolution of minerals that contain Sr either as a constituent or by isomorphic substitution. The most studied Sr-bearing minerals include carbonates, sulphates, and silicates. In carbonate minerals such as calcite and dolomite, strontium commonly substitutes for calcium, leading to elevated Sr concentrations in groundwater from carbonate aquifers [2]. Among sulphate minerals, celestite (SrSO_4) directly contributes strontium, while gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and anhydrite often contain Sr as an impurity. Silicate minerals, including feldspars (KAlSi_3O_8 – $\text{NaAlSi}_3\text{O}_8$ – $\text{CaAl}_2\text{Si}_2\text{O}_8$) and clays, may also release Sr during the weathering of aluminosilicate rocks. This process is typically slower and yields lower concentrations of Sr compared to carbonates [3]. Under natural conditions, typical Sr concentrations in fresh groundwater are on the order of tenths to a few mg/L. A global survey of freshwater indicates background Sr levels around 0.5 - 1.5 mg/L [2]. In many young, shallow aquifers with limited mineral contact, Sr remains <1 mg/L (for example, the median Sr in above 4,800 U.S. groundwater samples was 0.225 mg/L) [1]. Groundwater in carbonate-rich aquifers typically contains the highest strontium concentrations, due to mineral dissolution processes. Similarly, aquifers in arid regions can exhibit elevated Sr levels as a result of evaporative concentration [1]. While low Sr is common in dilute recharge, values of several mg/L or more may occur where geology and climate favour Sr enrichment.

MATERIAL AND METHODS

This study synthesizes current geochemical understanding of Sr behaviour in groundwater environment by integrating hydrochemical data from global case studies and previously published datasets, primarily from the U.S. Geological Survey (USGS), peer-reviewed literature, and regional hydrogeological surveys. Strontium concentrations and associated hydrochemical parameters were examined across various aquifer settings, including carbonate-rich, arid, and saline environments. Special attention was given to aquifer depth, residence time, mineral composition, redox conditions, and evaporative influences as controlling factors for Sr mobility and distribution.

RESULTS AND DISCUSSION

Strontium concentrations in groundwater exhibit systematic variations across different aquifer types and hydrogeological settings. Analysis of published data reveals a clear trend of increasing Sr levels with longer residence time, higher mineralization, and the influence of saline or evaporative processes.

In shallow, fresh recharge zones, typically in humid climates and karstic terrains, Sr concentrations are generally low, ranging from 0.1 to 0.5 mg/L. These systems exhibit minimal water-rock interaction and limited dissolution of Sr-bearing minerals. In contrast, shallow aquifers located in arid or semi-arid environments show significantly higher concentrations, between 1 and 5 mg/L, primarily due to evapoconcentration, irrigation return flow, and longer groundwater residence time.

Deep, confined aquifers in carbonate or evaporite-rich formations often contain Sr concentrations exceeding 4 mg/L, with typical values between 1 and 10 mg/L. This is attributed to prolonged contact with Sr-bearing carbonates and sulphates. The highest concentrations, often ranging from 5 to over 20 mg/L, are observed in deep saline or fossil groundwater, particularly in areas affected by upwelling brines or ancient seawater intrusion.

An overview of these patterns is shown in Table 1, which lists typical Sr concentrations and the corresponding geochemical conditions for each aquifer type.

Table 1. Representative strontium concentrations across different aquifer settings

Aquifer Setting	Typical Sr Concentration	Geochemical Context and Source Description
Shallow, fresh recharge (humid climate, short flow path; e.g., karst springs)	≈0.1–0.5 mg/L (typically <1 mg/L)	Limited water-rock interaction leads to low Sr mobilization. Sr concentrations reflect the geochemistry of shallow, young groundwater. [1]; [4]
Shallow, arid or evaporative (unconfined aquifers, high evapotranspiration or irrigation)	≈1–5 mg/L	Increased residence time and evapoconcentration enhance Sr levels, often along with higher total dissolved solids (TDS), Cl ⁻ , and Na ⁺ . [1]
Deep, long-residence freshwater (confined carbonate or evaporite aquifers)	≈1–10 mg/L (often >4 mg/L)	Prolonged contact with Sr-bearing minerals such as carbonates and sulphates leads to higher Sr concentrations. [1]; [4]

Deep, saline or fossil groundwater (brine or paleo-seawater mixing)	5–20 mg/L	High Sr reflects mixing with ancient marine-derived waters or upwelling brines. Modern seawater contains ~8 mg/L Sr. [1]
---	-----------	--

