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دراسة مؤشرات تلوث التربة بالعناصر الثقيلة في مدينة البصرة

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المستخلص:

يشير تراكم المعادن الثقيلة في التربة السطحية إلى زيادة وجود العناصر المعدنية الثقيلة داخل الطبقة العليا من التربة، وغالبًا ما يكون ذلك نتيجة للأنشطة الصناعية أو التلوث أو العمليات الطبيعية ، مما قد يؤثر على صحة النظام البيئي وسلامة الإنسان . يقدم هذا البحث الذي أجري خلال الفترة من تموز ٢٠٢٢ إلى آب ٢٠٢٣ تحليلاً متعمقاً لتراكم المعادن الثقيلة في التربة السطحية لمدينة البصرة باستخدام مؤشرات التلوث البيئي المتقدمة ، عامل التلوث (*CF*)، عامل الإثراء *(EF)*، ومؤشر حمل التلوث (*PLI*) اذ تم جمع ٥٧٦ عينة من التربة من ستة مواقع مختلفة داخل مدينة البصرة وتم تطبيق المناهج الوصفية والمختبرية والكمية والتحليلية واستخدام مؤشرات التلوث المتقدمة والتقنيات الإحصائية لقياس التلوث بالحديد والكوبالت والنحاس والكروم والرصاص والزرنيخ والخارصين والمنغنيز، أكدت نتائج الدراسة الى وجود تراكيز عالية للمعادن الثقيلة مثيرة للانتباه وخاصة في الموقع ٤ الذي سجل باستمرار مستويات مرتفعة من الحديد والكوبالت والكروم والرصاص والزنك والمنغنيز، وتشير قيم *P* التي تتجاوز ٠.٠٥ إلى عدم وجود اختلافات كبيرة في تركيزات المعادن عبر المواقع (*P-value >0.05*). عززت نتائج عامل التلوث (*CF*) الموقع (٤) باعتباره نقطة تلوث ساخنة مقارنة بمستويات خط الأساس البيئي و باستخدام الحديد كمعدن مرجعي لحسابات عامل الإثراء *(EF)*، تم العثور على إثراء ملحوظ للرصاص في الموقعين ٤ و٦. كذلك حدد تقييم حمل التلوث (*PLI*) المواقع ٣-٤-٦ كمناطق ذات مخاوف عالية من التلوث، في حين أظهرت المواقع الأخرى مستويات معتدلة. ويوضح التحليل المقارن مع أبحاث مماثلة في دول الجوار فائدة أداة حمل التلوث (*PLI*) مع تسليط الضوء على خصائص التلوث الإقليمية لمنطقة الدراسة ، وتؤكد دراستنا الحاجة إلى تدخلات فورية من قبل الجهات ذات الاختصاص لمعالجة

مستويات التلوث المرتفعة في مواقع البحث، والقيام بإزالة سموم التربة، والبحث عن مصادر التلوث، والرصد المنتظم، وتنفيذ حملات التوعية البيئية للتخفيف من تأثير مخاطر التلوث بالمعادن الثقيلة في مدينة البصرة.

الكلمات المفتاحية: التلوث بالمعادن الثقيلة، تحليل التربة السطحية، مؤشرات التلوث البيئي.

STUDY OF HEAVY METAL-POLLUTED SOIL INDICATORS IN BASRA

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Abstract:

