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POLITEHNIKA 2023

CONFERENCE PROCEEDINGS

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FOREWORD

The International Scientific and Professional Conference POLITEHNIKA 2023 represents the seventh edition of the POLITEHNIKA scientific and professional events, occurring biannually since its inaugural event in 2011. POLITEHNIKA 2023 upholds a distinguished tradition and commitment to integrating higher education and practical application across a diverse spectrum of disciplines represented by defined thematic scopes.

Organized with the patronage of the Ministry of Education of the Republic of Serbia, the Ministry of Environmental Protection of the Republic of Serbia, the Ministry of European Integration of the Republic of Serbia, the Directorate for Occupational Safety and Health, the Office for Dual Education and National Qualifications Framework, the Conference of Academies of Applied Studies in Serbia, the Chamber of Commerce of Serbia, the Chamber of Commerce of Belgrade, the Institute for Standardization of Serbia, the Association of Belgrade Architects, the City of Požarevac and the Tourist Organization of the City of Požarevac, POLITEHNIKA 2023 stands as a collaborative platform at the intersection of academia, governmental institutions and industry.

This year heralds a notable progression with its international status and the incorporation of 10 conference scopes. Expanding beyond the thematic domains featured in previous events, the Conference now encompasses Environment and Sustainable Development, Occupational Safety and Health and Fire Safety, Smart Management Systems, Graphic Engineering, Design, Traffic Engineering, Biotechnology and Healthcare, Mechanical Engineering, Ecotourism and Rural development, and Mechatronics. By engaging experts, emerging professionals, and practitioners from these domains, the conference unifies fields of study programs of the Academy of Applied Technical Studies Belgrade. The thematic scopes, coupled with the structure of the compiled papers in this Proceedings, exhibit a rich diversity and multidisciplinary approach, fundamentally contributing to a holistic examination and resolution of societal and scientific challenges.

Comprising over 220 peer-reviewed contributions, the Proceedings represent a substantial intellectual asset, aligning with the conference's overarching objective of fostering the exchange of knowledge, research findings, and professional experiences among experts from industry, research institutions, and higher education establishments.

The Proceedings of the International Scientific and Professional Conference POLITEHNIKA 2023 serve as a comprehensive snapshot of the current landscape within the thematic realms of the conference, offering both insights and directives for ongoing scientific and professional development. Moreover, they proffer concrete solutions to practical challenges grounded in contemporary trends and pertinent insights.

The Academy of Applied Technical Studies Belgrade extends its sincere appreciation to all conference supporters whose financial contributions played a pivotal role in its successful realization. Special acknowledgment is reserved for the authors of the papers, whose diligence and eagerness to present their work to a wider audience, alongside the reviewers and members of the International Scientific Committee, Program Committee and Organizational Committee, have collectively contributed to the triumph of the International Scientific and Professional Conference POLITEHNIKA 2023.

Belgrade, December 2023
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Analysis of the real number of tourist overnights based on the estimation of water consumption in Zlatibor

MECHATRONICS

INVITED PAPER

Andrea Matta, PhD, Dept. of Mechanical Engineering, Politecnico di Milano, Italy Mohsen Jafari, PhD, Dept. of Industrial and Systems Engineering, Rutgers University, USA
Towards a theory of digital twins: fundamental definition

