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Pollution of Some Agricultural Soils by Heavy Metals in Kubaisa Iraqi Western Desert – A Case Study

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ABSTRACT

The main objective of this research was to evaluate the presence of heavy metal pollution in the agricultural soil of the Kubaisa district in Anbar province, Iraq. The study focused on the areas affected by dust emissions from a nearby cement factory, specifically Maktom District (k1), Kubais (k2), Elkader District (k3), and Agricultural Elkader District (k4). Soil samples were collected from these locations, and a comprehensive analysis of both chemical as well as physical characteristics was conducted. The concentrations of heavy metals were found to range from (0–17.3), (39.1–82.6), (33.3–182.8), and (0–236.5) mg·kg^{-1} for Cd, Ni, Co, and Pb, respectively. These concentrations indicated elevated levels compared to the (Kapata, 2011) standard levels of 0.62, 34, 12, and 34 mg·kg^{-1} for cadmium, Ni, Co, and Pb, respectively. In terms of the Geological Accumulation Index (Igeo), the agricultural districts showed uncontaminated cadmium with accumulation values of 0. Nickel (Ni) levels varied between -0.58 and 0.53, classifying the sediment from uncontaminated to moderately contaminated. Cobalt (Co) exhibited significant contamination, with values ranging from -0.58 to 3.56. Conversely, lead (Pb) concentrations varied from uncontaminated to extremely contaminated, with values spanning from -0.58 to 5.922. The study underscored that the elevated levels of heavy metals were attributed to the airborne dust emissions from the Kubais cement factory and various human activities, such as motor vehicle transportation, industrial waste discharge, and household practices. Following established quality guidelines, the pollution levels in the study area were ranked in the order of Pb > Co > Ni > Cd, with lead (Pb) exhibiting the highest degree of contamination.

Keywords: heavy metals, point source pollution, geo-accumulation index, geostatistics analysis, soil pollution.

INTRODUCTION

The term "environmental pollution" as defined by Li (2020), refers to the chemical, physical, and biological alterations that manifest within an environment. These changes occur when substances are introduced into the environment-substances that either did not originally exist there or the concentrations of which in soil, air, or water exceed their natural levels. Such pollution has adverse effects on the environment and leads to reduced productivity. Soil and water pollution, recognized as a formidable and multifaceted environmental challenge, emanates from various sources. It primarily arises from the discharge of industrial waste and emissions, as well as the utilization of chemicals like pesticides and industrial fertilizers in agricultural practices. Additionally, pollution is exacerbated by the generation of waste from households and other facilities (Lemessa et al., 2022). The problem of pollution has persisted for an extended period and continues to escalate. This increase can be attributed to inadequate planning for industrialization. Interestingly, pollution may seem less severe in developed nations (Maji et al., 2023).

Environmental impact assessment involves the systematic evaluation of unintended consequences arising from a development project. Its primary objective is to mitigate or minimize adverse effects while enhancing the positive aspects of the project. In simpler terms, an environmental impact assessment serves as an early warning system for potential environmental issues associated with the project.

The term "heavy elements" applies to the elements with a volumetric weight exceeding 5 g.cm^{-3}. Mercury, cadmium, and lead are among the most hazardous to human and animal health, followed by copper, zinc, and other elements. These elements are detrimental to health due to their tendency to accumulate in critical organs within the body. Importantly, even at low concentrations, most of these recognized heavy metals exhibit toxicity (Jadaa and Mohammed, 2023).

The element cadmium (Cd) is relatively rare, with its total content in the soil not exceeding 1 mg kg^{-1} (Lenntech, 2008). Phosphate fertilizers are identified as the primary sources of cadmium pollution in agricultural regions. In the Earth's crust, cadmium constitutes 0.2 mg kg^{-1}, but in the areas directly adjacent to mines, mining factories, and dry loam factories, its concentration can reach up to 1000 mg kg^{-1}. Regarding plant absorption, the absorbable formula of cadmium by plants is measured in parts per billion, and the permissible concentration in the soil is set at 2.1 mg·kg^{-1} according to the US Environmental Protection Agency (USEPA, 1997). Environmental pollution with heavy metals as a critical issue linked to food safety, has become a major global concern in recent years. These metals can have severe health implications for all living organisms, with particular relevance to human health when they accumulate in the body at high concentrations, as highlighted by (Ohiagu et al., 2022).

Because vegetables are so important to human nutrition and diet, the desire for and usage of them has grown by leaps and bounds. People often grow vegetables for sale in cities, which means that these plants are exposed to the pollution from human activities, industry waste, as well as the mining, smelting, and metallurgical industries, as Kachenko (2006, 2004) pointed out. As a result, food safety and possible health risks have received a lot of attention and have become one of the most important environmental problems, as Bigdeli (2019) points out.

Heavy metals are naturally found elements in the Earth's surroundings. They can occur because of natural or human-made processes. Soils and the environment receive heavy metals because of more people living in cities, factories, and farms using more water for watering (Ali et al., 2019). The fact that there are too many heavy metals in the world is a great problem for all species. Their ability to stay around for a long time is very detrimental for human health (Caparros et al., 2022).