Heavy metal accumulation in topsoil refers to the increased presence of heavy metal elements within the top layer of soil, often as a result of industrial activities, pollution, or natural processes, which may impact ecosystem, health, and human safety. This research, conducted from July 2022 to August 2023, provides an in-depth analysis of heavy metal accumulation in the surface soil of the Basra City using advanced environmental pollution indicators: contamination factor (CF), enrichment factor (EF), and pollution load index (PLI). A total of 576 soil samples were collected from six different Bara-based locations. Descriptive, laboratory, and quantitative methodologies were applied, using advanced pollution indicators and statistical techniques to measure pollution with iron, cobalt, copper, chromium, lead, arsenic, zinc, and manganese. The results confirmed a striking presence of high concentrations of heavy metals, especially at Site 4, which consistently recorded high levels of iron, cobalt, chromium, lead, zinc, and manganese. P-values exceeding 0.05 indicate zero significant differences in metal concentrations across sites (P-value >0.05). The Contamination Factor (CF) results reinforced Site-4 as a pollution hotspot compared to environmental baseline levels. Using iron as the reference mineral for enrichment factor (EF) calculations, significant Pb enrichment was found at sites 4 and 6. The Pollution Load Assessment (PLI) also identified sites 3-4-6 as areas of high contamination concerns, while other sites showed moderate levels. Comparative analysis with similar research in neighboring countries demonstrates the utility of the Pollution Load Instrument (PLI) while highlighting unique regional pollution characteristics. Our study confirms the need for immediate interventions by the authorities to address the high levels of pollution at research sites, carry out soil detoxification, investigate pollution sources, regularly monitor, and implement community awareness campaigns to mitigate the impact of heavy metal pollution risks in the city of Basra.

Keywords: Heavy metal contamination, Surface soil analysis, Environmental pollution indicators.

Introduction

The pollution of heavy metals resulting from human activities, such as mining and agriculture constitutes one of the significant environmental risks facing the world today. When these metals are in the soil, they can damage agricultural crops, disrupt the food chain, and pose a risk to human health. Once these metals are in the soil, plants can absorb them and transfer them up the food chain. The primary goal should be to prevent such pollution. Various methods, both natural and industrial, can remove these metals, with phytoremediation being the most environmentally friendly and cost-effective [Priya AK, 2023, p.422].

Heavy metals (HM), including arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), lead (Pb), copper (Cu), zinc (Zn), and nickel (Ni), are widespread pollutants in the soil. These pollutants are biologically harmful, widespread, and permanently present in the soil's ecosystem. With the acceleration of economic and societal growth, the presence of these heavy metals in the soil poses increasing risks to the environment and public health [Zhao, H, p.3552, 2023].

Soil pollution caused by heavy metals (HM) raises significant concerns about the environment and public health in both industrial and non-industrialized countries. These metals are among the most worrying pollutants. Geological activities, human interventions, and economic growth worldwide have made soil pollution related to HM a widespread global issue [Hoque MM, p.11104, 2023].

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Heavy metals (HM) and metals, such as arsenic and antimony are among the main causes of soil pollution. Nearly 5 million soil sites worldwide are affected by their presence. It is concerning that concentrations of these elements at many of these sites exceed safety thresholds set by environmental agencies. These elevated levels pose risks to ecosystems, crop safety, groundwater quality, with potential long-term effects on human health and wildlife [Gonzalez Henao S, p.2, 2021].

Naturally, heavy metals (HM) exist in soil at low concentrations, usually non-toxic. These small amounts often arise from primary metal accumulation and deposition from the atmosphere. However, human interventions such as mining, industrial emissions, sewage disposal, and agricultural chemical use can significantly alter soil's intrinsic properties. Changes in soil properties like texture, cation exchange capacity (CEC), acidity, and bulk density directly affect the soil's ability to bind or filter these metals. Consequently, human activities can increase the deposition of HM in the soil, elevating pollution levels. This affects not only plant growth and soil microorganisms but also poses potential health risks to humans through long-term exposure or via the food chain [Sodango TH, p.54, 2018].

The delicate balance of natural environmental systems is increasingly threatened by human activities, with soil pollution emerging as a major global concern. Heavy metals, as non-degradable elements, present a unique challenge as they persist in environments for long periods, threatening environmental health and human well-being [FAO, 2023]. Basra city, a key area in terms of economic activity and environmental diversity, is not exempt from these environmental challenges.

