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Spatial distribution of heavy metals in the soil of different areas at a left bank in Mosul City, Iraq: Part 2

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ABSTRACT

Soil contamination with heavy metals is currently one of the greatest environmental threats. The left-bank soil in Mosul City has been studied to assess contamination by heavy metals. Concentrations of Cd, Cr, Ni, Pb, and Zn are measured for 96 topsoil samples collected randomly from green areas and parks on the left bank of Mosul City and analyzed using the ICP-MS technique to assess the distribution of these heavy metals in the urban environment; then to differentiate natural and anthropogenic contributions, and to identify possible sources of pollution. The average of the earth's crust is dependent on a reference value. Results for the elements (As, Cd, Cr, Ni, Pb, and Zn) show higher values than the average crust by (100%, 38.57%, 46.88%, 100%, 20.0%, and 33.33%) respectively. It is noted that the concentration of nickel and lead in the investigated urban soils of the left bank is higher than that of the right bank. Pollution factors (Igeo, EF, and CF) indicate that most of the contamination is attributed to the anthropogenic addition due to war activities and the use of various heavy weapons like bombs, missiles, and ammunition, whose residues contain many heavy metals, as well as pollutants generated from waste burning, vehicle exhausts, electric generators, and liquid waste in urban and industrial areas. To investigate the role of physicochemical parameters and their contribution to changing the distribution of heavy elements in the soil, pH, electrical conductivity (EC), and organic matter content (OM) have been measured showing rates of 7.92, 274.48 µs /cm, and 4.57% respectively. Maps of pollutant distribution were constructed for the left bank of Mosul City pointing to the more polluted areas and showing the contribution of possible sources of pollution to the soils.

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التوزيع المكاني للعناصر الثقيلة في تربة مناطق مختلفة للجانب الايسر من مدينة الموصل، العراق: الجزء الثاني

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الملخص

بهدف تقييم واقع التلوث بالعناصر الثقيلة لتربة الجانب الايسر من مدينة الموصل ولاسيما بعد الحرب الاخيرة التي شهدتها المدينة للفترة من 2014-2017 فقد تم جمع 70 عينة من ترب الجانب الأيسر باعتماد النظام العشوائي وأُجري عليها التحليل الكيميائي باستخدام جهاز ICP-MS في مختبرات (ALS) في اسبانيا لتقدير تراكيز العناصر الثقيلة (As, Cd, Cr, Ni, Pb, Zn) -ومن ثم حساب معاملات التلوث (Igeo, EF, CF) وتمثيل التوزيع المكاني لهذه العناصر، وقد أُعتمد معدل تراكيز هذه العناصر في صخور القشرة الأرضية كقيمة معيارية للمقارنة وتحديد الحدود المسموح بها، ولحساب معاملات التلوث. اظهرت نتائج التحليل الكيميائي ان تراكيز العناصر (As, Cd, Cr, Ni, Pb, Zn) كانت اعلى من معدلاتها في صخور القشرة الارضية وبنسبة (100%، 38.57%، 100%، 100%، 20%، 33.33%) على التوالي، وقد انعكس ذلك على نتائج مؤشرات عوامل التلوث (Igeo, EF, CF) وهذا يشير الى حدوث حالة اضافة لهذه العناصر الى تربة الجانب الأيسر من مدينة الموصل بفعل النشاط البشري، والتي يرجع مصدرها الى العمليات الحربية واستخدام أنواع مختلفة من الأسلحة مثل القنابل والصواريخ والذخائر وما تبعها من مخلفات حاوية على العديد من المعادن الثقيلة، فضلا عن الأدخنة والغازات المنبعثة من حرق المخلفات وعوادم السيارات ومولدات الكهرباء والنفايات السائلة في المناطق الحضرية والصناعية ومياه الصرف الصحي والاسمدة والمبيدات. ولغرض معرفة دور الصفات الفيزيوكيميائية ومدى مساهمتها في التأثير على توزيع العناصر الثقيلة في التربة تم قياس كلا من الأُس الهيدروجيني (pH) والتوصيلية الكهربائية (EC) وتعيين محتوى المادة العضوية (OM) وكانت بمعدل (7.92، 274.48 µs/cm, 4.57%) على التوالي.

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Introduction

Although some heavy metals are essential for life when they are in small quantities such as iron, copper, zinc, and selenium, however, they become toxic when they have high concentrations in the soil (Barbes et al., 2020). Therefore, long-term exposure to high levels of heavy metals leads to various health and environmental risks. Heavy metal pollution is important due to its potential toxicity to the humans and environment (Wang et al., 2019; Adimalla, 2020). The total concentration of heavy metals in soils varies with the variety of sources of pollution (Alloway, 1990), and atmospheric pollution and particulate matter deposition contribute to the deterioration of soil quality (Barbulescu and Postolache, 2021). Heavy metal contamination leads to a change in some of the physical and chemical properties of the soil and thus leads to disruption of the vital balance of elements (Alloway, 1990; Aydinalp and Marinova, 2003). One of the most important sources of soil pollution with heavy metals is natural events derived from parent materials or from human, agricultural, and industrial activities, which are associated with anthropogenic inputs such as the use of agricultural fertilizers, dumping, urban effluents, traffic emissions, and the long-term use of wastewater in agricultural land (Rinklebe and Shaheen, 2017; Kafle et al., 2022). Mining plants, fumes from burning materials, factory waste, and gases emitted from the exhaust of cars, vehicles, and power generation machines play a major role in increasing these elements (Wuau and Okieimen, 2011; Adimalla et al., 2019). Regardless of the source of heavy metals, the physical and chemical properties of the soil also affect the concentration of heavy metals in the soil. As well as, the role of the military operations and remnants of weapons that took place in the period (2014-2017) in Mosul City affected negatively the air, water, and soil by increasing the concentrations of some heavy metals (Rodríguez-Seijo et al., 2016; Campagna et al., 2017), including lead, cadmium, chromium, nickel, and zinc (Skalny et al., 2021). This study aims to identify the spatial distribution of some heavy metals (As, Cd, Cr, Ni, Pb, and Zn) contaminating soil. Assessment of the levels of contamination by these elements is carried out using the Geo-accumulation Index (I_{geo}), Enrichment Factor (EF), and Contamination Factor (CF) to identify the potential sources of the heavy metals causing soil pollution in the left bank of Mosul City.

Study Area

Geographically, the city of Mosul, the center of Nineveh Governorate is located in the northwestern part of Iraq. It is located between the longitudes (43° 02' 59.65") and (43° 13' 57.89") east and the latitudes (36° 17' 23.86") and (36° 25' 45.04") north. The city of Mosul is located on both banks of the Tigris River, the east (left) and west (right) banks as shown in Figure (1). In this paper, the left bank of the city is studied.

Structurally, Mosul City lies within the Low Folded Zone, which is characterized by a large number of geological structures. These folds are extended in two main directions, the first is northwest-southeast parallel to the Zagros belt in most of the northeastern parts of Iraq, and the second is east-west parallel to the Taurus belt (Bolton, 1958). According to the tectonic setting, Mosul City is located within the foothill zone in the unstable shelf of the Nubia-Arabian Platform (Buday and Jassim, 1987; Jassim and Buday, 2006). The oldest geological formations that have been exposed in the area are the Injana and Fatha formations within the Tertiary system. These two formations, Injana and Fatha appear within small and few detectors, as they are often covered by the sediments of the Quaternary system, represented by the deposits of river terraces, the floodplain, and the soil, which has overwhelmed most of the left bank, while the sediments of the terraces belonging to the Tigris River cover most of the left bank, starting from the eastern borders of the floodplain, which is the high parts in it and at different levels from the river (Al-Jubouri, 1988).

No geological structure was observed quite clearly, due to the lack of inclination of the layers and the lack of appearance of rock detectors for Fatha and Injana formations, except for some small geological structures such as faults and folds, as well as separations whose formation coincides with sedimentation (Al-Jubouri, 1988).