In 2010, Abdullahi et al. conducted a study to determine how the cement dust emissions from the Sokoto plant in Nigeria affected the Fadiman region's rich land. They took soil samples from three places near the plant that were affected by dust: east, north, and southeast. They also chose a spot 10 km away from the plant that was not affected by factory waste to use as a reference. The results showed that the amount of soil organic matter (S.O.M) around the plant was going down. Two and a half grams per kilogram of dirt were found in the spot that was used for comparison. However, it never went above 1.36 g·kg^{-1} dirt near the plant, even when everything was great. The trend was also seen in the amount of phosphorus that was in the soil. Things were different with pH levels, though. Levels of 7.77 were found near the plant and 6.25 were found at the reference spot.

It takes a lot of time and careful comparison of many sources to create a soil pollution map. One can use this method to determine what crops can grow on different types of land and how to best use those crops. There are different types of heavy metals in the soil, so the amount of them in the soil is used to sort them into groups (Liao et al., 2019). Nickel (Ni) is only safe in soil when it is in its lowered form (2+). Its electronic structure allows the formation of complexes containing organic substances. Additionally, nickel has the ability to be adsorbed on amorphous aluminum oxides, silicates, and silicate clay minerals when the soil pH exceeds 6. Due to low solubility at higher reaction grades, nickel exhibits limited mobility in alkaline and neutral soils. The typical range of nickel concentration in soil is usually in the range of 4–55 mg·kg^{-1} (Bowen, 1979).

The average concentration of lead in the Earth's crust is approximately 13 mg·kg^{-1}, as reported by Reeves and Biro (1984). However, significant natural variations in the levels of this element exist due to the input from lead mineral deposits. The highest permissible value for lead content in soil was established at 120 mg·kg^{-1}, according to the United States Environmental Protection Agency in 1997. The presence of lead in soil is influenced by various factors, as highlighted by Al-Jilani and Hamad (1988), these factors include the degree of soil reactivity, with lead concentrations increasing as the degree of soil reactivity decreases. In addition, the exchange capacity of cationic ions in the soil plays an important role, as higher exchange capacities lead to greater absorption of lead. The type of clay mineral found in soil colloids also contributes to high lead levels. The novelty of this work lies in its comprehensive investigation of the environmental impact caused by the Kubaisa cement plant on agricultural districts. The calculation of pollution indices and Igeo range values provide a localized and specific assessment of heavy metal contamination, highlighting environmental risks, particularly related to cobalt and lead. This granularity adds precision to pollution analysis.

This study was conducted to explore the influence of specific dust emissions from the Kubais plant and other pollutants on soils in various agricultural regions. These regions function as year-round human settlements for farmers involved in rain-fed and irrigated crop cultivation. The primary objective of this study was to offer recommendations for soil management practices and potential remediation measures to alleviate the heightened concentrations of heavy metals in the soil, consequently enhancing crop production safety in the region. Additionally, the study sought to improve comprehension of the chemical properties of the soils in the examined districts.

MATERIALS AND METHODS

Study area

The study was conducted in several agricultural districts surrounding the city of Kubaisa, which is part of Anbar government. Kubaisa is home to the Kubaisa Cement Factory, which is situated in the western part of the city. Kubaisa is located at approximately latitude (33° 38’ 51.886’’