TABLE OF CONTENTS

SCOPE 1. ENVIRONMENT AND SUSTAINABLE DEVELOPMENT

STUDENTS PAPER

SCOPE 2. OCCUPATIONAL HEALTH AND SAFETY AND FIRE SAFETY

STUDENTS PAPER

SCOPE 3. SMART MANAGEMENT SYSTEMS

SCOPE 4. GRAPHIC ENGINEERING

SCOPE 5. DESIGN

STUDENTS PAPERS

SCOPE 6. TRAFFIC ENGINEERING

STUDENT PAPER

SCOPE 7. BIOTECHNOLOGY AND HEALTHCARE

SCOPE 8. MECHANICAL ENGINEERING

SCOPE 9. ECOTOURISM AND RURAL DEVELOPMENT

STUDENT PAPER

SCOPE 10. MECHATRONICS

MULTIVARIATE ANALYSIS OF THE MORAVA RIVER PLAIN GROUNDWATER

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Abstract: *One of the most significant sources of drinking water is groundwater. Therefore, it is crucial to assess groundwater quality and ascertain potential causes of contamination to address pollution and provide people with clean drinking water. In this paper, groundwater in the Morava River plain is investigated and analyzed for 14 physicochemical parameters, such as pH, EC, HCO_3^-, NO_3^-, PO_4^{3-}, Cl^-, SO_4^{2-}, Na^+, K^+, Mg^{2+}, Ca^{2+}, Fe, Mn, and As. To determine groundwater facies and sources of pollution, three multivariate statistical analysis techniques were applied. Hierarchical Cluster Analysis (HCA) was used to group groundwater samples based on their similar chemical characteristics and to determine the dominant hydrochemical groundwater type. According to HCA results, groundwater samples were clustered into three groups, including Cluster 1 (72.3%), Cluster 2 (19.7%), and Cluster 3 (7.9%), and the main groundwater type was Ca-HCO_3 type. Factor Analysis (FA) incorporated with Pearson correlation analysis was conducted to determine the main sources of pollution. Water-rock interactions and agricultural practices were identified as primary pollution sources in the investigated area.*

Keywords: Pearson correlation, Hierarchical cluster analysis, Factor analysis, rock weathering, water pollution

1. INTRODUCTION

Globally, groundwater pollution has emerged as an environmental concern. Generally, groundwater quality depends on the dissolution of minerals, including processes such as water-rock interactions, rock weathering, and ion exchange. These processes represent natural sources of groundwater pollution. On the other hand, groundwater quality has recently been more affected by anthropogenic activities. Excessive use of pesticides and chemical fertilizers, industrial and municipal wastewater discharge, and traffic are anthropogenic activities that influence groundwater quality. These activities represent artificial groundwater contamination sources. Groundwater is used for numerous purposes, including domestic, industrial, irrigation, and drinking [1]. Due to the constant rise in population numbers, the demand for clean water is expanding. In addition, using polluted water for domestic purposes is responsible for over 80% of health problems and illnesses in the world [2]. Therefore, it

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is of great importance to assess the quality of groundwater, detect potential pollution sources, and take appropriate measures to prevent pollution. Multivariate techniques are commonly applied to determine groundwater characteristics and pollution sources [3–7]. They involve determining the interaction between chemical parameters, grouping groundwater samples based on their chemical properties, grouping groundwater parameters according to their similar origin, ascertaining groundwater facies, as well as finding the main sources of contamination. This study aims to determine groundwater facies and main factors impacting groundwater quality, combining three multivariate analyses, including Pearson correlation, hierarchical cluster analysis, and factor analysis.

2. MATERIALS AND METHODS

2.1 Study area

The study area (Figure 1) consists of three river plains: the South Morava, the West Morava, and the Great Morava river plain. Together, they form the Morava River plain. Zapadna Morava is formed in Western Serbia by joining the Golijska Moravica and Djetinja rivers. It flows 184 km from west to east, joining the South Morava near Stalać to form Velika Morava. South Morava is formed by the merging of Binačka Morava and Preševska Moravica near Bujanovac, South Serbia. It flows from south to north for 246 km as the longer headwater of Velika Morava. Velika Morava is 185 km long and represents Danube's tributary. The investigated area experiences a moderate continental climate.

