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Original Research

Ecological Risk of Toxic Metal Contamination in Soil around Coal Mine and Thermal Power Plant

Predrag Ilić[1]*, Svetlana Ilić[1], Dragana Nešković Markić[2], Ljiljana Stojanović Bjelić[2], Zoran Popović[1], Branko Radović[1], Sanja Mrazovac Kurilić[3], Zia Ur Rahman Farooqi[4], Tariq Mehmood[5], Mohamed Hassan Mohamed[6], Saber Kouadri[7]

[1]PSRI Institute for Protection and Ecology of the Republic of Srpska, Vidovdanska 43, Banja Luka, Republic of Srpska, Bosnia and Herzegovina
[2]Pan-European University "Apeiron", Pere Krece 13, Banja Luka, Republic of Srpska, Bosnia & Hercegovina
[3]University Union-Nikola Tesla, Cara Dušana 62-64, Beograd, Serbia
[4]Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad-38040, Pakistan
[5]College of Ecology and Environment, Hainan University, Haikou, Hainan Province, P.R. China
[6]The Somali International University, Faculty of Health Sciency Department of Public and Environmental Health, Mogadishu, Somalia
[7]University of Kasdi Merbah-Ouargla, Laboratory of Water and Environment Engineering in Saharan Environment, Ouargla, Algeria

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Abstract

Soil samples were collected near the thermal power plant and coal mine (Gacko, Republic of Srpska, Bosnia and Herzegovina) and analyzed to measure the concentration of 16 toxic metals (Pb, Cd, Cr, Ni, Zn, Cu, Hg, As, Mo, Co, Ba, V, Tl, B, S and F). The pollutant with the highest mean concentration was B (3,210.02 mg/kg), followed by the Ba (242 mg/kg), Zn (109.50 mg/kg), V (90 mg/kg), Ni (82.10 mg/kg), Cr (60.22 mg/kg), Cu (46.28 mg/kg), Pb (38.90 mg/kg) and Co (19.25 mg/kg). From the evaluation of the soil pollution indices (contamination factor (CF), pollution load index (PLI), ecological risk assessment (ERI), geoaccumulation index (I_{geo}) and degree of soil load), it can be seen that the studied soil samples in most cases are contaminated. CF values indicate that all values for Cu, Co, Ba and Va in all samplers, Ni in three samplers and Zn in one sampler indicate a moderate degree of contamination. In all soil samples, the values PLI indicates the presence of soil pollution. This study reveals that Ni for RI index is the toxic metal that poses the highest ecological threat. In according average values for I_{geo} for all toxic metals are >5, it can be concluded that the soil belongs to the class "extremely polluted". The values of degree of soil load for Ba and V load show that V class is a land of very high load (limit values in according of national legislation for Ba is 160 mg/kg and for V

*e-mail: predrag.ilic@institutzei.net

is 42 mg/kg). Values for Ni load show that IV class is a land of high loads (limit value 35 mg/kg). In accordance with the obtained results, it is necessary to prioritize the work on sustainable solutions to mitigate the current risks.

Keywords: Thermal Power Plant, toxic metals, ecology risk, soil

Introduction

Soil is one of the most precious natural resources [1], which is equally exposed to negative anthropogenic activity as other natural resources. The pollution of the biosphere of toxic metals became dramatic at the beginning of the industrial revolution and urbanization, since when it poses a major problem around the world [2-4], especially in developing countries [5]. In recent decades, environmental pollution by toxic metals has been a significant global problem with a characteristic cumulative effect and risk for the ecosystem [6, 7]. Toxic metals are natural components of Earth curst, but in many ecosystems, the concentration of some metals has reached toxic levels due to the effects of anthropogenic activity. Toxic metals in soils near factories generally enter the soil from industrial activities. Pollutants are ubiquitous in the environment, especially in industrialized zones [6-9] and can be strongly accumulated in soil [10]. The term toxic metals usually mean the so-called heavy metals. Although the term "heavy metals" is incorrectly defined [11], it is often accepted and usually refers to widespread contaminants in the ecosystem and are able to accumulate in natural environments [12] and destroy the soil texture and have strong impact in soil degradation [13].