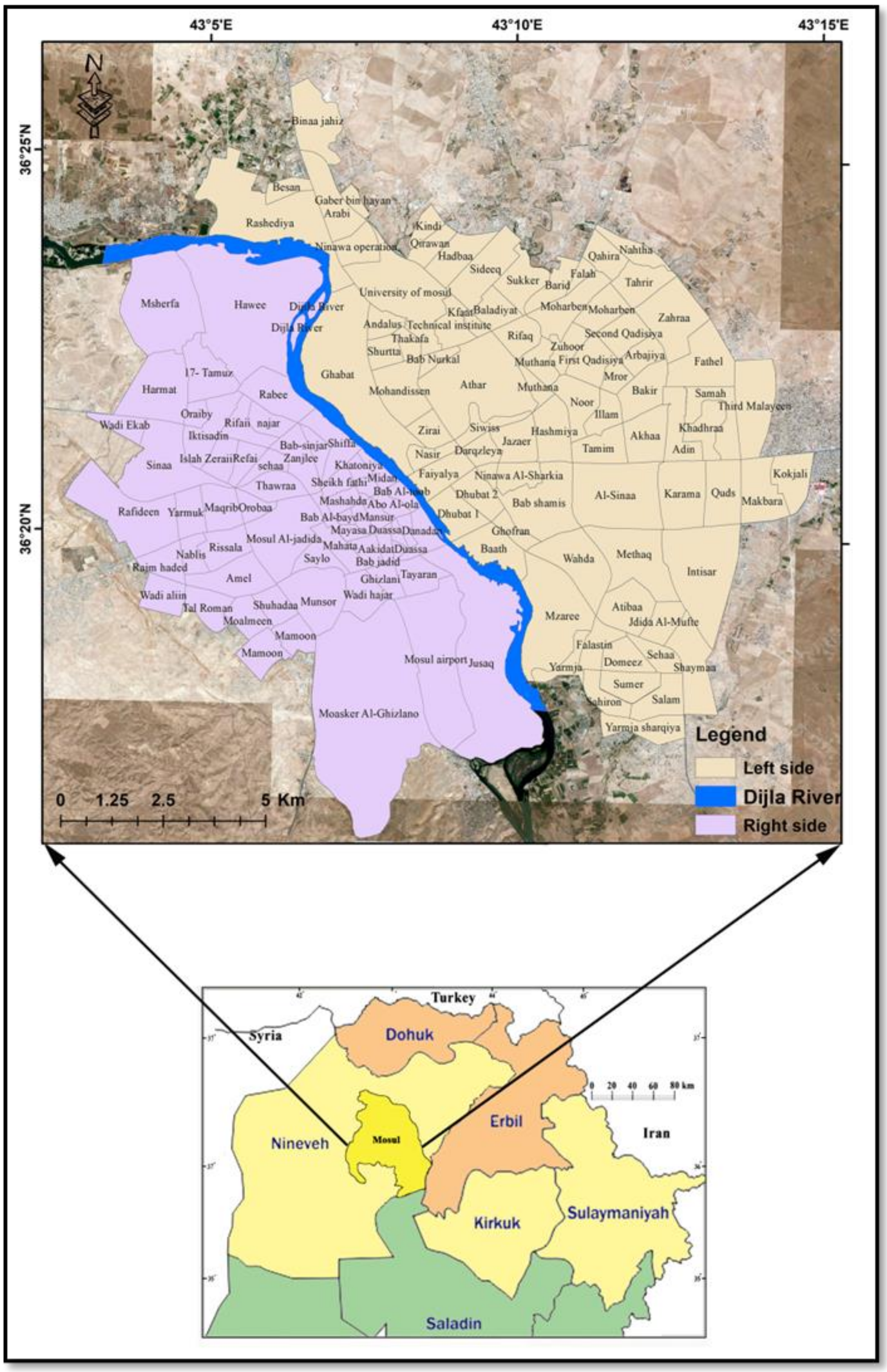


Fig. 1. Location map of Mosul City (modified from Mosul-Municipalities, 2022)

Materials and Methods

Sample Collection

For this purpose, the work in the current study includes three stages:

The first stage, which is the fieldwork stage (collecting samples) began in December 2020 to March 2021. After reconnaissance surveys and field observations as well as reviewing maps and satellite visuals of the city of Mosul, soil sampling areas are selected using the random system and 96 samples covering the left side of the city are collected. The GPS device is used to determine the locations as shown in Table (1) and Figure (2). The auger machine is used to collect soil samples with a depth of (0-30 cm) and placed them in plastic bags classified by location and area name.

The second stage is preparing the samples in the laboratory to conduct chemical analyses. The samples were cleaned of stones and plant residues and then dried in an electric oven at a temperature of (50 °C) for 24 hours. The samples were ground with a ceramic mill to ensure that they are not contaminated and then sieved with a sieve (75mm) to ensure their homogeneity and placed in sealed marked plastic bags for analysis.

In the third stage, measurements of pH and electrical conductivity (EC) were performed using the measurement of electrical conductivity and pH electrode based on Mclean (1982) in the Earth Sciences Laboratory at the University of Mosul, while the calculation of their organic matter content (OM) was done in the central laboratory of the College of Agriculture and Forestry at the University of Mosul according to the method of Walkey (1947). The measurement of concentrations of heavy elements (Arsenic, as; Cadmium, Cd; Chromium, Cr; Nickel, Ni; Lead, Pb; Zinc, Zn) in soil samples is accomplished using the Inductively Coupled Plasma_Mass Spectrometry (ICP-MS) in Australian Laboratory Services (ALS) in Spain.

Assessment of Metal Contamination

To assess the degree of soil contamination with heavy elements, three criteria are used: Geoaccumulation Index (I_{geo}), Enrichment Factor (EF), and Contamination Factor (CF). Due to the lack of a data set for urban soil analysis on the left bank of Mosul, the abundance of these elements in the rocks of the earth's crust (Average crust) is dependent as stated by Mason (1958).

Geoaccumulation Index (I_{geo})

To determine the extent of soil enrichment with heavy metals, Muller (1969) suggested using the coefficient (I_{geo}) to assess the extent of soil contamination with heavy metals based on the following equation:

$$I_{geo} = log_2\left[\frac{Cn}{1.5 * Bn}\right]$$

Cn is the concentration of the heavy metals in the samples of the current study, *Bn* is the concentration of the heavy metals in the earth's crust (the average crust) according to Mason (1958) and 1.5 is a fixed value that is used to reduce the differences and potential changes of the heavy metals that are exposed to natural and human influences (Muller, 1969; Kowalska et al., 2018) as shown in Table 2.

Table 2: Geoaccumulation (I_{geo}) classes (Muller, 1969; Kowalska et al., 2018)

Value	Soil Quality
$I_{geo} \leq 0$	Uncontaminated
$0 < I_{geo} < 1$	Uncontaminated to moderately contaminated
$1 < I_{geo} < 2$	Moderately contaminated
$2 < I_{geo} < 3$	Moderately to heavily contaminated
$3 < I_{geo} < 4$	Heavily contaminated
$4 < I_{geo} < 5$	Heavily to Extremely contaminated
$I_{geo} \geq 5$	Extremely contaminated

