Applied Chemical Engineering (2025) Volume 8 Issue 1 ISSN: 2578-2010 (O)
doi: 10.59429/ace.v8i1.5640

RESEARCH ARTICLE

Impact of power plant-east of AL-Diwaniyah /Iraq- on soil pollution with heavy metals (HMs)

Zainab Salih Mahdi, Ali O. Shaawiat*

Biology Department, College of Education, University of Al-Qadisiyah, Al-Qādisiyyah Governorate, 58002, Iraq

***Corresponding author:** Ali O. Shaawiat, ali.shaawiat@qu.edu.iq

ABSTRACT

Monitoring soil contaminants is crucial in addressing sustainability issues. This study directly addresses the environmental sustainability issue of soil contamination with heavy metals (HMs) due to anthropogenic activities, particularly in soil surrounding the Al-Diwaniyah power plant, which is one of Iraq's electricity sources. Samples were obtained at the power station's three sites: right (R), left (L), and direction (D) (term "direction" refers to sampling site located directly in front of power plant, aligned with prevailing wind path). Soil samples were collected from different locations throughout 2024, with two separate soil sub-samples from the same site. Samples were obtained at the power station's three sites: right (R), left (L), direction. The concentrations of HMs chromium, nickel, cadmium, and lead were evaluated using an atomic absorption spectrometry (AAS) and results were expressed in milligrams of metal per kilogram of dry soil (mg/kg). The findings showed that the total concentrations of HMs were Ni> Pb> Cr> Cd, with values of 17.32 -41.27, 33.61-0.32 -6.07, and 12.77 -46.89 mg/kg for Cr, Ni, Cd), and Pb, respectively. The Contamination Factor (CF) and Ecological Risk Index (Er) calculation showed that the soil samples were heavily polluted. Furthermore, HMs concentrations were usually high throughout the autumn season at all three investigated sites. The elevated concentrations observed during autumn season may be due to reduced rainfall and limited leaching, resulting in increased accumulation of HMs in upper soil layers. It may be concluded that human activities have an influence on soil health, and these findings might emphasize the need of preserving soil health and sustainability from HMs contamination induced by neighboring activities such as electricity generation facilities.

Keywords: soil pollution; heavy metals (HMs); power plant; Geo-accumulation index

ARTICLE INFO

Received: 24 March 2025
Accepted: 20 April 2025
Available online: 30 April 2025

1. Introduction

Heavy metals (HMs) contamination in soil has attracted widespread international interest because of the significant risk to human health[1,2]. Soil contamination, in all of its forms, endangers our world, but it is the most hazardous due to the significant consequences it has on human health and other living species. HMs concentrations in soil are a strong sign of pollution. Soil contamination is described as the destruction of its layers or any change in its natural qualities caused by the leaking of complex chemical compounds or industrial radioactive materials, increasing the amount and concentration of heavy elements in it. These changes have an impact on the soil's fertility and ability to support life, putting food security and biodiversity at risk. Soil pollution is one of nature's greatest difficulties. It may arise in a variety of ways, with various compounds functioning as pollutants. These pollutants might be natural or manmade chemicals produced by environmental changes or human involvement. Pollutants permeate into the soil as HMs penetrate the pores around soil particles and become stuck there[3,4]. HMs pollution requires immediate attention, and soil pollution with HMs is the primary source of human exposure to toxic elements, as many countries rely on agricultural land to provide food, and the presence of HMs in high concentrations in the soil indicates pollution. HMs-contaminated soil poses health concerns to those who live there, including farmers and locals[5]. Therefore, there is a need for analyzing heavy metal contamination in soil. To measure the level of HMs pollution in soil, soil contamination indices such as the contamination factor, ground accumulation index, and environmental hazard index are utilized. Soil contamination can also be determined by comparing measured metal levels to concentration levels in locations away from pollution sources (uncontaminated areas). Muller (1969)[6]originally utilized this approach to detect metal contamination in soil. The Geo-accumulation Index (Igeo) index is also used to determine the severity of human-caused pollution. HMs contamination in soil can be caused by the geographical accumulation of heavy elements that were initially present in soil rocks or by bioaccumulation. Human activities in contaminated soil, or the movement of these metals from contaminated areas within soil components to a place where they accumulate in higher proportions[7-9].

The pollution is the result of the widespread use of fertilizers and pesticides[10,11]. The pollutants are discharged into the soil and other environmental components[12,13], harming the ecosystem[14,15] and putting populations at danger[16,17]. The hunt for energy is the gasoline that drives our contemporary society, yet it frequently leaves an everlasting impact on the environment. Despite their critical role in powering our lives, power plants can cause considerable soil contamination from HMs[18-20]. Power plants are industrial activities that pollute the surrounding environment, including air, water, soil, and plants, as a result of the resulting gas emissions loaded with fly ash and HMs, as well as the high temperature of the water emitted from them loaded with chemicals. Therefore, the present study sought to investigate the influence of the power plant on the soil composition of various total heavy elements at varied distances from the plant. Although numerous studies have assessed heavy metal contamination near industrial facilities, limited research has specifically addressed seasonal variations in both available and total heavy metal concentrations in soils surrounding power plants in Iraq. Furthermore, the comparative ecological risk and contamination indices across multiple directions relative to the plant are scarcely reported. This study fills that gap by evaluating Cr, Ni, Cd, and Pb distribution patterns over four seasons and across multiple sites, highlighting anthropogenic impacts and environmental risks[21-23].

2. Materials and methods

2.1. Description of the study area and period

The station, which has a rectangular shape, is situated east of Al-Diwaniyah city next to the AL-Diwaniyah-Afak Road at the junction of longitude (26 58 44° East) and latitude (41 56 31° North). The establishment of this power plant took place in 2012. It has 28 manufacturing facilities that run on diesel and heavy fuel oil. Each engine has a design capability of about 200 megawatts (MW), the SI unit for power. The distance from the governorate center is around 6 Km (**Figure 1**). Three locations were chosen close to the power plant, one in each of the following directions: right (R), left (L), and direction (D). Based on the direction of the predominant wind, samples were taken from the northwest, east, northwest, and west directions of the three locations. During the 2024 growing season, soil samples were taken from the research sites, with three separate soil sub-samples taken from each site. In addition to the power plant, other potential sources of pollution in the study area include fuel and chemical storage zones, transportation routes for fuel delivery, and maintenance areas for machinery and engines, all of which may contribute to the dispersion of heavy metals into the surrounding soil. Seasonal differences in heavy metal concentrations can be attributed to several environmental and operational factors. Wind direction and intensity may enhance pollutant dispersion toward specific sites, while variations in power plant activity across seasons can alter emission rates. Additionally, meteorological factors such as rainfall (affecting leaching and runoff) and dry deposition patterns influence metal accumulation. The presence of adjacent green areas, as seen in **Figure 1,** may also impact local metal uptake and soil retention capacity, contributing to site-specific differences.

Figure 1. The studied sites around of the power plant station.

2.2. Soil Sample collection

Soil samples were collected from the research sites using a metal shovel as a tool, excavating a V-shaped hole with a depth of 0-20 cm (following protocols aligned with established environmental sampling guidelines[24], Metal analysis was conducted using atomic absorption spectroscopy (AAS) after extraction procedures, and contamination indices such as Igeo were interpreted based on classification schemes proposed by Müller (1969) and further supported by models in recent literature[25] and three separate sub-samples for each of the stated study sites and for four seasons in the following order:(Winter samples were taken in December and February; spring samples were obtained in March and April; summer samples were collected in June and July; and autumn samples were collected in September and October. The soil sample was collected, crushed, smoothed, and blended, with gravel, plant pieces, and other components removed. Following that, it was placed in flexible plastic bags labeled with the sample's information and preserved until measurements were taken in the lab[26]. Soil samples were placed in a thin layer on plastic trays in the laboratory for air drying, after which they were gently crushed to expose all of their portions to drying using a non-heated air source at a temperature of no more than 35 °C[27].

