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Nenad MALIĆ[1*], Predrag ILIĆ[2] and Sanja MRAZOVAC KURILIĆ[3]

CONTAMINATION, RISK ASSESSMENT AND SPATIAL DISTRIBUTION OF HARMFUL METALS IN SOIL NEAR STANARI (B&H)

Abstract: Soil pollution arises as a consequence of human activities, such as agriculture, industrial projects, and mining. Toxic elements in the soil manifest in the form of liquid metals. These activities, particularly thermal power plants and mining, constitute the primary sources of soil pollution that surpass standard levels. Pollution of soil around coal mines and power plants occurs as a result of the emission of potentially harmful metals and other pollutants into the air, which then settle on the soil. Potentially harmful metals represent a very important group of environmental pollutants because they are potential metabolic inhibitors. The paper describes research focused on presenting and discussing data related to soil pollution by potentially harmful metals near the Stanari Mine and Thermal Power Plant in the Republic of Srpska, Bosnia and Herzegovina. Ecological risk were assessed based on the concentrations of selected metals (Fe, Mn, Pb, Ni, Cr, Zn, Co and Hg) in nine surface soil samples taken from the sites around the thermal power plant Stanari. The research expended through two-years period (2018 and 2020). Various statistical measures such as mode, median, mean, standard deviation, coefficient of variation, variance, skewness, kurtosis, and Shapiro-Wilk test results have been provided for each element. Fe has the highest mean concentration (23195 mg/kg) followed by Mn, Pb, Ni, Cr, Zn, Cu, and Hg. *PCA* analysis provides information on the relationship between metals and the two components, as well as the amount of variance in each variable that is not explained by these components.

Keywords: soil, potentially harmful metals, thermal power plant, mine, ecology risk

Introduction

The widespread contamination of soil by potentially harmful (toxic) metals has emerged as a significant global apprehension [1] and the major component of the biosphere that is exposed to pollutants such as potentially harmful metals [2]. Soil pollution is a serious environmental issue that can have harmful effects on plant and animal life, as well as human health. Toxic elements (usually called liquid metals) in the soil are present due to agricultural and other anthropogenic activities such as mining, thermal power plants and other industrial projects. These activities are the main cause of soil contamination exceeding standard levels [3]. Soil pollution from coal mines and power plants occurs as a result of the emission of metals and other pollutants, including organic pollutants [4-8]

[1] Power Plants Stanari, Stanari 74208, Republic of Srpska, Bosnia and Herzegovina, email: nenad.malic@e-stanari.net, ORCID: 0009-0002-3585-9483
[2] PSRI Institute for Protection and Ecology of the Republic of Srpska, Vidovdanska 43, Banja Luka 78000, Republic of Srpska, Bosnia and Herzegovina, email: predrag.ilic@institutzei.net, ORCID: 0000-0002-0316-5615
[3] University Union-Nikola Tesla, Cara Dušana 62-64, Beograd, Serbia, email: mrazovac@gmail.com, ORCID: 0000-0001-9644-8309
[*] Corresponding author: nenad.malic@e-stanari.net

into the air, which then settle on the soil. The soil serves as the main reservoir for both pollutants and biota, facilitating the transfer of elemental pollutants to living organisms, groundwater, food crops, and the surrounding environment [9]. These metals can be toxic to plant and animal life, as well as to humans who consume contaminated plants and animals. Additionally, some of these pollutants can also reach groundwater, which further increases the risk of environmental pollution and health problems [10]. The pollution of soil from coal mines and power plants may be due to the emission of metals, such as lead, cadmium, mercury, and arsenic, as well as other hazardous substances, such as carbon monoxide and sulphur dioxide, which are released during the combustion of coal. These pollutants can be deposited in the soil, contaminating it and affecting its fertility and quality.

When present in elevated concentrations, potentially harmful metals primarily disrupt the microbiological balance of the soil and inevitably alter its structural composition. As these metals accumulate in the soil, they are absorbed by plants and subsequently enter the food chain, posing a risk to both animals and humans [11, 12].

A study conducted in China showed high levels of potentially harmful metals in soil around power plants, including lead, cadmium, and mercury [13].

The impact range of metal emissions from coal-fired power plants on soil quality tends to be comparable across different locations. Research conducted in India on land surrounding the Delhi Thermal Power Plant estimated this influence to extend up to approximately 4 km [1, 12]. Other studies have provided a more precise assessment, indicating that metal concentrations are notably elevated within a 2 km to 4 km radius from the power plant, particularly along the dominant wind direction [14, 15].

Potentially harmful metals are often a problem in the soils around thermal power plants in Republic of Srpska and Bosnia and Herzegovina. Thus, in the research of soil loading in the Gacko coal basin in Republic of Srpska, concentrations above the limit values for Ni, Cd and Cr were found [16].

While thermal power plants will be phased out in the coming decades due to decarbonisation efforts, their legacy will remain. It is for this reason that research like this paper is crucial for regions across the globe. This type of study enables us to understand the long-term environmental impacts of industrial activities better and to develop more effective strategies for mitigating these effects, thus contributing to sustainable development and the protection of natural resources.