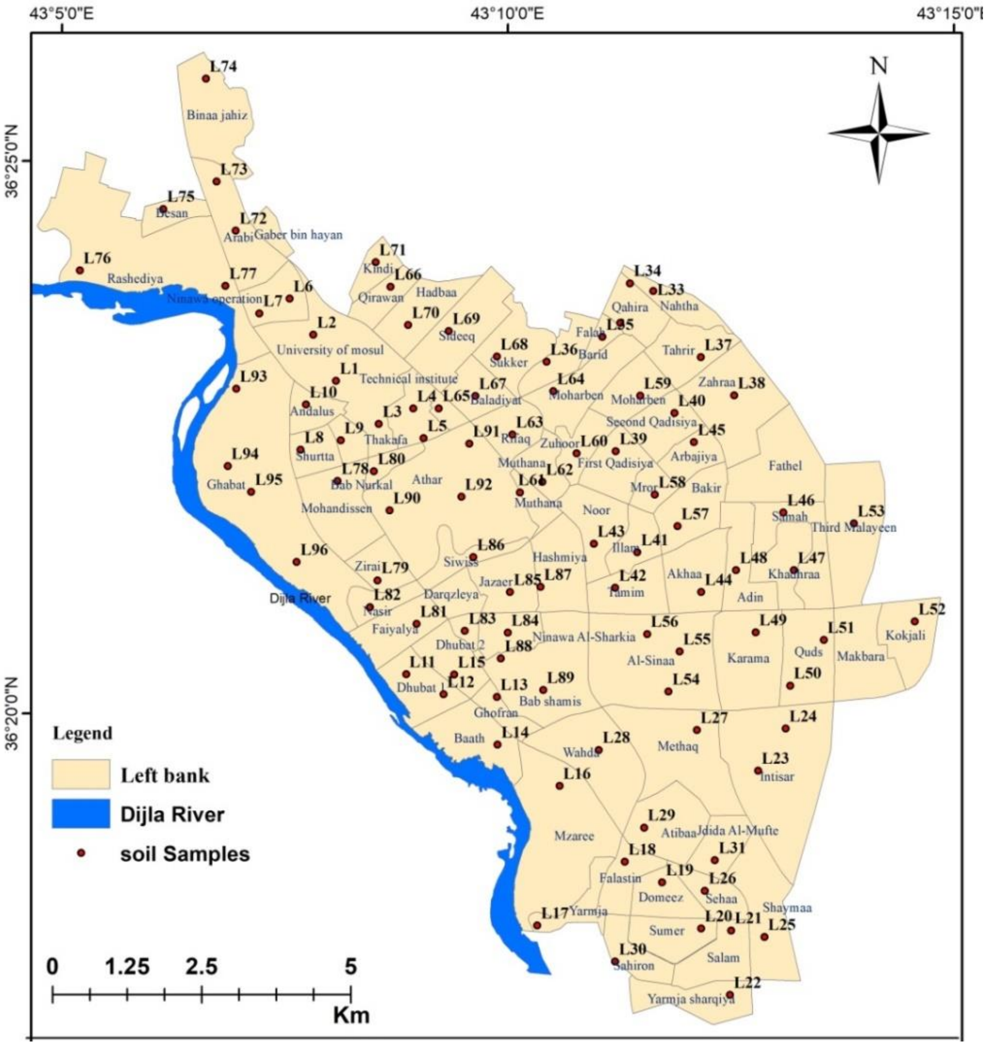


Fig. 2. Location map of soil samples in the studied area.

Enrichment Factor (EF)

The relative amount of heavy metal in the soil in comparison to the source rock is calculated using the enrichment factor (EF). It is also employed as an indication to determine whether the source of these components in the soil is natural or the result of human or industrial activity (Zhao et al., 2015; Kumar et al., 2017). The following equation is used to calculate EF (Sinex and Helz, 1981; Barbieri et al., 2015):

$$EF = \frac{(Cn/Fe)samples}{(Bn/Fe)background}$$

It is the ratio of heavy metals concentration to iron concentration in soil samples taken from the research area and written as (*Cn/Fe*) *samples*. The heavy metal concentration relative to the iron content in the background rocks is shown by the *(Bn/Fe) background*. Iron, which is one of the elements whose value is accepted as a standard, is used in the earth's crust, along with Sc, Mn, Al, Ti, and Fe (Sinex and Helz, 1981) because it is one of the geochemical elements that are common in the ecosystem (Chandrasekaran et al., 2015). If the value of EF is less than 1, then the heavy elements come from the source rocks or natural weathering processes, and if it is greater than 1, the heavy metals were derived from human or industrial activity (Zhang and Liu, 2002; Jiang et al., 2019). There are five classes of fortification plants proposed by Mmolawa et al. (2011) and Barbieri et al. (2015) as shown in Table (3).

Table 3: Enrichment Factor (EF) Category (Mmolawa et al., 2011, Barbieri et al., 2015)

Value	EF Category
EF < 2	Deficiency to minimal enrichment
2< EF < 5	Moderate enrichment
5< EF < 20	Significant enrichment
20 < EF < 40	Very high enrichment
EF > 40	Extremely high enrichment

Contamination Factor (CF)

One of the indicators that illustrate the effect of human activities on soil contamination is referred to as the Contamination Factor (Ahmed et al., 2016). The Contamination Factor is a useful tool for measuring the extent of heavy metal contamination in soil (Hakanson, 1980) using the following equation in calculating the contamination factor:

$$CF = \frac{(Cn)\,\text{sample}}{(Bn)\,\text{background}}$$

Cn represents the concentration of heavy metals in the soil, Bn represents the concentration of heavy elements in the rocks of the earth's crust (Average crust) according to Mason (1958). The Contamination Factor (CF) was classified into four groups by Hakanson (1980) (Table 4).

Table 4: Contamination Factor (CF) Category (Hakanson, 1980)

Value	**CF Category**
CF < 1	Low contamination
1 < CF < 3	Moderate contamination
3 < CF < 6	Considerable contamination
CF > 6	Very high contamination

Geochemical maps

The geochemical map is an important tool for studying the spatial distribution patterns of heavy metals in soils (Wang et al., 2017; Jiang et al., 2019; Adimalla, 2020). It can be used to find areas with high and low concentrations of these elements. Using the Arc GIS application and the IDWI method, maps of the locations of As, Cd, Cr, Ni, Pb, and Zn in the soil models of the left bank of Mosul are shown in Figure (3).

Result and Discussion

Physicochemical parameters

The main physicochemical properties assigned to the surface soils in Mosul City include pH, electrical conductivity (EC), and organic matter content (OM) as shown in Table (5). The pH is an important factor that can be used to estimate the movement of chemical elements, including heavy metals, in the soil and to measure the level of toxicity and soil contamination (Sintorini et al., 2021). The pH values in the left bank of Mosul range between 7.6 and 8.3, at a rate of 7.93, that is the pH values are between neutral and weakly basic. Due to the narrow range of pH on the left bank, this criterion has limited importance on the distribution of heavy elements, which largely determines their mobility due to the neutral alkaline environment (Manta et al., 2002).

