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Using Contamination Indices for Assessments of Heavy Metals Status of Soils around Mercury Mine, in Kurşunlu, (Konya) Province

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ABSTRACT

The objective of this study was to establish contamination level for, Pb, Zn, Cu, Ni, Cr, As, Hg, Sb, Co, and Cd in soils around the old Hg mine area central part of Turkey. 34surface samples from mine area were collected. Samples were digested and the metals were determined by ICP-OES and assess metal contamination in soils by using Enrichment factor (EF), contamination factor (Cf), Geoaccumulation index (Igeo), hazard quotient (HQ) (individual metal), contamination index (Cd), modified contamination index (mCd), pollution load index (PLI), and hazard load index (HLI) (multi metal).
Enrichment factor (EF), contamination factor (Cf), Geoaccumulation index (Igeo), hazard quotient (HQ)indicate that the soil in the most of studied points were unpolluted, slightly polluted or moderate degree of pollution with respect to Pb, Cr, Cd, Zn, Cu, Co and Ni, while the soils in all studied stations were extremely contaminated with respect to Hg, Sb and As. When the obtained result to by evaluated the cumulative effect of metal pollution load index (PLI), the contamination degree (Cd) and modified Contamination Degree (mCd), and hazard load index were found to be very high high pollution, ultra-high degree pollution and medium pollution respectively indicating that the studied soils in were polluted by total of studied heavy metals.

1. Introduction

C Soil is a dynamic natural resource for the survival of human life and due to its complex matrix is the principal receiver of the persistent contaminants such as heavy metals (Luo et al., 2006). Every soil comprises some natural quantities of heavy metals, at concentrations called backgrounds. The magnitude of a metal's background depends upon the composition of the parent rock material from which the soil was derived (Scazzola et al., 2003).Heavy metals pollution assessment nowadays is becoming an important task due to the increase in anthropogenic actions related to industrialization central sources of heavy metals in terms of petrochemicals, compost, pesticides, animal manures, sewage sludge, leaded paints as well as the indiscriminate dumping of wastes inland fills (Sajn et. all 1998;Davidson et al, 2006;Stafilov et al., 2010; Dumitrescu et al. 2012). Pollution of the natural environment by heavy metals is a universal problem because these metals are indestructible and most of them have toxic effects on living organisms, when permissible concentration levels are exceeded.

Heavy metal contamination of soils concern several scientists because of the potential toxicity of metals (Homa et al., 2003). Heavy metals accumulation has shown to be detrimental to both plants and animals in human body, for example, it is capable of causing neurological disorders, damage to the internal organs of the body and even death while in plants it shows negative effects on photosynthesis and absorption /exchange of gases (Dumitrescuet al, 2012; Edward et al, 2013; Senila et al, 2013; Alia et al, 2015).

Heavy metals contamination assessment in soils has been carried out successfully all over the world using quality index method. These quality index methods have proved to be a significant tool for effectively gathering composite influence of indicators to the overall contamination (Bhuiyan et al. 2015). Several evaluation methods have been utilized by various authors in heavy metal pollution assessment in soils and sediments: Single in-

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dex factor (Pi), Nemerow's pollution index (PN), potential ecological risk index (RI), enrichment factor (EF), contamination factor (CF), Geoaccumulation index (Igeo), contamination index (Cd), pollution load index (PLI) as well as hazard quotient. Pi and CF are computed as basis for obtaining PN and PLI respectively. Igeo can be used to distinguish the effects that human activities have on the environment (Bello et al. 2016). RI considers the toxicity of the pollutant as a means of evaluating the ecological risk, the value does so by comparing the concentration of the pollutant with the back ground value. EF represents the values that assess anthropogenic influences on heavy metals in sediments; the measurement uses aluminum (Al) as a conservative element (Zhang et al. 2015).

Studies on heavy metal levels in soils and waters of different fresh water systems in Turkey. There are many studies on the determination of pollution status due to anthropogenic (urban, agriculture, industrialization, road and railway environment) activities and the determination of the effects of various applications on heavy metal contents using pollution quality indexes. (Uğulu, 2015¸ Uğulu et al.2019; Coşkun et al. 2006; Yılmaz et al. 2003; Çelebi and Kara 2007; Demir et al. 2016; Göçmez 2006; Haktanır et al., 1995; Kara et al., 2004; Tokalıoğlu and Kartal 2005; Sezgin et al., 2003; Horasan and Arık 2019; Sungur et al., 2014). In addition, the mobility and bioavailability of heavy metals were determined by sequential extraction method in soils and greenhouses in various regions (Sungur et al., 2015; Sungur et al., 2021).