Heavy metals naturally exist in the soil at low concentrations, usually non-toxic. These small quantities often result from primary metal accumulation and deposition from the atmosphere. However, human-induced increases above natural levels pose significant environmental risks, affecting plant growth and entry into the food chain, thus impacting human health. The industrial boom in the twentieth century led to a substantial increase in exposure to harmful metals such as mercury and arsenic. Their consumption through various means causes toxicity through common pathways such as

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oxidative stress. While traditional removal techniques face constraints like secondary pollution, microbial bioremediation, using fungi and bacteria's bioaccumulation capabilities, emerges as a potential solution [Abd Elnabi MK, p.580, 2023].

Physical pollution indicators assess the functions of the terrestrial environmental system. Combining physical, chemical, and biological measures provides a comprehensive assessment. Polluted ecosystems exhibit material reductions in infiltration, cohesion, ventilation, and increased surface runoff. To develop effective remedial strategies and informed policy decisions, accurately measuring the extent and severity of heavy metal pollution is essential. This requires using advanced pollution indicators. Pollution factor (CF), enrichment factor (EF), and pollution load index (PLI) are advanced tools that offer precise insights into pollution levels, sources, and potential risks [Zaghloul, A, p.120, 2019].

1.Study Problem

Industrialization and urbanization in the twentieth and twenty-first centuries have resulted in significant environmental problems, including the accumulation of heavy metals in terrestrial ecosystems. The problem of the study lies in answering the following questions:

Does Basra, with its agricultural and industrial history and its oil wealth, face dangerous contamination with these metals?

Does this contamination affect the environment and public health, particularly when these metals enter the food chain?

2.Objective

The research aims to conduct a comprehensive assessment of the accumulation of heavy metals in the surface soil of Basra city center. It includes objectives to measure and identify concentrations of heavy metals, calculate pollution indices (CF, EF, PLI), conduct laboratory and statistical analyses to evaluate spatial patterns and significant differences between sample sites, and assess environmental impacts. The study provides a comprehensive understanding of heavy metal pollution and its potential risks to ecosystems and human health. It aims to offer recommendations for environmental management and remediation efforts in selected areas.

Through data and insights drawn from these measures, the study is set to elaborate on the current soil pollution status in the studied area. Understanding precise differences in metal accumulation is highly important, not only environmentally but also concerning public health and sustainability. Moreover, this is evidence-based policymaking and proactive environmental management, ensuring Basra's capacities to directly face these challenges and protect its urban ecosystem. This approach highlights how scientific analysis can be critical in managing our environment, providing a comprehensive understanding of the current situation, and paving the way for informed environmental management in the area.

3.Hypothesis

Given the environmental pressures on Basra from industrial activities and oil reserves, this study hypothesizes that the surface soil in Basra city contains significant accumulations of heavy, health-threatening metals. Using advanced pollution indicators, this study identifies pollution patterns and explain how natural and human events contribute to the increased concentrations of heavy metals in Basra's soils.

4.Methodology

The research methodology for this study has been meticulously formulated, considering the delicate balance between field observations and laboratory assessments. Thus, these aspects have been designed to ensure accuracy and suitability. These aspects can be broadly classified into three distinct methodologies, aligning with the requirements of both field and laboratory investigations:

Descriptive Method: it is a research design that emphasizes data-driven sources, including published scientific literature, reports, previous studies, reliable maps, and complex aerial images.

Laboratory Analysis Method: it is a research design that takes into account Basra's significance and the primary indicators of potential pollution. Thus, an organized system for sample collection has been established. Over a year from July 2022 to August 2023, soil samples were collected from six strategically defined sites across Basra. Such approach is pivotal for

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conducting an accurate assessment of the accumulation of heavy metals in the surface soils.

Quantitative Method: it is a research design that calculates repeated pollution indices, especially pollution factor (CF), enrichment factor (EF), and pollution load index (PLI). These advanced tools provide accurate insights into the extent of pollution, its origins, and associated risks. Additionally, advanced statistical techniques were used to determine the significance level in the spread of heavy metal concentrations in the six selected sites in the center of Basra city.