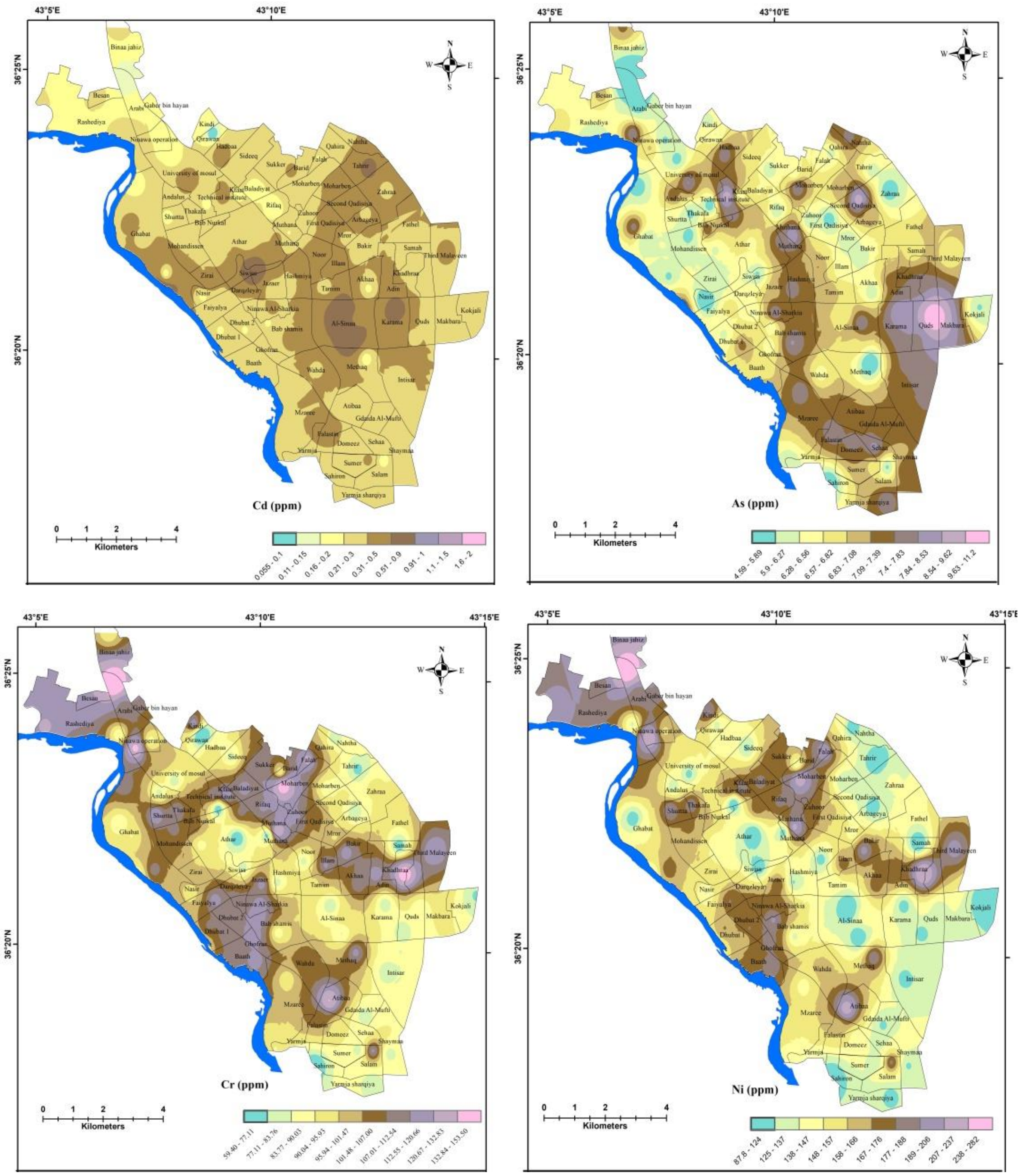


Fig. 3. Spatial distribution maps of the six heavy metals (As, Cd, Cr, Ni, Pb, and Zn) in the urban soils of the study area.

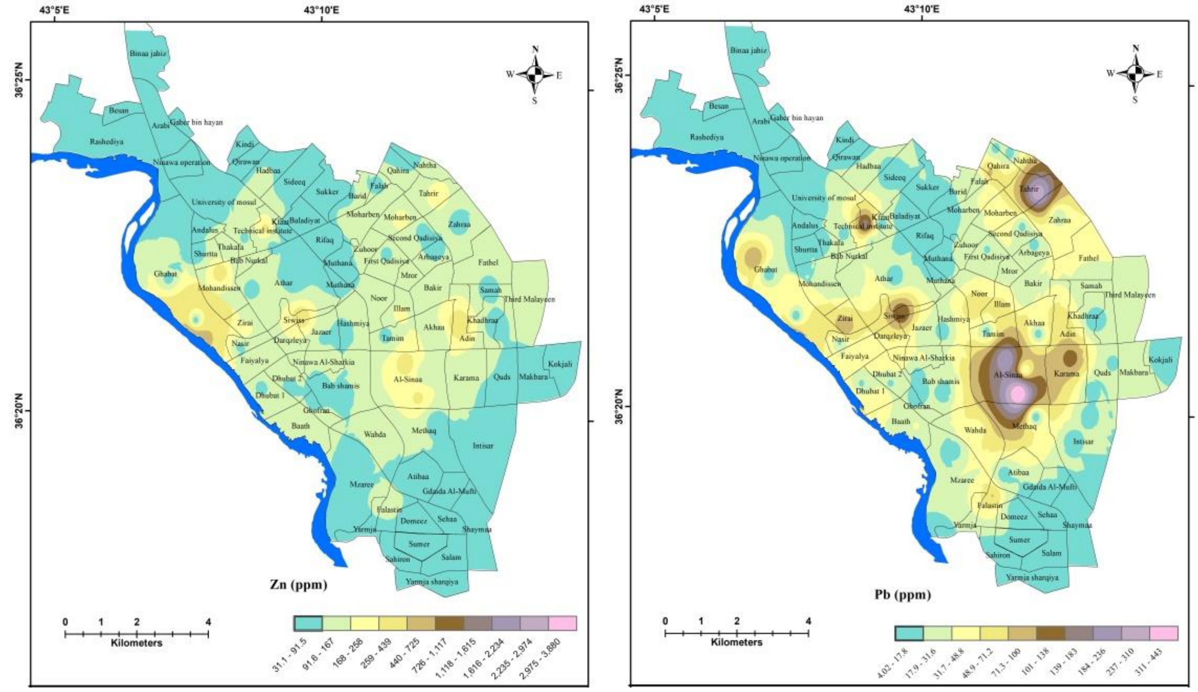


Fig. 3 Continued

In general, the movement of heavy metals decreases with increasing pH of the solution (Sintorini et al., 2021), i.e., the absorption of elements in the soil increases with increasing pH. If compared with the pH values of the soil of the right bank of the city, which range between (7.1-8.3) and (7.56) (Al-Sheraefy et al., 2023), it is noted that there is no difference between the pH values on both banks.

Electrical conductivity (EC) represents the ability of materials to transmit electric current and is expressed in µs/cm. The presence of certain ions in the soil changes the electrical conductivity value of the soil (Seifi et al., 2010). Increasing the concentration of salt in the soil also increases electrical conductivity (Doerg et al., 1999). The electrical conductivity values of the soil of the left bank of Mosul City range between 106 and 470 µs/cm with an average of 270.55 µs/cm and this variation in electrical conductivity values is due to the amount of waste that is excreted and wastewater, which contain a large amount of salts, as increasing the concentration of salt in the soil may lead to an increase in electrical conductivity (Doerg et al., 1999). As well as the presence of some ions in the soil that change the value of the electrical conductivity of the soil (Seifi et al., 2010). If compared with the electrical conductivity values of the soils of the right bank of the city, which range between 109 and 494 µs/cm with an average of 270.77 µs/cm (Al-Sheraefy et al., 2023), it is noted that there is no difference between the electrical conductivity values on both banks.

Organic matter content (OM) is one of the important properties that have a role in determining the quality of the soil, its stability, color, and ability to store water, so the properties of the soil change with the change of its organic matter content. Organic matter in the soil consists of decomposing plant and animal residues, organisms, and soil microbes, and is affected by the presence of humus and humic materials and thus reduces the ability of these components to move heavy metals in the soil (Bradl, 2004) as organic matter in the soil retains heavy metals through three mechanisms (complexation, adsorption, and Ion exchange) (Rieuwerts et al., 1998). The movement of heavy elements generally decreases with the increase of organic matter in the soil (Sintorini et al.,2021). The content of organic matter in the soils of the left bank of Mosul City ranges between 1.16 and 6.47% with an average of 4.59%, and this is due to the nature of the waste that is excreted in addition to wastewater as a result of population density, which contributes to increasing the content of organic matter. If compared with the values of organic matter content in the soils of the right bank of the city, which range between 2.41 and 6.19% with an average of 4.5% (Al-Sheraefy et al., 2023), it is also noted that there is no difference in the content of organic matter in the soils of the right and left banks of the city.

Spatial distribution of soil heavy metals

The results of the concentrations of heavy metals (As, Cd, Cr, Ni, Pb, and Zn) in the soils of the left bank of Mosul City, as well as other parameters, are shown in Table (6).

Arsenic (As)

The concentration of as in the soil of the left bank of the city of Mosul is between 4.59 and 11.2 ppm with an average of 6.78 ppm, which is 100% higher in all samples of the present study than its rate in the average crust (1.8 ppm) according to (Mason, 1958) as shown in Figure (4A). Note that there is no significant difference in the concentration of the element on both banks of the city. The fortification of the soil with the element as in the study area can be attributed to the increase in the pH which reached about 8.3, and this is consistent with what was mentioned by Vandana et al. (2011) as the concentration of the element as in soils with an acidic function increases between 8.9-5.7. Most natural soils contain low levels of arsenic, but large amounts of arsenic are added to the soil by deposition from the atmosphere or agricultural activities as a result of the use of pesticides and phosphate fertilizers as well as industrial effluents (Dehghani et al.,2017; Hu et al., 2017), in addition to the role of military operations and the use of many munitions including rifle fires, which contain arsenic in their components (Scheuhammer and Norris, 1995; Lidija et al., 2018).