The soil sample was collected, crushed, smoothed, and blended, with gravel, plant pieces, and other components removed. Following that, it was placed in flexible plastic bags labeled with the sample's

information and preserved until measurements were taken in the lab[26]. Soil samples were placed in a thin layer on plastic trays in the laboratory for air drying, after which they were gently crushed to expose all of their portions to drying using a non-heated air source at a temperature of no more than 35 °C[27]. The soil sample was collected, crushed, smoothed, and blended, with gravel, plant pieces, and other components removed. Following that, it was placed in flexible plastic bags labeled with the sample's information and preserved until measurements were taken in the lab[26]. Soil samples were placed in a thin layer on plastic trays in the laboratory for air drying, after which they were gently crushed to expose all of their portions to drying using a non-heated air source at a temperature of no more than 35 °C[27].

The soil samples were collected, crushed, smoothed, and blended, with gravel, plant pieces, and other components removed. Following that, it was placed in flexible plastic bags labeled with the sample's information and preserved until measurements were taken in the lab[26]. Soil samples were placed in a thin layer on plastic trays in the laboratory for air drying, after which they were gently crushed to expose all of their portions to drying using a non-heated air source at a temperature of no more than 35 °C[27]. The samples were crushed, smoothed, and blended, with gravel, plant pieces, and other components removed. Following that, it was placed in flexible plastic bags labeled with the sample's information and preserved until measurements were taken in the lab (26). Soil samples were placed in a thin layer on plastic trays in the laboratory for air drying, after which they were gently crushed to expose all of their portions to drying using a non-heated air source at a temperature of no more than 35 °C [27]. After the drying of the samples, they were crushed and sieved using a sieve with a 2 mm aperture width before being stored in sealed plastic containers in a cold area for examination and laboratory testing.

2.3. Determination of HMs in soil samples

HMs were determined in soil using the Lindsay and Norvell (1978) [28] and Estefan et al. (2013)[26]methods, which involved weighing 10 g of dried soil in a beaker, and adding 20 mL of DTPA extraction solution containing 0.005 N of DTPA (Diethylene triamine pentaacetic acid), 0.1 N of TEA (Triethanolamine), and 0.1N of $CaCl_2$, and placing the beaker in a shaker device. The method described by Estefan et al., (2013) [26] was used for Estimation of total concentration of heavy elements in soil. briefly, 0.5 g of dried soil was placed in a beaker, 3 mL of concentrated nitric acid solution was added, and the samples were left for 1 h before being filled to the needed amount with 4 mL of concentrated $HClO_4$ acid. An atomic absorption spectrometer was used to detect the ready and total concentrations of heavy elements (chromium, nickel, cadmium and lead).

2.4. Pollution indicators

Pollution indices were calculated for total and accessible HMs concentrations (Cr, Ni, Cd, and Pb) in the soil of the studied sites. Accessible (available) heavy metal concentration refers to fraction of metals that are loosely bound to soil particles and are readily available for plant uptake or environmental interaction, whereas total concentration includes all forms of metal, regardless of bioavailability. The geo-accumulation index (Igeo) was calculated according to Muller (1969) [6], whereas the contamination factor (CF) and ecological risk index (Er) were calculated according to Hakanson (1980) [29].

2.5. Quality assurance and quality control (QA/QC)

The soil samples were analyzed in the Environmental Laboratory, Department of Life Sciences, College of Education, University of Al-Qadisiyah, and the Biochemistry Laboratory, College of Pharmacy / University of Kufa, Iraq. The integrity of Quality Assurance and Quality Control (QA/QC) of the sample analysis process was controlled by following the practical steps and using blank and standard solutions for heavy elements (Chromium, Nickel, Cadmium, and Lead) (BDH from UAE) at a rate of five for each element from standard and blank. All standard solutions were accurate and of excellent quality. To decrease random standard error, samples were carefully collected, and the element was determined using three separate soil sub-samples. The resultant value was the average of the three measurements. Metal recovery rates in the standard reference material varied from 99.22 to 99.92 percent for each element tested.

2.6. Statistical analysis

The data was analyzed using the Statistical Analysis System (SAS) (2018) to investigate the influence of the power plant on the presence of HMs in the selected study locations, as well as the effect of the site and seasons of the year on the distribution of the examined HMs. The least significant difference test (LSD) and the P value were used to compare the significant differences between the means.

3. Results and discussion

3.1. Available heavy elements concentration in soil

The results revealed that Cr values ranged between (0.01 - 3.01 mg/kg), with the highest concentration in autumn at site 1 (right of the power plant) at 3.01 mg/kg, and the lowest value in winter at site 2 (right of the power plant) and site 3 (direction of the power plant) at 0.01 mg/kg. The results also revealed that the lowest concentration of Cr at the control site (located at a considerable distance from power plant and unaffected by its emissions, was selected to represent background heavy metal levels in uncontaminated soil for comparison purposes) was 0.019 mg/kg in the spring, while the maximum concentration was in the winter (0.021 mg/kg), as shown in **Table 1.** The results in **Table 1** also showed that the level of Ni ranged from 0.02-1.17 mg/kg, with the highest available level in autumn at site 3 at 1.17 mg/kg and the lowest concentration in winter at site 1 at 0.02 mg/kg, while the concentrations at the control site were close to the value of 0.022 mg/kg. The data presented in **Table 1** also revealed that the values of the available Cd concentrations ranged between 0.01 and 1.21 mg/kg, with the highest cadmium concentration in autumn at site 3 with a value of 1.21 mg/kg and the lowest concentration in winter at sites 2 and 3 with a value of 0.01 mg/kg, while the available Cd concentrations in the control were lower than the available concentrations in the sites around the power plant. The available concentration of Pb varied from 5.17 to 14.22 mg/kg, with the greatest concentration reported in autumn at site 1 (14.22 mg/kg) and the lowest concentration reaching 5.17 mg/kg in winter at site 2. However, in the control location, it reached 2.351 mg/kg (**Table 1**), with the lowest available value reported in the autumn. The statistical results (LSD) and (P value) show that the available Cr, Ni, Cd, and Pb concentrations vary significantly between seasons and locales.

3.2. Total HMs concentration

Total Cr concentrations in soil samples ranged from 17.32 to 41.27 mg/kg, with the highest concentration recorded in the summer at site 2 (41.27 mg/kg) and the lowest concentration found in the winter at the same site (17.32 mg/kg). The total Cr values at the control location varied from 0.020 to 0.118 mg/kg (**Table 2**). The Ni levels ranged from 33.61 to 73.65 mg/kg. The maximum concentration was observed at site 1 in the summer (73.65 mg/kg), whereas the lowest concentration was recorded at site 1 in the winter (33.61 mg/kg). While Ni concentrations at the control site were much lower than at all other research locations near the power plant (**Table 2**). The total content of Cd varied from 0.32 to 6.07 mg/kg. At site 2, the maximum total concentration was 6.07 mg/kg in the summer, while the lowest concentration was 0.32 mg/kg in the winter. While total Cd values in the control location varied seasonally, they approached 0.065 mg/kg (**Table 2**). The results ranged from 12.77 to 46.89 mg/kg of Pb; the maximum concentration of total Pb was observed in autumn at site 1 at 46.89 mg/kg, while the lowest concentration was reported in winter at site 3 at 12.77 mg/kg (see **Table 2).** The statistical values (LSD) and (P value) show statistically significant variations in Cr, Ni, Cd, and Pb available concentrations between seasons and places.

3.3. HMs pollution indices in soil

3.3.1. HMs pollution indicators based on available concentrations in soil

1) Geoaccumulation index (Igeo)

The geo-accumulation index (Igeo) of the available Cr concentrations ranged from 0.32 to -6.62. The greatest value was 6.62 in fall at site 1, and the lowest was 0.32 in winter at site 1 (**Table 3**). This index's values for available Ni concentrations varied from 0.63-5.14. The maximum value,6.62, was recorded in the autumn at site 3, while the lowest,0.63, was recorded during the winter at site 1. Whereas the geo-accumulation index for the available Ni concentration at the control location tended to be 12.43 (**Table 3**). As The index values for accessible Cd concentration varied from 0.01 to 5.99, with the maximum value in the fall at site 3 (5.99) and the lowest value in the winter at site 3 (-0.01). While the geo-accumulation Index (Igeo) for Cd at the control location tended to have a value of -3.70 (**Table 3**). This index's values for the available Pb varied from 0.50 to 1.97, with the maximum value discovered in the fall at site 1 (1.97), and the lowest value found in the winter at site 2 (0.50). The geo-accumulation Index (Igeo) for Pb at the control location averaged -3.12 (**Table 3**). The statistical values (LSD) and (P value) show that there are statistically significant changes in the geo-accumulation index (Igeo) for Cr, Ni, Cd, and Pb accessible concentrations between seasons and sites.