5. Significance

The growing concern about environmental pollution has placed soil pollution, especially from heavy metals, under the spotlight. Basra, due to its unique geographical, historical, and industrial significance, is a compelling case for such studies. Therefore, this research measures the accumulation of heavy metals in surface soil across different areas of Basra, using advanced pollution indicators, not only in academic tems, but also through real and profound implications. By assessing the levels and distributions of these pollutants, the results could benefit public health policies, agricultural practices, and pro-environmental efforts. Furthermore, understanding the current status of soil pollutants in Basra can serve as a reference for other areas facing similar environmental pressures as well as guiding sustainable urban planning and development. The significance of this research lies not only in immediate findings but also in potentially inspiring informed actions that benefit the environment and the populace of Basra in general, given the scarcity of detailed indicator-based studies on that area.

6. Location of Studied Area

Basra is located between latitudes (30°34'30"-30°25'30"N) and longitudes (47°52'30"-47°43'30"E), as depicted in Map (1). It is bordered to the north by Al-Haritha District and the Karama River, to the south by Abu Al-Khasib District and Al-Zubair District, to the east by Shatt al-Arab District, and Shatt al-Basra to the west. The area of Basra is approximately (5116.8) hectares, with a population of (1,218,251) according to estimates in 2022,

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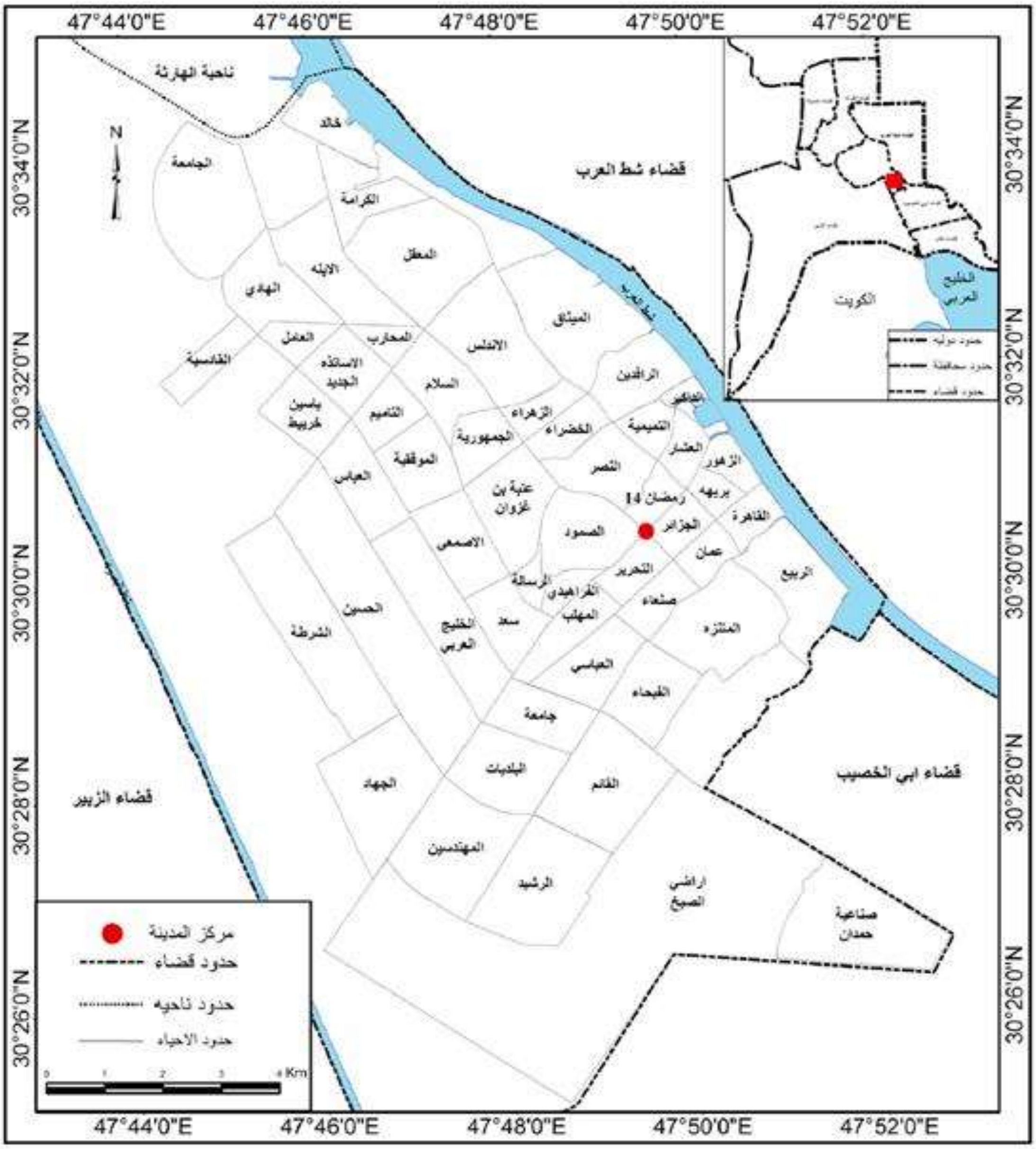
comprising (54) residential districts (Ministry of Development Planning, 2019, without a citation).