Cadmium (Cd)

The concentration of Cd in the soil of the left bank of Mosul ranges between 0.06 and 0.90 ppm with a rate of 0.28 ppm, which is 38.57% higher in all samples of the present study than in the average crust (0.2 ppm) according to (Mason, 1958) as shown in Figure (4B). If compared with the concentration of cadmium on the right bank of the city, which ranges between 0.13 and 0.67 ppm with an average of 0.23 ppm (Al-Sheraefy et al., 2023), we notice a slight increase in the concentration of the element on the left bank compared to its concentration on the right bank. The pH function in the soil is the main factor that controls the concentration of cadmium in the soil as the absorption of cadmium is greater in neutral or alkaline soils than in acidic soils and this leads to an increase in cadmium levels in the soil (Fuller, 1977). The presence of Cd is associated with increased traffic density and thus increased friction of car tires with the ground, as well as the combustion of fuel derivatives containing some heavy elements, including cadmium, as well as the frequent spread of generators, batteries, and electronic panels, as well as the accumulation of waste piles that are mostly burned site-to-site for disposal (Karim et al., 2014; Saeed et al., 2017), cadmium is released from nickel/cadmium (Ni/Cd) batteries and plastics containing pigments and stabilizers for cadmium compounds, as well as in phosphate fertilizers, detergents, and sewage sludge. The deposition of atmospheric pollutants also played a role in increasing the concentration of cadmium in the soil in the last war (2014-2017) and the accompanying massive use of weapons and ammunition played a major role in increasing the concentration of cadmium (Rodríguez-Seijo et al., 2016; Lidija et al.,2018). High concentrations of cadmium may be attributed to the burning of cadmium-containing petroleum derivatives, such as kerosene and diesel oil, as well as to welding materials (solder) (Boutron and Wolff, 1989).

3 Chromium (Cr)

The concentration of the Cr in the soils of Mosul's left bank ranges between 59.50 and 153.50 ppm with an average of 99.57 ppm, which is 46.88% greater in all samples of the present study than its rate in the average crust, which is (100 ppm) according to Mason (1958) as shown in Figure (4C). When compared to the concentration of chromium on the right bank of the city, which ranges between 59.40 and 135.50 ppm with an average of 95.32 ppm (Al-Sheraefy et al., 2023), an increase in the concentration of chromium at the left bank soil samples is noted, which was affected by agricultural and industrial human activities (Al-Jumaily, 2009; Chen and Lu, 2018).

Table 5. pH, EC, and OM results of soil samples on the left bank of Mosul City.

Samples	*pH*	*EC* µs/cm	*OM%*	*Samples*	*pH*	*EC* µs/cm	*OM%*
L1	8.3	325	3.82	*L51*	8.1	176	2.67
L2	7.6	303	4.01	*L52*	7.9	249	4.25
L3	7.7	345	4.43	*L53*	7.6	136	4.6
L4	7.8	210	4.61	*L54*	8.1	190	2.49
L5	8.0	190	3.72	*L55*	7.9	293	5.13
L6	7.9	379	4.96	*L56*	8.1	358	6.47
L7	8.0	386	4.96	*L57*	7.8	106	4.22
L8	8.2	252	4.18	*L58*	7.8	280	4.78
L9	8.0	290	4.43	*L59*	7.8	268	5.84
L10	7.8	276	4.78	*L60*	8.0	347	3.02
L11	7.9	363	4.78	*L61*	8.1	380	1.96
L12	8.0	257	4.08	*L62*	8.0	413	5.03
L13	7.8	195	4.45	*L63*	7.8	123	5.13
L14	8.0	436	5.66	*L64*	7.9	296	3.65
L15	7.8	108	5.66	*L65*	7.9	378	5.31
L16	8.0	240	4.78	*L66*	8.1	218	5.02
L17	8.1	340	5.38	*L67*	7.8	399	2.96
L18	7.9	229	4.43	*L68*	8.1	208	4.08
L19	7.9	153	4.08	*L69*	8.1	247	4.11
L20	8.0	358	5.13	*L70*	7.9	470	4.96
L21	8.1	226	5.13	*L71*	8.0	141	6.01
L22	7.8	292	5.13	*L72*	8.1	344	5.66
L23	8.1	163	5.66	*L73*	8.0	329	5.59
L24	7.9	188	5.14	*L74*	7.9	249	5.84
L25	8.1	393	5.84	*L75*	8.0	222	5.77
L26	7.9	156	2.14	*L76*	7.8	429	4.71
L27	7.9	370	5.31	*L77*	8.0	198	3.8
L28	8.0	300	4.18	*L78*	7.9	223	4.25
L29	7.9	250	4.36	*L79*	8.0	263	4.6
L30	8.0	399	4.32	*L80*	7.9	233	4.6
L31	8.0	354	4.46	*L81*	8.0	180	5.13
L32	7.8	298	5.13	*L82*	8.0	343	5.38
L33	8.0	299	3.83	*L83*	8.1	175	5.48
L34	7.9	247	4.96	*L84*	7.9	203	5.31
L35	7.9	311	4.75	*L85*	8.0	239	4.96
L36	8.0	239	3.51	*L86*	8.0	256	5.48
L37	7.6	376	4.78	*L87*	8.0	236	5.13
L38	7.7	224	3.94	*L88*	7.7	166	3.62
L39	8.0	123	4.78	*L89*	7.9	378	3.9
L40	8.0	211	6.19	*L90*	7.6	342	4.25
L41	7.8	227	3.55	*L91*	7.9	258	3.9
L42	8.0	265	4.96	*L92*	8.1	172	5.66
L43	7.7	395	5.13	*L93*	8.1	303	5.13
L44	7.7	223	5.45	*L94*	7.8	333	6.19
L45	7.9	226	1.16	*L95*	8.0	335	1.54
L46	7.8	163	4.67	*L96*	8.0	164	4.25
L47	8.0	127	4.96	*Min.*	7.6	106	1.16
L48	8.0	439	3.62	*Max.*	8.3	470	6.47
L49	7.8	237	3.9	*Av.*	7.93	270.55	4.59
L50	8.0	368	5.41	*SD*	1.14	86.90	0.99

Nickel (Ni)

The concentration of Ni in the samples ranges between 99.7 and 282 ppm with an average of 154.950 ppm, which is about 100% higher in all present study samples than in the average crust (75 ppm) according to Mason (1958) as shown in Figure (4D). If compared with the concentrations of nickel on the right bank of the city, which range between 87.8 and 202.0 ppm with an average of 149.09 ppm (Al-Sheraefy et al., 2023), the concentration of nickel in the soils on the left bank of the city is nearly similar. The high concentrations of nickel are thought to be caused by the effects of sewage, home waste as well as the closeness of many models to busy traffic (Papazotos et al., 2016; Long et al., 2018). Additionally, the high concentrations of nickel are thought to be caused by the combustion of fossil fuels, agricultural activities, and phosphate fertilizers, which have a significant impact on increasing nickel concentrations (Kabata-Pendias and Mukherjee, 2007; Montgomery, 2011). In addition, nickel is released into the air by electric power plants and garbage incinerators and stabilized in the soil after undergoing sedimentation processes (Nazzal et al., 2021). In addition to the contaminants from rockets and bombs dropped in the last war, nickel alloys and plates are used in many weapons (Rodríguez-Seijo et al., 2016; Lidija et al., 2018).

Lead (Pb)

Pb is found in soil samples from the left bank of Mosul ranges between 4.02 and 401 ppm with an average of 32.83 ppm, which is 20.0% higher than the total present study models than its average in the earth's crust (13 ppm) according to Mason (1958) and as shown in Figure (4E).In addition, when compared to the concentrations of lead in the right bank of the city, which range between 6.69 and 244 ppm with an average of 26.13 ppm (Al-Sheraefy et al., 2023), we note a rise in the concentration of lead in the Left bank samples. As a result, the elevated lead contents represent the degree of contamination to which the soil was subjected. Soil contamination with lead is proportional to the number of vehicles on the road; vehicle exhaust is a major source of lead contamination in urban areas (Heil, 1999), and industrial activity also contributes to an increase in lead concentration (Adimalla, 2020; Adimalla et al., 2019; Saljnikov et al., 2019). There is a correlation between general sources of lead contamination in the soils of the research region and human activities such as fallout from the burning of civil waste fuels and traffic emissions (Gao and Wang, 2018; Nazzal et al., 2021). Military operations have also contributed to increasing lead concentration because the guns, artillery, and rocket fire used to bombard the city contained significant amounts of lead (Barker et al., 2021).