This study aims to present and analyse data on soil contamination caused by potentially harmful metals. The main objective was to assess the extent of soil pollution in the vicinity of the Mine and Thermal Power Plant in Stanari (TPP), Republic of Srpska, Bosnia and Herzegovina.

Experimental section

Study region

Stanari is a municipality situated in the Republic of Srpska, an entity within Bosnia and Herzegovina. The Stanari coal basin is positioned between 44°40' and 44°50' N latitude and 17°45' and 18°00' E longitude, located in the northern part of the Republic of Srpska. The Power Plants Stanari, which includes both a coal mine and a thermal power plant with a capacity of 300 MW, are situated in close proximity to the city of Stanari. The estimated coal reserves in this region are approximately 70 million tonnes (tonne = 10^6 g = Mg).

Sampling and analysis

In 2018 and 2020, soil samples were collected a total 20 samples. Soil samples from the surface layer (0-30) cm depth were taken for analysis in nine locations around the coal basin Stanari: thermal power plant Stanari and open pit Raskovac (Fig. 1). Coordinates of location of soil samples are shown in Table 1.

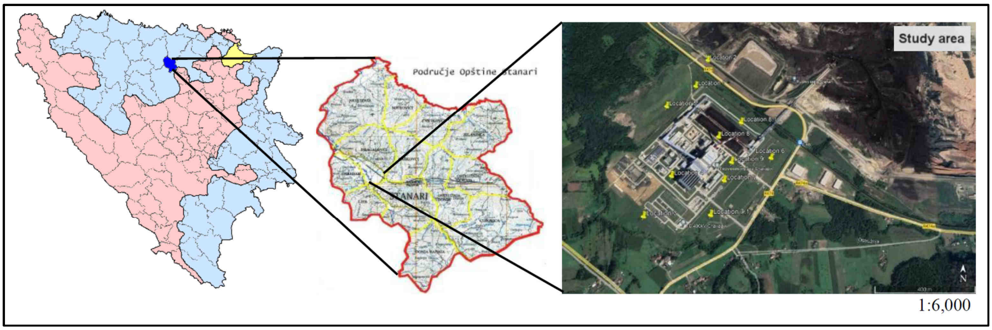


Fig. 1. Position of TPP Stanari and soil samples location

Table 1

Coordinates of location of soil samples

Location	GPS coordinates		
	Y	X	Altitude Z
1	6483887.00	4956984.00	166.56
2	6483925.50	4957141.50	167.50
3	6483649.50	4956347.50	166.40
4	6483802.00	4956512.97	167.34
5	6483749.50	4956877.50	172.24
6	6484253.50	4956535.00	168.80
7	6484042.00	4956487.00	167.40
8	6483973.50	4956734.00	167.20
9	6484070.00	4956586.50	167.30

The chemical analysis of the soil included the determination of the content of toxic metals (Fe, Mn, Pb, Cd, Ni, Cr, Zn, Cu and Hg), in mg/kg. The concentration of toxic metals was determined following the guidelines outlined in Standard Methods, utilising appropriate disintegration techniques. The analysis of Fe, Mn, Pb, Cd, Ni, Cr, Zn, and Cu was conducted in accordance with BAS ISO 11466:2000 [17] and BAS ISO 11047:2000 [18], while Hg was analysed using Hydride technique.

Ecological Risk Assessment

Ecological Risk Assessment employed several key parameters, including the Contamination Factor, *CF*, Pollution Load Index, *PLI*, Ecological Risk Index, *ERI*, Geoaccumulation Index, I_{geo}, and Degree of Soil Load.

Contamination Factor, CF

Following the Tomlinson model [19], the contamination factor was calculated by determining the ratio of metal concentrations in the soil to their respective threshold values. According to national regulations, the established limit concentrations for the analysed metals are as follows: 85 mg/kg for Pb, 35 mg/kg for Ni, 100 mg/kg for Cr, 140 mg/kg for Zn, 36 mg/kg for Cu, and 0.30 mg/kg for Hg [20]. It is important to mention that no established limit values exist for Fe, and Mn is not included in the calculations for toxic metals. Given that these limit values can vary from one country to another, *CF* values may differ even when the metal concentrations are the same [21]. *CF* serves as a crucial metric for monitoring metal contamination in the soil [20]. Equation (1) is utilised for the calculation of *CF*:

$$CF = \frac{Potential\ toxic\ element\ conc. in\ study\ area}{Potential\ toxic\ element\ conc. (limit\ values)} \qquad (1)$$

The *CF* is classified into four categories based on the level of soil contamination. A CF_1 value below 1 indicates a low degree of contamination, values between 1 and 3 represent moderate contamination, values from 3 to 6 signify considerable contamination, while a CF_1 value of 6 or higher denotes a very high degree of contamination [22].

Pollution Load Index, PLI

The Pollution load index is utilised for an overall evaluation of metal contamination at a specific site or area [23]. It is derived from *CF* values to assess the extent of toxic metal pollution, determine the condition of the soil, and guide decisions regarding necessary remediation measures [21]. The *PLI* was computed using the formula presented in the following equation [23]:

$$PLI = \sqrt[n]{CF1 \cdot CF2 \cdot CF3 \cdot \ldots \cdot CF_n} \qquad (2)$$

CF to CF_n represents the contamination levels of individual metals, where n denotes the total number of analysed metals. A *PLI* value greater than 1 signifies the presence of soil pollution [21].