Map 1. Study Area



Source: 1) General Directorate of Surveying - Map of Iraq, Baghdad 2021

2) General Directorate of Surveying - Administrative Map of Basra Governorate 1:500,000, Baghdad 2021

7. Sample Collection and Methods

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576 soil samples were collected from (6) selected areas from urban Basra communities from July 2022 to August 2023. These urban localities are Al-Hadi, Al-Andalus, Algeria, Al-Khalij, Ar-Rabea, and Al-Qibla, as shown in Map (2) and Table (1). Using custom tools, each sample was extracted deep at 10 cm from respective experimental site in data collection to ensure representation of each location.

Subsequently, each sample was dried in an oven at 105 °C for 24 hours. After drying, the samples were sieved through 2-mm sieves, ensuring a uniform texture and effectively removing larger particles.

Map 2. The locations of sample collection of heavy elements sourced from the Basra soils

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Source: Author's contribution based on the Basra topographic map in 2019 using ArcMap software.

Table (1) Coordinates of sample locations

Sample number	*y*	*x*
١	*3379064*	*771720*
٢	*3380931*	*768812*

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٣	3383557	765687
٤	3375961	768356
٥	3376221	774260
٦	3374094	771395

Source: Field study

To obtain further detailed analysis of heavy metals, a finer 63-µm sieve was also used. The sieved samples were digested using aqua regia, a mixture of concentrated hydrochloric acid, and nitric 1-3 rated acid. Following digestion, the mineral content for each soil sample was determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS), providing accurate concentrations of elements including iron, cobalt, copper, chromium, lead, arsenic, zinc, and manganese.

8.Soil Pollution Indicators

To investigate heavy elements in the soil, several environmental indicators were identified, as follows:

a) Contamination Factor (CF)

The Contamination Factor (CF) serves as a fundamental measure in environmental studies, specifically in tracking the extent of heavy metal pollution in different environmental systems. CF provides a clear and effective method of measuring pollution intensity. By applying the following equation: (CFi = Ci/Bi), one can differentiate between the significant concentration (Ci) of a specific metal in the environment and its natural or background concentration (Bi). The resulting value (CFi) represents the contamination factor for that specific heavy metal in the sediments. CF offers an immediate understanding of deviations from natural heavy metal concentrations, aiding both current assessments and future mitigation strategies for affected areas. Therefore, this method remains effective in environmental research, policy development, and related planning [Hakanson L., 1980, p. 976].

b) Enrichment Factor (EF)

The Enrichment Factor (EF) is a critical indicator in environmental studies, assisting researchers in understanding the extent of human activities' impact on specific element concentrations in different mediums, such as soil or water. Primarily, EF compares the notable concentration of an element in a sample to its average naturally provided concentration. When EF values significantly exceed 1, it often indicates human influences, such as industrial emissions, agricultural surface runoff, or urban waste discharge. Through EF, scientists can not only infer the extent of pollution but also identify its sources. This metric has become particularly valuable today, where rapid manufacturing and urbanization have led to increased alterations in natural element abundance, thereby impacting ecosystems and human health [Bern, C. R, 2019, p. 91].