Table 1. Available heavy elements concentration in soil of study sites.

Element	**Seasons**	**Sites and Directions**									
		Site 1			**Site 2**			**Site 3**			**control**
		Right of Electric power station	**Direction of Electric power station**	**Left of Electric power station**	**Right of Electric power station**	**Directio of Electric power station on**	**Left of Electric power station**	**Right of Electric power station**	**Directio of Electric power station**	**Left of Electric power station**	
Cr	**Winter 2024**	0.61	0.04	0.43	0.01	0.02	0.28	0.75	0.01	0.11	0.021
	Spring 2024	0.29	0.14	0.09	0.11	0.03	0.07	0.24	0.09	0.18	0.019
	Summer 2024	1.32	0.63	0.76	0.81	1.12	0.79	0.99	0.99	0.81	0.02
	Autumn 2024	3.01	1.09	1.03	1.06	2.18	1.17	1.07	1.86	1.26	0.02
LSD			**Sites = 0.0023**						**Seasons =0.0014**		
P value			**0.0363**						**0.0114**		
Ni	**Winter 2024**	0.44	0.05	0.02	0.68	0.53	0.97	0.17	0.41	0.26	0.022
	Spring 2024	0.31	0.11	0.07	0.38	0.28	0.14	0.07	0.19	0.29	0.0217
	Summer 2024	0.69	0.61	0.67	0.71	0.68	0.77	0.72	0.68	0.66	0.022
	Autumn 2024	1.06	1.03	1.11	1.07	1.05	1.14	1.16	1.07	1.17	0.0222
LSD			**Sites = 0.0017**						**Seasons =0.0024**		
P value			**0.001**						**0.004**		
Cd	**Winter 2024**	0.03	0.02	0.06	0.16	0.04	0.01	0.17	0.01	0.02	0.0126
	Spring 2024	0.06	0.03	0.07	0.07	0.09	0.09	0.17	0.12	0.21	0.0128
	Summer 2024	0.59	0.38	0.31	0.61	0.42	0.37	0.64	0.44	0.41	0.0126
	Autumn 2024	1.07	0.92	0.81	1.18	0.93	0.91	1.21	0.98	0.87	0.0127
LSD			**Sites = 0.0013**						**Seasons =0.0084**		
P value			**0.003**						**0.008**		
Pb	Winter 2024	11.24	6.58	6.64	5.17	9.18	7.59	5.65	12.11	13.78	2.418
	Spring 2024	9.29	10.64	10.76	7.51	10.01	12.32	11.49	10.53	8.52	2.351
	Summer 2024	13.52	12.75	11.59	13.25	12.88	12.04	11.35	13.75	11.43	2.403
	Autumn 2024	14.223	10.91	10.74	13.53	11.91	11.73	12.94	13.79	13.08	2.412
LSD			**Sites = 0.0027**						**Seasons =0.0041**		
P value			**0.0036**						**0.0021**		

Table 2. Total heavy elements concentration in soil of study sites.

Element	Seasons	Sites and Directions									
		Site 1			Site 2			Site 3			control
		Right of Electric power station	Direction of Electric power station	Left of Electric power station	Right of Electric power station	Direction of Electric power station on	Left of Electric power station	Right of Electric power station	Direction of Electric power station	Left of Electric power station	
Cr	Winter 2024	19.14	28.21	24.98	23.39	17.32	25.14	22.32	22.56	24.69	0.020
	Spring 2024	35.71	36.93	28.27	35.33	37.63	27.39	36.12	34.78	28.18	0.021
	Summer 2024	40.39	40.38	35.39	36.04	41.27	36.22	36.97	41.11	34.63	0.118
	Autumn 2024	37.39	34.24	30.73	31.86	34.39	31.65	30.65	32.76	32.15	0.021
LSD			Sites = 0.0013						Seasons =0.0037		
P value			0.004						0.0014		
Ni	Winter 2024	33.61	49.59	42.28	44.45	35.94	42.58	39.21	40.84	42.61	0.481
	Spring 2024	67.74	71.24	70.41	69.38	70.79	71.69	69.25	68.27	72.13	0.471
	Summer 2024	62.19	73.65	64.78	63.24	71.24	64.97	61.99	70.74	67.19	0.481
	Autumn 2024	50.62	61.39	52.22	51.77	64.29	53.92	58.08	63.31	55.77	0.478
LSD			Sites = 0.0028						Seasons =0.0041		
P value			0.005						0.001		
Cd	Winter 2024	1.63	0.39	1.48	1.22	0.45	0.32	0.64	0.54	0.45	0.065
	Spring 2024	4.17	4.02	4.06	4.46	4.66	4.02	4.53	5.03	4.13	0.062
	Summer 2024	5.34	3.92	5.63	6.07	4.91	5.71	5.98	5.86	5.73	0.065
	Autumn 2024	3.98	2.76	4.09	4.62	3.11	4.11	3.99	4.12	3.76	0.064
LSD			Sites = 0.0038						Seasons =0.0024		
P value			0.0054						0.0029		
Pb	Winter 2024	15.11	15.79	13.79	22.13	23.48	37.54	12.77	20.26	23.39	5.60
	Spring 2024	38.73	36.61	38.63	39.72	36.11	39.25	39.28	37.26	36.13	5.61
	Summer 2024	42.08	43.41	40.56	42.74	41.89	44.59	44.39	42.87	43.85	5.63
	Autumn 2024	39.87	43.24	46.89	41.19	41.52	37.54	39.59	42.09	38.54	5.62
LSD			Sites = 0.0025						Seasons =0.0014		
P value			0.003						0.002		

Table 3. Pollution indices values of available concentration HMs (Cr, Ni, Cd and Pb) in soil of study sites: geo-accumulation index (Igeo), Contamination Factor (CF) and Ecological Risk index (Er).

Element	**Seasons**		**Sites and Directions**									
			Site 1			**Site 2**			**Site 3**			**control**
			Right of Electric power station	**Direction of Electric power station**	**Left of Electric power station**	**Right of Electric power station**	**Direction of Electric power station on**	**Left of Electric power station**	**Right of Electric power station**	**Direction of Electric power station**	**Left of Electric power station**	
Cr	**Winter 2024**	I-geo	3.55	-0.32	3.60	-1.60	-0.62	2.68	4.51	-1.94	0.93	-12.83
		CF	30.09	1.71	21.00	0.56	0.98	13.87	36.78	0.40	5.03	0.0002
		Er	120.36	6.86	83.99	2.23	3.91	55.48	147.11	1.62	20.10	0.000413
	Spring 2024	I-geo	3.35	2.20	1.63	1.44	-0.35	1.23	3.11	1.70	2.68	-12.97
		CF	15.77	7.52	5.03	5.46	1.39	3.78	12.95	5.06	9.91	0.0002
		Er	63.07	30.08	20.13	21.85	5.54	15.14	51.81	20.25	39.63	0.000373
	Summer 2024	I-geo	5.12	4.10	4.57	4.70	4.53	4.57	5.00	4.65	4.53	-12.87
		CF	65.55	31.52	37.48	39.72	55.85	39.16	49.49	49.25	40.10	0.0002
		Er	262.19	126.08	149.93	203.46	223.42	156.65	197.96	196.99	160.41	0.000403
	Autumn 2024	I-geo	6.62	5.17	5.08	5.12	6.16	5.26	5.14	5.93	5.37	-12.87
		CF	147.84	54.16	50.86	52.32	107.30	57.73	52.94	91.67	62.21	0.0002
		Er	591.37	216.62	203.46	209.30	429.21	230.92	211.77	366.68	248.83	0.000406
LSD			**Sites = 0.0042(I-geo),0.0147(CF),0.0047(Er)**						**Seasons =0.0048(I-geo),0.0142(CF),0.0021(Er)**			
P value			**0.0025(I-geo),0.0031(CF),0.0019(Er)**						**0.0142(I-geo),0.0021(CF),0.0055(Er)**			
Ni	**Winter 2024**	**I-geo**	3.64	0.63	-0.97	4.37	4.02	4.87	0.80	3.63	2.96	-12.41
		CF	19.80	2.36	0.77	31.01	24.32	43.91	3.94	18.70	11.65	0.000275
		Er	198.00	23.61	7.66	310.13	243.16	439.09	39.40	187.01	116.51	0.001378
	Spring 2024	**I-geo**	3.20	1.53	1.04	3.50	3.06	2.08	1.02	2.50	3.18	-12.43
		CF	13.91	5.01	3.15	17.54	13.02	6.55	3.33	8.55	13.70	0.000271