Ecological Risk Index, ERI

The potential ecological risk index method, proposed by Hakanson [23], was applied to assess the potential ecological risk associated with soil contamination [24, 25]. The ecological risk index, *ERI* for toxic metals in soil is determined using this approach to evaluate their overall impact:

$$ERI = T_r \cdot CF \qquad (3)$$

The toxic response factor (T_r) represents the relative toxicity of each metal, while the *CF* indicates the concentration of metals in the soil. The T_r values for the analysed metals are as follows Mn = 1, Pb = 5, Ni = 5, Cr = 2, Zn = 1, Cu = 5, Hg = 40. Factor for Fe not available. The ecological risk is classified into five categories based on the ecological risk index as follows:

- $ERI < 40$ - Low ecological risk
- $40 \leq ERI < 80$ - Moderate ecological risk
- $80 \leq ERI < 160$ - Appreciable ecological risk

- $160 \leq ERI < 320$ - High ecological risk
- $ERI \geq 320$ - Serious ecological risk

These classifications provide a systematic way of assessing and categorising the level of ecological risk associated with the metal concentrations in the soil, with higher *ERI* values indicating a greater potential for adverse ecological impacts [24, 26-29].

Statistical analysis

Statistical data processing was conducted to examine the relationships between metal concentrations, utilising correlation analysis to identify potential associations. The Bivariate Correlations study, specifically employing the Spearman's correlation coefficient test, was conducted. A significance level was set at p values less than 0.05 and p values less than 0.001. In addition to correlation analysis, descriptive statistical methods were applied, including calculations of mean, median, standard deviation, *SD*, variance, minimum (Min.), maximum (Max.), as well as Skewness and Kurtosis tests, to comprehensively analyse the measured data. These operations provided a comprehensive understanding of the central tendency, variability, and distribution characteristics of the dataset. To gain qualitative insights into the sources of the eight types of metals, further statistical analyses, including correlation Spearman's correlation coefficient test and factor analysis, specifically Principal Component Analysis, *PCA*, were employed to assess pollutant distribution and identify underlying patterns in the data. These analyses aimed to uncover patterns and associations among the pollutants. The entire statistical data processing was carried out using Excel 2016 and JASP 0.8.5.1 software, ensuring robust and accurate analysis of the collected data.

Results and discussion

Assessment of toxic metal levels in soil and statistical evaluation

In the research, the concentrations of toxic metals were measured and recorded. Subsequently, all the gathered data underwent initial processing for statistical analysis, and the results are presented in Table 2. This table serves as a comprehensive summary of the statistical properties and characteristics of the toxic metal concentrations, providing valuable insights into the distribution, central tendencies, and variability within the dataset. The given data represents the analysis of soil samples for various elements, including Fe, Mn, Pb, Ni, Cr, Zn, Cu, and Hg. The different statistical measures such as mode, median, mean, standard deviation, coefficient of variation, variance, skewness, kurtosis, and Shapiro-Wilk test results have been provided for each element. As can be seen, Fe exhibits the highest average concentration among the analysed pollutants (23.195 mg/kg), followed by Mn, Ni, Zn, Cr, Cu, Pb, and Hg, with their respective mean concentrations as follows: (915.10, 136.67, 72.39, 71.01, 23.15, 18.10 and 0.11) mg/kg, respectively.

From the given data, it can be observed that the elements have different ranges and levels of variability, with some elements having a high standard deviation and coefficient of variation, indicating greater variability in their concentrations. Some elements such as Pb, Cr, and Hg have higher skewness and kurtosis values, indicating that their distribution is highly skewed and may have outliers.

The significance of Skewness test values is assessed using specific thresholds: an absolute value exceeding 1.96 or below –1.96 indicates significance at $p < 0.05$, values greater than 2.58 or less than –2.58 are significant at $p < 0.01$, while values surpassing 3.29 or dropping below –3.29 are considered significant at $p < 0.001$. In some cases, especially with small sample sizes, values greater or lesser than 1.96 may suffice to establish the normality of the data [30]. Upon conducting the Skewness test for Pb, Cd, and Cu, it was observed that the data distribution is not normal. This observation is further corroborated by the Kurtosis test, indicating a departure from a normal distribution. These findings suggest that the data for Pb, Cd, and Cu may exhibit skewness and kurtosis significant enough to deviate from the assumptions of normality.