Zinc (Zn)

The content of Zn in soil samples from the left bank of Mosul ranges between 31.1 and 383 ppm with an average of 101.67 ppm. It is 33.33% higher in the present study's total samples than an average crust, which is (70 ppm) according to (Mason, 1958) (figure 4F). If compared with the concentrations of zinc on the right bank of the city, which range between 42.8 and 410ppm with an average of 95.85 ppm (Al-Sheraefy et al., 2023), we note that there is no significant difference in the concentration of the element in the soils of both banks of the city. Human activities, like using phosphate fertilizers in agriculture (Kabata-pendias and Mukherjee, 2007), as well as the spread of electric generators and waste-burning processes that release a lot of heavy elements, as well as traffic density and the results of combustion processes, wastewater waste, and other garbage, all contribute to an increase in zinc concentration (Awadh and Al-Hamdani, 2019; Al-jumaily and Al-Berzenje, 2020), In addition to the role of military operations in the last war, which led to an increase in the concentrations of heavy elements as a result of aerial bombardment and the accompanying bombs, missiles and various weapons containing many heavy elements (Wallace, 2008; Skalny et al.,2021).

Table 6. Heavy metal concentration in ppm of soil samples on the left bank of Mosul City.

Samples	As	Cd	Cr	Ni	Pb	Zn	Samples	As	Cd	Cr	Ni	Pb	Zn
L1	7.84	0.44	80.10	120.5	13.00	72.80	L52	5.86	0.23	76.30	109.5	14.10	76.20
L2	5.72	0.16	101.0	153.0	13.15	67.70	L53	6.62	0.31	119.00	194.0	19.60	137.0
L3	5.52	0.17	105.0	153.5	11.30	81.20	L54	6.79	0.83	83.60	110.5	401.0	281.0
L4	9.13	0.43	111.0	177.0	158.0	290.0	L55	7.72	0.45	95.80	144.0	32.00	106.5
L5	7.80	0.23	69.90	107.0	16.90	77.70	L56	6.64	0.82	78.50	99.70	237.0	328.0
L6	5.83	0.15	87.60	155.0	8.01	61.60	L57	6.03	0.26	116.50	191.5	19.10	134.0
L7	6.84	0.22	136.5	230.0	10.80	74.80	L58	5.95	0.29	95.20	143.0	27.70	120.0
L8	6.31	0.19	120.5	190.5	8.23	61.70	L59	6.95	0.39	85.30	124.5	41.80	206.0
L9	5.74	0.20	113.5	186.0	13.60	99.80	L60	5.97	0.25	114.50	173.0	20.30	101.5
L10	7.31	0.25	81.80	128.5	12.90	77.60	L61	7.54	0.32	75.40	119.0	15.80	71.50
L11	6.21	0.19	108.0	166.5	15.75	83.40	L62	8.27	0.20	130.00	211.0	11.00	62.10
L12	7.21	0.30	109.0	161.0	40.60	112.5	L63	5.93	0.15	113.50	178.0	8.04	54.70
L13	6.37	0.22	115.5	179.0	11.75	82.70	L64	7.80	0.25	144.00	220.0	14.50	120.0
L14	6.80	0.29	115.0	182.5	32.30	142.5	L65	6.30	0.16	118.50	187.0	9.73	63.40
L15	6.81	0.19	111.0	176.5	15.35	73.10	L66	6.27	0.06	59.50	133.5	4.02	31.10
L16	7.62	0.30	92.10	143.0	11.05	66.20	L67	6.52	0.15	116.00	181.0	7.66	60.30
L17	6.03	0.26	90.00	141.5	13.65	91.30	L68	6.04	0.24	112.50	174.0	14.80	89.50
L18	7.74	0.42	105.5	159.0	71.80	127.5	L69	6.79	0.24	81.80	122.0	10.45	57.20
L19	7.51	0.28	92.10	144.0	11.90	66.30	L70	7.64	0.40	93.00	142.5	26.00	115.5
L20	6.75	0.32	81.30	130.5	11.30	72.00	L71	6.20	0.18	115.00	188.0	10.45	68.90
L21	5.84	0.17	113.5	178.0	10.35	65.50	L72	5.66	0.16	110.00	177.5	9.35	59.50
L22	7.63	0.29	78.90	119.0	10.55	58.70	L73	4.59	0.10	153.50	282.0	6.94	57.00
L23	7.28	0.28	80.70	119.5	9.98	57.50	L74	7.13	0.21	92.30	165.5	8.18	55.40
L24	7.62	0.30	83.70	133.5	11.15	73.70	L75	6.96	0.21	120.00	182.5	11.25	79.40
L25	7.30	0.29	81.60	123.0	12.50	67.20	L76	6.78	0.20	122.00	199.0	10.85	74.60
L26	7.97	0.24	85.90	130.5	10.05	60.20	L77	7.63	0.27	85.50	135.0	9.22	61.60
L27	5.24	0.15	114.0	184.5	9.43	56.70	L78	5.67	0.20	108.00	168.0	18.20	339.0
L28	6.43	0.28	105.5	159.5	41.80	105.0	L79	6.12	0.41	98.3.0	151.5	98.50	195.5
L29	7.17	0.21	133.0	219.0	9.43	62.00	L80	7.27	0.25	105.50	159.0	20.60	105.0
L30	5.38	0.20	67.80	102.0	9.68	55.70	L81	6.75	0.25	115.50	176.5	37.90	145.5
L31	7.33	0.27	79.20	121.5	9.30	61.50	L82	4.99	0.17	92.00	136.0	15.90	71.50
L32	6.13	0.24	102.5	158.5	75.40	106.5	L83	6.24	0.26	108.00	171.5	50.00	134.0
L33	7.58	0.27	77.60	113.5	13.60	75.40	L84	7.79	0.34	116.00	175.0	33.60	127.5
L34	7.26	0.24	95.80	146.5	14.25	70.80	L85	7.03	0.24	115.00	174.5	20.90	81.20
L35	6.39	0.19	125.0	208.0	17.55	82.60	L86	5.84	0.90	81.50	113.0	136.0	350.0
L36	6.36	0.33	91.80	140.0	15.00	82.80	L87	7.57	0.26	81.10	123.5	10.95	58.80
L37	6.14	0.61	74.80	110.0	279.0	222.0	L88	6.28	0.18	119.00	189.5	9.23	62.30
L38	5.49	0.28	93.00	140.0	18.90	71.40	L89	7.86	0.34	86.80	134.5	15.70	81.10
L39	5.59	0.34	102.5	157.5	17.10	84.30	L90	6.24	0.23	88.30	140.5	21.50	65.80
L40	8.93	0.32	91.00	133.0	13.90	75.10	L91	6.93	0.22	108.50	173.0	13.45	65.30
L41	6.47	0.44	113.5	171.5	59.60	184.5	L92	6.46	0.21	69.70	105.5	7.92	45.30
L42	7.00	0.22	95.60	141.5	12.55	65.90	L93	5.61	0.17	112.00	174.0	15.35	70.90
L43	7.08	0.43	82.20	119.0	67.30	149.5	L94	7.49	0.37	84.60	115.0	98.40	149.0
L44	6.03	0.18	109.5	171.0	11.80	94.70	L95	5.95	0.22	89.90	145.0	9.79	61.30
L45	7.01	0.29	79.10	116.0	13.30	65.10	L96	5.80	0.15	110.50	174.0	8.79	55.90
L46	6.57	0.27	72.90	107.0	19.65	72.60	Min.	4.59	0.06	59.50	99.70	4.02	31.10
L47	7.41	0.21	143.5	236.0	8.07	57.20	Max.	11.20	0.90	153.5	282.0	401.0	383.0
L48	7.13	0.32	116.0	176.0	65.30	383.0	Mean	6.78	0.28	99.57	154.9	32.83	101.6
L49	8.25	0.67	79.50	118.5	115.5	153.0	SD	0.97	0.14	18.75	33.92	57.48	68.95
L50	7.71	0.28	79.70	119.5	9.00	54.10	CV	14.36	50.14	18.83	22.00	175.9	68.18
L51	11.20	0.25	85.90	131.0	16.05	66.70	Av. Crust	1.80	0.20	100	75.00	13.00	70.00
Mean Right bank	6.50	0.23	95.32	149.1	26.13	95.85							