Sr Mobility and Controlling Hydrochemical Factors

Once released from minerals, Sr²⁺ behaves geochemically similarly to Ca²⁺ in groundwater. Its mobility and concentration are influenced by several the most influential hydrochemical parameters. Groundwater pH controls and significantly impacts the dissolution and precipitation of carbonate minerals. Under neutral to moderately acidic conditions, calcite and dolomite dissolve, releasing Sr²⁺ alongside Ca²⁺. Sr mobility peaks during early water-rock interactions. As calcite saturation is reached, Sr may co-precipitate or become incorporated into carbonate minerals, particularly in systems with high carbonate alkalinity. In high-pH environments, strontianite (SrCO₃) or mixed Ca-Sr carbonates may form, decreasing Sr concentrations in solution.

Elevated Ca²⁺ can induce common ion effects and promote calcite precipitation, which also removes Sr. Due to its larger ionic radius, Sr²⁺ is less readily incorporated into calcite, often remaining longer in solution. Sr/Ca ratios in groundwater can reveal selective incorporation patterns. Strontium can also be temporarily retained through ion exchange with clays and freshly formed minerals, but once those exchange sites become saturated, Sr tends to remain in solution [3].

Sr remains in the +2 oxidation state and is largely redox-independent. However, redox can influence cooccurring elements such as sulphate. In reducing environments, sulphate reduction may dissolve Sr-bearing sulphate minerals. In contrast, under oxidizing conditions, precipitation of celestite (SrSO₄) may occur if sulphate and Sr concentrations are high [5].

There is significant positive correlation between TDS and elevated Sr levels. Saline environments, whether from marine intrusion, evaporation, or brines, maintain Sr in solution due to complexation and suppressed mineral precipitation [1]. Marine-derived groundwater or paleoseawater often contributes significantly to increase of Sr concentrations, with ocean water containing ~8 mg/L Sr.

Prolonged water-rock interaction enhances Sr mobilization in water solution. While carbonates rapidly release Sr, silicate minerals contribute more gradually. Older, deeper groundwater typically shows higher Sr due to cumulative dissolution over time.

High Sr levels in shallow aquifers often serve as a geochemical indicator of mixing with deeper groundwater. Deep carbonate systems often exceed 4 mg/L Sr due to extended interaction with Sr-bearing lithologies. If such indications are found in overlying shallow wells, upward leakage may be occurring. In semi-arid regions, evaporation concentrates Sr and other solutes in shallow aquifers. These elevated levels may mimic deep water inputs but can be distinguished through isotopic analysis and simultaneous determination of chloride, sulphate, and TDS [2], [6]. The most distinct source of high Sr is up-coning of deep, saline groundwater. These waters are enriched in Sr due to ancient seawater origins and extensive geochemical aging.

Strontium Isotopes (⁸⁷Sr/⁸⁶Sr) as Tracers of Aquifer Mixing

Strontium has four stable isotopes, of which ⁸⁷Sr is radiogenic and formed through the decay of ⁸⁷Rb. Because the ⁸⁷Sr/⁸⁶Sr ratio varies depending on lithology and geological age, it can be used as a powerful natural tracer for groundwater source and mixing processes identification. Groundwater receives its isotopic signature through water-rock interaction, and variations in ⁸⁷Sr/⁸⁶Sr reflect differences in mineralogy and rock age across aquifer systems. For example, studies in the Yucatan Peninsula demonstrated that ⁸⁷Sr/⁸⁶Sr ratios can clearly distinguish between freshwater recharge and mixing with seawater or older marine-derived waters [7]. In

fractured granite aquifers in Korea, Sr isotopic ratios revealed limited mixing between deep geothermal and shallow meteoric waters, indicating slow exchange and long residence times [8].

Strontium isotopes are especially valuable for distinguishing deep from shallow groundwater origin in systems where the results of conventional tracers may be ambiguous. In the Eastern Snake River Plain (Idaho), combining $^{87}\text{Sr}/^{86}\text{Sr}$ ratios with uranium isotopes enabled quantification of mixing between distinct aquifer zones [9]. Likewise, in Taiwan's Choushui River alluvial fan, $^{87}\text{Sr}/^{86}\text{Sr}$ ratios differentiated paleo-seawater contributions from recent recharge, highlighting their utility in coastal aquifers [10].

In areas influenced by salinity or brines, the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio often shifts away from modern seawater values (≈ 0.7092), pointing to older marine inputs or long-term geochemical evolution. These variations can help distinguish whether elevated Sr comes from ancient seawater mixing, evaporation, or the dissolution of local minerals [7], [10].