Element	**Seasons**		**Sites and Directions**									
			Site 1			**Site 2**			**Site 3**			**control**
			Right of Electric power station	**Direction of Electric power station**	**Left of Electric power station**	**Right of Electric power station**	**Direction of Electric power station on**	**Left of Electric power station**	**Right of Electric power station**	**Direction of Electric power station**	**Left of Electric power station**	
		Er	139.07	50.09	31.54	175.36	130.16	65.50	33.30	85.46	136.96	0.001358
	Summer 2024	**I-geo**	4.28	4.06	4.06	4.27	4.23	4.36	4.32	4.28	4.16	-12.41
		CF	31.44	27.39	30.25	31.98	30.90	34.99	32.84	30.66	30.02	0.000275
		Er	314.41	273.94	302.51	319.80	309.05	349.91	328.40	306.60	300.17	0.001378
	Autumn 2024	**I-geo**	5.00	4.95	5.06	5.01	4.98	5.10	5.12	5.01	5.14	-12.41
		CF	47.99	46.42	50.20	48.21	47.51	51.61	52.36	48.54	52.96	0.000276
		Er	479.86	464.20	501.98	482.13	475.11	516.14	523.60	485.36	529.58	0.001385
LSD			**Sites = 0.0033(I-geo),0.415(CF),0.0025(Er)**						**Seasons =0.0047 (I-geo), 0.321(CF),0.0027(Er)**			
P value			**0.014(I-geo),0.0054(CF),0.0030(Er)**						**0.0021(I-geo),0.0031(CF),0.0025(Er)**			
Cd	**Winter 2024**	**I-geo**	-0.09	-4.35	1.21	2.96	0.41	-2.62	3.15	-3.51	-0.01	-3.71
		CF	2.54	0.18	5.02	12.38	3.30	0.38	13.35	1.09	1.50	0.11
		Er	152.39	10.63	301.07	742.99	197.89	22.94	801.28	65.44	89.87	3.45
	Spring 2024	**I-geo**	0.77	0.66	1.83	1.79	2.10	1.55	3.06	2.23	3.43	-3.69
		CF	4.55	2.40	5.36	5.18	7.35	7.46	13.08	9.25	16.74	0.12
		Er	272.77	144.02	321.51	310.71	440.81	447.79	784.75	555.29	1004.51	3.48
	Summer 2024	**I-geo**	4.57	4.14	4.04	4.62	4.17	4.26	4.70	4.03	4.37	-3.70
		CF	47.51	30.27	25.06	48.64	33.28	29.65	51.19	34.93	32.34	0.12
		Er	2850.48	1816.20	1503.83	2918.43	1996.84	1778.73	3071.52	2095.92	1940.65	3.42
	Autumn 2024	**I-geo**	5.81	5.59	5.40	5.95	5.62	5.58	5.99	5.70	5.52	-3.69
		CF	84.56	72.76	63.59	93.14	73.79	71.83	96.07	77.95	68.95	0.12

	Seasons		**Sites and Directions**									
			Site 1			**Site 2**			**Site 3**			**control**
Element			**Right of Electric power station**	**Direction of Electric power station**	**Left of Electric power station**	**Right of Electric power station**	**Direction of Electric power station on**	**Left of Electric power station**	**Right of Electric power station**	**Direction of Electric power station**	**Left of Electric power station**	
		Er	5073.32	4365.66	3815.49	5588.58	4427.67	4309.87	5764.43	4677.07	4137.30	3.45
LSD			**Sites = 0.0017(I-geo), 0.0339(CF),0.0029**						**Seasons =0.0022(I-geo),0.0221(CF),0.0021(Er)**			
P value			**0.0014(I-geo),0.0055(CF),0.0031(Er)**						**0.0042(I-geo),0.0034(CF),0.0030(Er)**			
Pb	**Winter 2024**	**I-geo**	1.63	0.82	0.86	0.50	1.33	1.05	0.63	1.73	1.91	-3.12
		CF	4.65	2.72	2.75	2.14	3.79	3.14	2.34	5.00	5.70	0.17
		Er	46.48	27.21	27.47	21.37	37.94	31.41	23.35	50.05	56.99	0.86
	Spring 2024	**I-geo**	1.38	1.58	1.61	1.07	1.50	1.80	1.70	1.58	1.27	-3.16
		CF	3.96	4.54	4.58	3.20	4.26	5.24	4.88	4.47	3.62	0.17
		Er	39.62	45.37	45.80	32.03	42.62	52.45	48.81	44.75	36.21	0.84
	Summer 2024	**I-geo**	1.90	1.79	1.66	1.88	1.83	1.72	1.66	1.91	1.66	-3.13
		CF	5.63	5.31	4.83	5.52	5.36	5.02	4.72	5.67	4.76	0.17
		Er	56.25	53.10	48.26	55.16	53.64	50.15	47.25	56.66	47.56	0.86
	Autumn 2024	**I-geo**	1.97	1.59	1.57	1.90	1.72	1.70	1.84	1.92	1.85	-3.12
		CF	5.90	4.53	4.45	5.61	4.94	4.86	5.37	5.72	5.42	0.17
		Er	59.01	45.28	44.54	56.09	49.36	48.64	53.67	57.18	54.25	0.86
LSD			**Sites = 0.0041(I-geo), 0.0514(CF),0.0041(Er)**						**Seasons =0.0036 (I-geo),0.0252(CF),0.0038(Er)**			
P value			**0.0063(I-geo),0.0024(CF),0.0051(Er)**						**0.0014(I-geo),0.0055(CF).0.0014(Er)**			

Table 3. (*Continued*)

2) Contamination factor (CF)

The CF values for the available Cr concentration varied from 0.40 to 147.84. The maximum value was found in autumn at site 1 with a value of 147.84, while the lowest value was recorded in the winter at site 3 with 0.40. While the Contamination Factor index for this element at the control site was typically about 0.0002 (**Table 3**). The CF index values for the concentration of accessible Ni varied from 0.77 to 52.96, with the maximum value in the fall at site 3 (52.96), and the lowest value in the winter at site 1 (0.77). While the CF index for Ni at the control location varied between 0.000271 and 0.000276 (**Table 3**). The CF index values for the concentration of accessible Cd varied from 0.18 to 96.07, with the maximum value in autumn at site 3 (96.07) and the lowest value in the winter at site 1 (0.18). The CF index for this element at the control site typically varied between 0.11 and 0.12 (**Table 3**). On the other hand, the CF index values for the concentration of accessible Pb ranged between 2.14 and 5.90, with the maximum value in the fall at site 1 at 5.90 and the lowest value in the winter at site 2 at 2.13. The CF index for accessible Pb at the control location was typically about 0.17 (**Table 3**). The statistical values (LSD) and (P value) reveal that there are statistically significant variations in the CF index of available concentration of Cr, Ni, Cd, and pb across seasons and various locations.

3) Ecological risk index (Er)

The Er index values for the available Cr varied from 1.62 to 591.37, with the maximum value in autumn at site 1 (591.37) and the lowest value in the winter at site 3 (1.62). While the Er index for Cr at the control site varied from 0.000373 to 0.000413 between seasons (**Table 3**). The Cr index values for the available Ni ranged from 7.66 to 529.58, with the highest value in the autumn at site 3 at 529.58, and the lowest value in the winter at site 1 at 7.66, whereas the Er index values for Ni at the control site ranged from 0.001358 to 0.001385 between seasons (**Table 3**). The Er index values for the available Cd ranged between 10.63 and 5764.43, with the highest value of 5764.43 in the autumn at site 3 and the lowest value of 10.63 in the winter at site 1, while the Er index values for this element at the control site varied between 3.42 and 3.48 between seasons (**Table 3**). The Er index values for the available Pb ranged between 21.37 and 59.01, with the highest value in the autumn at site 1 and the lowest value in the winter at site 2, respectively, while the Er index values for Pb at the control site ranged between 0.84 and 0.86 across seasons (**Table 3**). The statistical values (LSD) and (P value) show that there are statistically significant changes in the Er index of Cr, Ni, Cd, and Pb available concentrations between seasons and various places.