The Enrichment Factor (EF) is used to differentiate between human and natural sources of minerals in the environment. The formula for EF is:

$$EF = (X/Y)_{sample} / (X/Y)_{background}$$

Where:

(X/Y) sample is the ratio of the concentration of the target metal (X) to the reference metal (Y) in the sample.

(X/Y) background is the ratio of the concentration of the metal of interest (X) to the reference metal (Y) in the background sample or baseline.

Generally, elements like Aluminum (Al) or Iron (Fe) are used as reference metals because they usually originate from the earth's crust and are less affected by human activities. EF helps interpret whether the significant metal concentration is a result of natural processes or human activities. Additionally, an EF close to 1 primarily indicates a natural origin, while an EF significantly greater than 1 implies human enrichment [Sappa, G., p. 1409 and Hızlı S., 2023, p. 8558].

c) Pollution Load Index (PLI)

The Pollution Load Index (PLI) is a comprehensive tool used to evaluate the overall extent and intensity of pollution in a specific environment. PLI illustrates the collective impact of multiple pollutants, providing a comprehensive view of pollution status in the ecosystem. By integrating data from different pollutants, it offers insight into both cumulative burden and variations in pollution levels over time. The value derived from the PLI can serve as a measure of environmental health, indicating areas of concern and aiding in guiding remedial efforts. PLI, in essence, not only measures pollution but elucidates patterns, trends, and potential threats, making it an indispensable indicator for environmental monitoring and management [Tomlinson, D., 1980, p. 567].

The Pollution Load Index (PLI) is calculated using the geometric mean of Pollution Factors (CF) for 'n' number of metals, and the formula is as follows:

$$PLI = (CF1 \times CF2 \times \cdots \times CF\ n)^{(1/n)}$$

Where:

(CFi) is the pollution factor for the metal.

(n) is the total number of metals considered.

A PLI value of 1 indicates baseline levels (no enrichment), values greater than 1 indicate pollution, and values less than 1 indicate depletion of metals in the sample concerning baseline or background values.

9.Statistical Analysis

Several statistical methods were used to analyze the data. Initially, descriptive statistics were used to provide fundamental insights into the dataset, including the measures of central tendency (mean, median, mode), and measures of dispersion (range, standard deviation). The Kruskal-Wallis H test, a non-parametric statistical test, was used to compare heavy metal concentrations in different areas or groups. It is used as an alternative to the one-way analysis of variance (ANOVA) when data do not meet the normality assumption. The test ranks all observations from lowest to highest and computes the test statistic based on the ranks. The resulting p-value indicates significant differences between the groups. Subsequently, the post hoc Tukey test was used to compare soil pollution level means. Additionally, Dunn's post-hoc test, another statistical test used after Kruskal-Wallis, was used to determine specific groups that significantly differ from each other by comparing all possible pairs of groups.

All statistical analyses were conducted using the SPSS software version 27, 2022. The significance level was set at (P≤0.05). These methods ensured a comprehensive understanding of the accumulation of heavy metals in the Basra soils.