Important group metals includes elements necessary for the growth and development of plants (Cu, Zn, Mn, Fe, Co and Mo), whose high concentrations are toxic. Thus, either deficits or excessive levels of the six elements can seriously impair the growth, development and health of plants, microbes and animals, including humans [14]. Micronutrients Fe, Cu, Co, Ni, Mn and Zn, which are toxic usually in high concentration [15] but and in low concentrations [7, 16].

Toxic metals, such as Pb, As, Cd and Ni, are emitted from anthropogenic sources [17], under the effect of industrial activities, soils were moderately contaminated with Cd, uncontaminated to moderately contaminated with As and Zn, and uncontaminated with Cr, Cu, V, and Pb [18]. Mining and thermal power plants are significant sources of soil toxic metal pollution [1, 6, 19-21]. Areas near thermal power plant, mining areas and urban areas are high-risk areas for soil toxic metal pollution. Soil Cd, Zn, As, and Pb contamination was attributed to high-temperature coal combustion [18]. The combustion of coal in thermopower plants release various pollutants, which once released into the air reach the land where they are deposited [6]. Toxic metals Cd, Pb, Hg, Cr and As are known for their plant toxicity. Toxic metals enter the soil through the diffusion or leaching of dust, residual tailings, slag, and waste rock generated by mining, stacking, and transportation activities [1]. The remediation of soil polluted by toxic metals is very expensive and complex, it is essential to develop and establish a pollution prevention system [6].

So far, two surveys of soil quality have been conducted at this site [6, 22], which were based only on quantifying the concentration of pollutants. Currently, there is very little data on soil pollution and ecological assessments in Bosnia and Herzegovina (BiH), but studies showed a high level of toxic metals in urban and industrial soil (old metallurgical area, chloralkali production facility etc.) [10, 23, 24], and children playgrounds [25]. Usually, research in industrial zones is conducted for other pollutants, not toxic metals [10, 26-30].

Thermal power plant and mine of coal were the dominant industrial activity that impacted the toxic metal concentrations in soil and ecologicaly risks near Gacko Municipality, Republic of Srpska, BiH. The aim of this study is to determine the level of toxic metals contamination in soils and evaluate the ecology risks in the vicinity of Thermal Power Plant and Mine in the city of Gacko, with neglecting the sources of pollutants from the atmosphere, fertilizers, pesticides and other pollutants. The goal of this study can hopefully offer valuable insight and critical information that can be used for ecology risk mitigation and give guidelines for future planning in the analyzed areas.

Material and Methods

Study Area

Gacko is a town and municipality located in Republic of Srpska, an entity of BiH, in the region of East Herzegovina. Gacko coal basin is located in Gacko Polje, near Gacko Municipality. The Gacko coal mine and thermal power plant (300 MW) are located near the Gacko, and estimated coal reserves iznose approximately 400 million tonnes. The construction of the coal mine and power plant started in 1974 and was completed in February 1983 [31]. It covers an area of about 40 km² at an altitude of about 940 m, in a typical karst area. The terrain is mostly flat. According to the phases of the research, the basin is divided into four parts, i.e. fields: West field, Central field, East field and South field (roof coal zone). Gacko coal basin is surrounded by pastures and meadows. The soils are mineral-wetland of the following types: wetland gley soils (euglej) and red soil.

Sampling and Analysis

Surface soil samples (0-30 cm depth) were collected. In total, 4 topsoil samples around the thermal power plant in location with potentially toxic substances during 05-06. December 2019. Samples for analysis were taken in places around the surface mine «Gacko-Centralno polje» (Gacko-Central field). Soil sampling locations are: (1) open pit mine (43°08'37.7''N, 18°31'15.4''E), south side in relation to the open pit mine, town of Gacko; (2) settlement Zečica (43°10'12.8»N, 18°31'18.9''E), northern side in relation to the open pit mine; (3) municipality Gacko – below the stadium (43°09'36.4''N, 18°32'03.8''E), east side in relation to the open pit mine and (4) village Srđevići (43°09'42.5''N, 18°29'06.9''E), southwest side in relation to the open pit mine (Fig. 1).