3.3.2. Pollution indices of total concentration HMs in soil samples

1) Geo-accumulation index (Igeo)

The values of the Igeo index for the total Cr concentration ranged between 8.40 and 10.24, with the highest value in autumn at site 1 around 10.24 and the lowest value in summer at site 3 of 8.40, while the Igeo-accumulation index of the total Cr concentration at the control site tended to have values between -12.78 and 12.88 (**Table 4**). Also, the values of the Igeo index for total Ni concentration varied from 5.54 to 6.67, with the maximum value recorded in summer at site 1 at 6.67 and the lowest value recorded in winter at site 1 at 5.54. While the Igeo index for Ni at the control location ranged between 7.96 and 7.99, (**Table 4**).

In addition, the values of Igeo index for total Cd concentration ranged between 0.63 and 7.56, with the highest value in spring at site 3 at 7.56) and the lowest value in winter at site 1 (0.63), while the Igeo index of total Cd concentration at the control site tended to have values between 1.34 and 1.42 (**Table 4**). The Igeo index values for total Pb concentration ranged from 0. 50 to 2.47, with the highest value recorded in spring at site 1 (2.47), and the lowest value recorded in winter at site 3 (0.50), while the Pb index at the control site tended to be between 1.90 and 1.91 (**Table 4**). The statistical values (LSD) and (P value) show that there are statistically significant variations in Igeo index of Cr, Ni, Cd, and Pb concentrations between seasons and locations.

2) Contamination factor index (CF)

The CF index for total Cr concentrations ranged between 896.40 and 1809.48, with the highest value in the autumn at site 1 at 1809.48 and the lowest value in the winter at site 2 at 896.40, whereas the CF index for total Cr concentrations at the control site tended to range between 0.000199 and 0.000214 (Table). The CF index for total Ni concentrations ranged between 69.90 and 154.78, with the highest value in the summer at site 1 (154.78) and the lowest value in the winter at site 1 (69.90), whereas the CF index for total Ni concentrations at the control site tended to range between 0.0059 and 0.0060 (**Table 4**). The CF index for total Cd concentrations ranged from 5.15 to 95.08, with the highest value in the summer at site 2 (95.08) and the lowest value in the winter at site 3 (5.15), whereas the CF index for total Cd at the control site tended to be between 0.56 and 0.59 (**Table 4**). The CF index for total Pb concentrations ranged from 2.28 to 8.31, with the highest value in the fall at site 1 (8.31) and the lowest value in the winter at site 3 (2.28), whereas the CF index for total Pb at the control site tended to be close to 0.40 (**Table 4**). The statistical values (LSD) and (P value) show that there are statistically significant variations in the CF index of Cr, Ni, Cd, and Pb available concentrations between seasons and places.

3) Ecological risk index (Er)

The Er index values for total Cr concentrations ranged between 3585.16 and 7237.93, with the highest value in the autumn at site 1 (7237.93) and the lowest value in the winter at site 2 (3558.16), whereas the Er index values for total Cr concentrations at the control site ranged between 0.000398 and 0.00235, depending on the season (**Table 4**). The values of the Er index for total Ni concentrations ranged between 699.03 and 1547.75, with the highest value in the summer at site 1 (1547.75) and the lowest value in the winter at site 1 (699.03), whereas the values of the Er index for total Ni concentrations at the control site ranged between 0.000398 and 0.00235, depending on the season (**Table 4**). The Er index values for total Cd concentrations ranged from 309.07 to 5704.60, with the highest value recorded in the summer at site 2 (5704.60) and the lowest value recorded in the winter at site 2 (699.03), while the values of this index for total Cd concentrations at the control site ranged from 16.86 to 17.76 between seasons (**Table 4**). The Er index values for total Pb concentrations ranged from 22.83 to 83.08, with the highest value found in autumn at site 1 (83.08) and the lowest value recorded in winter at site 3 (22.08), while the Er index values for total Pb at the control site tended to be 2 in all seasons for all sites (**Table 4**). The statistical values (LSD) and (P value) show that there are statistically significant changes in the Er index of the Cr, Ni, Cd, and Pb available concentration across seasons and various places.

Table 4. Pollution indices values of Total concentration HMs (Cr, Ni, Cd and Pb) in soil of study sites: geo-accumulation index (Igeo), Contamination Factor (CF) and Ecological Risk index (Er).

Element	Seasons		Sites and Directions									
			Site 1			Site 2			Site 3			control
			Right of Electric power station	Direction of Electric power station	Left of Electric power station	Right of Electric power station	Direction of Electric power station on	Left of Electric power station	Right of Electric power station	Direction of Electric power station	Left of Electric power station	
Cr	Winter 2024	I-geo	9.15	9.88	9.71	9.62	9.02	9.72	9.55	9.56	9.68	-12.88
		CF	990.97	1413.34	1257.09	1181.55	896.29	1265.58	1122.12	1132.51	1235.01	0.000199
		Er	3963.90	5653.35	5028.38	4726.19	3585.16	5062.32	4488.49	4530.03	4940.02	0.000398
	Spring 2024	I-geo	10.10	10.14	9.78	10.09	10.18	9.73	10.12	10.07	9.78	-12.78
		CF	1668.92	1725.49	1321.03	1650.78	1758.56	1279.97	1687.87	1625.27	1316.65	0.000214
		Er	6675.66	6901.95	5284.13	6603.13	7034.25	5119.88	6751.47	6501.08	5266.60	0.000428
	Summer 2024	I-geo	8.63	8.61	8.43	8.45	8.64	8.46	8.47	8.63	8.40	-12.78
		CF	1125.16	1203.59	1033.04	1063.58	1234.32	1064.87	1124.09	1246.60	1008.45	0.000214
		Er	4500.65	4814.36	4132.17	4254.33	4937.29	4259.50	4496.36	4986.41	4033.79	0.00235
	Autumn 2024	I-geo	10.24	10.11	9.95	10.01	10.11	10.00	9.95	10.04	10.02	-12.80
		CF	1809.48	1656.69	1487.85	1542.01	1662.49	1532.44	1484.13	1584.02	1555.32	0.000211
		Er	7237.93	6626.77	5951.40	6168.05	6649.97	6129.75	5936.52	6336.06	6221.29	0.000414
LSD			Sites = 0.0011(I-geo), 0.1147(CF),0.0045(Er)						Seasons =0.0012 (I-geo),0. 1412(CF),0.0024(Er)			
P value			0.0025 (I-geo),0.0525(CF),0.0058(Er)						0.0032(I-geo),0.0623(CF).0.0044(Er)			
Ni	Winter 2024	I-geo	5.54	6.03	5.85	5.89	5.64	5.86	5.75	5.80	5.87	-7.96
		CF	69.90	103.18	87.95	92.47	74.76	88.59	81.55	84.97	88.63	0.0060
		Er	699.03	1031.83	879.53	924.73	747.57	885.89	815.51	849.67	886.25	0.03
	Spring 2024	I-geo	6.58	6.65	6.64	6.62	6.64	6.66	6.61	6.58	6.66	-7.99
		CF	143.73	151.13	149.37	147.20	150.18	152.11	146.92	144.82	153.04	0.0059
		Er	1437.27	1511.33	1493.65	1472.02	1501.79	1521.12	1469.21	1448.19	1530.37	0.03
	Summer 2024	I-geo	6.40	6.67	6.46	6.43	6.61	6.47	6.40	6.60	6.52	-7.96
		CF	130.79	154.78	136.27	133.00	149.74	136.65	130.37	148.71	141.30	0.0060