10.Results and Discussion

Table 2 illustrates the data extracted from six sites in Basra regarding concentrations of heavy metals in surface soil samples. The study finds that Site 4 had the highest concentration of iron (Fe) at 5722.3 ppm, while for Cobalt (Co), Site 4 showed the highest level at 17.5 ppm. Copper (Cu) had the highest concentration at Site 4, recording 13.4 ppm. Chromium (Cr) peaked at Site 4, inching 20.3 ppm, and Lead (Pb) displayed its highest concentration at Site 4, reaching 57.1 ppm. Site 4 also displayed the highest concentration of Arsenic (As) at 12.7 ppm. Concerning Zinc (Zn), Site 4 again indicated the highest concentration at 42.4 ppm. Finally, the concentration of Manganese (Mn) was found to be higher at Site 4, thereby reaching 137.2 ppm. All values were compared with the specified reference environmental concentration to determine the extent of heavy metal pollution studied.

Table 2. Average concentrations of heavy metals / ppm in surface soil samples in Basra City for the period July 2022-August 2023.

Element / Location	Fe	Co	Cu	Cr	Pb	Az	Zn	Mn
Location 1	4255.2	16.3	9.5	18.7	32.5	9.3	31.3	119.7
Location 2	3122.7	11.3	8.2	17.9	13.3	5.1	28.2	101.5
Location 3	4423.7	17.5	11.6	19.7	40.3	7.7	36.5	122.7
Location 4	5722.3	17.7	13.4	20.3	57.1	12.7	42.4	137.2
Location 5	2982.5	10.9	7.7	17.2	12.2	3.2	25.3	99.3
Location 6	4253.7	17.2	11.5	18.8	42.5	7.1	37.8	135.3
Environmental Factor	530	15	10	10	14	1.5	36	200

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Source: Laboratory analyzes were conducted at the Environmental Research Center, Soil Analysis Department, Baghdad, 2023.

In assessing the differences in concentrations of heavy metals across the six study sites, we used the Kruskal-Wallis H test, a non-parametric alternative to one-way ANOVA. This test is particularly suitable for datasets with small sample sizes and does not assume the normal distribution of data. The consistent results yielded a p-value of approximately 0.4159 for all heavy metals, including Fe, Co, Cu, Cr, Pb, Az, Zn, and Mn. Usually, a p-value of 0.05 is used to determine statistical significance, where results below this value indicate significant differences between groups. However, considering our findings, p-values larger than 0.05 indicate no statistically significant differences in the concentrations of these heavy metals across the studied sites. This means that statistically speaking, the sites do not significantly differ in their concentrations of heavy metals.

Table (3) and Figure (1) depict the results related to the Contamination Factor (CF) of heavy metals at six selected sites in Basra City, revealing some noteworthy findings. The results clearly indicate a substantial contamination of Iron (Fe) with an average CF of approximately 7.785, making it the most polluting metal within the study scope. Arsenic (Az) closely follows with an average approaching 5.01. On the other hand, Manganese (Mn) shows the lowest pollution levels, reflected in a CF average of only 0.598. A significant revelation from our study was the consistently high pollution levels at "Site 4," identified as the most polluted site for all the studied metals. This observation emphasizes the critical need for further investigation into the sources or processes leading to such elevated pollution values at this specific site.

For statistical analysis, the Kruskal-Wallis H test was employed, producing intriguing results: each metal yielded an identical p-value of 0.4159. This value, surpassing the traditional significance threshold of 0.05, indicates no significant differences in the Contamination Factor (CF) values for the metals across the six sites in Basra City. However, the consistent repetition of the same p-value for all metals suggests a clear similarity in CF data across all the studied sites for each metal.

In our quest to distinguish differences in soil pollution levels across distinct sites, we resorted to the non-parametric post-hoc Dunn's test after performing the Kruskal-Wallis H test. Interestingly, the results for all metals exhibited a consistent p-value of 0.317311 for each comparison between the studied sites. These values, exceeding the conventional significance threshold of 0.05, indicate no statistically significant differences in pollution levels between any pair of sites. The noticeable uniformity in these results suggests a potential overall similarity in pollution profiles for each metal across the examined sites, calling for a deeper exploration of the sources leading to this consistent pollution.

Table 3. Contamination Factor (CF) of heavy metals in surface soil samples in Basra City.