Physical and chemical analyses of samples were conducted to determine the pH, humus, and toxic metals (Pb, Cd, Cr, Ni, Zn, Cu, Hg, As, Mo, Co, Ba, V, Tl, B, S and F), in mg/kg. As this is an agricultural area, which is not cultivated, four samples are representative for further analysis.

The toxic metal concentration were processed based on the principles described in Standard Methods with disintegration techniques and analyzed [32, 33] and according with national legislation [34]. Analysis of Pb, Cd, Ni, Cr, Fe, Mn, Cu, Zn was performed according to BAS ISO 11466:2000 and BAS ISO 11047:2000 and Hg were AAS, Hydride technique. ICP-OES technique was used for Mo, Co, Ba, V, Tl, B, S and F. Acidity (pH) measured in deionized water, organic matter content (humus) applied by Tyurin's method.

Ecological Risk Assessment

In order to measure Ecological Risk Assessment, the following were used: Contamination factor (CF), Pollution Load Index (PLI), Pollution Load Index (PLI), Ecological risk assessment (ERI), Geoaccumulation Index (I_{geo}) and Degree of soil load [35-46].

Contamination Factor (CF)

According to Tomlinson model [35], the CF was determined as the ratio of the metal concentration in the soil, to the limit concentration. According to national regulations, the limit values for analyzed metals are for Pb, Cr, Ni, Zn, Cu, Co, Ba, V and Tl are 85, 100, 35, 140, 36, 9, 160 and 42 mg/kg, respectively [36]. Limit values do not exist for B and CF is not calculated for this toxic metal. As the values sometimes vary from country to country, CF values may be different, even if the metal concentrations are identical [8]. CF is an important factor that is used to monitor the metals contamination in the Soil [37]. The following Eq. (1) is used to calculate the CF:

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

The CF has four categories according to the degree of contamination in the soil. $CF_i<1$ indicate low degree of contamination, $1\leq CF_i<3$ moderate, $3\leq CF_i<6$ considerable and $CF_i\geq 6$ very high degree of contamination [38].

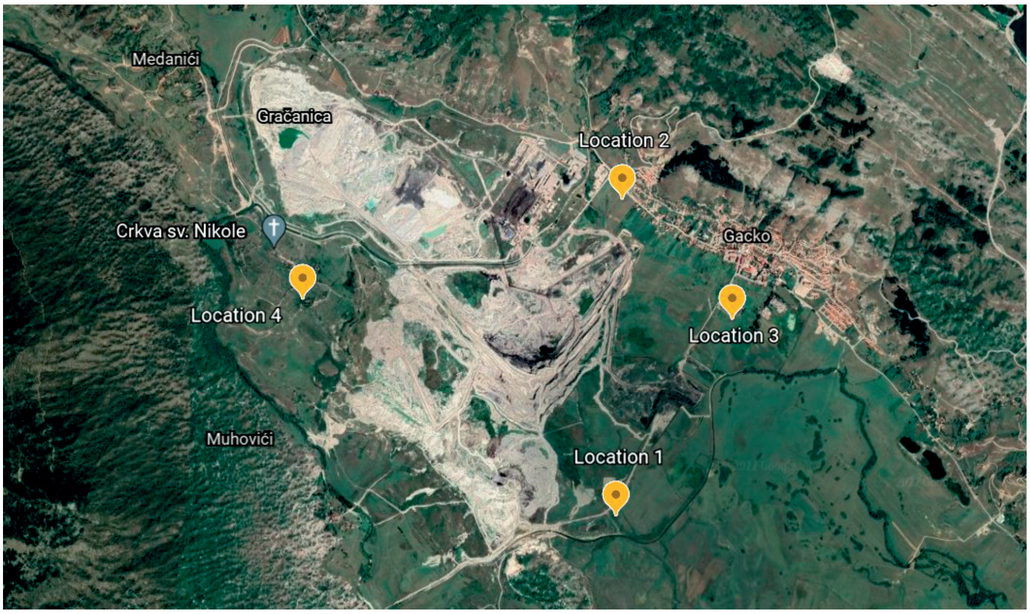

Fig. 1. Location of sampling.