Element	Seasons		Sites and Directions									
			Site 1			Site 2			Site 3			control
			Right of Electric power station	Direction of Electric power station	Left of Electric power station	Right of Electric power station	Direction of Electric power station on	Left of Electric power station	Right of Electric power station	Direction of Electric power station	Left of Electric power station	
		Er	1307.92	1547.75	1362.68	1329.98	1497.41	1366.47	1303.68	1487.14	1412.96	0.03
	Autumn 2024	**I-geo**	6.14	6.42	6.19	6.18	6.49	6.23	6.34	6.47	6.28	-7.97
		CF	105.96	128.51	109.31	108.38	134.57	112.89	121.64	132.52	116.74	0.0060
		Er	1059.58	1285.08	1093.11	1083.80	1345.74	1128.85	1216.40	1325.19	1167.37	0.03
LSD				**Sites = 0.0029(I-geo), 0.1252 (CF),0.1452(Er)**						**Seasons =0.0051 (I-geo),0.4152(CF),0.0038(Er)**		
P value				**0.0033(I-geo),0.0521(CF),0.0547(Er)**						**0.0025(I-geo),0.0236(CF).0.0541(Er)**		
Cd	**Winter 2024**	**I-geo**	3.77	0.63	3.69	3.50	1.12	0.76	2.70	2.02	1.97	-1.34
		CF	24.40	6.28	22.26	18.40	7.25	5.15	9.99	8.51	7.11	0.59
		Er	1464.26	376.56	1335.78	1104.03	434.84	309.07	599.56	510.67	426.32	17.76
	Spring 2024	**I-geo**	7.33	7.37	7.35	7.36	7.48	7.33	7.30	7.56	7.38	-1.42
		CF	67.45	65.09	65.76	72.18	75.39	65.02	73.25	81.35	66.87	0.56
		Er	4047.06	3905.24	3945.38	4330.95	4523.30	3901.12	4394.92	4880.91	4012.36	16.86
	Summer 2024	**I-geo**	5.69	4.88	5.76	5.88	5.47	5.76	5.86	5.80	5.77	-1.35
		CF	83.77	62.43	88.30	95.08	77.49	89.69	93.84	92.10	89.98	0.59
		Er	5026.03	3745.94	5297.70	5704.60	4649.34	5381.70	5630.62	5526.24	5398.98	17.72
	Autumn 2024	**I-geo**	5.39	4.86	5.43	5.59	5.03	5.43	5.39	5.44	5.31	-1.34
		CF	62.98	43.48	64.55	72.48	49.14	64.97	63.12	65.12	59.32	0.59
		Er	3778.98	2609.06	3873.06	4348.74	2948.32	3898.22	3787.20	3907.22	3559.46	17.35
LSD				**Sites = 0.0039(I-geo), 0.3014(CF),0.0145(Er)**						**Seasons =0.0027 (I-geo),0.2014(CF),0.1245(Er)**		
P value				**0.0047 (I-geo),0.1024(CF),0.0543(Er)**						**0.0024(I-geo),0.1241(CF).0.014(Er)**		
Pb	**Winter 2024**	**I-geo**	0.84	0.91	0.69	1.36	1.36	1.58	0.50	1.18	1.42	-1.91
		CF	2.70	2.82	2.46	3.95	4.19	6.68	2.28	3.61	4.17	0.40
		Er	26.98	28.21	24.60	39.47	41.86	66.85	22.83	36.13	41.71	2.001

Element	**Seasons**		**Sites and Directions**									
			Site 1			**Site 2**			**Site 3**			**control**
			Right of Electric power station	**Direction of Electric power station**	**Left of Electric power station**	**Right of Electric power station**	**Direction of Electric power station on**	**Left of Electric power station**	**Right of Electric power station**	**Direction of Electric power station**	**Left of Electric power station**	
	Spring 2024	**I-geo**	2.20	2.11	2.20	2.24	2.09	2.22	2.22	2.14	2.08	-1.91
		CF	6.90	6.52	6.88	7.08	6.43	7.00	7.00	6.64	6.43	0.40
		Er	69.02	65.23	68.83	70.81	64.33	69.96	70.01	66.37	64.33	2.004
	Summer 2024	**I-geo**	2.31	2.38	2.24	2.34	2.31	2.39	2.39	2.34	2.36	-1.90
		CF	7.47	7.80	7.20	7.59	7.44	7.92	7.88	7.61	7.78	0.40
		Er	74.70	77.95	71.98	75.88	74.36	79.16	78.79	76.09	77.83	2.012
	Autumn 2024	**I-geo**	2.24	2.36	2.47	2.29	2.30	2.15	2.23	2.32	2.19	-1.90
		CF	7.06	7.66	8.31	7.30	7.35	6.65	7.01	7.46	6.83	0.40
		Er	70.62	76.59	83.06	72.96	73.55	66.49	70.14	74.57	68.28	2.008
LSD			**Sites = 0.0031(I-geo), 0.0523(CF),0.0441(Er)**						**Seasons =0.0018 (I-geo),0.2124(CF),0.0047(Er)**			
P value			**0.0033 (I-geo),0.02514(CF),0.0863(Er)**						**0.0025(I-geo),0.02323(CF).0.0254(Er)**			

Table 4. (*Continued*)

4. Discussion

HMs are often present in soil, and geological and human activity have elevated the concentration of these metals to levels that are toxic to life. Some of these operations include fossil fuel combustion, mining, battery manufacture, power plants, and other industrial components[4]. The high concentration of HMs in soil is a useful indication for determining soil quality. Traditional approaches for examining HMs contamination in soil, such as combining sampling from soil polluted sources with samples taken distant from the source of contamination, are increasingly being employed to research soil contamination[30,31]. These increases in the concentration of some elements in the sites are caused by their proximity to pollution sources, which contain fuel combustion products, fly ash, and high concentrations of some of these heavy elements, as well as the rocks that make up these soils, which determine the soil content of heavy elements. Power plants are among the industrial activities that damage the surrounding environment, since contamination encompasses air, water, soil, and plants as a result of the resultant gaseous emissions loaded with fly ash and HMs[21,32]. Lead contamination in soil may result from the burning of gasoline containing tetraethyl lead, which is used to prevent friction. Lead concentrations may increase with decreasing soil pH due to the presence of other ions that cause hydrogen ion exchange in the soil solution, resulting in a decrease in the pH of the soil solution, affecting the concentrations of HMs in it, as pH values tend to decrease. In this study, lead content declined as the distance between the study site and the power plant increased, as did its concentration at the second and third sites. It has been noted that lead levels in soil rise dramatically around power plants[33]. Based on the Igeo values, the study sites fall under the categories of moderately to extremely polluted, particularly with Cr and Cd. The Contamination Factor (CF) indicates high to very high contamination levels, while the Ecological Risk Index (Er) reveals that the sites pose a considerable to very high ecological risk, especially due to Cd. These qualitative assessments confirm significant pollution and environmental threat near the power plant.

The sites close to the pollution source are affected by the high concentration of already prepared lead and the total concentration of nickel, which results from its increase in the area's air due to the combustion of fuel in the power plant, as it contains high concentrations of elements (lead), in addition to the effect of gasoline-powered vehicles[34,35]. The high lead contents at the research sites might be attributed to car emissions from transportation, which are the primary source of lead in soil. Although the ban on leaded gasoline in recent years has resulted in a decrease in lead content in the troposphere, the concentration of lead in soil still reflects a high level of lead pollution, owing to lead's long half-life, which remains in soil for a very long time[31]. Lead concentrations in soil may be due to car exhaust fumes and air pollutants from the power plant, which can promote bioaccumulation in plants via soil absorption and eventually reach the food chain[36]. The results showed that the highest concentrations of heavy elements were found in sites close to the station, which was confirmed by[37] during their study of soil pollution caused by industrial facilities in the surrounding environment, where they confirmed that the highest nickel content was near the source of pollution, which decreased as we moved away. This rise was also ascribed to the power station's fuel combustion waste, which includes high levels of nickel, chromium, cadmium, and lead[22]. Convergent HMs concentrations were found in soil samples, including lead in the current study. This might be related to the convergence of lead concentration values due to the high stability of lead and some of the components under investigation in the soil, since[38] shown that lead is not biodegradable and remains linked to soil particles. The low lead levels in soil samples might be attributed to the high sensitivity of plant roots in the soil of the research locations to absorb this element from the soil and accumulate it inside plant parts, as corroborated by[39].