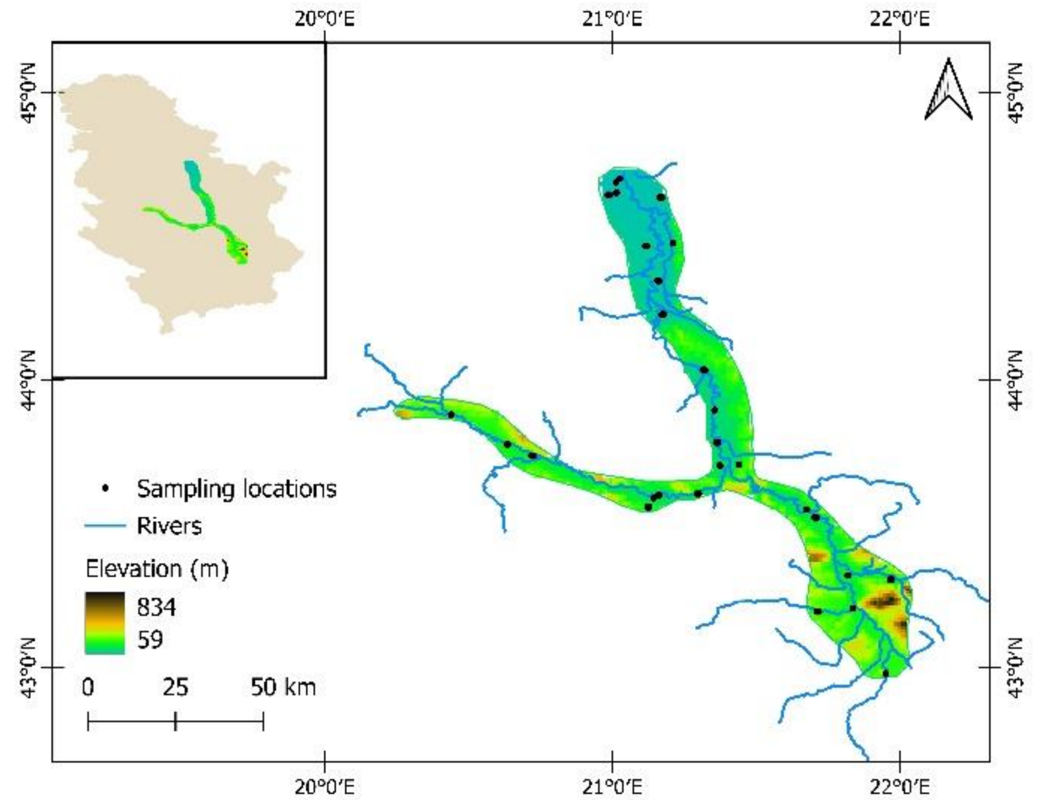

Figure 1. The study area

2.2 Sampling and chemical analysis

In the investigated area, 177 groundwater samples were collected and analyzed for 14 physicochemical parameters, including pH, EC, HCO_3^-, NO_3^-, PO_4^{3-}, Cl^-, SO_4^{2-}, Na^+, K^+, Mg^{2+}, Ca^{2+}, Fe, Mn, and As. High-density polypropylene bottles of 500 mL volume were used for sampling. EC and pH were measured *in situ* using a portable multimeter (YSI 556 MPS, YSI, USA), while HCO_3^- was determined by titrimetry. Before laboratory analyses samples were kept at 4 °C. Major ions (Na^+,

K^+, Mg^{2+}, Ca^{2+}, NO_3^-, PO_4^{3-}, Cl^-, SO_4^{2-}) were determined using ion chromatography (DX-500, Dionex, USA). Inductively coupled plasma optical emission spectrometry (ICP-OES, iCAP 6500, Thermo Scientific, USA) was used to measure Fe and Mn, and As were determined using inductively coupled plasma mass spectrometry (ICP-MS, iCAP Qc, Thermo Scientific, USA).

2.3 Pearson correlation analysis

Pearson correlation analysis is used to determine the interaction between chemical parameters through the calculation of Pearson correlation coefficient (*r*) [5]. Prior to calculation, data was normalized. Pearson correlation coefficient is calculated as follows.

$$r = \frac{\sum_i^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i^n (x_i - \bar{x})^2}\sqrt{\sum_i^n (y_i - \bar{y})^2}} \tag{1}$$

Where n is the number of samples; x_i and y_i are chemical parameters; and $\bar{x}$ and $\bar{y}$ are their mean values. Pearson correlation coefficient ranges from -1 to 1. If $0<r<1$, that means a positive correlation between two variables, whereas $-1<r<0$ indicates a negative correlation. In addition, the correlation is stronger if the absolute value of r is higher. Furthermore, the correlation is strong if $|r|>0.7$, moderate if $0.5<|r|<0.7$, and weak if $|r|<0.5$ [6, 7].

2.4 Hierarchical cluster analysis

Hierarchical cluster analysis (HCA) is employed to group groundwater samples into similar groups, called clusters. Samples within the same cluster experience similar chemical characteristics, while being different from the other clusters. Ward linkage and Euclidean distance were used to determine the distance between clusters and the distance between water samples, respectively. A graphical representation of the HCA results is called a dendrogram [8].

2.5 Factor analysis

Factor analysis (FA) is a commonly used multivariate statistics technique in which data dimensions are reduced without losing any of the data's information. FA converts the dataset into parameters called factors, where the first factor accounts for the majority of the variance in the dataset, with other factors accounting for the remainder. In order to maximize factor loadings, Varimax rotation was utilized. In this work, FA was employed to determine sources that control groundwater chemistry and their impact on groundwater quality.

