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The Evaluation of Heavy Metal Pollution Degree in the Soils around the Zangezur Copper and Molybdenum Combine

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***Abstract*—**The heavy metal pollution degree in the soils around the Zangezur copper and molybdenum combine in Syunik Marz, Armenia was assessed. The results of the study showed that heavy metal pollution degree in the soils mainly decreased with increasing distance from the open mine and the ore enrichment combine which indicated that the open mine and the ore enrichment combine were the main sources of heavy metal pollution. The only exception was observed in the northern part of the open mine where pollution degree in the sites (along the open mine) situated 600 meters far from the mine was higher than that in the sites located 300 meters far from the mine. This can be explained by the characteristics of relief and air currents as well as the weak vegetation cover of these sites and the characteristics of soil structure. According to geo-accumulation index (*I-geo*), contamination factor (*Cf*), contamination degree (*Cd*) and pollution load index (*PLI*) values, the pollution degree in the soils around the open mine and the ore enrichment combine was higher than that in the soils around the tailing dumps which was due to the proper and accurate operation of the Artsvanik tailing damp and the recultivation of the Voghji tailing dump.

The high Cu and Mo pollution of the soils was conditioned by the character of industrial activities, the moving direction of air currents as well as the physicochemical peculiarities of the soils.

***Keywords*—**Armenia, Zangezur copper and molybdenum combine, soil, heavy metal pollution degree.

I. Introduction

MODERN industrial and agricultural production results in toxic effects on biota that appears to be one of the main factors of man-caused ecological risk. Chemicals entered into the ecosystem circulation are accumulated within different links of trophic chains, concentrate in air, water, soil and sediments and get the property of long-term after-effects. Currently the impact of human activities on natural landscapes has reached such a level that it affects both their qualitative and quantitative characteristics.

Heavy metals are natural, nondegradable substances and aren't broken down in the environment [1]. The contents of heavy metals in soils may originate from natural pedo-geochemical properties, anthropogenic sources or a mixture of these two fractions. Ratios of these fractions vary widely depending on the type of substances and soil, land use and the nature and extent of external impacts [2].

Contamination of soils by heavy metals is a significant problem, which leads to a negative influence on soil characteristics and the limitation of productive and environmental functions [3], [4]. The problem is not restricted to soils with high metal levels, such as mining areas, but also includes those with moderate to low contamination of metals. These toxic elements, such as Cd, Cu, Pb and Zn, exist at elevated levels mainly through human activities [5]. Heavy metals are included in the main category of serious environmental pollutants due to their persistence and bioaccumulation problems. Their accumulation leads to well-known toxic effects on ecological systems [3]-[8].

The presence of heavy metals in water and soils can pose a significant threat to human health. As trace elements, some heavy metals (e.g. iron, copper, zinc) are essential to maintain the metabolism of human body; however, at higher concentrations they can lead to poisoning. Heavy metal recently increased toxicity influencing upon human beings can result in damaged or reduced mental and central nervous function. Long-term exposure may result in slowly progressing physical, muscular and neurological degenerative processes that mimic Alzheimer's disease, Parkinson's disease, muscular dystrophy and multiple sclerosis. Multiple long-term exposures to a number of metals and their compounds may result in origination of malignant tumors as well [9].

Mining industry is developed in the Republic of Armenia. This economic sphere has been the mainstay of the Armenian economy for over 20 years. Since last decades of the twentieth century, mining and benefication of a variety of minerals, in particular copper and gold, have been the driving force behind economic development, particularly in Lori Marz and Syunik Marz of RA. This branch of industry is one of the main sources of soil pollution with heavy metals/metalloids (Pb, Cu, Ni, Cd, Mo, As etc.) which are considered as dangerous pollutants causing the desertification of soils [10].

Therefore, the research of the accumulation and migration of heavy metals in soils is currently a very important and relevant issue. The research results will strongly benefit environment protection and future generations' health. The main objective of the study was the assessment of heavy metal pollution level in the soils around the Zangezur copper and

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molybdenum combine. Pollution indices are powerful tools for processing, analyzing and conveying raw environmental information to decision makers, managers, technicians and public [11], [12].