The present study's highest findings for nickel and lead in total concentration might be attributed to a variety of human activities and environmental conditions that can raise HMs concentrations in soil. Salinity, for example, plays an essential role in decreasing the toxicity of HMs by forming complexes with chloride ions, rendering the metal inaccessible. Nickel and HMs concentrations might potentially rise as a result of atmospheric deposition of elements in the soils of the research sites by migrating from the pollution source, such as a power plant, particularly in neighboring places[40]. HMs may remain suspended in the air for some time after fuel combustion in a power plant. A month or longer, and this influences the rise or reduction of their concentrations in the soil exposed to them. The deposition of these particles is also determined by the density of the ash or smoke flying or expelled from the power plant's chimneys, as well as the square of the half-particle of the fly ash produced by fuel combustion and the temperature of the medium in which it is placed. As a result, the deposition rate of big particles is quicker than that of tiny particles, as proven by Hassan (2012) [41] and Uzun and Arslan (2018) [42]. This verifies the clear fluctuation in the concentrations of heavy elements under examination within their distances between the research sites, their distance and direction from the power plant selected for the study, and the amount to which they are impacted by environmental conditions, including winds. In addition to the nature of the soil, which can be traced back to the parent rocks from which the soil is derived, and on which the soil content of heavy elements is heavily reliant, the proportions of heavy elements in the soil vary depending on the type of rock that formed it. For example, the amount of HMs in basic igneous rocks is higher than in sedimentary rocks that produce soil, and it also relies on the degree of weathering of the rocks that generated it due to environmental variables [22]. The low concentration of HMs in soil is due to ion exchange, which occurs when an ion penetrates the crystalline clay network through gaps in the surfaces and channels leading to it and replaces the heavy ion with other ions, which are often sodium and calcium[5]. There are various other factors that lead to a considerable rise in heavy element accumulation in soil, including the fact that most soil microbes are unable to degrade this metal as quickly as other fast disintegrating minerals[34]. Furthermore, atmospheric sediments from vehicle exhausts on highways and power plants near some study sites increase the percentage of HMs accumulation in soil, whereas the low soil content of total organic carbon and the quality of sandy clay soil may reduce HMs accumulation in soil, including lead. This indicates a positive link between total organic carbon and HMs in soil[43]

HMs concentrations in soil, particularly chromium, fluctuate depending on the geography, the level of pollution caused by human activities, and the closeness and distance to the source of pollution, such as a power plant[44,45]. Other factors contributing to variations in metal concentrations in soil include the quantity lost by volatilization, runoff, leaching, and plant absorption at the research locations. Because the sampling site is where agriculture and irrigation take place, variation in the concentration of metals in soil is expected, and this also causes variation in the values of pollution indicators used in the current study, such as the geographic accumulation index (Igeo) [46,47]. The geo-accumulation index (Igeo), the Contamination factor index (CF), and the Ecological risk (Er) index score for metal contamination are frequently used to quantify HMs levels in soils. These indicators are used to quantify the severity of anthropogenic pollutant deposition in soil surface layers[48].

The values of the geo-accumulation index (Igeo) showed that the soil is highly polluted, as the highest value of the geo-accumulation index (Igeo)was for the available concentration of chromium in the soil, then the geo-accumulation index (Igeo)for the concentration of cadmium, then nickel, and the lowest value was for lead, where the order of the geo-accumulation index (Igeo)values for the HMs under study is (Cr > Cd > Ni > Pb). The Contamination factor index (CF) also showed that the soils of the study sites are highly polluted with all the HMs under study, as the highest value of The Contamination factor index was recorded for the available concentration of chromium, then cadmium, then nickel, and the Contamination factor index for lead was the lowest value compared to the other metals, where the order of the Contamination factor index values under study is as follows (Cr > Cd > Ni > Pb). The ecological risk (Er) index also revealed that the pollution in the research areas had a very high. The Ecological danger due to contamination with HMs Cr, Ni, Cd, and Pb, where the order of the Er index values for the available concentration of the components was as follows: (Cd > Cr > Pb > Ni).

The geo-accumulation index (Igeo) for the overall concentration of the heavy elements under examination in the present research locations was high for chromium, followed by cadmium and nickel. The soils were highly contaminated, whereas lead was moderately to severely polluted. Thus, the degree of contamination in the soils of the research locations was ranked as follows: Cr > Cd > Ni > Pb. The Contamination Factor Index, based on the overall concentration of the metals under investigation, revealed that the soils were extremely to very highly contaminated, with Cr > Ni > Cd > Pb. The Ecological risk index also revealed that the soils are at very high or extremely high risk of pollution with HMs, Cr, Ni, and Cd, with the exception of Pb, which was heavily contaminated at the study locations. This index was ranked according to the concentration of the HMs under study (Cr > Cd > Ni > Pb).

5. Conclusion

In this study, a distinct pattern of change in the accessible concentrations of chromium, nickel, and cadmium is seen, progressively increasing from winter to fall. In addition, there is a distinct pattern of change in accessible lead content in soil, which steadily increases from spring to fall. Furthermore, a clear pattern of change in chromium and lead total concentrations is observed in soil, gradually increasing from winter to summer, as well as a clear pattern of change in total nickel concentration, which increases significantly from winter to spring before gradually decreasing in summer and autumn. Cadmium concentration increases dramatically from winter to summer before decreasing somewhat in fall. Differences in HMs concentrations (available and total) are also seen between seasons and cites in power plant chimneys. While pollution indices The Geo-accumulation index (Igeo) of HMs, together with their total and accessible amounts, revealed that the soil at the research locations was heavily contaminated. The severity of soil contamination with HMs at the research locations was graded using (Igeo) as follows: (Cr > Cd > Ni > Pb) of total and accessible HMs concentrations, whereas the Contamination Factor (CF) suggested that the soil at the locations is extremely contaminated. The severity of metal contamination in soil was determined by the accessible concentrations (Cr > Cd > Ni > Pb) and total concentrations (Cr > Ni > Cd > Pb). The Ecological Risk Index (Er) indicates that the soil at the research locations had a very high Ecological Risk. The environmental risk of the metals under investigation was as follows: (Cd > Cr > Pb > Ni). of the available concentration and the total concentrations (Cr > Cd > Ni > Pb).

Acknowledgement

The authors thank the Department of Biology, College of Education, University of Al-Qadisiyah, Iraq, for supporting this work.

Author contributions

Authors contributed equally to the manuscript.

Conflict of interest

The authors declare no conflict of interest

References

1. Meravi N. Effects of heavy metals/metalloids present in fly ash from coal fired thermal power plant on photosynthetic parameters of Mangifera indica. Environmental Skeptics and Critics. 2014;3(4):88.
2. Naveed M, Javed T, Zawar MD, Shafqat U, Taj MB, Wasim M, Batool M, Zawar MA. Applications of heavy metal-based nanoparticles in cosmetics: a comprehensive review. Cutaneous and Ocular Toxicology.1-18.
3. Bu Q, Li Q, Zhang H, Cao H, Gong W, Zhang X, Ling K, Cao Y. Concentrations, spatial distributions, and sources of heavy metals in surface soils of the Coal Mining City Wuhai, China. Journal of chemistry. 2020;2020(1):4705954.