Pollution Load Index (PLI)

PLI has been used for the total assessment of metal contamination for a site or area [39]. From the CF values, the PLI was derived to assess the toxic metal pollution and status of the soil [8]. The PLI was calculated by following calculations given in equation (2) [39]:

$$PLI = \sqrt[n]{CF1 \times CF2 \times CF3 \times \ldots \times CFn} \quad (2)$$

CF to CFn shows the contamination factor and n is the number of metals.

PLI>1 indicates the presence of soil pollution [8].

Ecological Risk Assessment (ERI)

The potential ecological risk index method put forward by Hakanson (1980) was used to evaluate the potential soil ecological risk [17, 38]. The ERI of toxic metals in soil can be accessed by a potential ecological risk index (Eq. 3):

$$ERI = Tr \times CF \quad (3)$$

Where Tr showing the toxic response factor and CF is concentration factor. Tr for the metals are Pb = 5, Cr = 2, Ni = 5, Zn = 1, Cu = 5, Co = 5, Ba = , V = 2. The classification of ecological risk is in five class: Eri<40 - Low Ecological Risk, 40<Eri<80 – Moderate, 80<Eri<160 – Appreciable, 160<Eri<320 – High and Eri>320 – Serious Ecological Risk [35, 38-41].

Geoaccumulation Index (I_{geo})

Soil pollution assessment can also be done by comparing current toxic metal presence with pre-industrial levels of concentration [8, 44]. I_{geo} has been widely used to comprehend the pollution levels of toxic metals in the soils around worldwide [5], that is, for the calculation to assess the toxic metal pollution status of soil [17]. The I_{geo} was computed as follows (Eq. 4):

$$I_{geo} = \log_2\left(\frac{C_n^{hm}}{1.5 \text{ x } BV_n}\right) \quad (4)$$

where C_n^{hm} is the measured concentration of the toxic metal "n" of the soil sample, and BV_n is the average geochemical background value of the measured toxic metal "n". Geochemical background values for Pb, Cr, Ni, Zn, Cu, Co, Ba, V and B are 20, 35, 20, 71, 25, 10, 550, 60 and 15, respectively [38]. There are classified seven levels based on I_{geo} values, namely [45, 5], not polluted, I_{geo} <0; not polluted to moderately polluted, 0<I_{geo}≤1; moderately polluted, 1<I_{geo}≤2; moderately polluted to heavily polluted, <I_{geo}≤3; heavily polluted, 3<I_{geo}≤4; heavily polluted to extremely polluted, 4<I_{geo}≤5; and extremely polluted, I_{geo}>5.

Degree of Soil Load

The degree of soil load is calculated according to the Rulebook on allowable quantities of dangerous and hazardous matters in soil [46]. To interpret the results of testing heavy metals and potentially toxic elements in agricultural land, the following classes and criteria are used depending on the degree of soil load (% Soil Loading Degree – SLD (now)) Class I – clean unloaded soil: SLD up to 25%; Class II – low soil load: SLD from 25.01% to 50%, Class III – medium soil load: SLD from 50.01% to 100%, Class IV – high soil load, above the maximum allowable amount (Maximum Allowable Quantity – MAQ (now)) SLD from 100.01% up to 200% and Class V – very high soil load: SLD more than 200%.

Statistical Analysis

A significance level of p-value p<0.01 and p<0.001 was used. Descriptive statistical operations (mode, median, mean, standard deviation (SD) with coefficient of variation (CV), skewness, kurtosis, shapiro-wilk, minimum, maximum) were applied for the analysis of the collected data. Correlation (Pearson's) was applied for getting the qualitative information about the possible source of the toxic metals. Excel 2016, JASP 0.16.0.0 softwares were used for statistical data processing.