Understanding the contamination characteristics of heavy metals in soils and identifying their environmental exposure risks not only are the basic preconditions for soil pollution prevention, but also provide important information for making decisions for remediation of contaminated soils. The objectives of this study are to identify the heavy metal pollution level of soils around Ladik-Sızma mercury mine (about 30 km north - northwest of Konya province) using enrichment factor (EF), contamination factor (Cf), Geoaccumulation index (Igeo), hazard quotient (HQ) (individual metal), contamination index (Cd), modified contamination index (mCd), pollution load index (PLI), and hazard load index (HLI) (multi metal).

2. Materials and Methods

Site description

Kurşunlu Hg mine (33° 04' N; 6° 38' W), which is placed north - northwest of the Konya Province, Turkey. Ladik-Kurşunlu Hg bed located in an environment where the metamorphic rocks located like as a lot of Hg bed in Turkey. Phyllite, schist and carbonated rocks are the main lithological units observed around the beds. The carbonate rocks are composed of gray-dark gray colored limestone, marble and dolomitic marbles which are recrystallized locally. This unit (Bozdağ formation; is a Silurian-Carboniferous age (Wesner, 1968) and it is generally composed of phyllite (sericite-quartzphyllite, chlorite-quartz phyllite), schist (sericite-biotite-(Bagnkurt formation), which consists of quartzite, quartz schist, sericite-quartz schist), quartzite, metaconglomera and transported methacarbonate blocks (Aydın, 1996). Both carbonates and phyllites and schists were cut by Karatepe metamorphic rocks after the Carboniferous age (Yıldız, 1978). These magmatites, which are called metaporfir by Bayiç (1968), contain mainly feldspar, and less frequently, muscovite, quartz and sfen. The study area is under the influence of semi-arid continental climate in Central Anatolia. The average annual precipitation in the region is 323,6 mm, and the annual evaporation is 978,2 mm. The annual average temperature is 11,3ºC, the average soil temperature at 50 cm is 14,2. A significant part of the precipitation falls in the winter months, and drought is observed in June, July and August. (MGM, 2016). In the light of these data, the climate type of the region is "BSk" Semi-Arid Steppe Climate (Cold) according to the Köppen climate classification. When the De Martonne-Bottman drought index formula is applied to the climate data of the study region, it is determined that the semi-arid-less humid Mediterranean climate is dominant (Akman 1990). According to the diagrams (precipitation-evaporation-temperature) prepared in the light of the information obtained, the temperature regime of the study area is mesic and the humidity regime is xeric (Nachtergaele 2001).

Soil samples collection and analysis

Surface soil samples (0 to 20 cm) were collected in the Kurşunlu Hg mine area. Soil samples were taken from randomly chosen spots at certain distances from the land around the mine. Each sample was composed of five subsamples collected around the point. In total, 34 composed samples were analyzed. Partical size distribution, pH, electrical conductivity (EC) and heavy metal contents were determined after drying the samples at 50°C in a hot air oven (USDA 2004). Element concentrations include Cu, Ni, Co, Zn, Pb, As, Cr, Sb, Hg and Cd were determined in Aqua regia acid mixture (HNO3: HCl: 1: 3), and the extracts obtained using Atomic Absorption Spectrometers (AAS) with standard solutions in a similar manner to described by procedure(Sparks et al.,1996).

Pollution Indices

Enrichment factor (EF) (Lacatusu, R. 1998), contamination factor (Cf) (Tomlinson ve ark 1980), geoaccumulation index (Igeo) (Muller 1979), hazard quotient (HQ) (Epa, 1992) (individual metal), contamination index (Cd) (Hakanson (1980), modified contamination index (mCd) (Abrahim and Parker 2008), pollution load index (PLI) (Tomlinson et al. 1980), and hazard load index (HLI) (multi metal) were employed to assess the pollution of metals in the soil situated the mine. Calculating the degree of contamination by a specified heavy metal obliges that the contaminant metal concentration be compared with a reference material (geochemical background). Such reference material should be an uncontaminated substance that is comparable with the studied samples, as reported with Maanan et al. (2014), Nouri and Haddıouı (2016). To calculating the hazard quotient (HQ) for Sb, Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health (Turekian and Wedepohl 1961).For other elements, Ministry of Environment and Forestry Regulation on Control of Soil Pollution were used. By considering Fe as a reference element the enrichment factor for heavy metals were calculated.