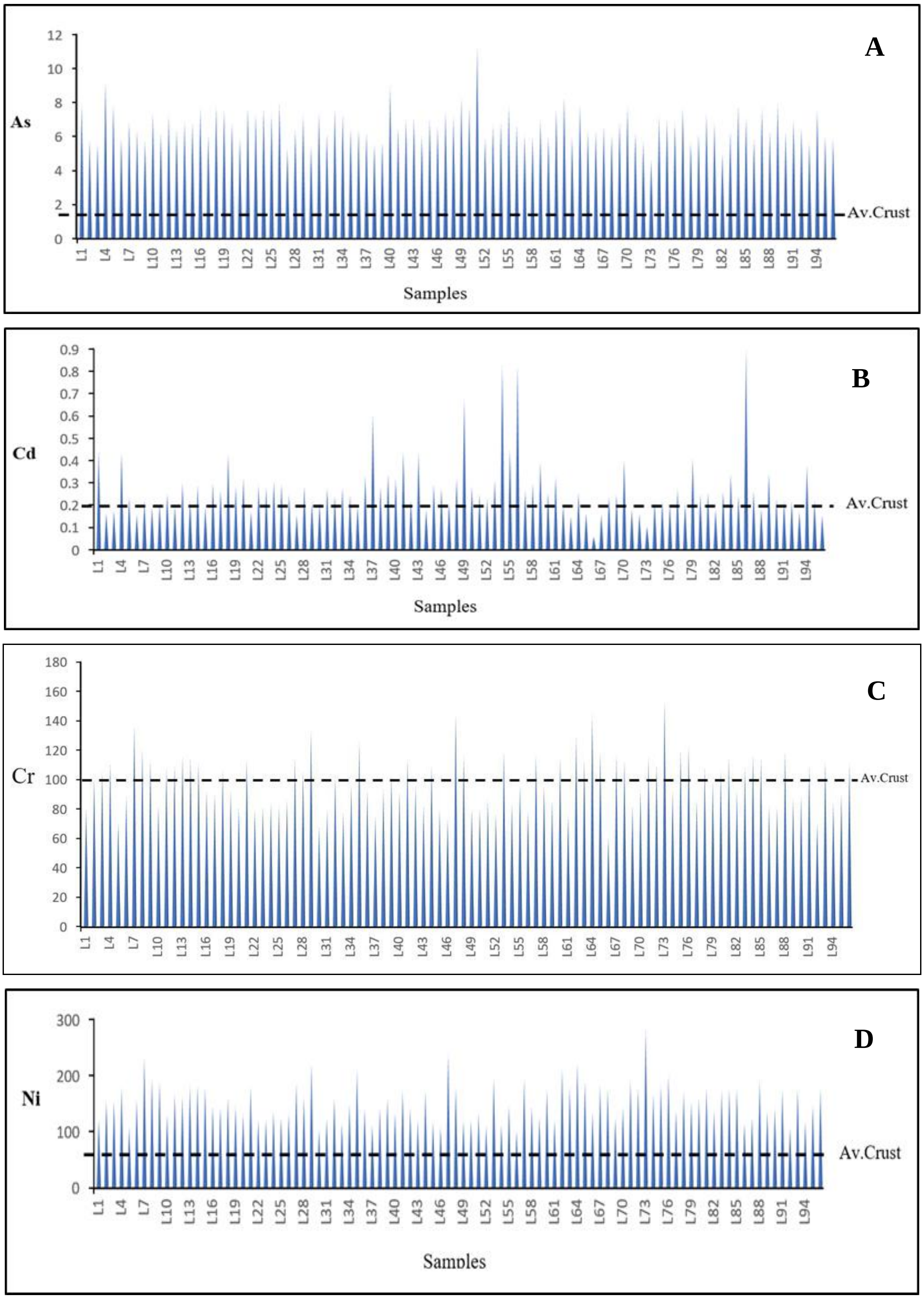
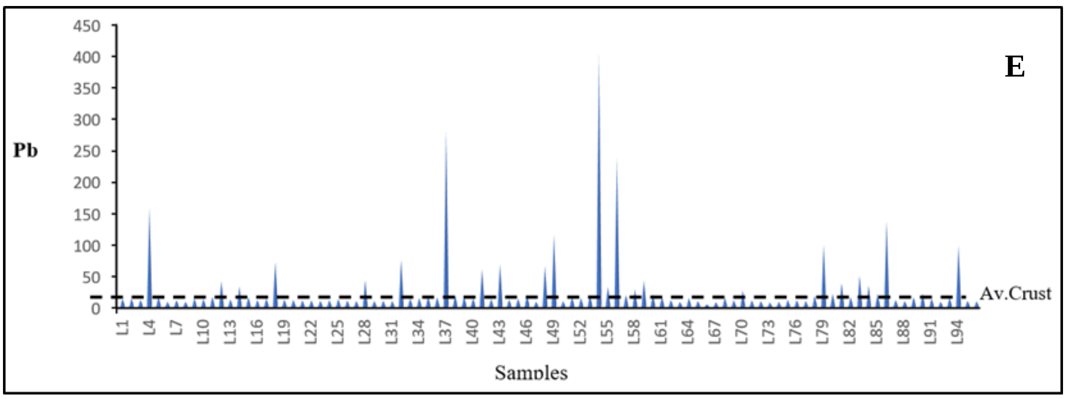


Fig. 4. Heavy metals in the soil samples from the left bank.



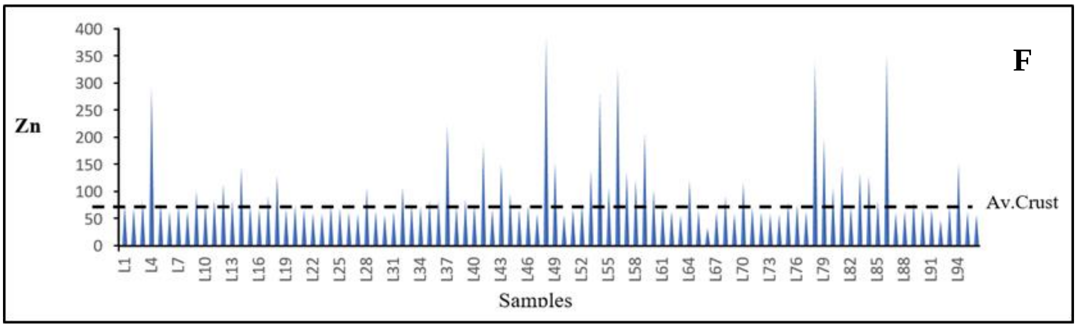


Fig. 4. Continued

Assessment of Heavy Metal Contamination

Evaluation of geo-accumulation index (I_{geo})

The results of a geo-accumulation index (I_{geo}) for the soil of the left bank of Mosul City with the minimum, maximum values and mean, are presented in Table (7) and Figure (5). The arsenic (I_{geo}) values for the left bank of the city range between 0.77 and 2.05 with an average of 1.31, indicating that the concentration of the As element in the samples from the study area falls within the range of "uncontaminated to moderately contaminated" according to the classification of Muller (1969). The geo-accumulation index (I_{geo}) for cadmium on the left bank ranges from (-2.45 to 1.58) with an average of (-0.23), putting Cd in the "uncontaminated to moderately contaminated" classification field of Muller (1969). For the chromium element, the (I_{geo}) in the study area ranges between (-1.34 to 0.03) with an average of (-0.62); these values indicate that the (I_{geo}) is within the "Uncontaminated to Moderately contaminated" field of Muller (1969). For the Pb element, the I_{geo} in the left bank samples ranges between (-2.28 to 4.36) with an average of (-0.08); these values indicate that the (I_{geo}) is located within "Uncontaminated to Moderately contaminated" (Muller, 1969). Finally, the values of (I_{geo}) of Zn range between (-1.76) to 1.87) with an average of (-0.26); these values indicate that I_{geo} of the zinc is located within "Uncontaminated to Moderately contaminated" (Muller, 1969).

The results of (I_{geo}) for the studied elements on the left bank of the city when compared with the results of (I_{geo}) for the same elements on the right bank of the city (Al-Sheraefy et al., 2023). convergence in the results for both banks is seen, from which it is inferred that the soil of the city of Mosul, in general, is Uncontaminated to Moderately contaminated with heavy elements; this is due to the lack of huge industrial activities in most areas of the city; i.e., s there is no great pollution. As the areas whose I_{geo} values are high, they are heavily contaminated. This indicates the presence of many sources of pollution due to anthropogenic activities represented by (fumes emitted from the burning of materials, waste, and gases emitted from car exhaust and generators, in addition to liquid waste in urban and industrial areas and sewage), which in turn led to soil pollution with these elements. Moreover, the city was subjected in the last war, to the accompanying aerial bombardment, bombs, missiles and ammunition containing many heavy elements led to an increase in the heavy metal concentrations.