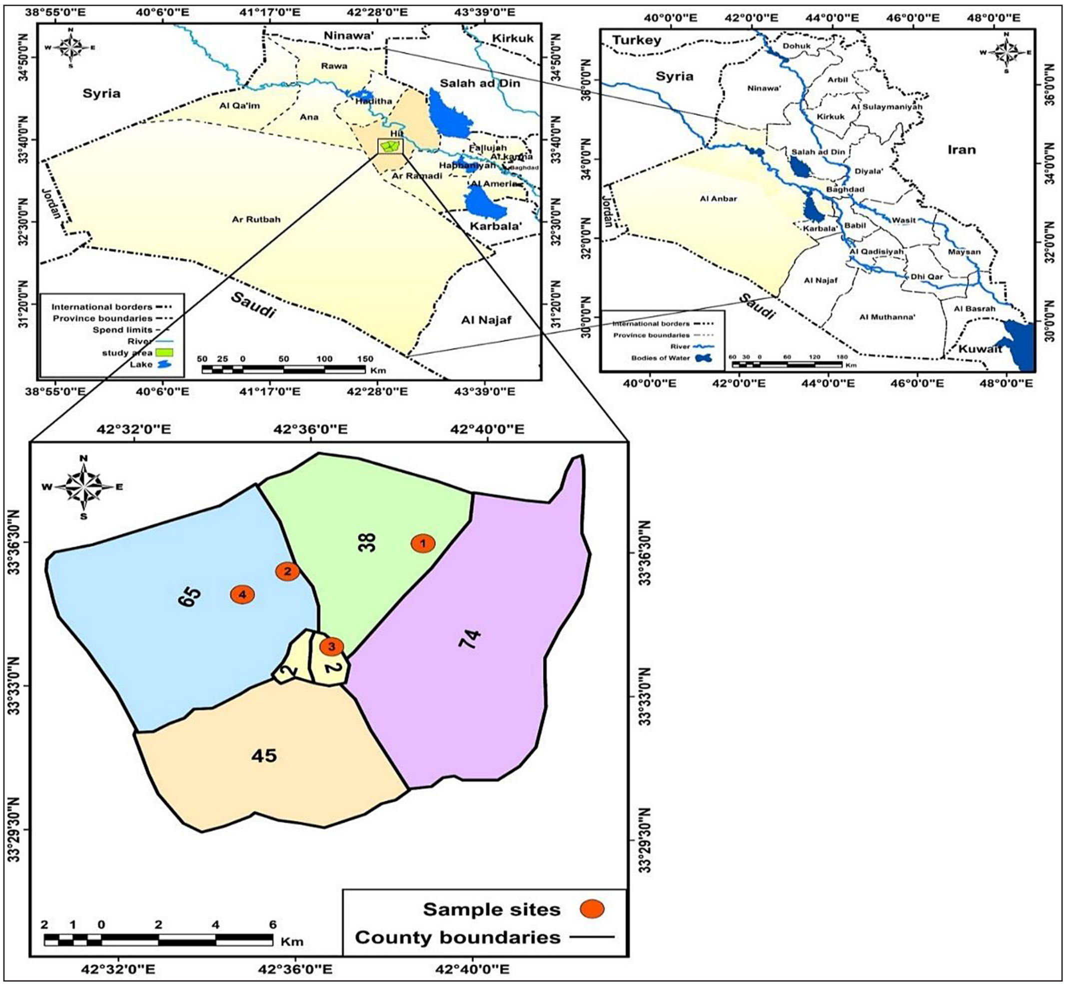

Figure 1. Land use and land cover and Locations of soil samples within the studied agricultural districts

- 33° 29’ 40.972”) north and longitude (40° 30’ 52.215” – 42° 42’ 29.59”) east, within the Iraqi western desert region. Figure 1 illustrates the land use/cover as well as the locations of soil samples within the study area. The presence of the factory affects the surrounding environment, including the soils and open areas.

Climate

Climate is a fundamental factor that influences the development and composition of soils, the distribution of natural vegetation, and the range of geomorphological processes. It serves as the foundation for various soil classification systems worldwide, as noted by Fitzpatrick (1971). Additionally, climate plays a pivotal role in determining land suitability for various purposes, particularly agriculture. With reference to the available climatic data from the meteorological station in the Hit region for the years 1995–2019, climate emerges as a significant factor in the formation, composition, and categorization of soils due to the changes it induces within the soil matrix through chemical and physical weathering processes. In arid regions characterized by low rainfall and high temperatures, physical weathering predominantly occurs, accompanied by limited chemical weathering, resulting in the accumulation of soluble materials near the surface, especially bases. This phenomenon arises from the excessive soil water loss due to evaporation compared to the inflow of water, leading to salinization (AL-Agidi, 1986).

Notably, the average annual soil temperature at a depth of 50 cm in the Heet monitoring station exceeded 22°C, with significant temperature variations between summer and winter months, exceeding 5°C. Consequently, the soil temperature regime in the region is classified as Hyperthermic. Given that the soils in this region remain dry for more than six consecutive months each year, coupled with low precipitation, the moisture soil system is characterized as Torric (Aridic). Figure 2 shows the relationship between some climate elements in the region.

The study region climate is characterized as semi-arid during the months of June, July, and August, with a shorter rainy season occurring in January, February, March, and April. The average annual precipitation ranges from a minimum to a maximum amount in millimeters. Furthermore, the region experiences both maximum and minimum annual temperatures of °C and °C, respectively, based on the data from the Heet Climate Station in 2023. The wind rose for the Heet region, as illustrated in Figure 3, indicates the number of hours per year during which the wind blows from specific directions. For example, “NW” signifies that the wind blows from the northwest to the southeast (SE). Notably, the study area is characterized by prevailing westerly winds, which result in the transport of industrial pollutants from west to east, carrying them into agricultural areas. This wind pattern contributes to the movement of pollution from its source towards these agricultural regions.

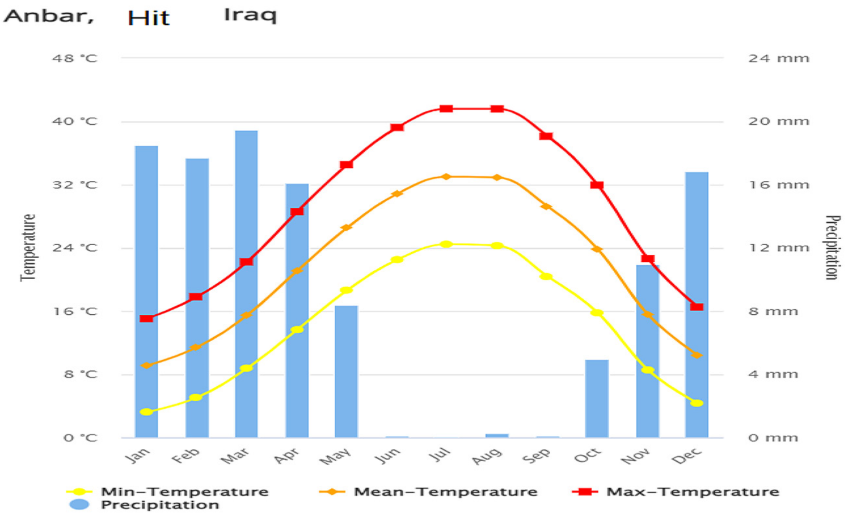

Figure 2. The relationship between temperature and the amount of rainfall in the study area