-Enrichment factor is calculated with the following formula.

EF = (CX/CFe) soil (CX/CFe) reference

Here, (CX/CFe) Soil: The ratio of the metal concentration studied in the soil sample to the Fe concentration

(CX/CFe)Reference: The ratio of the metal concentration studied in the reference sample to the Fe concentration The metal concentration of the reference sample is the abundance of elements in the earth's crust.

The contamination factor (Cf) was calculated by the ratio of the metal content at each sampling point to the abundance of the element in the earth's crust of that metal. Cf is found by the equation given below (Hakanson, 1980).

Cf=Cmetal/Co

Cmetal: The metal concentration in the soil sample,

Co: The abundance value of the metal in the earth's crust

Contamination index (Cd)" is the sum of all pollution factors of a given basin. Cd was calculated as the sum of Cf for each sample.

Cd=∑_(i=1)^(i=n)▒Cf

Similarly, it is possible to approximate the exact degree of impurity using the modified contamination index (mCd), method, and for this purpose, the modified contamination index (mCd) is calculated by the following equation.

MCd=(∑_(i=1)^(i=n)▒Cf)/n

The geoaccumulation index (Igeo) of any metal is found by calculating the base 2 logarithm of the measured total metal concentration over the background concentration using the following mathematical relationship

Igeo=log2(Cn/(1.5xBn))

Here, Cn is the measured concentration of "n" heavy metal in the soil sample, Bn is the geochemical background (reference) value of the element "n" in the earth's crust, and 1.5 is the background matrix correction factor resulting from lithogenic effects.

Pollution load index (PLI) is frequently used to compare the pollution status of different places, since all the metals examined are handled in a single index. The index is obtained by calculating the pollution factors (Cf) of each metal. Pollution load index (PLI) is calculated with the following formula al.,

PLI=(Cf1 * Cf2 * Cf3 * ….. * Cfn)1/n

Cf= Cmetal / Co

Here Cmetal : Metal concentration in the sediment sample

Co : The basic (background) value of the metal

Cf : Pollution factor

n : Number of metals

-The soil Hazard Quotient (HQ) is the ratio of the heavy metal concentration of surveyed soil samples to reference permissible limit and is computed using the relation,

HQ=Cc/Cp (3)

Where, Cp and Cc=reference maximum permissible limit of heavy metal concentration and the concentration obtained in the sampled area, respectively

The hazard load index: Similar to the pollution load index that takes contamination factors as inputs, an analogous relation termed hazard load index was developed by adoption and amendment of the pollution load equation and was presented in equation

3. Results and Discussion

Soil Properties

Some soil properties were presented in table1. According to Table 1 soil pH was slightly alkaline and changed between 6.76 and 7.55, EC values ranged from 59.1 to 270 (µS/cm) and lime contents were ranged 1.03% to 21.06%. The organic matter content was highly variable and varied between 1.43% and 7.16%. Clay content is very low in most of samples and changedbetween4.2% and 28.8%. Sand contents were very high and ranged from 48% to 89.2%. High coefficients of variation were observed in some of the soil properties, and this was due to the fact that the sampling points were located on different physiographic units and were accordingly affected by the transport and accumulation processes. The high coefficient of variation observed especially in organic matter, EC, clay and silt values supports this situation.