II. Materials and Methods

A. Study Area

The Zangezur copper and molybdenum combine is situated in the south-east of Armenia. The soils in the riskiest sites of this region were studied (Fig. 1):

- surroundings of the open mine and the ore enrichment combine near Kajaran town (samples № 1-29),
- surroundings of the recultivated Voghji tailing dam (samples № 30-35),
- surroundings of the active Artsvanik tailing dam (samples № 36-41).

The main soil type in the study sites was the mountain cambisol. In Armenia, this soil type is distributed 500-1700 meters above sea level, and on arid southern slopes, it reaches up to 2400 meters [13]. This soil type in the studied territories is distributed 909-2037 meters above sea level. The relief of mountain brown forest soils is characterized by many heights (mountain ranges and water-divider mountain peaks) as well as trenches which descend to canyons and floodplains. The degraded structures of porphyrites, dolomites, limestone, conglomerates, sand, granodiorites are the main soil-producing rocks of mountain brown forest soils. They are mainly represented by weathered carbonic and strong basic sand clay and are rarely represented by clay, the power of which can reach 1.5-2 m. Mean annual air temperature is 8-12°C, air temperature in August is 37°C which in January decreases to 23°C. Mean annual precipitation ranges from 450 to 560 mm.

B. Sample Collection

41 sampling sites were selected around the Zangezur copper and molybdenum combine, and a control site was chosen in a place which was 4.5 km away from the open mine. The coordinates of the sampling sites were recorded by GPS. The sampling of soils was carried out in May, 2014 by the traditional way, well-known in soil science. 4 soil samples were taken from each site, and the mean value of the 4 samples was taken into consideration. All labware and sampling apparatus were pre-soaked in 5% nitric acid solution followed by distilled water for a day prior to sampling for removing trace concentrations of metals.

The samples of soils were taken from a depth of 0-20 cm at 5 m intervals on a grid measuring 20 m x 20 m and with the center point of the grid at the sample location. The sections were done manually. All samples were collected into polyethylene sampling bottles and transported to the laboratory. After the homogenization and removal of unwanted content (stones, plant material, etc.), the samples were air-dried at room temperature, sieved through a 1 mm mesh and stored in an all-glass jar for the analysis of their properties.

C. Pretreatment and Heavy Metal Analysis of Soil Samples

Before analysis, the soil samples need required digestion. The soils were grounded using mortar and pestle. The digestion of the soil samples was done by Aqua Regia (HCl-HNO3, 3:1) extraction method. 3g of the soil sample was digested for 2h at 180°C. Heavy metal concentrations were determined by the atomic absorption spectrometry method using "PG990" Atomic Absorption Spectrophotometer (PG Instruments LTD).

D. Assessment of Metals Contaminations

The level of soil contamination by heavy metals was assessed by contamination indices. The contamination factor (*Cf*), the degree of contamination (*Cd*), the pollution load index (*PLI*) and the geo-accumulation index (*I-geo*) were used.

Cf and *Cd* were calculated as suggested by [14] through:

$$Cf^i = Cs^i / Cb^i \tag{1}$$

$$Cd = \Sigma Cf \tag{2}$$

where Cs^i is the measured concentration of the examined metal *i* in the soil sample, and Cb^i is the background value of heavy metal *i* in the uncontaminated soil (control). Hakanson has suggested four classes of *Cf* to evaluate the metal contamination levels as shown in Table I [14]. Four categories of *Cd* as suggested were used to evaluate metal contamination levels (Table I). If the *Cd* value exceeds 20, then it is necessary to take immediate counter measures to reduce heavy metal contamination in soil.