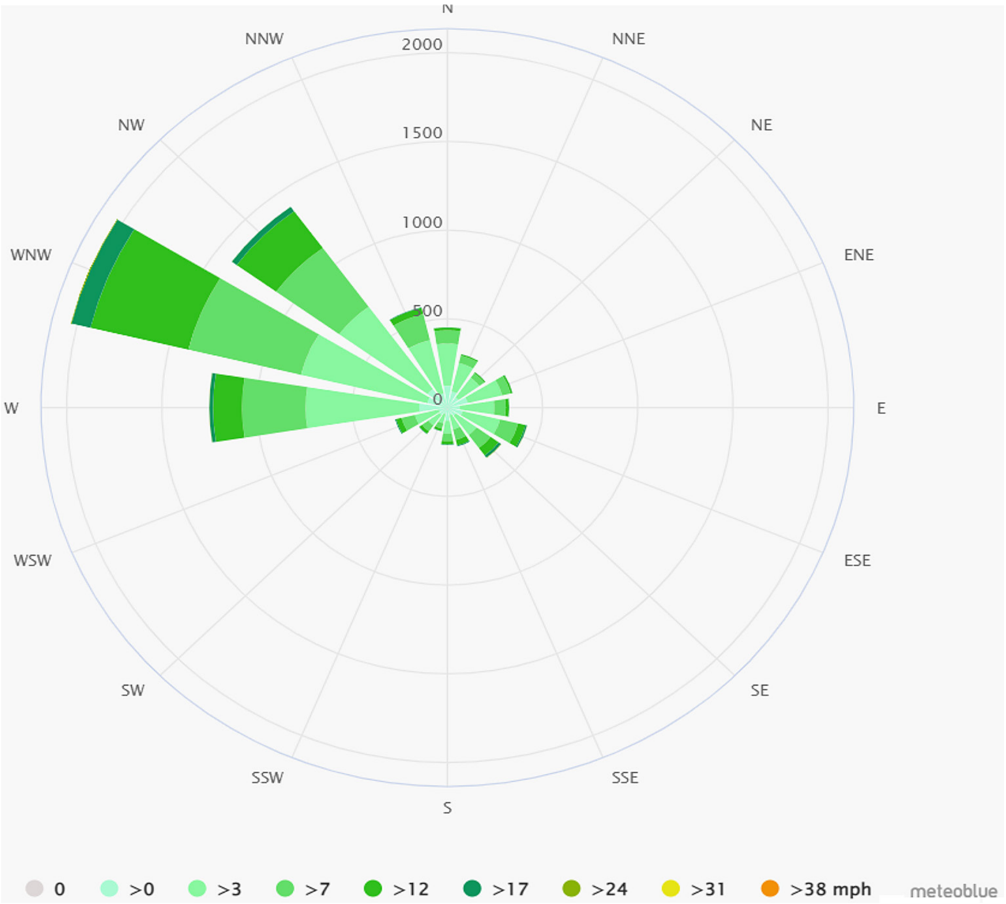

Figure 3. The wind rose of the study area

Geology

The study area within the leap district Kubaisa a part of the western plateau, the formation of which dates back to the Miocene era, Structurally, the study area is located within the transitional range between the stable shelf and the unstable shelf, specifically within the range of the Abu Al-Jir Fault (Hussein and Gharbi, 2010), geomorphology, Kubaisa district is located within the Lower Valleys region, where six valleys cross it from north to south (Hawran, Al-Assad, Khabza, Gsaibeh, Al-Hajiya and Al-Mohammadi), noting that the city of Kubaisa is located at a distance of 14 km from the confluence of the valleys of Gsaibeh and Al-Hajja, which meet in the east of the city, to form one valley. It flows into the Euphrates River.

It consists of the layers of sedimentary rocks exposed on the surface of the geological formations in the sedimentation basin for the eras extending from the Miocene to the modern era (Sissakian, et al., 1994), The exposed geological formations are the formation of the Euphrates and the opening as well as the deposits of the Quaternary era (local soils, valley deposits, depression deposits, organic soil deposits and sabkha deposits).

Soil sample collection and preparation

Soil samples were collected in July 2022 from four distinct regions situated in different locations, namely, the districts of Maktoum (k1), Kubaisah (k2), Al-Khader (k3), and Al-Khader Agricultural (k4). These regions are located in proximity to the city of Kubaisa and are situated at an approximate distance of 9.96 kilometers in the southwest direction from the cement factory. The topography in this area slopes towards the city of Kubaisa and the Euphrates River. The selection of these agricultural districts was based on the agricultural practices followed by local farmers.