Table 2

Statistical summary of the content of toxic metals [mg/kg]

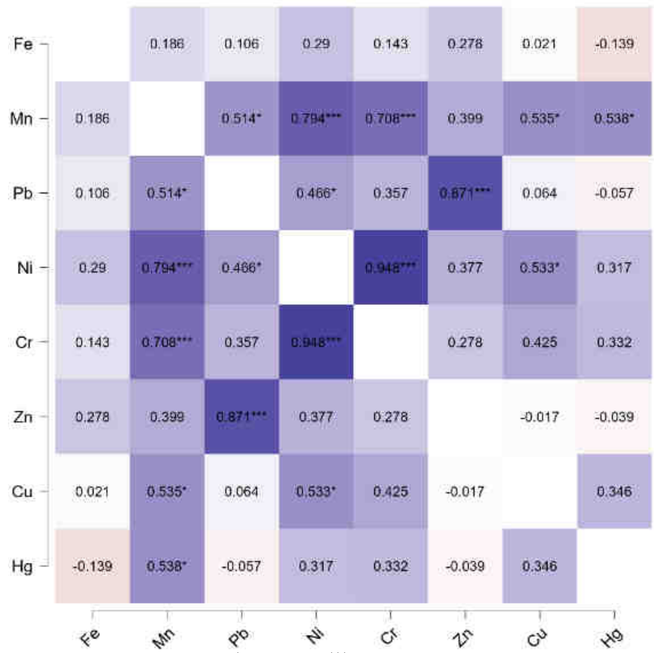
Stat. \ Element	Fe	Mn	Pb	Ni	Cr	Zn	Cu	Hg
Mode	19400	230	15.0	250	0	39	21.9	0.10
Median	22700	820	16.4	63	54	66	22.4	0.09
Mean	23200	920	18.1	140	71	72	23.2	0.11
SD	8900	550	9.3	130	58	31	9.9	0.13
Coefficient of variation	0.38	0.60	0.52	0.94	0.82	0.43	0.43	1.11
Variance	$8\cdot10^{+7}$	298635	87	16377	3408	951	98	0.02
Skewness	–0.18	0.52	2.38	1.18	1.50	2.48	0.85	4.13
Kurtosis	0.71	–0.86	7.33	0.61	3.29	7.87	0.36	17.86
Shapiro-Wilk	0.96	0.92	0.76	0.82	0.88	0.76	0.93	0.43
P-value of Shapiro-Wilk	0.53	0.08	< .001	0.002	0.02	< .001	0.16	< .001
Minimum	1932	232	8	22	0.05	38	10.3	0.05
Maximum	42000	2024	50	469	247	180	46	0.63

The coefficient of variation, *CV*, which measures variability relative to the sample mean, is commonly used in environmental studies to evaluate the extent of anthropogenic influence. A *CV* less than 0.10 or greater than 0.90 signifies low and high anthropogenic contributions, respectively [31]. Upon analysis, it was found that only the pollutant Hg exhibited a *CV* greater than 0.90. Specifically, values for Ni, Cr, Mn, Pb, Cu, Zn, and Fe were calculated as 0.936, 0.822, 0.597, 0.515, 0.428, 0.426, and 0.384, respectively. These results indicate that the average anthropogenic contribution and pollutant concentrations in soil samples remained relatively consistent across different locations, except for Hg, which exhibited significant variation. The Shapiro-Wilk test results show that some elements such as Pb, Ni, Cr, and Hg have *p*-values less than 0.05, indicating that they do not follow a normal distribution. The maximum and minimum values for each element show the range of concentrations found in the soil samples.

The comparison of obtained metal concentrations with national regulatory limits indicates that Ni, Cr, Zn, Cu, and Hg exceed their respective thresholds in certain locations, while Pb remains within safe limits. Nickel (mean 136.67 mg/kg, Max. 469 mg/kg) presents the most significant contamination, consistently surpassing the 35 mg/kg limit. Although Cr (Max. 247 mg/kg), Zn (Max. 180.90 mg/kg), Cu (Max. 46.30 mg/kg), and Hg (Max. 0.63 mg/kg) exceed their respective limits (100 mg/kg, 140 mg/kg, 36 mg/kg, and 0.30 mg/kg), their mean concentrations remain within acceptable ranges, indicating localised contamination.

Correlation analysis

The results of the correlation analysis are presented in Figure 2. A strong positive correlation ($p < 0.001$) was observed between Mn and Ni, Mn and Cr, Pb and Zn, as well as Ni and Cr. Additionally, significant correlations ($p < 0.001$) were identified between Mn and Pb, Mn and Cu, Mn and Hg, Pb and Ni, and Ni and Cu, based on Spearman's correlation coefficient test.



* $p < 0.05$, *** $p < 0.001$

Fig. 2. Correlation between toxic metals-Pearson's heatmap

Correlation Ni and Cr/Mn and Ni have the value of R is 0.871 and 0.794, respectively.

There exists a strong positive correlation, indicating that elevated Ni/Mn variable scores correspond to heightened Cr/Ni variable scores, and vice versa. The coefficient of determination, R^2, for these associations is 0.8989 and 0.6312, respectively.

The correlation between Mn and Cr yields an R value of 0.708, indicating a moderate positive correlation. The coefficient of determination (R^2) for this correlation is 0.5011. Other correlations in the dataset are characterised as moderate positive and weak. The variables do not follow a normal distribution, underscoring the relevance of the Spearman rank correlation method. Based on Spearman's correlation, the relationships between the variables were analysed to identify significant associations (Ni and Cr; Mn and Ni; Mn and Cr) are deemed statistically significant by conventional standards. These outcomes suggest that these pairs of pollutants may share common sources or have been influenced by similar factors. Correlation analysis values for other pollutants are not deemed relevant in this context.