The metals concentration

Heavy metal statuses of soils were shown in Table 2. According to table highest content of Cu concentration is 109.70 ppm while mean value is 52.86 ppm. The Pb content was changed from 26.9 to 154.0 ppm. Zn concentrations were changed between 8.0 and 152 ppm and all Zn values were under reference value. Ni content ranged between 30.2 and 165.7 ppm. Co contents ranged 10.3 and 44.2 ppm. Mean Co value is upper then reference value. As contents are changed between 21.0 and 382 ppm and all As content bigger than background value. Cd concentrations were changed between 0.25 and 3.30 ppm and mean Cd value were upper reference value. Sb content ranged between 11.0 and 2443.5 ppm. All Sb values very high according to reference value. Similar results were observed for Hg. Hg content ranged between 0.6 and 100 ppm and all Hg values were upper reference value. Cr contents ranged 50.0 and 333.0 ppm. Mean Cr value is upper then reference value.

Table 1
Some soil properties of soil samples

Samplenumber	pH	Organic matter (%)	EC (µS/cm)	Lime (%)	Particle size distribution Sand (%)	Silt (%)	Clay (%)
1	7,13	3,61	123,30	2,85	54,0	35,2	10,8
2	7,17	4,40	120,05	2,28	69,2	22,0	8,8
3	7,33	2,02	139,75	7,06	68,0	22,6	9,4
4	7,53	3,49	113,00	2,62	68,0	25,2	6,8
5	6,96	3,90	94,85	2,51	73,2	16,0	10,8
6	7,10	3,08	75,25	1,82	89,2	4,0	6,8
7	7,37	4,60	106,80	2,39	85,2	4,0	10,8
8	6,82	4,80	79,35	2,62	57,2	14,0	28,8
9	7,15	7,16	79,45	3,98	79,2	16,0	4,8
10	6,84	4,03	216,60	2,05	65,2	8,0	26,8
11	6,89	4,95	108,75	1,72	67,2	18,0	14,8
12	6,76	1,99	65,80	2,17	65,2	22,0	12,8
13	7,13	3,28	165,75	2,73	48,0	38,2	13,8
14	7,55	4,68	154,30	5,12	55,2	20,0	24,8
15	7,15	3,93	96,45	2,73	68,0	27,8	4,2
16	7,13	5,34	59,10	1,03	50,0	39,8	10,2
17	7,10	1,88	139,30	1,72	61,2	10,0	28,8
18	7,14	3,44	162,35	1,59	53,4	33,8	12,8
19	7,08	2,88	67,35	1,26	68,0	25,2	6,8
20	7,10	3,70	102,95	1,59	71,2	16,0	12,8
21	7,14	5,90	97,95	1,26	73,2	18,0	8,8
22	7,21	4,91	269,00	21,06	49,0	37,5	13,50
23	7,26	1,43	134,45	4,32	52,0	39,2	8,8
24	7,24	2,01	88,65	3,30	67,4	23,8	8,8
25	7,04	2,13	86,15	2,05	54,0	33,2	12,8
26	7,35	6,74	124,55	3,87	54,0	41,2	4,8
27	7,50	3,14	66,60	1,94	68,0	25,9	6,1
28	6,99	3,39	91,90	1,71	75,2	14,0	10,8
29	7,13	1,99	270,00	1,71	61,2	30,0	8,8
30	7,13	3,52	59,90	1,59	50,0	39,8	10,2
31	7,36	6,29	114,15	5,35	65,4	29,2	5,4
32	7,13	6,83	219,50	6,72	58,0	35,2	6,8
33	7,29	2,19	80,00	2,62	68,0	25,9	6,1
34	7,43	4,79	259,50	20,58	57,4	36,8	5,8
Min	6,76	1,43	59,1	1,03	48.0	4.0	4,2
max	7,55	7,16	270	21,06	89,2	41,2	28,8
mean	7,17	3,89	124,49	3,82	63,78	24,93	11,29
SD	0,19	1,54	59,50	1,47	11,73	10,06	7,68
CV (%)	2,6	39,5	47,7	2,3	18,4	40,3	68,0

Table2
Means and ranges of heavy metals of soil samples

	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ni (ppm)	Co (ppm)	As (ppm)	Cd (ppm)	Sb (ppm)	Cr (ppm)	Hg (ppm)
Min	19,60	26,90	8,00	30,20	10,30	21,00	0,25	11,00	50,00	0,60
Max	109,70	154,00	152,00	165,70	44,20	382,00	3,30	2443,50	333,00	100,00
Mean	52,86	58,96	105,15	98,47	25,43	74,16	0,94	492,56	160,78	22,23
SD	19,63	32,86	24,03	38,01	9,87	73,70	0,78	595,31	77,75	23,24
CV(%)	37,14	55,73	22,85	38,60	38,83	99,38	82,81	120,86	48,36	104,58