To gather these soil samples, approximately 1 kilogram of soil was collected from each site using clean polyethylene bags. The samples were obtained from a depth of 0–20 centimeters using a solid steel auger and were subsequently combined to create composite samples. Following collection, the soil samples were carefully packaged and labeled, after which they were transported to the laboratory of the Desert Studies Center at the University of Anbar for analysis.

In the laboratory, the soil samples were processed as follows: they were air-dried in a clean, dust-free environment at room temperature (approximately 25°C) for a period of 5 days. Subsequently, they were placed in a dry oven until a constant weight was achieved. Next, the samples were ground to a fine consistency using a mortar and pestle to pass through a 2 mm sieve, ensuring homogenization. The prepared soil samples were then stored in dried, sieved, and homogenized condition within polyethylene bags and kept in desiccators until they were ready for digestion and analysis.

Soil analyses

Samples were collected for the analysis of various chemical properties of different soils. Soil reactivity, measured as pH, was determined using a potentiometer in a 1:1 soil-to-water ratio, employing the pH scale. Electrical conductivity (ECe) was measured to assess soil salinity. The content of potassium and sodium was determined, while calcium and magnesium were quantified using the EDTA method, as described by Devis and Feitas in 1970. For the assessment of particle size distribution, the analysis was conducted using the Head and Meter method, following the procedure outlined by Bouyoucos in 1962. Soil texture was determined using the soil texture triangle. To determine the total concentration of heavy elements, specifically cadmium (Cd), nickel (Ni), cobalt (Co), and lead (Pb), the soil samples were subjected to digestion. The procedure was based on Haswel's method from 1990, after air-drying, the soil samples were ground and passed through a No. 60 US sieve (mesh size 60). Approximately 0.5 grams of soil were transferred into a 120 ml digestion vial. Then, 9 ml of concentrated HNO_3 acid, 4 ml of concentrated HF acid, and 1 ml of concentrated HCl acid were added. The mixture was thoroughly mixed and digested for a duration of 20 minutes. Following digestion and cooling, 2 grams of boric acid were added to neutralize the excess HF acid. The solution was then filtered through filter paper (Whitman 42), and the volume was adjusted to 100 ml. The filtered solution was stored in plastic containers in a refrigerator until further estimation. The total concentrations of heavy metals were determined using an atomic absorption spectrometer of Australian origin, specifically the GBC type. This comprehensive analysis allowed for the assessment of various chemical properties and the determination of heavy metal concentrations in the soil samples.

Natural vegetation

According to the natural flora map of Iraq, which was compiled by Guest in 1966, the governorate of Anbar is situated within a desert region, falling under the zonal distribution of natural plants typical of desert zones. Field observations have revealed that the natural vegetation in the study area is characterized by low density and limited growth due to the arid climate and insufficient rainfall.

During these field observations, the following plant species were identified: Tamarix aucheryana, Alhagi graecorum, Juncus bufonius, Gynandriris sisyrinchium, and Lycium barbarum. Notably, these plant species exhibit a lack of shrubs and herbs, a consequence of the arid conditions prevalent in the study area.

Geological accumulation index (I_{geo})

Numerous pollution indicators exist, and among them, four are single indicators: Geographical Accumulation Index (Igeo), Pollution Factor (CF), Enrichment Factor (EF), and Environmental Risk Factor (Er). Additionally, three integrated indices include the Degree of Pollution (DC), Pollution Load Index (PLI), and Environmental Risks of Pollution Index (PRI). In the present study, the Geological Accumulation Index (Igeo) was employed due to its ability to effectively and meaningfully express the pollution state in an area.

The Geological accumulation index (Igeo) was determined based on (Muller, 1969) to identify and define mineral pollution in the sediments by comparing current concentrations with pre-industrial pollution levels and according to the following equation:

$$Igeo = Log2(Cn/1.5Bn) \qquad (1)$$

where: Cn is the measured concentration of heavy metals in the sediment, Bn is the geochemical background value in mean soil element n and 1.5 is the background matrix correction due to anthropogenic influences. The Geological accumulation index

(Igeo) has been distinguished into seven categories under Buccolieri *et al.,* 2006: Igeo ≤ 0, class 0, uncontaminated; 0 < Igeo ≤ 1, class 1, non-polluted to moderately polluted; 1 < Igeo ≤ 2, class 2, moderately polluted; 2 < Igeo ≤ 3, Class 3, moderate to severe pollution; 3 < Igeo ≤ 4, class 4, highly polluted; 4 < Igeo ≤ 5, class 5, severely polluted to highly polluted; and Igeo >5, Class 6, highly polluted, Table 1.

Geostatistcal analysis

Lriking is a geostatistical analysis technique commonly used in GIS (Geographic Information System) studies for spatial prediction and mapping. The spatial variation of the Geological Accumulation Index (Igeo) was delineated using the Ordinary Kriging method. Soil sample locations were georeferenced with GPS, and these randomly selected points were then mapped for Igeo utilizing ESRI ArcMap v.10 to execute Normal Kriging. The program underwent two analytical steps: the first step involved estimating the autocorrelation model, while the second step involved predicting values at unmeasured sampling points.