Principal component analysis

Factor Analysis, *FA* was applied in this research to identify the most influential variables. The purpose of *FA* is to reduce the number of variables by grouping related ones into fewer factors. Given the complexity of environmental data, factor analysis helps in extracting key components that define a theoretical framework [32]. Principal Component Analysis, *PCA* was utilised, with the primary output displaying the correlation between each variable and the principal components (RC1 and RC2), as shown in Table 3.

Table 3

Component loading for toxic metals

Element	RC1	RC2	Uniqueness
Mn	0.845		0.152
Ni	0.837		0.115
Cr	0.815		0.239
Cu	0.763		0.430
Hg	0.711		0.447
Zn		0.911	0.149
Pb		0.866	0.176
Fe		0.437	0.805

PCA is a robust pattern recognition technique designed to explain the variance within a large dataset of intercorrelated variables using a smaller set of independent variables [33]. Its data reduction approach involves generating one or more index variables (components) derived from the original measured variables. The Figure 3a shows the component loadings for potentially harmful metals, which are measured in terms of RC1 and RC2. These components are expressions formed by linear combinations of the original variables, designed to capture the highest possible amount of variation present in the data. The uniqueness represents the proportion of variance in each variable that is not explained by the two components. The direction of the arrows indicates the contribution of the variables (Mn, Ni, Cr, Cu, Hg, Zn, Pb, and Fe) to the variable factors. The weights emphasise Mn, Ni, Cr, Cu, and Hg more for RC1, and Zn, Pb, and Fe more for RC2, compared to the other variables. The component loading serves as a measure of the strength of the relationship between each variable and the respective components. The uniqueness values for each variable indicate the proportion of variance that is not accounted for by the two components. For example, Cu and Hg have high uniqueness values, indicating that much of their variance is not explained by the two components. Through *PCA*, two factors were derived to elucidate the grouping of pollutants. Factor RC1 primarily represents the toxic metal factor, encompassing Mn, Ni, Cr, Cu, Hg, Zn, Pb, and Fe and can be interpreted as a factor of metals that are usually present in soils as a result of anthropogenic activities, such as industrial processes, agriculture, mining, and the like. These metals are known for their toxicity and can adversely affect human and animal health if present in excessive amounts. Factor RC2 represents the second group metals (Zn, Pb and Fe) and can be interpreted as a factor of grouped metals that are naturally present in soils. These metals are usually present in soils as a result of natural geological processes and erosion, and their concentrations in soils can vary depending on the geographical area and geological characteristics of the soil. These metals can be useful as plant nutrients in appropriate concentration, but can be toxic if present in excessive amounts.

The RC1 factor represents the anthropogenic influence on metal distribution at the study location, encompassing Mn, Ni, Cr, Cu, Hg, Zn, Pb, and Fe, and accounting for 68 % of the total variance. Mn, Ni, Cr, and Cu exhibited strong positive loadings (> 0.75), while Hg showed a moderate loading (0.50-0.75) (Tables 3 and 4). Hg is not an essential element at low concentrations for any living organisms. Ni, a naturally occurring element in the Earth's crust, can enter the environment through natural processes but is predominantly introduced by human activities [33].

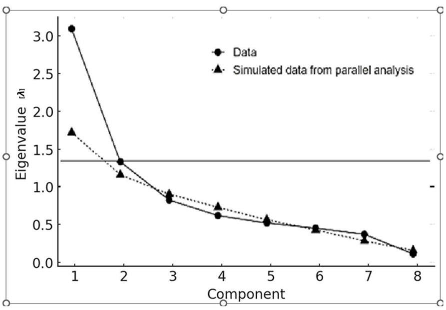
The RC2 factor is associated with natural environmental processes in the study area, explaining 32 % of the total variance. Zn and Pb displayed strong positive loadings (> 0.75), whereas Fe had a weak loading (0.30-0.50) (Tables 3 and 4).

Table 4

Eigenvalue and percentage variance for factors

RC	Eigenvalue [-]	Variance [%]
1	3.73	68
2	1.75	32

a)



b)

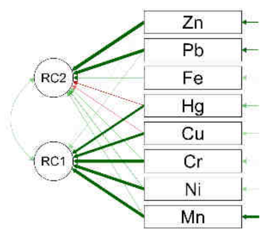


Fig. 3. a) Path diagram and b) scree plot

The scree plot shows that the samples differ in terms of metal concentrations in the soil. In summary, *PCA* analysis enabled us to identify two main components that explain most of the variance in the data and interpret these components in the context of the presence of potentially harmful and natural metals in the soil.

Research has shown similar conclusions regarding the factors of potentially harmful metals and grouped metals in soils. A study involving the analysis of Mn, Ni, Cr, Cu, and Hg in soils around several industrial zones in China [34] found comparable results. On the other hand, a study about metal concentrations in soils from different geological areas in Spain and identified factors including Zn, Pb, and Cd [35]. These studies demonstrate that metal concentrations in soils vary depending on geographical location and different sources of pollution. However, they all agree that excessive concentrations of metals in soils can be harmful to human and animal health, and careful monitoring of pollution levels in soils is necessary.