Results and Discussion

Concentration of Toxic Metals in Soil and Descriptive Analysis

Present work explores the toxic metal concentrations (Pb, Cr, Ni, Zn, Cu, Co, Ba, V and B), pH and humus that originate from human activity in Gacko. The other toxic metals such as Cd, Hg, As, Mo, Tl, S and F were also measured, however, their concentrations were below the detection limit. Descriptive statistics of toxic metals from the surface soil level, as well as from all other collected samples, can be found in Table 1 and Fig. 2.

It can be seen from Table 1 that B is the pollutant with the highest mean concentration (3,210.02 mg/kg) followed by the Ba, Zn, V, Ni, Cr, Cu, Pb and Co while their mean concentrations were 242, 109.50, 90, 82.10, 60.22, 46.28, 38.90 and 19.25 mg/kg, respectively. Concentrations of toxic metals detected in the present work are greater than measured values during previous surveys in the same area [6]. Soil pollution is not comprehensively regulated at the European level [8], so national regulations are used [36], which are in full compliance with Dutch list for soil pollution [47]. Mean values for Ni, Cu and Co were above to standards values of national regulation [36]. Ni is the element that particularly stands out for its high concentrations. The natural origin of Ni in the soil is

Table 1. Statistical summary of toxic metals in soil.

	Pb	Cr	Ni	Zn	Cu	Co	Ba	V	B	pH	Humus
Mode	[a] 17.80	50.30	62.00	75.00	36.20	15.00	170.00	64.00	0.10	7.30	4.20
Median	32.30	57.65	73.20	87.50	45.15	18.50	241.50	93.50	3510.00	7.50	4.75
Mean	38.90	60.23	82.10	109.50	46.27	19.25	242.00	90.00	3210.02	7.56	4.95
SD	23.90	11.029	26.39	52.83	9.24	4.35	61.75	19.78	3023.27	0.32	0.81
CV	0.61	0.18	0.32	0.48	0.20	0.23	0.25	0.22	0.94	0.04	0.16
Variance	571.31	121.41	696.21	2791.53	85.32	18.92	3812.67	391.33	9.14+6	0.10	0.66
Skewness	1.48	1.11	1.54	1.89	0.72	0.83	0.04	-0.81	-0.15	0.51	1.35
Kurtosis	2.71	0.69	2.25	3.62	1.79	-0.04	-0.73	-0.39	-5.15	-3.13	2.50
Shapiro-Wilk	0.87	0.93	0.85	0.75	0.93	0.96	0.10	0.95	0.82	0.87	0.89
P-value of Shapiro-Wilk	0.30	0.57	0.22	0.04	0.58	0.76	0.99	0.72	0.15	0.29	0.37
Minimum	17.80	50.30	62.00	75.00	36.20	15.00	170.00	64.00	0.10	7.30	4.20
Maximum	73.20	75.30	120.00	188.00	58.60	25.00	315.00	109.00	5820.00	7.95	6.10
Limit values (mg/kg) [34]	**85**	**100**	**35**	**140**	**36**	**9**	**160**	**42**	-	-	-

magmatic wall rocks. Other sources of nickel are coal-fired power stations and other human activities [6]. The limit value implies that contamination is present and further investigation is required [8]. Values for other metals are not exceeded.

The Shapiro-Wilk test was applied to test the data normality [48], considering that the available sample was small (<50) [49]. For data normality testing, the usual significance threshold of $\alpha = 0.05$ was applied. Finally, the null hypothesis was set up: H_0–The sample is from a normal distribution. If $p>\alpha$, the null hypothesis is accepted and assumes that data have a normal distribution, otherwise it is rejected [6]. It is the only one in the research p values for Zn less than 0.05 and does not exist normal distribution.

In small samples, Skewness test values greater or lesser than 1.96 are sufficient to establish normality of the data (for all toxic metals) [50]. Similarly confirms and Kurtosis test. Coefficient of variation (CV), as an index showing the extent of variability in relation to the mean of the samples, can be used to identify the anthropogenic contribution degree for pollution in the environmental studies. If CV <0.10 and >0.90 are mean low and high anthropogenic contributions, respectively [51]. CV>0.90 is only for B and values is 0.942. Values for other toxic metals were in range from 0.10 to 0.90. These values indicate the average anthropogenic impact and concentrations of pollutants in the soil samples. These findings are in accordance to previously reported toxic metals concentrations at this site, indicating site is polluted with toxic metals [6, 22].