TABLE I
THE DIFFERENT TYPES OF MODEL AND CATEGORIES FOR THE DESCRIPTION OF SOIL CONTAMINATION

Model	Class	Description	Sources
Contamination Factor	$Cf<1$	Low	[14]
	$1<Cf<3$	Moderate	
	$3<Cf<6$	Considerable	
	$6<Cf$	Very high	
Degree of Contamination	$Cd<6$	Low	[14]
	$6<Cd<12$	Moderate	
	$12<Cd<24$	Considerable	
	$24<Cd$	Very high	
Pollution level Index	$PLI<1$	Perfection	[15]
	$PLI=1$	Base line level of pollution	
	$PLI>1$	Deterioration of site quality	
Geo-accumulation index	$I\text{-}geo<0$	Uncontaminated	[16]
	$0<I\text{-}geo<1$	Uncontaminated to moderately contaminated	
	$1<I\text{-}geo<2$	Moderately contaminated	
	$2<I\text{-}geo<3$	Moderately to strongly contaminated	
	$3<I\text{-}geo<4$	Strongly contaminated	
	$4<I\text{-}geo<5$	Strongly to very strongly contaminated	
	$5<I\text{-}geo$	Very strongly contaminated	

Furthermore, each site was evaluated for the extent of metal pollution by employing the method based on the pollution load index (*PLI*) developed by [15], as:

$$PLI=\sqrt[n]{(Cf1 \times Cf2 \times Cf3 \times \ldots \times Cfn)} \quad (3)$$

where n is the number of metals studied, and *Cf* is the contamination factor calculated as described in (1). The *PLI* provides simple but comparative means for assessing site quality. The rank of the values of the *PLI* and its implication are shown in Table I [15].

The geo-accumulation index (*I-geo*) was used to calculate metal contamination level in the soils. The *I-geo* was originally defined by Muller in 1969, in order to determine and define metal contamination in sediments, by comparing current concentrations with pre-industrial levels. The index was calculated as [16]:

$$I\text{-}geo = log_2 Cs^i / 1.5\, Cb^i \quad (4)$$

where Cs^i is the concentration of the element *i* in the samples, Cb^i is the background value of the element *i*, and the factor 1.5 is used to take into account the possible lithological variability. The rank of the values of the *I-geo* and its implication are shown in Table I.