Pollution assessment of soil metals using geochemical indicators

Popular soil contamination assessment methods can be classified into two categories: quantitative and qualitative. The qualitative methods, such as principal component analysis (PCA), factor analysis, and cluster analysis, are inferential and indicative. These multivariate analyses require that each variable shows a normal distribution and that the whole dataset shows a multivariate normal distribution Some of the most commonly used quantitative methods are the contamination factor (CF), enrichment factor (EF), and Geoaccumulation index(Igeo).

Table 3 presents the contamination status of metals in the topsoil of the research site. As shown in Table 3 the results showed that the average EF values of Pb, Hg, Sb, As, Cr, Cd, Zn, Cu, Co, Ni, were 3.89, 53.22, 468.2, 8.10, 1.78, 4.19, 1.23, 1.26, 1.36 and 2.22 respectively. The mean EF values of Cr, Zn, Co were < 2, suggesting relatively minimal enrichment. EF is upper 2 Pb, Cd, Zn and Pb shown medium enrichment and for Hg, Sb and As very high enrichment.

The average Contamination factor (Cf) of Pb, Cr, Cd, Zn, Cu, Co, Ni, were, respectively which approves that the soils have a low or medium degree of pollution. Contamination factor of Hg, Sb and As with a mean of 59.46, 355.59, 8.10 respectively which approves that the soils have a very high degree of pollution

The mean Igeo values of vary the most but most of values have negative value for Pb, Cr, Cd, Zn, Cu, Co and Ni. But for Hg, Sb, and As the mean Igeo values very high. The result can be drawn from Table 3 that the Igeo values for Hg, Sb, and As are extremely contaminated level.

When HQ values are >1.0, the soils are considered to be contaminated by anthropogenic inputs. The degree of contamination of soils is low or medium (1 < PLI) for Pb, Cr, Cd, Zn, Cu, Co, and Ni but only for Hg, Sb and As which have very high (PI>5) contamination

Table 3
Assessed level of contamination effect founded on the enrichment factor (EF)[A]; Contamination factor (Cf)[B]; geo-accumulation index (Igeo)[C]; Hazard quation index (HQ)[D]; pollution load indices (PLI)[E]; degree of contamination (Cd)[F], modified degree of contamination (mCd)[G]and Hazard Load Index(HLI)[H]. Metals are reported in mg g-1 (*n=34*).

Individual Metal												
	Pb				Hg				Sb			
	EF	Cf	Igeo	HQ	EF	Cf	Igeo	HQ	EF	Cf	Igeo	HQ
Min	0,97	1,35	-0,16	0,09	1,01	1,50	0,00	1,01	8,0	7,33	2,29	0,55
Max	15,94	7,70	2,36	0,51	345,03	250,00	7,38	345,03	2258,1	1629,0	10,08	122,18
Mean	3,89	3,04	0,82	0,20	53,22	59,46	4,20	53,22	468,2	355,59	6,49	26,67
SD	3,76	1,78	0,73	0,12	80,27	64,89	2,12	80,27	679,3	439,88	2,37	32,99
	As				Cr				Cd			
	EF	Cf	Igeo	HQ	EF	Cf	Igeo	HQ	EF	Cf	Igeo	HQ
Min	1,51	1,62	0,11	1,05	0,63	0,56	-1,43	0,50	0,65	0,83	-0,85	0,08
Max	46,46	29,38	4,29	19,10	2,79	3,70	1,30	3,33	16,34	11,0	2,87	1,10
Mean	8,10	6,25	1,55	4,06	1,78	1,81	0,09	1,62	4,19	3,29	0,69	0,33
SD	11,03	6,72	1,11	4,37	0,56	0,91	0,73	0,82	4,74	2,83	1,10	0,28
	Zn				Cu				Co			
	EF	Cf	Igeo	HQ	EF	Cf	Igeo	HQ	EF	Cf	Igeo	HQ
Min	0,10	0,08	-4,15	0.03	0,49	0,44	-1,78	0,14	0,62	0,54	-1,47	0,52
Max	2,57	1,60	0,09	0.51	2,70	2,44	0,70	0,78	1,96	2,33	0,63	2,21
Mean	1,23	1,09	-0,61	0.35	1,26	1,19	-0,45	0,38	1,36	1,34	-0,27	1,28
SD	0,53	0,31	0,89	0.10	0,51	0,48	0,60	0,16	0,32	0,54	0,58	0,51
	Ni				Multi-Metal							
	EF	Cf	Igeo	HQ	PLI		Cd			mCd		HLI
Min	0,76	0,44	-1,76	0,40	1,31		20,36			2,04		0,40
Max	3,27	2,44	0,70	2,21	7,21		1700,23			170,02		2,19
Mean	2,22	1,45	-0,19	1,31	3,99		428,01			42,80		1,22
SD	0,60	0,58	0,66	0,53	1,88		474,77			47,48		0,57