In Figure 3b, the *PCA* scree plot is presented. Eigenvalues exceeding one were used as a criterion for determining the principal components necessary to elucidate the sources of variance in the data. Employing the applied rotation method, Promax, it was observed that two factors accounted for 100 % of the total variance.

Contamination Factor and Pollution Load Index, *PLI*

After determining each metal's limit values, the contamination factor, *CF*, was calculated. The *CF* and *PLI* were used to assess the status of the toxic metals in the soil. *CF* was determined as the ratio of the metal concentration in the analysed soil. Hg, Zn, Cu, and Cr exhibited low contamination levels, with respective *CF* values of 0.37, 0.52, 0.64, and 0.71. *PLI* value of ≤ 1 indicates a low degree of contamination. None of the analysed metals fell within the moderate contamination range ($1 \leq CF_i < 3$). However, Pb and Ni demonstrated a considerable degree of contamination ($3 \leq CF_i < 6$), with *CF* values of 272.89 and 3.91, respectively (Table 5) [36].

Table 5

Contamination factors, *CF* and pollution load index, *PLI* of toxic metals in soil per samplers

Samples	***CF* [-]**						***PLI***
	Pb	**Ni**	**Cr**	**Zn**	**Cu**	**Hg**	**[-]**
1.	329.41	8.26	1.14	0.71	0.73	0.15	**4.50**
2.	298.82	1.49	0.32	0.43	0.36	0.33	**1.40**
3.	364.71	7.91	1.20	1.29	0.33	0.17	**2.51**
4.	303.53	7.14	0.85	0.48	1.16	0.33	**2.64**
5.	494.12	0.64	0.00	0.47	0.33	0.32	**0.61**
6.	202.35	0.99	0.34	0.28	0.29	0.33	**1.1**
7.	352.94	0.66	0.00	0.34	0.64	0.22	**0.46**
8.	178.82	1.29	0.54	0.34	0.76	0.19	**1.36**
9.	400.00	1.71	0.56	0.68	0.52	0.23	**1.78**
10.	187.06	1.37	0.44	0.45	0.43	0.19	**1.26**
11.	22.73	1.77	0.53	0.53	0.63	0.47	**1.22**
12.	235.29	0.71	0.04	0.36	0.77	0.28	**0.89**
13.	325.88	5.20	0.96	0.39	0.61	0.33	**2.24**
14.	227.88	9.00	1.56	0.53	1.00	2.10	**3.91**
15.	181.18	3.17	0.79	0.41	0.49	0.16	**1.57**
16.	227.53	1.82	0.52	0.47	0.61	0.30	**1.63**
17.	185.88	1.43	0.39	0.51	0.41	0.23	**1.3**
18.	369.41	13.40	2.47	0.39	0.85	0.33	**3.32**
19.	342.35	7.14	1.00	0.74	1.29	0.33	**3.03**
20.	227.88	3.00	0.55	0.55	0.68	0.47	**2.01**
Mean	**272.89**	**3.91**	**0.71**	**0.52**	**0.64**	**0.37**	**2.13**

PLI was calculated based on contamination factor values to evaluate toxic metal pollution. In 17 soil samples, *PLI* values exceeded 1, as presented in Table 5, indicating the presence of soil contamination. The mean *PLI* values further support this finding, confirming soil pollution in the analysed area.

Ecological Risk Index, *ERI*

The *ERI* serves as an indicator for the potential ecological risk associated with all tested toxic metals [8, 37]. The Risk Index, *RI* values for each toxic metal were calculated for every sample, as presented in Table 6. Upon evaluating these results and considering the established criteria, the mean ecological risk for soil samples, with the exception of Pb, indicates a low ecological risk. Mean for Pb is 1299.71 and indicate serious ecological risk in location according to the criteria of Wang et al. [34]. The maximum mean values for *RI* is 1299.71, and the lowest ecological *RI* is 0.54 (for Zn). The findings of this study indicate that Pb is the most significant ecological risk among the analysed toxic metals (Table 6).