CONCLUSION

Sr exhibits several geochemical characteristics that support its use as a tracer for detecting deep groundwater contributions to shallow aquifers. Its solubility, conservative behaviour under most redox and biological conditions, and typically distinct concentration gradient between shallow and deep groundwater make it a useful indicator of mixing processes. In systems where deep, mineralized groundwater with elevated Sr concentrations enter shallow zones with low Sr background, even small mixing inputs can produce detectable shifts in concentration.

Although elevated Sr levels can suggest a deep source, they may also result from local processes such as evaporation or lithological release, making it difficult to distinguish. Shallow aquifers in arid regions or carbonate-rich regions may naturally contain elevated Sr, making it difficult to distinguish deeper inflow impacts from local influences. Under specific geochemical conditions, such as sulphate-rich or carbonate-saturated environments, Sr may precipitate as celestite (SrSO_4) or co-precipitate with calcite, reducing its dissolved concentration and affecting its tracer behaviour.

Despite these limitations, Sr remains a valuable component in a multi-tracer framework. When there is a complementary interpretation with other indicators like Cl^- , Br^- , Li^+ , or isotopic ratios (e.g., $^{87}\text{Sr}/^{86}\text{Sr}$), Sr concentrations can provide robust evidence for identifying deep groundwater mixing. Elevated Sr in shallow aquifers, particularly when accompanied by increased total dissolved solids, specific ions, or isotopic signatures, strongly suggests influence from older, deeper, or more mineralized groundwater sources.

Strontium proves to be a feasible and effective tracer for identifying deep groundwater contributions, particularly when interpreted within a broader hydrogeochemical context.

REFERENCES

- [1] Musgrove, M. (2021). The occurrence and distribution of strontium in U.S. groundwater. *Applied Geochemistry*.
<https://doi.org/10.1016/j.apgeochem.2020.104867>
- [2] Li, D., Gan, S., Li, J., Dong, Z., Long, Q., Qiu, S., Zhou, Y., & Lu, C. (2021). Hydrochemical characteristics and formation mechanism of strontium-rich groundwater in Shijiazhuang, North China Plain. *Journal of Chemistry*, 2021, Article ID 5547924, 10 pages. <https://doi.org/10.1155/2021/5547924>
- [3] Malov, A. I. (2024). The Conditions for the Formation of Strontium in the Water of Ancient Silicate Deposits Near the Arctic Coast of Russia. *Water*, 16(17), 2369. <https://doi.org/10.3390/w16172369>
- [4] U.S. Geological Survey (USGS). (2010). The occurrence and distribution of strontium in U.S. groundwater (Scientific Investigations Report 2010–5079). U.S. Department of the Interior. <https://pubs.usgs.gov/sir/2010/5079>

- [5] Clauer, N., Techer, I., & Chaudhuri, S. (2017). Geochemical tracing of potential hydraulic connections between groundwater and run-off water in northeastern Kansas, USA. *Hydrology*, 4(4), 56. <https://doi.org/10.3390/hydrology4040056>
- [6] U.S. Geological Survey (USGS). (2020). The occurrence and distribution of strontium in U.S. groundwater. U.S. Department of the Interior. <https://www.usgs.gov/centers/ogw/science/occurrence-and-distribution-strontium-us-groundwater>
- [7] McKay, J., Lenczewski, M., & Leal-Bautista, R. M. (2020). Characterization of flowpath using geochemistry and ⁸⁷Sr/⁸⁶Sr isotope ratios in the Yalahau region, Yucatán Peninsula, Mexico. *Water*, 12(9), Article 2587. <https://doi.org/10.3390/w12092587>
- [8] Lee, S.-G., Kim, T.-K., Lee, J.-S., Lee, T.-J., Cho, B.-W., & Koh, H.-J. (2008). Geochemical implication of ⁸⁷Sr/⁸⁶Sr ratio of high-temperature deep groundwater in a fractured granite aquifer. *Geochemical Journal*, 42(5), 429–441
- [9] Rattray, G. W., & Paces, J. B. (2020). Evaluation of hydrologic processes in the Eastern Snake River Plain Aquifer using uranium and strontium isotopes, Idaho National Laboratory, Eastern Idaho (Professional Paper 1837–D). U.S. Geological Survey. <https://doi.org/10.3133/pp1837D>
- [10] Huang, H.-W., Huang, S.-T., Wang, R.-M., Chen, W.-F., Chung, C.-H., & You, C.-F. (2024). Strontium isotopic composition as tracers for identifying groundwater recharge sources in the Choushui River alluvial plain, western Taiwan. *Water*, 16(15), 2151. <https://doi.org/10.3390/w16152151>