A Minimal enrichment (EF < 2), moderate enrichment (2 ≤ EF < 5), significant enrichment (5 ≤ EF < 20), very high enrichment (20 ≤ EF < 40) or extremely high enrichment (EF ≥ 40).
B Contamination factor No pollution (PI ≤ 1), slight pollution (1 < PI ≤ 3), moderate pollution (3 < PI ≤ 6) sever pollution (PI > 6).
C Uncontaminated (*I*geo ≤ 0), uncontaminated to moderately contaminated (0 <*I*geo ≤ 1), moderately contaminated (1 <*I*geo ≤ 2), moderately to heavily contaminated (2 <*I*geo≤3), heavily contaminated (3 <*I*geo≤4), heavily to extremely contaminated (4 <*I*geo ≤ 5), or extremely contaminated (*I*geo> 5).
D No pollution (HQ=PI ≤ 1), slight pollution (1 < PI ≤ 3), moderate pollution (3 < PI ≤ 5) and sever pollution (PI > 5).d *Cd* < 6 indicates a low degree of pollution; 6 <*Cd* < 12 is a moderate degree of pollution; 12 <*Cd* < 24 is a considerable degree of pollution; and *Cd* > 24 is a high degree of pollution indicating serious anthropogenic pollution.
E Background concentration (PLI = 0), uncontaminated (0 < PLI ≤ 1), uncontaminated to moderately contaminated (1 < PLI ≤ 2), moderately contaminated (2 < PLI ≤ 3), moderately to highly contaminated (3 < PLI ≤ 4), highly contaminated (4 < PLI ≤ 5), or very highly contaminated (PLI > 5).
F *Cd*< 6 indicates a low degree of pollution; 6 <*Cd* < 12 is a moderate degree of pollution; 12 <*Cd* < 24 is a considerable degree of pollution; and *Cd* > 24 is a high degree of pollution indicating serious anthropogenic pollution
G m*Cd*< 1.5 is nil to a very low degree of pollution; 1.5 ≤ m*Cd*< 2 is a low degree of pollution; 2 ≤ m*Cd*< 4 is a moderate degree of pollution; 4 ≤ m*Cd*< 8 is a high degree of pollution; 8 ≤ m*Cd*< 16 is a very high degree of pollution; 16 ≤ m*Cd*< 32 is an extremely high degree of pollution; m*Cd*≤ 32 is an ultra-high degree of pollution.
H Low contamination HLI ≤1, medium contamination 1< HLI ≤3, 3< HLI ≤6 Considerable, PI>6 very high contamination

In addition to give a comprehensive situation of heavy metals, the integrated pollution load index (PLI) for each sample was evaluated. The results showed that the PLI values of heavy metals in soils ranged from 1.31 to 7.21 with an average of 3.99 also indicating highly contaminated. The degree of contamination varied from 20.36 to 7.01 with a mean of 1700.23, which approves that the soils have high degree of pollution. The revised Hakanson formula was utilized to determine the mCd for all the studied elements. The results are shown in Table 3. The values vary from 2.04 to 170.02 with an average 42.80, representing that the investigate site presents an ultra-high degree of pollution. Hazard load index varied from 0.50 to 2.19 with a mean of 171.22, which approves that the soils have medium degree of pollution.