Table 6

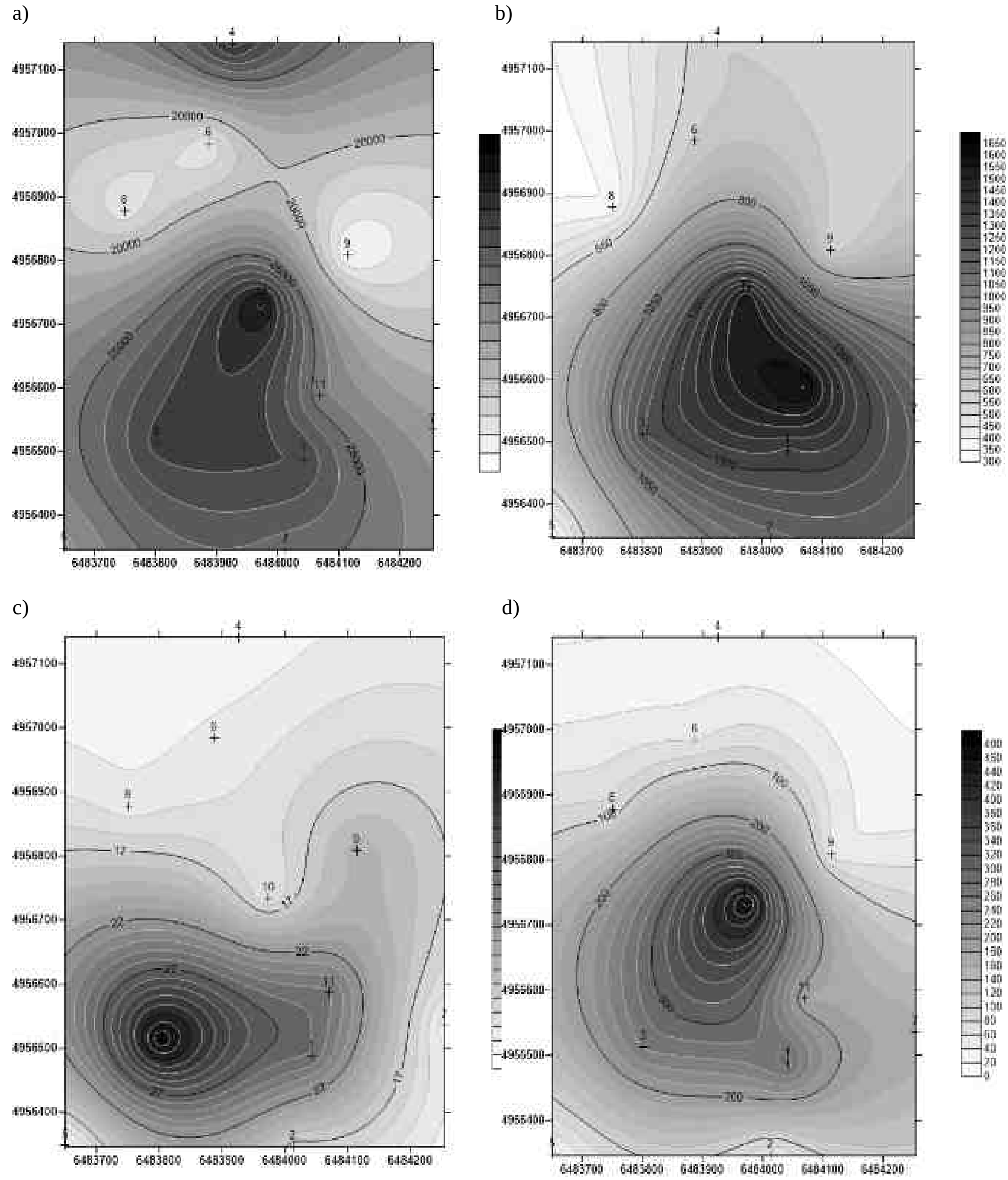
Ecological risk assessment, *ERI* of toxic metals in soil per sample

Samples	***ERI* [-]**					
	Pb	**Ni**	**Cr**	**Zn**	**Cu**	**Hg**
1.	1647.06	41.29	2.27	0.71	3.63	6.13
2.	1494.12	7.47	0.65	0.43	1.79	13.33
3.	1823.53	39.57	2.40	1.29	1.63	6.93
4.	1517.65	35.71	1.70	0.48	5.79	13.33
5.	2470.59	3.20	0.01	0.47	1.67	12.67
6.	1011.76	4.94	0.68	0.28	1.43	13.33
7.	1764.71	3.30	0.00	0.34	3.21	8.80
8.	894.12	6.44	1.08	0.34	3.81	7.73
9.	2000.00	8.54	1.12	0.68	2.61	9.33
10.	935.29	6.83	0.88	0.45	2.13	7.47
11.	113.65	8.86	1.07	0.53	3.17	18.67
12.	1176.47	3.53	0.08	0.36	3.83	11.20
13.	1629.41	26.00	1.92	0.39	3.04	13.33
14.	1139.41	45.00	3.12	0.53	5.01	84.00
15.	905.88	15.84	1.59	0.41	2.46	6.40
16.	1137.65	9.10	1.04	0.47	3.04	12.00
17.	929.41	7.16	0.77	0.51	2.03	9.20
18.	1847.06	67.00	4.94	0.39	4.24	13.33
19.	1711.76	35.71	2.00	0.74	6.43	13.33
20.	1139.41	15.00	1.09	0.55	3.39	18.67
Mean	**1299.71**	**18.83**	**1.45**	**0.54**	**3.30**	**16.15**

Similar results were obtained in the research of soil in Gacko (Republic of Srpska, Bosnia and Herzegovina), near the Gacko mine and thermal power plant, but no Hg analysis was performed [37]. Water analyses were also performed, which confirmed toxic metal pollution as well as in the soil [38].