4. Chibuike GU, Obiora SC. Heavy metal polluted soils: effect on plants and bioremediation methods. Applied and environmental soil science. 2014;2014(1):752708.
5. Selim H, Zhang H. Modeling approaches of competitive sorption and transport of trace metals and metalloids in soils: A review. Journal of environmental quality. 2013;42(3):640-53.
6. Muller G. Index of geoaccumulation in sediments of the Rhine River. 1969.
7. Fagbote EO, Olanipekun EO. Evaluation of the status of heavy metal pollution of soil and plant (Chromolaena odorata) of Agbabu Bitumen Deposit Area, Nigeria. American-Eurasian Journal of Scientific Research. 2010;5(4):241-8.
8. Kowalska J, Mazurek R, Gąsiorek M, Setlak M, Zaleski T, Waroszewski J. Soil pollution indices conditioned by medieval metallurgical activity–A case study from Krakow (Poland). Environ Pollut. 2016;218:1023-36.
9. Pejman A, Bidhendi GN, Ardestani M, Saeedi M, Baghvand A. A new index for assessing heavy metals contamination in sediments: A case study. Ecological indicators. 2015;58:365-73.
10. Shah A, Arjunan A, Manning G, Batool M, Zakharova J, Hawkins AJ, Ajani F, Androulaki I, Thumma A. Sequential novel use of Moringa oleifera Lam., biochar, and sand to remove turbidity, E. coli, and heavy metals from drinking water. Cleaner Water. 2024:100050.
11. Javed T, Kausar F, Zawar MD, Khalid N, Thumma A, Ismail A, Alzaidy AH, Abed MJ, Jasim LS, Taj MB, Tirth V, Haider MN. Investigating the adsorption potential of coconut coir as an economical adsorbent for decontamination of lanthanum ion from aqueous solution. Journal of Dispersion Science and Technology. 2024.
12. Abdulsahib WK, Sahib HH, Mahdi MA, Jasim LS. Adsorption Study of Cephalexin Monohydrate Drug in Solution on Poly (vinyl pyrrolidone-acryl amide) Hydrogel Surface. International Journal of Drug Delivery Technology. 2021;11(4):1169-72.
13. Tariq Z, Alwan NA. Optimization of Switchable Hydrophilicity Solvent-Based Liquid-Liquid Microextraction for Tartrazine Dye Separation and Preconcentration using Central Composite Design and Response Surface Methodology. Methods and Objects of Chemical Analysis. 2024;19(4):200-5.
14. Atyaa AI, Radhy ND, Jasim LS, editors. Synthesis and Characterization of Graphene Oxide/Hydrogel Composites and Their Applications to Adsorptive Removal Congo Red from Aqueous Solution. Journal of Physics: Conference Series; 2019.
15. Radhy ND, Jasim LS. A novel economical friendly treatment approach: Composite hydrogels. Caspian Journal of Environmental Sciences. 2021;19(5):841-52.
16. Shah A, Arjunan A, Thumma A, Zakharova J, Bolarinwa T, Devi S, Batool M. Adsorptive removal of arsenic from drinking water using KOH-modified sewage sludge-derived biochar. Cleaner Water. 2024:100022.
17. Shah A, Zakharova J, Batool M, Coley MP, Arjunan A, Hawkins AJ, Bolarinwa T, Devi S, Thumma A, Williams C. Removal of cadmium and zinc from water using Sewage sludge-derived biochar. Sustainable Chemistry for the Environment. 2024.
18. AL-Heety LF, Hasan OM, Al-Heety EAMS. Heavy metal pollution and ecological risk assessment in soils adjacent to electrical generators in Ramadi city, Iraq. Iraqi Journal of Science. 2021:1077-87.
19. Alshamusi QKM, Hameed KAA, Taher AM, Batool M, Jasim LS. Efficiency of Chitosan-Grafted Poly (Carboxymethyl Cellulose-Co-Acrylamide) Nano Hydrogel for Cadmium (II) Removal: Batch Adsorption Study. Journal of Nanostructures. 2024;14(4):1122-33.
20. Taher A, Jasim LS, Mehmood Z, Zawar MD, Haider MN, Batool M. Applications of Nano Composites for Heavy Metal Removal from Water by Adsorption: Mini Review. Journal of Nanostructures. 2024;14(4):1239-51.
21. Pokale W. Effects of thermal power plant on environment. Scientific Reviews and chemical communications. 2012;2(3):212-5.
22. Saloumi YJH, Alabadi LAS, editors. A study of the effect of electric power plants on the soil content of some heavy elements (Ni, Pb, Cu, Cd, Zn, Mn, Fe). IOP Conference Series: Earth and Environmental Science; 2023: IOP Publishing.
23. Hamzah SK, Jabbar NK, Almzaiel AJ, Sabit RA. The role Caspase-8 and dna methylation in patients with ovarian cancer: Relationship with oxidative stress and inflammation. Research Journal of Pharmacy and Technology. 2021;14(5):2676-80.
24. Iticescu C, Georgescu LP, Murariu G, Circiumaru A, Timofti M, editors. The characteristics of sewage sludge used on agricultural lands. AIP conference proceedings; 2018: AIP Publishing.
25. Barbieri M. The importance of enrichment factor (EF) and geoaccumulation index (Igeo) to evaluate the soil contamination. Journal of Geology & Geophysics. 2016;5(1):1-4.
26. Estefan G. Methods of soil, plant, and water analysis: a manual for the West Asia and North Africa region. 2013.
27. Hesse PR, Hesse P. A textbook of soil chemical analysis. 1971.
28. Lindsay WL, Norvell W. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil science society of America journal. 1978;42(3):421-8.
29. Hakanson L. An ecological risk index for aquatic pollution control. A sedimentological approach. Water Res. 1980;14(8):975-1001.
30. Wu Q-T, Hei L, Wong J, Schwartz C, Morel J-L. Co-cropping for phyto-separation of zinc and potassium from sewage sludge. Chemosphere. 2007;68(10):1954-60.

31. Yang Z, Lu W, Xin X, Li J, Li P. Lead isotope signatures and source identification in urban soil of Changchun City. J Jilin Univ (Earth Sci Ed). 2008;38:663-9.
32. Prabasiwi DS, Sukirno S, Murniasih S, editors. Assessment of heavy metals pollution and risks around Tuban steam power plant using neutron activation analysis. AIP Conference Proceedings; 2020: AIP Publishing.
33. Alloway B. Heavy metals in Soil Halsteed press. John Wiley and Sons Inc. London; 1996.
34. Abdulhussein FM. Hydrochemical assessment of groundwater of Dibdibba aquifer in Al-Zubair area, Basra, South of Iraq and its suitability for irrigationpurposes. Iraqi Journal of Science. 2018:135-43.
35. Ali MO. Study of pollution by heavy elements in some parts of Baghdad. Baghdad Science Journal. 2010;7(2):955-62.
36. Opaluwa OD, Aremu MO, Ogbo LO, Abiola KA, Odiba IE, Abubakar MM, Nweze NO. Heavy metal concentrations in soils, plant leaves and crops grown around dump sites in Lafia Metropolis, Nasarawa State, Nigeria. Advances in Applied Science Research. 2012;3(2):780-4.
37. Mehes-Smith M, Nkongolo K, Cholewa E. Coping mechanisms of plants to metal contaminated soil. Environmental change and sustainability: IntechOpen; 2013.
38. Endale YT, Ambelu A, Sahilu G. Tracking sources and contributing factors of Pb contamination in drinking water supply system of Addis Ababa, Ethiopia. International Journal of Environmental Analytical Chemistry. 2024;104(14):3263-79.
39. Al-Kazaeh DKK, Al-Tamimi H. Role of bioremedation in removal of cadmium and lead from soils fertilized with phosphorus and organic manures and irrigated with different irrigation source of water. Journal of Basrah Research. 2014;40(3B):146-60.
40. Qi X, Zhang Y, Chai T. Characterization of a novel plant promoter specifically induced by heavy metal and identification of the promoter regions conferring heavy metal responsiveness. Plant Physiology. 2007;143(1):50-9.
41. Hassan SKM. Metal concentrations and distribution in the household, stairs and entryway dust of some Egyptian homes. Atmos Environ. 2012;54:207-15.
42. Uzun A, Arslan F. Termik Santral Projelerinin Sosyal Kabul Boyutu: Paşaköy (Balikesir) Termik Santrali Örneği. Balıkesir Üniversitesi Sosyal Bilimler Enstitüsü Dergisi. 2018;21(40):27-52.
43. Dolenec T, Serafimovski T, Tasev G, Dobnikar M, Dolenec M, Rogan N. Major and trace elements in paddy soil contaminated by Pb–Zn mining: a case study of Kočani Field, Macedonia. Environ Geochem Health. 2007;29:21-32.
44. Kabata-Pendias A. Trace elements in soils and plants: CRC press; 2000.
45. Kamaludeen SP, Megharaj M, Juhasz AL, Sethunathan N, Naidu R. Chromium-microorganism interactions in soils: remediation implications. Reviews of Environmental Contamination and Toxicology. 2003:93-164.
46. Al-Rubaiee A-KH, Al-Owaidi MR. Assessment of heavy metal contamination in urban soils of selected areas in Hilla City, Babylon, Iraq. Iraqi Journal of Science. 2022:1627-41.
47. Avudainayagam S, Megharaj M, Owens G, Kookana RS, Chittleborough D, Naidu R. Chemistry of chromium in soils with emphasis on tannery waste sites. Reviews of environmental contamination and toxicology. 2003:53-91.
48. Kowalska JB, Mazurek R, Gąsiorek M, Zaleski T. Pollution indices as useful tools for the comprehensive evaluation of the degree of soil contamination–A review. Environ Geochem Health. 2018;40:2395-420.