RESULTS AND DISCUSSION

To comprehensively assess the current environmental conditions and mineral pollution in an ecological context, the Igeo (geo-accumulation index) serves as a valuable tool. It provides a common criterion for evaluating heavy metal contamination in sediments by comparing existing concentrations to reference or normal values.

Environmental quality assessments are typically governed by pollution indices, which play a pivotal role in evaluating the presence of heavy metals in both soil and sediment. These indices can be categorized as single-element pollution indicators (Qingjie et al., 2008; Hafizur Rahman et al., 2012). Heavy metals primarily enter the environment through various pathways, including emissions from cement plants in the form of volatile dust, as well as anthropogenic activities, such as industrial effluents, volatile compounds, domestic sewage, and mining waste. Lead and cadmium are of particular concern, being toxic to living organisms even at extremely low concentrations. In contrast, zinc and copper, while biologically essential to other organisms as normal components of ecosystems, typically exhibit toxicity only at exceptionally high concentrations (Jadaa and Mohammed, 2023).

Physical and chemical characteristics of soils in study area

The analytical data for the studied soils (Tables 2 and 3) indicate that the soil textures in the studied regions fall within the range of Sandy Loam to Loamy Sand. The values of ECe (electrical conductivity) exhibited variation, ranging from 2.9 to 86.4 dSm^{-1}. Most of the soil samples

Table 1. The six pollution level classes from the geological accumulation index

Class	Value	Soil quality
0	$I_{geo} \leq 0$	Practically uncontaminated
1	0 < I_{geo} < 1	Uncontaminated to moderately contaminated
2	1 < I_{geo} < 2	Moderately contaminated
3	2 < I_{geo} < 3	Moderately to heavily contaminated
4	3 < I_{geo} < 4	Heavily contaminated
5	4 < I_{geo} < 5	Heavily to extremely contaminated
6	5 < I_{geo}	Extremely contaminated

Table 2. Some physical characteristics of the studied agricultural districts

District code	Clay	Silt	Sand	Texture
(k1)	8	27.6	64.4	Sandy loam
(k2)	4	35.2	60.8	Sandy loam
(k3)	4	23.6	72.4	Loamy sand
(k4)	2	25.2	72.8	Loamy sand

Table 3. Some chemical characteristics of the studied agricultural districts

District code	ECe dSm^{-1}	TDS ppm	NaCl %	pH 1:1	SO_4^{2-} ppm	Ca^{2+} ppm	Mg^{2+} ppm	Na^+ ppm	K^+ ppm	Cl^- ppm	CO_3^{2-} ppm	HCO_3^- ppm
(k1)	86.4	34300	169.4	7.58	0.054	2677	3832	19391	2229	4326	none	390
(k2)	10.4	5200	20.3	7.71	0.034	1130	257	4940	100	9219	none	244
(k3)	62.6	31100	121	7.65	0.047	4272	1016	17298	1081	33332	none	244
(k4)	2.9	1457	5.6	7.89	0.024	344	150	1899	58	1269	none	317

fell into the categories of low salinity and high salinity, based on established classifications. Notably, elevated salinity levels can have adverse effects on crop productivity in these districts. District (k4) displayed lower salinity values, while district (k1) exhibited very high salinity levels.

Additionally, the total dissolved solids (TDS) values ranged from 1457 to 34300 ppm, with NaCl salt percentage values ranging between 5.6 and 169.4. Soil pH values fell within the range of 7.58 to 7.89, with most of the soil samples trending towards basality (pH > 7). The concentrations of positive ions in the studied districts were as follows: (Ca^{2+}) ranged from 344 to 4272 ppm, (Mg^{2+}) ranged from 150 to 3832 ppm, (Na_+) ranged from 1899 to 19391 ppm, and (K^+) ranged from 58 to 2229 ppm. On the other hand, the concentrations of negative ions were: (SO_4^{2-}) ranged from 0.024 to 0.054 ppm, (Cl^-) ranged from 1269 to 33332 ppm, and (HCO_3^-) ranged from 317 to 390 ppm.

Distributions heavy elements within study area

The cadmium (Cd) content in the soils of the studied provinces ranged between 0 and 17.3 mg kg^{-1}. To assess these concentrations in relation to universally permissible levels, comparisons were made with established limits, as indicated by Sharma et al. in 2018, Hong et al. in 2014, and Crommentuijn et al. in 1997. Similarly, the concentrations of other heavy metals, including nickel (Ni) ranged from 24.7 to 82.6 mg kg^{-1}, cobalt (Co) ranged from 10.3 to 182.8 mg kg^{-1}, and lead (Pb) ranged from 0 to 236.5 mg kg^{-1}. The lowest recorded concentration of cadmium was observed in the areas less influenced by external factors, while the highest concentration was detected in Kubaisa District (k2). Notably, the highest concentration of