Spatial distribution

The spatial distribution of Fe, Mn, Pb, Ni, Cr, Zn, Cu, and Hg was conducted using Surfer 12 software, which employs the kriging method to generate an interpolated grid. The resulting distribution of concentration for these elements in selected areas is illustrated in Figure 4. Despite the relatively small number of samples utilised in this spatial distribution, it provides a valuable and informative visual representation, particularly considering that spatial distribution had not been conducted in the area before. It is worth noting that future research endeavours should aim to incorporate a larger number of samples to establish the validity of these calculations.


a)
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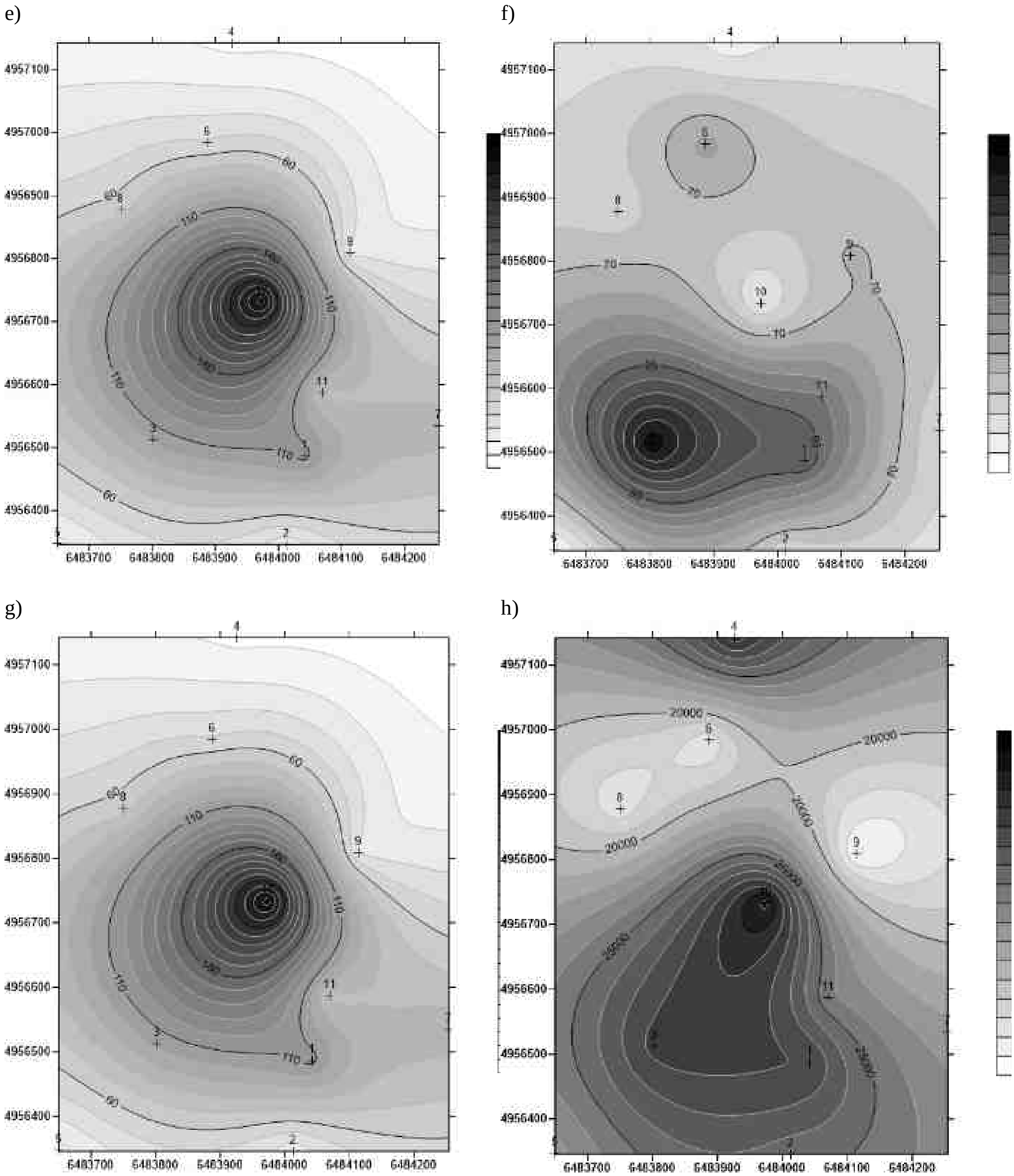

Fig. 4. The distribution of: a) Fe, b) Mn, c) Pb, d) Ni, e) Cr, f) Zn, g) Cu and h) Hg

Conclusion

This study assessed soil contamination near Stanari, Republic of Srpska, analysing Fe, Mn, Pb, Ni, Cr, Zn, Cu, and Hg. Fe had the highest mean concentration (23195 mg/kg), while Hg exhibited significant variability. Statistical analysis revealed that Pb, Cr, and Hg showed high skewness and kurtosis, indicating potential outliers. The Shapiro-Wilk test confirmed that Pb, Ni, Cr, and Hg did not follow a normal distribution. *PCA* analysis identified two major components influencing metal distribution, reflecting both anthropogenic and natural sources.

The findings indicate that Ni, Cr, Zn, Cu, and Hg exceeded regulatory limits in certain locations, posing ecological risks. Mercury pollution was particularly concerning due to its persistence and toxicity. To mitigate contamination, key recommendations include improving industrial emission control, regular soil monitoring, applying remediation techniques, and raising public awareness about health risks.

Potentially harmful metals persist in the environment, affecting biodiversity, soil fertility, and human health. Effective pollution prevention measures, including emission reduction, proper waste management, and cleaner production technologies, are essential. A comprehensive approach integrating monitoring and sustainable practices can minimise the long-term environmental impact of toxic metal contamination.

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