Heavy metals in uncontaminated soils and sediments are found in their silicate and primary mineral forms and are essentially inert. However, heavy metals in contaminated soils are more mobile and bind to other phases (Rauret, 1998). For this reason, the mentioned elements are considered to be of parent material origin, that is, of lithosphere origin, since there is no source of pollutants in the vicinity of the region.

There was a very high variability in the general analysis results of the studied soil samples. This situation is also reflected in the standard deviation and coefficient of variation of the results. However, the variability of the topography in the sampling area and the variability of the erosion and sedimentation timers accordingly caused the high coefficient of variation at the sample points.

Similarly, the coefficient of variation was found to be high in heavy metal contents. Especially in Hg, As and Sb, these values are quite high. This is due to the sampling strategy and the factors described below that affect the metal contents. While sampling, the mine area and waste dumping areas were chosen as the center, and sampling was made from different distances from the waste dumping area. Accordingly, the heavy metal contents of the soil samples showed significant changes. Especially the high coefficients of variation (CV) seen in Hg, Sb, As explain this situation. Much lower CV rates in other metals compared to these three metals also support the findings.

It is known that the ecological effects of heavy metals in the soil are closely related to the composition of the solid and liquid phase, the presence and behavior of heavy metals, the mobility and transformation and accumulation processes and forms in the ecosystem, the type of bedrock from which the soil is formed, the degree of weathering, pH, redox conditions, oxidation conditions, temperature. It depends on factors such as the presence of organic matter, conversion of heavy metals during the biocycle, and microbiological activity. Movement of heavy metals depends on temperature, speed and direction of movement of surface waters, circulation of air masses and wind speed. Apart from these, there are other factors such as polarity, pressure and molecular stability that affect the distribution and movement of these pollutants (Briffa et al., 2020). The geological and geomorphological differences in the region, the distance to the waste area, and the changes in the above-mentioned factors caused the heavy metal contents to show a high coefficient of variation between the sample points.

When the average values of metals are compared with the values allowed in the Turkish soil pollution regulation, it is seen that the values of Cd, Cu, Pb, Co and Zn are below or slightly above the allowable values, while the values of Cr, Ni, and especially As, Sb and Hg are found to be very high. It has been determined that these high-value metals are in close contact with plant roots and thus can potentially affect soil fertility, and further trace metal entry into soils in these areas should be avoided by agricultural management or other means in order to avoid long-term threats to productivity and food security. As, Sb and Hg are a toxic substance for living things and this state of As, Sb and Hg in the study area causes concern for the environment

In addition to this, the mobility of heavy metals in the region should be determined as well as the total content of the metals in different fractions of the soils by sequential extraction methods. Because the high amount of heavy metals associated with the non-residual phases is in a condition that can be easily transferred to the food chain through water sources, uptake by soil-grown plants or any other mechanism..

For example, although the total Sb content of the soils is below the maximum permissible pollutant concentration, its high concentrations in the mobile fractions have been observed to require caution in this metal. Because, in general, the total Sb content in the soil does not significantly correlate with the Sb in the plant, but it can be positively correlated with the exchangeable Sb content in the soil, because plants tend to readily absorb soluble or exchangeable Sb from the soil (Baroni et al., 2000). Although the proportion of bioavailable Sb is only 0.15–2.45% of total Sb in rhizospheric soil, high Sb concentrations in contaminated soil resulted in high bioavailable Sb, which could mean high uptake and accumulation potential by plants.

4. Conclusion

Different useful methods and indices were employed to evaluate soil pollution and contamination status of soils around Kurşunlu mine. According to the results of Enrichment factor (EF), contamination factor (Cf), Geoaccumulation index (Igeo), hazard quotient (HQ) (individual metal), contamination index (Cd), modified contamination index (mCd), pollution load index (PLI), and hazard load index(HLI) (multi metal) based on the averages, heavy metal pollution in soils of study area was observed considerable level for the studied metals for both individual metals and multi-metal. These results indicate that the soils around Kurşunlu mine are not contaminated by Cr, Zn, Ni, Cd, Cu, Pb, Co but contamination is maximum for Hg, Sb As. Considering the geological structure of the region rock formations it was explain sources of Hg, Sb, As. Therefore, the source of the very limited pollution seen in the region is not anthropogenic but natural source. According to results very high contamination for Hg, Sb,As is caused by natural geological factors related to rock formation of studied soils.

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