TABLE II
THE MEAN CONCENTRATIONS (MG/KG) OF SOME HEAVY METALS IN THE STUDIED SOIL SAMPLES

Sample number	Ni	Zn	Cu	Pb	Mo	As
1	31.0±6	91.0±22	1500.0±290	28.0±7	200.0±40	12.0±4.0
2	25.0±4	54.0±14	1400.0±310	25.0±8	180.0±30	8.0±3.0
3	15.0±4	49.0±10	1600.0±250	48.0±14	680.0±110	75.0±15.0
4	25.0±2	56.0±13	2500.0±390	100.0±24	390.0±90	12.5±5.0
5	50.0±8	132.0±27	780.0±110	46.0±10	1100.0±320	5.0±2.0
6	50.0±12	143.0±25	730.0±130	345.0±87	1500.0±380	56.0±13.0
7	44.0±8	107.0±19	690.0±110	180.0±51	390.0±90	1.0±0.4
8	52.0±10	572.5±59	1230.0±180	28.0±8	390.0±120	4.0±1.0
9	41.0±7	103.0±24	810.0±100	110.0±18	280.0±90	30.0±6.0
10	25.0±6	131.0±21	940.0±150	50.0±12	220.0±60	13.0±4.0
11	25.0±3	75.0±18	1000.0±140	37.0±7	155.0±50	14.0±4.0
12	38.0±6	75.0±17	470.0±90	74.0±14	155.0±55	16.0±5.0
13	33.0±5	87.0±17	1200.0±210	35.0±9	235.0±85	12.0±4.0
14	37.0±8	75.0±14	550.0±80	40.0±12	100.0±20	33.0±8.0
15	10.0±3	87.0±20	2900.0±480	46.0±13	200.0±50	1.0±0.3
16	20.0±3	110.0±31	970.0±210	92.0±21	200.0±40	37.0±10.0
17	18.0±4	56.0±9	580.0±130	64.0±18	120.0±30	5.0±2.0
18	29.0±7	63.0±12	1600.0±280	44.0±10	130.0±30	12.0±3.0
19	15.0±3	60.0±12	500.0±80	46.0±10	80.0±20	10.0±3.0
20	25.0±6	56.0±8	380.0±60	59.0±16	180.0±40	14.0±5.0
21	35.0±9	61.0±11	1200.0±270	78.0±20	90.0±30	13.0±4.0
22	40.0±8	91.0±19	960.0±170	58.0±9	125.0±45	10.0±4.0
23	15.0±4	60.0±12	380.0±70	50.0±12	65.0±15	10.0±2.0
24	22.0±5	94.0±34	360.0±70	41.0±11	125.0±35	12.0±4.0
25	35.0±8	238.0±47	290.0±50	59.0±19	220.0±70	11.0±3.0
26	32.0±7	79.0±15	360.0±80	58.0±13	120.0±40	10.0±3.0
27	27.0±6	73.0±16	380.0±60	160.0±28	100.0±30	13.0±5.0
28	56.0±11	259.0±38	1030.0±160	92.0±22	760.0±240	1.0±0.4
29	50.0±13	194.0±29	390.0±70	110.0±26	260.0±100	22.0±8.0
30	38.0±6	63.0±9	100.0±20	45.0±12	65.0±25	37.0±12.0
31	80.0±15	82.0±17	1000.0±210	35.0±13	110.0±35	12.0±5.0
32	25.0±4	78.0±18	80.0±20	43.0±15	100.0±30	12.0±3.0
33	37.0±7	65.0±14	123.0±35	52.0±19	55.0±15	20.0±7.0
34	44.0±8	76.0±9	310.0±80	57.0±17	145.0±45	25.0±6.0
35	31.0±5	70.0±15	98.0±22	69.0±21	110.0±20	25.0±10.0
36	25.0±5	55.0±9	42.0±14	92.0±24	130.0±20	50.0±18.0
37	40.0±9	56.0±7	41.0±11	50.0±16	120.0±30	12.0±4.0
38	50.0±11	68.0±11	37.0±9	57.0±16	45.0±10	24.0±7.0
39	37.0±5	57.0±12	44.0±10	41.0±12	100.0±30	12.0±4.0
40	25.0±4	57.0±8	43.0±13	71.0±21	110.0±40	18.0±6.0
41	37.0±7	48.0±10	32.0±10	46.0±10	40.0±10	5.0±2.0
Cont.	35.0±6	122.0±23	360.0±100	46.0±8	155.0±65	26.0±9.0

III. RESULTS AND DISCUSSION

The concentrations of Ni, Zn, Cu, Pb, Mo and As in the soils surrounding the open mine and the ore enrichment combine near Kajaran town, the recultivated Voghji and active Artsvanik tailing dams were determined, and heavy metal pollution degree in the soils was assessed. The mean concentrations of Ni, Zn, Cu, Pb, Mo and As in the study area ranged between 10 and 80 mg/kg, 48 and 572.5 mg/kg, 32 and 2900 mg/kg, 25 and 325 mg/kg, 40 and 1500 mg/kg, 1 and 75 mg/kg respectively (Table II). Since the contents of metals in soils are specific and depend on the composition of soil-producing rocks and the conditions of soil formation, for the determination of pollution level, the obtained results were compared to the control sample which was considered as a background.