3. RESULTS

3.1 Correlation analysis

Table 1 presents the Pearson correlation matrix for the 14 selected chemical parameters. For further interpretation, only parameters showing moderate correlation ($0.4<r<0.7$) or strong correlation ($0.7<r<1$) are selected and in bold.
EC showed strong positive correlation with HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, and Mg^{2+}, and moderate correlation with Na^+ and K^+. Strong positive correlations were also observed between HCO_3^- Ca^{2+}, and Mg^{2+}, while moderate correlation was present between HCO_3^- and Na^+, Cl^-, and SO_4^{2-}. There was also a moderate positive correlation between Mg^{2+}, Na^+, and Ca^{2+}. These findings suggest that rock-water interaction plays an important role in controlling groundwater chemistry. NO_3^- was moderately correlated with PO_4^{3-} and K^+. SO_4^{2-} also showed a moderate correlation with Mg^{2+}. These indicate the influence of agricultural activities.

Table 1. Pearson correlation analysis of the physicochemical parameters

	pH	EC	HCO_3^-	NO_3^-	PO_4^{3-}	Cl^-	SO_4^{2-}	Na^+	K^+	Ca^{2+}	Mg^{2+}	Fe	Mn	As
pH	1													
EC	-0.19	1												
HCO_3^-	-0.16	**0.86**	1											
NO_3^-	0.07	0.36	0.26	1										
PO_4^{3-}	-0.08	0.36	0.18	**0.41**	1									
Cl^-	-0.18	**0.79**	**0.6**	0.29	0.31	1								
SO_4^{2-}	-0.14	**0.83**	**0.64**	0.26	0.34	**0.72**	1							
Na^+	-0.15	**0.6**	**0.50**	0.14	0.1	**0.51**	**0.53**	1						
K^+	-0.11	**0.43**	0.23	**0.46**	0.26	0.36	0.37	0.31	1					
Ca^{2+}	-0.25	**0.82**	**0.71**	0.26	0.36	**0.6**	**0.69**	**0.43**	0.29	1				
Mg^{2+}	-0.16	**0.74**	**0.77**	0.29	0.14	**0.65**	**0.64**	**0.47**	0.28	**0.41**	1			
Fe	0.02	0.17	0.13	-0.16	-0.04	0.18	0.23	0.24	0.05	0.17	0.13	1		
Mn	-0.05	-0.11	-0.07	-0.2	-0.05	-0.08	-0.11	0.04	-0.07	-0.07	-0.05	0.07	1	
As	0.01	-0.05	-0.04	-0.1	0.14	-0.12	-0.05	-0.01	-0.02	-0.12	0.01	0.32	0.07	1

3.2 Cluster analysis

Hierarchical cluster analysis was applied in order to classify groundwater samples according to their similar chemical properties. To create a dendrogram of groundwater samples, Ward linkage incorporated with Euclidean distance is used (Figure 1). Results show that groundwater samples were classified into three clusters: Cluster 1 (72.9%), Cluster 2 (19.7%), and Cluster 3 (7.9%). All three clusters are characterized by dominance of Ca^{2+} cation and HCO_3^- anion. Therefore, groundwater in the investigated area shows a dominance of Ca-HCO_3 hydrochemical type. Cluster 1 characterizes the highest average values of NO_3^- and PO_4^{3-} concentrations, suggesting that anthropogenic activities, such as agricultural practices, highly influence these samples. Cluster 2 showed the highest average concentrations of HCO_3^-, Cl^-, Na^+, Ca^{2+}, Fe, and As, indicating that these samples are highly influenced by natural or geogenic sources, such as water-rock interactions and rock weathering [9]. Considering average concentrations of examined chemical parameters in Cluster 3, this cluster shows the impact of both natural and anthropogenic sources.