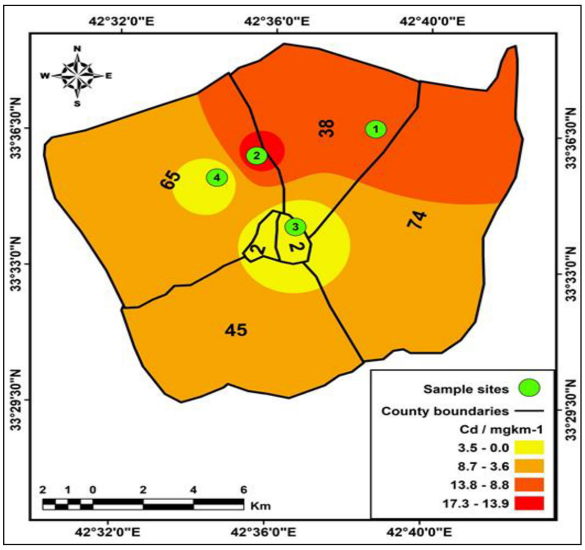

Figure 4. Spatial distribution map of total Cd concentration in the surface soils of studied provinces using GIS technology

Table 4. Main statistical characteristics of the total concentration of heavy metals and their distribution in soil of agricultural districts in the district of Kubaisa

District name	Cd	Ni	Co	Pb
	mg km^{-1}			
Maktom Di.(k1)	12. 6	53. 7	33.3	217. 3
Kubaisa Di. (k2)	17. 3	39. 1	44. 8	2.6
Elkader Di. (k3)	0	24. 7	182. 8	101. 9
Agricultural Elkader Di. (k4)	0	82. 6	10. 3	236. 5
Mean	7.47	50.02	67.8	138.9
Standard deviation	7.65	21.42	67.54	95.30
Variance	58.6	458.8	4562.6	9083.6

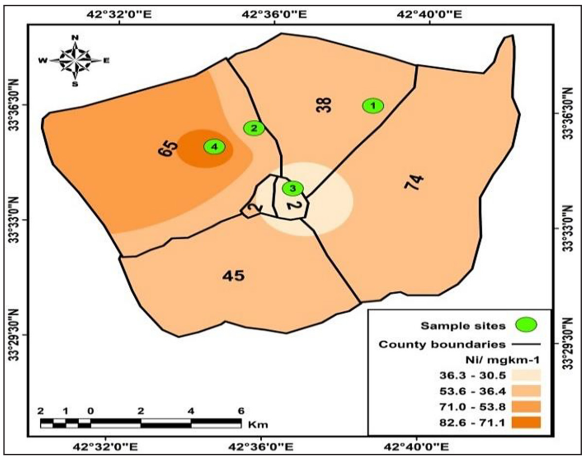

Figure 5. Spatial distribution map of total Ni concentration in the surface soils of the studied provinces using GIS technology

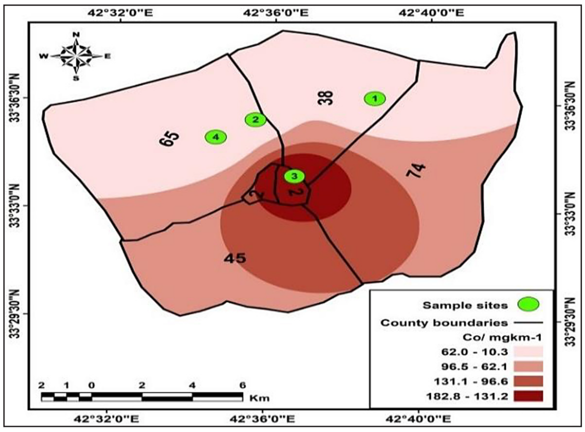

Figure 6. Spatial distribution map of total Co concentration in the surface soils of the studied provinces using GIS technology

nickel was found in Agricultural Elkader District (k4), while the lowest concentration of cobalt was recorded in Agricultural Elkader District (k4), with the highest concentration in Elkader District (k3). In the case of lead, the highest values were identified in Agricultural Elkader District (k4), whereas the lowest values were observed in Kubaisa District (k2). Cheng (2003) attributed the high lead concentration in the sites affected by factory emissions to fuel combustion processes, where lead concentrations reached up to 1.0 mg kg^{-1}. Consequently, it can be inferred that the observed soil pollution primarily stems from air pollution, as presented in Table 4 (total concentration of heavy metals) as well as Figures 4, 5, 6, and 7 (spatial distribution map).

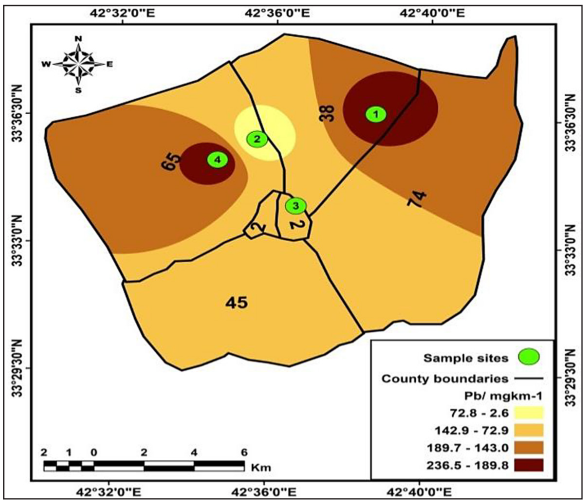

Figure 7. Spatial distribution map of total Pb concentration in the surface soils of the studied provinces using GIS technology