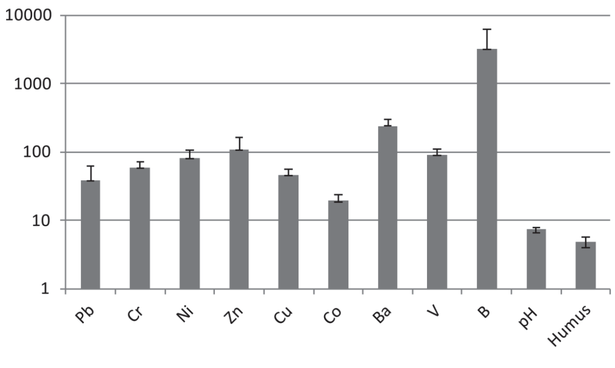

Fig. 2. Statistical summary of toxic metals in soil.

Correlation Analysis

The results of correlation analysis are shown in Fig. 3. The results of the correlation analysis Cr and Ni is strong positive correlation ($r = 0.991$) for the level of significance $p<0.01$, which has been confirmed in previous research in the same field. A strong correlation between the Ni and Cr indicateses, their common source driven wind that arise from ash landfill side [6]. These toxic metals in the soil are a very common occurrence in the vicinity of thermopower plants (coal-fired), and lignite combustion and its unburned residuals are responsible for this situation [6, 52, 53]. Correlation Pb and V is negative ($r = - 0.961$) and shown for the level of significance $p<0.05$. The results for Pb and Cu, Pb and Zn, Zn and Cu, Cr and V and Ni and V have a strong positive correlation, which means that high X variable scores go with high Y variable scores (and vice versa). Co and B, Cu and V and Zn and V have a strong negative correlation. Pb and Cr, Pb and Ni, Pb and Co, Zn and Co have negative moderate correlation. Pb and B, Cr and Ba, Ni and Ba, Cu and Ba and Zn and B are moderate positive, which means there is a tendency for high Pb/Cr/Ni/Cu/Zn variable scores go with high B/Ba/Ba/Ba/B variable scores (and vice versa).

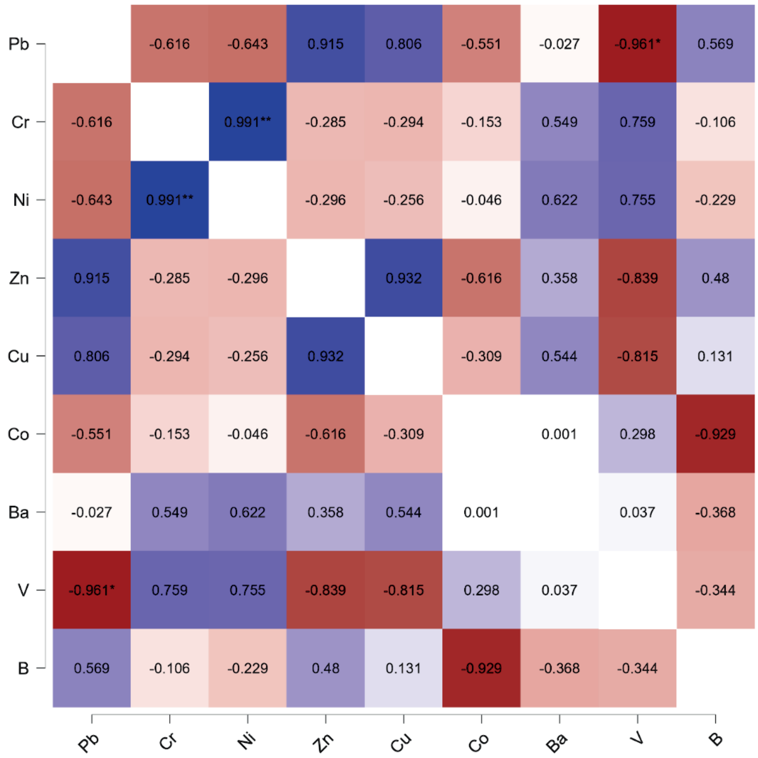

Fig. 3. Heatmap for toxic metals Pearson's correlation. * p<.05, ** p<.01, *** p<.001.