TABLE III
I-GEO VALUES IN THE SOIL SAMPLES

Sample number	Ni	Zn	Cu	Pb	Mo	As
1	-0.76	-1.01	1.47	-1.30	-0.22	-1.70
2	-1.07	-1.76	1.37	-1.46	-0.37	-2.29
3	-1.81	-1.90	1.57	-0.52	1.55	0.94
4	-1.07	-1.71	2.21	0.54	0.75	-1.64
5	-0.07	-0.47	0.53	-0.58	2.24	-2.96
6	-0.07	-0.36	0.43	2.32	2.69	0.52
7	-0.25	-0.77	0.35	1.38	0.75	-5.29
8	-0.01	1.65	1.19	-1.30	0.75	-3.29
9	-0.36	-0.83	0.58	0.67	0.27	-0.38
10	-1.07	-0.48	0.80	-0.46	-0.08	-1.58
11	-1.07	-1.29	0.89	-0.90	-0.58	-1.48
12	-0.47	-1.29	-0.20	0.10	-0.58	-1.29
13	-0.67	-1.07	1.15	-0.98	0.02	-1.70
14	-0.50	-1.29	0.03	-0.79	-1.22	-0.24
15	-2.39	-1.07	2.43	-0.58	-0.22	-5.29
16	-1.39	-0.73	0.85	0.42	-0.22	-0.08
17	-1.54	-1.71	0.10	-0.11	-0.95	-2.96
18	-0.86	-1.54	1.57	-0.65	-0.84	-1.70
19	-1.81	-1.61	-0.11	-0.58	-1.54	-1.96
20	-1.07	-1.71	-0.51	-0.23	-0.37	-1.48
21	-0.58	-1.58	1.15	0.18	-1.37	-1.58
22	-0.39	-1.01	0.83	-0.25	-0.90	-1.96
23	-1.81	-1.61	-0.51	-0.46	-1.84	-1.96
24	-1.25	-0.96	-0.58	-0.75	-0.90	-1.70
25	-0.58	0.38	-0.90	-0.23	-0.08	-1.83
26	-0.71	-1.21	-0.58	-0.25	-0.95	-1.96
27	-0.96	-1.33	-0.51	1.21	-1.22	-1.58
28	0.09	0.50	0.93	0.42	1.71	-5.29
29	-0.07	0.08	-0.47	0.67	0.16	-0.83
30	-0.47	-1.54	-2.43	-0.62	-1.84	-0.08
31	0.61	-1.16	0.89	-0.98	-1.08	-1.70
32	-1.07	-1.23	-2.75	-0.68	-1.22	-1.70
33	-0.50	-1.49	-2.13	-0.41	-2.08	-0.96
34	-0.25	-1.27	-0.80	-0.28	-0.68	-0.64
35	-0.76	-1.39	-2.46	0.00	-1.08	-0.64
36	-1.07	-1.73	-3.68	0.42	-0.84	0.36
37	-0.39	-1.71	-3.72	-0.46	-0.95	-1.70
38	-0.07	-1.43	-3.87	-0.28	-2.37	-0.70
39	-0.50	-1.68	-3.62	-0.75	-1.22	-1.70
40	-1.07	-1.68	-3.65	0.04	-1.08	-1.12
41	-0.50	-1.93	-4.08	-0.58	-2.54	-2.96

A. Contamination Evaluation Based On Geo-Accumulation Index (I-geo)

The geo-accumulation index (*I-geo*) was used to calculate metal contamination level in the soils (Table III). *I-geo* values for Ni showed that 95% of the soil samples corresponded to the uncontaminated class (≤ 0), and 5% of them corresponded to the uncontaminated–moderately contaminated class (0-1). *I-geo* values for Zn showed that 90% of the samples were corresponded to the uncontaminated class (≤ 0), 7% of the samples corresponded to the uncontaminated–moderately contaminated class (0-1), and 3% of them corresponded to the moderately contaminated class (1-2). *I-geo* values for Cu showed that 49% of the samples belonged to the uncontaminated class (≤ 0), 29% of the samples belonged to the uncontaminated–moderately contaminated class (0-1), 17% of the samples belonged to the moderately contaminated class (1-2), and 5% of them belonged to the moderately-strongly contaminated class (2-3). *I-geo* values for Pb showed that 68% of the samples belonged to the uncontaminated class (≤ 0), 24% of the samples belonged to the uncontaminated–moderately contaminated class (0-1), 5% of the samples belonged to the moderately contaminated class (1-2), and 3% of them belonged to the moderately-strongly contaminated class (2-3). *I-geo* values for Mo showed that 75% of the samples corresponded to the uncontaminated class (≤ 0), 15% of the samples corresponded to the uncontaminated–moderately contaminated class (0-1), 5% of the samples corresponded to the moderately contaminated class (1-2), and 5% of them corresponded to the moderately-strongly contaminated class (2-3). *I-geo* values for As showed that 93% of the samples belonged to the uncontaminated class (≤ 0), and 7% of them belonged to the uncontaminated–moderately contaminated class (0-1). Average *I-geo* values for the observed metals were in the decreasing order of Pb (-0.22) > Cu (-0.40) > Mo (-0.50) > Ni (-0.75) > Zn (-1.12) > As (-1.66). No *I-geo* value was greater than 3 (i.e. strongly contaminated), and only two values of Cu (samples № 4 and 15), two values of Mo (samples № 5 and 6) and one value of Pb (sample № 16) corresponded to the moderately-strongly contaminated class.