Geological accumulation index

The Geological Accumulation Index (I_{geo}) values for all heavy metals Cd, Ni, Co, and Pb in soil sediments are presented in Table 6 and classified according to Muller (1969). Specifically, the Igeo values for Cd in agricultural District fall under class 0, indicating no sediment contamination. For Ni, the values range between (-0.58) and 0.53, signifying moderate contamination

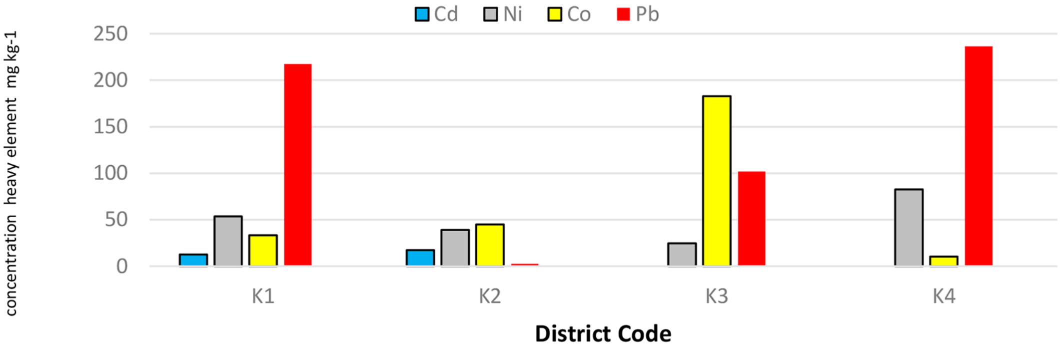

Figure 8. Quantitative distributions of pollutants for agricultural districts

Table 5. Index of geo-accumulation index (I_{geo}) values for the studied samples

Sample No.	Location	Type	Cd	Ni	Co	Pb
k1	Maktom Di.	Agricultural soil	0	0.53	1.10	5.80
k2	Kubasa Di.		0	0.07	1.53	-0.58
k3	Elkader Di.		0	-0.58	3.56	4.70
k4	Agricultural Elkader Di.		0	1.15	-0.58	5.922

Table 6. Geo-accumulation index (I_{geo}) and classifications for heavy metals in study areas

Elements	I_{geo} range	Classes	Description
Cd	0	0	Practically uncontaminated
Ni	(-0.58)–0.53	1	Uncontaminated to moderately contaminated
Co	(-0.58)–3.56	0–4	Uncontaminated to heavily contaminated
Pb	(-0.58)–5.922	0–6	Uncontaminated to extremely contaminated

levels. As for the Co element, it exhibits pollution levels within the range of -0.58 to 3.56, spanning from uncontaminated (class 0) to heavily contaminated (class 4), indicating a high level of pollution. Meanwhile, the Pb element indicates values ranging from uncontaminated to extremely contaminated in all Districts, as illustrated in Figure 8. For a quantitative representation of pollutants, refer to Table 5 for Index of geo-accumulation (I_{geo}) values.

Statistical analyses

The results obtained from the geochemical analysis were subjected to statistical treatment. Mean, Standard Deviation, and Variance analysis were conducted using SPSS and Microsoft Excel. Mean results showed between (7.47–138.9), while the Standard Deviation value ranged between (7.65–95.30), variance value ranged between (58.6–9083.6). for the studied items (Table 4), Table 6, Geo-accumulation index (Igeo) and classifications.

CONCLUSIONS

The Kubaisa cement plant has significantly impacted agricultural districts near the city, mainly due to dust dispersion. This dust has been identified as a contributor to adverse effects on the local population and increased accumulation of polluting heavy elements near the source. The presence of substantial dust, especially on agricultural lands farther from the source, negatively affects soil conditions, particularly in terms of basic chemical properties. Further research is needed to understand the precise impact of dust on soil properties under controlled conditions. This study recommended discouraging agricultural activities within a 10 km radius of the plant due to potential heavy metal uptake by crops, reaching the human food chain. Factory management should invest efforts in biologically treating soil minerals to reduce environmental toxicity, with oversight from environmental authorities.

Calculated pollution indices indicate a moderate to severe heavy metal contamination load in the study area. Cultivated soils show high environmental risks, especially concerning cobalt and lead. The Igeo Range values highlight a substantial heavy metal load in cultivated soil samples. Farmers are advised to reduce the use of unauthorized fertilizers and pesticides, largely resulting from industrial activities and irrigation water discharge. Pollution effects increase from west to east, consistent with prevailing wind direction. Urgent control operations are recommended to reduce heavy metal levels in surface soil around the cement plant, especially lead and cobalt contents.

Conclusively, more research is needed to assess the potential hazards of heavy elements to crops and humans. Human exposure risk assessment, based on pollutant concentrations in locally grown vegetables using the (Human Exposure to Dust Residues in Soil) model, is suggested. Future research should also investigate disease spread among the local population and potential associations with heavy metal and radioactive contamination in the area.

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