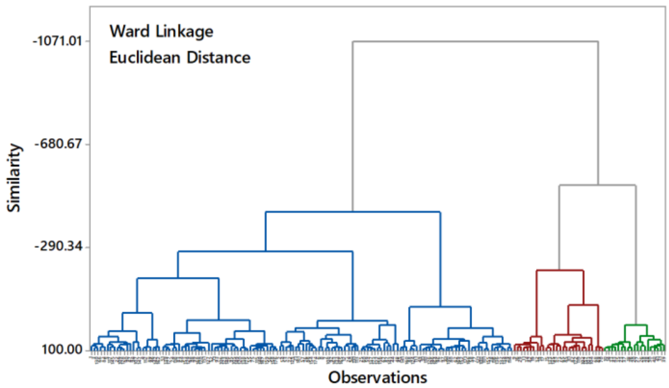

Figure 2. Dendrogram of the groundwater samples

3.3 Factor analysis

Factor analysis was conducted to identify the main pollution sources of groundwater. Varimax rotation was applied, and 14 factors were obtained. Furthermore, only factors with eigenvalues greater than one are extracted (Figure 2a), accounting for 59.50% of the total variance. Extracted factors with their loadings are presented in Table 2. Parameter values greater than 0.7 are considered significant and are in bold. Factor 1 explains 35.10% of the total variance, with high loadings of EC, HCO_3^-, Cl^-, SO_4^{2-}, Na^+, Ca^{2+}, and Mg^{2+}. Major cations and anions mainly reach groundwater due to water-rock interactions, weathering of rocks, or ion exchange processes. Therefore, Factor 1 can represent the influence of natural sources on groundwater contamination. Factor 2 comprised 14.40% of the total variance, showing high loadings of NO_3^- and PO_4^{3-}. Nitrates and phosphates may originate from anthropogenic sources, such as agricultural practices, wastewater disposal, or sewage intrusion. The investigated area is known for its fertile land. In addition, large amounts of fertilizers are used in order to increase the yield of cultivated crops. Therefore, Factor 2 demonstrates the influence of agricultural practices on groundwater contamination. Factor 3 showed high loadings of Fe and As, explaining 10.0% of the total variance. Contents of Fe and As in groundwater are usually controlled by geomorphology. Thus, Factor 3 represents a geogenic source. Loading plot of Factor 1 vs. Factor 2 is shown in Figure 2b.

Table 2. Extracted factors after Varimax rotation

Parameter	Factor 1	Factor 2	Factor 3
pH	-0.322	-0.164	0.073
EC	**0.918**	-0.313	0.025
HCO_3^-	**0.860**	-0.112	-0.019
NO_3^-	0.152	**-0.806**	-0.185
PO_4^{3-}	0.144	**-0.721**	0.172
Cl^-	**0.801**	-0.247	0.003
SO_4^{2-}	**0.819**	-0.268	0.085
Na^+	**0.688**	-0.020	0.163
K^+	0.300	-0.584	0.047
Ca^{2+}	**0.774**	-0.236	-0.012
Mg^{2+}	**0.788**	-0.130	0.019
Fe	0.251	0.174	**0.735**
Mn	-0.001	0.341	0.247
As	-0.153	-0.117	**0.831**
Eigenvalue	5.478	1.580	1.265
Variance (%)	35.10	14.40	10.00
Cumulative variance (%)	35.1	49.50	59.50

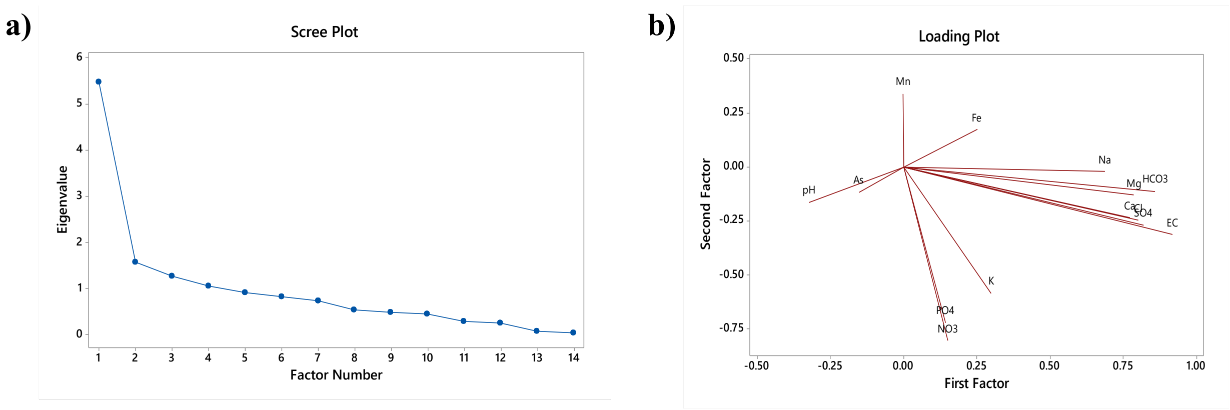

Figure 3. (a) Scree plot, (b) Loading plot

4. CONCLUSION

This work uses three multivariate statistical techniques to examine groundwater in the Morava River Plain, Serbia. HCA clustered groundwater samples into three groups, with Ca-HCO_3 being the prevailing hydrochemical type in all groups. HCA also revealed that both natural and anthropogenic factors impact groundwater chemistry. Pearson correlation matrix and FA results were consistent with the HCA results. FA extracted three factors, accounting for 59.50% of the total variance. Water-rock interactions, geogenic sources, and agricultural activities were identified as the main sources of pollution.

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