B. Contamination Evaluation Based On Contamination Factor (Cf) and Degree of Contamination (Cd)

Values obtained for the contamination factor (*Cf*) for each metal in their specific location are as shown in Fig. 1. The higher *Cf* values in the soil samples taken from the vicinity of the open mine and the ore enrichment combine (except samples № 5 and 8) were observed in case of Cu and Mo. It is necessary to mention that the concentrations of these metals in ore are also high, and soil pollution in this territory was conditioned by mining activity. Comparatively high *Cf* value was also observed in case of Pb. *Cf* values for Ni showed that 51% of the samples corresponded to the low level of contamination ($Cf \leq 1$), and 49% of them corresponded to the moderate level of contamination ($1<Cf<3$). *Cf* values for Zn showed that 83% of the samples corresponded to the low level of contamination ($Cf \leq 1$), and 15% of the samples corresponded to the moderate level of contamination ($1<Cf<3$), and 2% of them corresponded to the considerable level of contamination ($3<Cf<6$). *Cf* values for Cu showed that 29% of the samples corresponded to the low level of contamination ($Cf \leq 1$), 49% of the samples corresponded to the moderate level of contamination ($1<Cf<3$), 17% of the sample corresponded to the considerable level of contamination ($3<Cf<6$), and 5% of them corresponded to the very high level of contamination ($6<Cf$). *Cf* values for Pb showed that 29% of the samples corresponded to the low level of contamination ($Cf \leq 1$), 64.5% of the samples corresponded to the moderate level of contamination ($1<Cf<3$), 7.5% of them corresponded to the considerable level of contamination ($3<Cf<6$). *Cf* values for Mo showed that 54% of the samples corresponded to the low level of contamination ($Cf \leq 1$), 37% of the samples corresponded to the moderate level of contamination ($1<Cf<3$), 5% of the samples corresponded to the considerable level of contamination ($3<Cf<6$), and 5% of them corresponded to the very high level of contamination ($6<Cf$). *Cf* values for As showed that 83% of the samples corresponded to the low level of contamination ($Cf \leq 1$), and 17% of them corresponded to the moderate level of contamination ($1<Cf<3$). Average *Cf* values for the observed metals were in the decreasing order of Cu (2.01) > Mo (1.55) > Pb (1.52) > Ni (0.97) > Zn (0.82) > As (0.68).

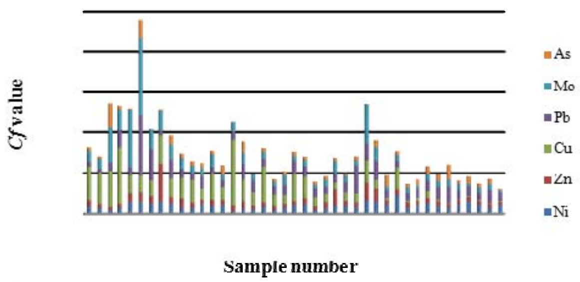

Fig. 1 *Cf* values for different metals in the soils around the open mine, ore enrichment combine and tailing dumps of the Zangezur copper and molybdenum combine

The values of the degree of contamination (*Cd*) are presented in Fig. 2. According to *Cd* values, 41% of the soil samples were lowly contaminated with investigated heavy metals ($Cd<6$), 44% of the samples were moderately contaminated with investigated heavy metals ($6<Cd<12$), and 15% of them were considerably contaminated with investigated heavy metals ($12<Cd<24$).