Previous research has indicated that strong negative correlation exists between pairs: Pb-Ni (k = −0.90) and Pb-Cr (k = −0.85) [6]. Such results suggest that these pollutants pairs might have similar sources or have been affected by similar factors for Pb with Ni and Cr and confirm the different sources of Pb. Values of correlation analysis for other pollutants were not relevant.

Contamination Factor (CF) and Pollution Load Index (PLI)

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 analyzed soil [8]. The Pb and Cu showed low contamination in all samplers (respectively 0.21-0.86 and 0.50- 0.75) and Zn in three samplers (0.54-1.34). The Zn reaches moderate contamination for the all samples. Values PLI≤1 indicate a low degree of contamination. All values for Cu, Co, Ba and Va in all samplers, Ni in three samplers and Zn in one sampler (respectively 1.01-1.63, 1.89-2.78, 1.06-1.97, 1.52-2.60, 1.77-2.28 and 1.34) indicate a moderate degree of contamination ($1 \leq CF_i < 3$). The Ni value in location 4 (village Srđevići) indicates a considerable degree of contamination ($3 \leq CF_i < 6$) (Table 2) [38].

The PLI was derived from the CF values to calculate the toxic metal pollution. In all soil samples, the analyzed PLI>1 (Table 2) and indicates the presence of soil pollution.

Ecological Risk Assessment (ERI)

ERI index stands for the potential ecological risk factor of all toxic metals tested [8]. The RI values of

Table 2. Contamination factors (CF) and pollution load index (PLI) of toxic metals in soil per samplers.

Samples	Contamination factors (CF)								PLI
	Pb	Cr	Ni	Zn	Cu	Co	Ba	V	
1.	0.40	0.50	1.77	0.59	1.25	2.78	1.38	2.05	1.09
2.	0.36	0.61	2.28	0.54	1.01	1.89	1.06	2.40	1.03
3.	0.86	0.54	1.90	1.34	1.63	1.67	1.64	1.52	1.3
4.	0.21	0.75	3.43	0.66	1.26	2.22	1.97	2.60	1.23
Mean	0.46	0.60	2.35	0.78	1.29	2.14	1.51	2.14	1.21

Table 3. Ecological risk assessment (ERI) of toxic metals in soil per samplers.

Samples	Ecological risk assessment (ERI)						
	Pb	Cr	Ni	Zn	Cu	Co	V
1.	2	1	8.85	0.59	6.25	13.9	4.1
2.	1.8	1.22	11.4	0.54	5.05	9.45	4.8
3.	4.3	1.08	9.5	1.34	8.15	8.35	3.04
4.	1.05	1.5	17.15	0.66	6.3	11.1	5.2
Mean	2.3	1.2	11.75	0.78	6.45	10.7	4.28

Table 4. Geoaccumulation Index (I_{geo}) of toxic metals in soil per samplers.

Samples	Geoaccumulation Index (I_{geo})							
	Pb	Cr	Ni	Zn	Cu	Co	Ba	V
1.	8.82	10.20	9.69	11.93	9.55	7.38	16.30	11.75
2.	8.68	10.48	10.06	11.79	9.24	6.82	15.93	11.98
3.	9.93	10.30	9.79	13.12	9.93	6.64	16.56	11.32
4.	7.89	10.78	10.64	12.10	9.56	7.06	16.82	12.09
Mean	8.83	10.44	10.05	12.24	9.57	6.98	16.40	11.79

Table 5. Degree of soil load (%) of toxic metals in soil per samplers.