Table 7. Minimum, maximum, and mean values of I_{geo}, EF, and CF factors of soil heavy metals in a left bank

Igeo	Min.	Max.	Mean	EF	Min.	Max.	Mean	CF	Min.	Max.	Mean
As	0.77	2.05	1.31	As	4.22	13.07	6.75	As	2.55	6.22	3.76
Cd	-2.45	1.58	-0.23	Cd	0.85	9.32	2.53	Cd	0.28	4.48	1.40
Cr	-1.34	0.03	-0.62	Cr	1.40	2.51	1.74	Cr	0.60	1.54	1.00
Ni	-0.17	1.33	0.43	Ni	2.47	6.31	3.62	Ni	1.33	3.76	2.07
Pb	-2.28	4.36	-0.08	Pb	0.88	51.76	4.60	Pb	0.31	30.85	2.53
Zn	-1.76	1.87	-0.26	Zn	1.24	10.42	2.57	Zn	0.44	5.47	1.45

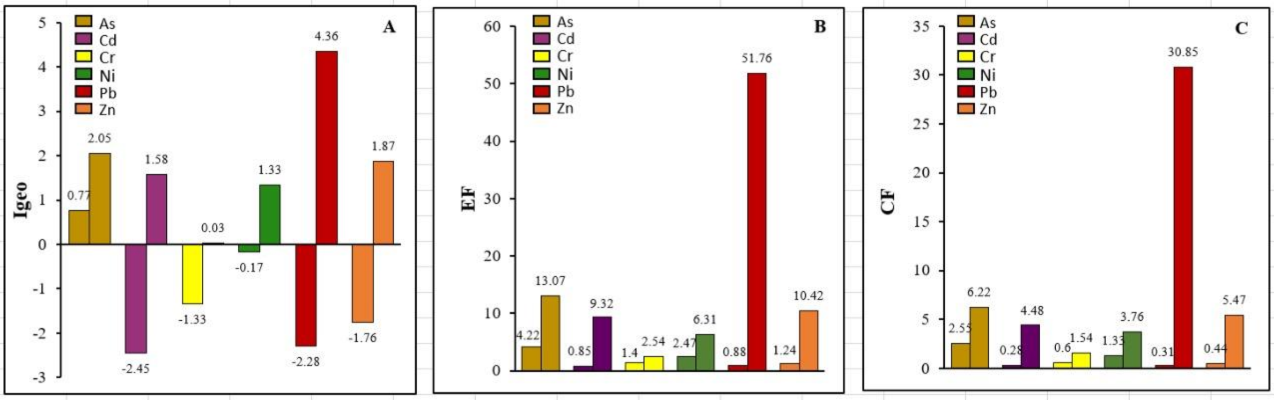


Fig. 5. Minimum and maximum values of (A) geo-accumulation index (I_{geo}), (B) enrichment factor (EF), and (C) contamination factor (CF) of soil heavy metals in the left bank study area

Enrichment Factor (EF)

Calculating the enrichment factor (EF) for the heavy elements is the focus of this research as shown in Table (7) and Figure (5). The EF of as in the soils of Mosul's left bank ranges between (4.22 and 13.07) with a rate of 6.75, which is classified as "moderate enrichment to significant enrichment." For the Cd, the EF is between (0.85 and 9.32) at a rate of 2.53, which places it within the field of moderate to significant enrichment (Mmolawa et al., 2011; Barbieri et al., 2015). EF for Cr ranges from (1.4 to 2.51) with an average of 1.74. This means that the Cr is in the class of "deficiency to minimal enrichment-moderate enrichment".

The enrichment factor for the Ni is found to range between (2.47 and 6.31) with a rate of 3.62, which is classified as "moderate enrichment". The EF of Pb is between (0.88 and 51.76) at a rate of 4.6, which means it falls within the ranges of "deficiency to minimal enrichment- moderate enrichment, and significant enrichment". Finally, the EF for Zn ranges between (1.24 and 10.42) with a rate of 2.57, which is classified as "deficiency to minimal enrichment-moderate enrichment".

It has been established that the EF values for the same elements tested in the soils on the left and right sides of the city are equivalent (Al-Sheraefy et al., 2023). The single exception is lead, which has been demonstrated to be more prevalent on the left bank of the city. Since the EF values of the examined components are greater than one, they are probably made by human activities like transportation, electricity generators, industrial waste, mining operations, the use of chemical fertilizers and pesticides, and industrial waste (Adimalla et al., 2019). Additionally, the elements can be attributed to the pollution left behind by missiles, bombs, and their waste during military operations.

The results of EF for the studied elements in the soils of the left bank of the city can be compared with the results of EF of the same elements in the soils of the right bank of the city (Al-Sheraefy et al., 2023), where it is noted that there is convergence in the results for both banks, except for the element lead as there is an increase in its concentrations on the left bank more than on the right bank. The EF values of the elements under study (which were greater than one) indicate that they are caused by human activities such as (transportation, generators, industrial waste, mining operations, the use of chemical fertilizers, pesticides, and industrial waste) (Adimalla et al.,2019; Adimalla, 2020) as well as the impact of pollutants resulting from rockets, bombs and their remnants used during military operations in the city, which is one of the most sources of soil contaminants with heavy elements.

Contamination Factor (CF)

After calculating the contamination factor (CF) for the samples of the study area given in Table (7) and Figure (5), it is found that the CF of the as is between (2.55-6.22) with an average of 3.76. CF of Cd is between (0.28-4.48) with an average of 1.40. Cr has between (0.60-1.54) with an average of 1.0. CF of Ni is between (1.33-3.76) with an average of 2.07. For Pb, CF values range between (0.31-0.85) with an average of 2.53. CF for Zn is between (0.44-5.47) with an average of 1.45. The values of the CF of the six elements (As, Cd, Cr, Ni, Pb, Zn) in the study area indicate that they are classified between "Moderate Contamination – Considerable Contamination" according to the classification of Hakanson (1980).

The results of CF for the elements studied in the left bank of the city can also be compared with the results of CF for the same elements in the right bank of the city (Al-Sheraefy et al., 2023), where it is noted that there is a similarity in the results of both banks, except the high pollution coefficient values of the lead element on the left bank, where the highest value reached 30.846, while on the right bank 18.77. This indicates that the soil of Mosul City in general is affected by the continuous human activities and urban development that has been witnessed in recent times in Mosul City, which caused the addition of elements to the ecosystem, in addition to the role of military operations and the pollution they left as a result of the bombardment of the city with bombs, missiles and various weapons containing many heavy elements.

Conclusion

To determine the role of physicochemical traits and their contribution to affecting the distribution of heavy metals in the soil, pH, electrical conductivity (EC), and determination of organic matter content (OM) are measured. The average pH is 7.93, and due to the limited range of pH in the study samples, this criterion is of limited influence on the distribution of heavy metals, which largely determines their mobility due to the neutral semi-alkaline environment. The average of the electrical conductivity (EC) values is 270.55 µs/cm. This variation in electrical conductivity values is due to the amount of waste that is excreted and wastewater that contains salts. The average value of organic matter (OM)is 4.59%. This is due to the nature of the waste excreted in addition to wastewater as a result of the high population density, which contributes to increasing the content of organic matter.

The results of the chemical analysis show that the concentrations of the elements (As, Cd, Cr, Ni, Pb, Zn) are higher than their averages in the Earth's crust by (100%, 38.57%, 100%, 100%, 20%, 33.33%) respectively in all samples of the current study, which indicates the occurrence of an additional case of these elements in the soil of the left bank of Mosul. If compared with the same elements in the right bank soil, a significant increase in the concentration of Ni and Pb in the left bank samples is observed. The results of the calculation of pollution indicators Igeo, EF, CF for the group of heavy metal under study indicate that their source is anthropogenic activity represented by fumes emitted from the burning of materials, factory waste, waste and gases emitted from car exhaust, and generators, and the contribution of effluent in urban and industrial areas and sewage, which in turn led to soil pollution with these elements. In addition to what the city was subjected to in the last war (2014-2017) to liberate it and the accompanying aerial bombardment, bombs, rockets, ammunition, and their remnants containing heavy elements, which led to an increase in the concentrations of many heavy metals.

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