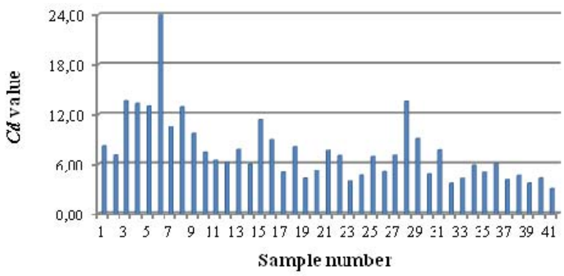

Fig. 2 *Cd* values in the soils around the open mine, ore enrichment combine and tailing dumps of the Zangezur copper and molybdenum combine

C. Contamination Evaluation Based On Pollution Load Index (PLI)

Pollution severity and its variation along the observation sites were determined with the use of pollution load index (*PLI*). This index is a quick tool in order to compare the pollution statuses of different places [17]. *PLI* values are presented in Fig. 3. According to *PLI* values, 54% of the soil samples corresponded to the perfection level of pollution ($PLI < 1$), 22% of the samples were characterized by the base line level of pollution ($PLI=1$), and 24% of them were characterized by the deterioration of site quality ($PLI>1$). The highest *PLI* value ($PLI = 2.8$) was observed in the № 6 sampling site, and the lowest *PLI* value ($PLI = 0.4$) was registered in the № 41 sampling site.

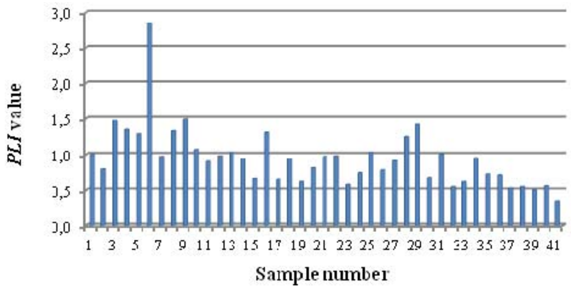

Fig. 3 *PLI* values in the soils around the open mine, ore enrichment combine and tailing dumps of the Zangezur copper and molybdenum combine

IV. Conclusion

The heavy metal pollution (Ni, Zn, Cu, Pb, Mo and As) of the soils around the open mine, ore enrichment combine and tailing dumps of the Zangezur copper and molybdenum combine was assessed by comparing with the control site. According to *I-geo*, *Cf*, *Cd* and *PLI* values, the distribution pattern of trace metals in the soil profile showed that the pollution degree in the soils around the open mine and the ore enrichment combine was higher than that in the soils around the tailing dumps. Heavy metal pollution degree mainly decreased with increasing distance from the open mine and the ore enrichment combine which indicated that the open mine and the ore enrichment combine were the main sources of pollution. The only exception was observed in the northern part of the open mine where pollution degree in the sites (along the open mine) situated 600 meters far from the mine was higher than that in the sites located 300 meters far from the mine. This can be explained by the characteristics of relief and air currents as well as the weak vegetation cover of these sites and the characteristics of soil structure.

The pollution level in the soils around the Artsvanik tailing dump wasn’t high which was due to the proper and accurate operation of the tailings storage facility. After the recultivation works, the Voghji tailing dump has been used as a pasture. Heavy metal pollution degree increased slightly in some parts of the tailing dump (especially № 31 sampling site).

The high Cu and Mo pollution of the soils was due to the character of industrial activities, the moving direction of air currents as well as the physicochemical peculiarities of soils. It is necessary to state that this issue becomes actual as the some parts of these highly polluted regions are inhabited by population, and agriculture is highly developed here, therefore, heavy metals can enter human organism through soil-plant-human or soil-plant-animal-human chains causing various diseases.

Therefore, further investigation is required to assess heavy metal concentrations and health implications around the Zangezur copper and molybdenum combine.

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