Samples	Degree of soil load (%)							
	Pb	Cr	Ni	Zn	Cu	Co	Ba	V
1.	40	63	124	55	50	55	287	235
2.	31	76	160	50	40	38	232	260
3.	73	68	133	125	65	33	330	181
4.	18	94	240	62	50	44	384	280
Mean	40.5	75.25	164.25	73	51.25	42.5	308.25	239

toxic metals were estimated for each sample (Table 3). From these results and criteria, all soil samples show a low ecological risk [35]. The maximum RI is 13.9, and the lowest ecological RI is 0.54. The average ecological risk of individual toxic metals is as follows: 2.3 Pb; 1.2 Cr; 11.75 Ni; 0.78 Zn; 6.45 Cu; 10.72 Co and 4.28 V. This study reveals that Ni is the toxic metal that poses the highest ecological threat (Table 3).

Geoaccumulation Index (I_{geo})

The average values obtained for I_{geo} were Pb, 8.83; Cr, 10.44; Ni, 10.05; Zn, 12.24; Cu, 9.57; Co, 6.98; Ba, 16.40; and V, 16.40. Maximum I_{geo} values for the same metals are 9.93; 10.78; 10.64; 13.12; 9.56; 7.38; 16.82; and 12.09, respectively. For values $I_{geo}>5$ [5, 45] soil is extremely polluted. Based on the average values of all toxic metals, it can be concluded that the soil belongs to the class "extremely polluted" (Table 4).

Degree of Soil Load

The degree of soil load is calculated according to the Rulebook [46]. Average values degree of soil for Ba and V load show that V class is a land of very high load, with degree of soil more than 200%. Average values degree of soil for Ni load show that IV class is a land of high loads, above the maximum allowable amount, with degree of soil more than 100.01-200%. Average values degree of soil for Cr, Ni and Cu load show that III class is a land of medium load, with degree of soil more than 20.01-100.00%. Values for Pb and Co indicate of soil low loads, with degree of soil more than 25.01-50.00%.

Conclusions

To our knowledge, this is the first report on the determination and ecology assessment of toxic metals in surface and deeper layer soil samples in Gacko's area. Toxic metals are environmental pollutants, posing potential threats to the environment.

The average individual metal content in the soil samples is ordered, from high to low, as follows: B>Ba >Zn>V>Ni>Cr>Cu>Pb>Co. B is the pollutant with the highest mean concentration (3,210.02 mg/kg), and then followed by the Ba, Zn, V, Ni, Cr, Cu, Pb and Co, their mean concentrations are 242, 109.50, 90, 82.10, 60.22, 46.28, 38.90 and 19.25 mg/kg, respectively. Pearson's correlation coefficient analysis identified the relationship between toxic metals and their probable sources. Mean values for Ni, Cu and Co were higher than the permissible limits of national regulation. Values of coefficient of variation (CV) indicate average anthropogenic impact and concentrations of pollutants in the soil samples.

From the evaluation of the soil pollution indices (CF, PLI, ERI and I_{geo}), it can be seen that the studied soil samples in most cases are contaminated.

CF values indicate that Pb and Cu showed low contamination in all samplers and Zn in three samplers. The Zn reaches moderate contamination for the all samples. All values for Cu, Co, Ba and Va in all samplers, Ni in three samplers and Zn in one sampler indicate a moderate degree of contamination. The Ni value in only one location indicates a considerable degree of contamination. In all soil samples, the values PLI indicates the presence of soil pollution.

This study reveals that Ni for RI index is the toxic metal that poses the highest ecological threat.

Based on the average values of all toxic metals, in according average values for I_{geo}, it can be concluded that the soil belongs to the class "extremely polluted".

The values of degree of soil load for Ba and V load show that V class is a land of very high load. Values for Ni load show that IV class is a land of high loads. Values for Cr, Ni and Cu load show that III class is a land of medium load. Only values for Pb and Co indicate of soil low loads.

This calls for mandatory and long-term monitoring of toxic metals in the soil, as well as comprehensive research about adverse ecology and health factors. The national government and the local residents in general need to acknowledge the grave risks of toxic metals contamination and prioritize the work on sustainable solutions to mitigate the current risks.

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Conflict of Interest

The authors declare no conflict of interest.

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