Location \ Element	Fe	Co	Cu	Cr	Pb	Az	Zn	Mn
Location 1	8.03	1.09	0.95	1.87	2.32	6.20	0.87	0.60
Location 2	5.89	0.75	0.82	1.79	0.95	3.40	0.78	0.51
Location 3	8.34	1.17	1.16	1.97	2.88	5.13	1.01	0.61
Location 4	10.79	1.18	1.34	2.03	4.08	8.47	1.18	0.69
Location 5	5.63	0.73	0.77	1.72	0.87	2.13	0.70	0.50
Location 6	8.03	1.15	1.15	1.88	3.04	4.73	1.05	0.68

Source: Laboratory analyzes were conducted at the Environmental Research Center, Soil Analysis Department, Baghdad, 2023.

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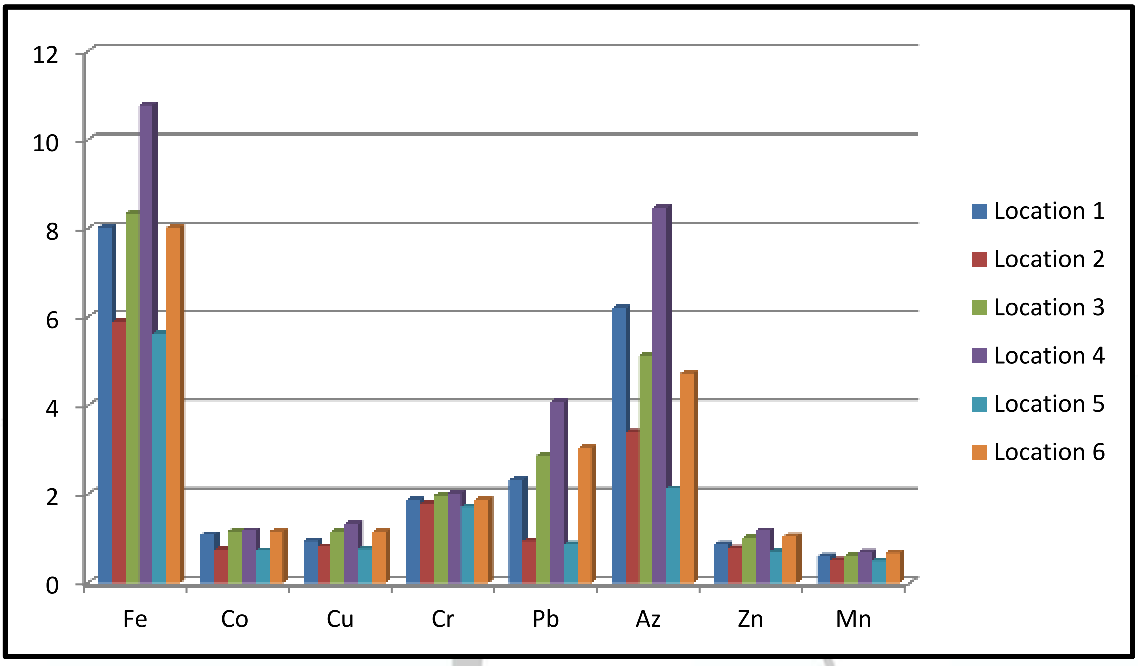
Figure 1. values of Contamination Factor (CF) for heavy metals in surface soil in Basra City.



Source: Data from Table 3 .

The results of the Contamination Factor (CF) observed at different sites in Basra City reveal varying degrees of heavy metal pollution in the soil. Several factors can explain these variations in CF values:

Industrial Activities: Areas with high CF values, especially Site-4, might be close to industrial zones. Industries often discharge liquid waste containing heavy metals, leading to soil contamination [Mohammed Ghassan Saloum, Adnan, 2010 p.348 and Mohammed Abdel Aziz Al-Jindi, 2018 p.30].

Agricultural Practices: Excessive use of fertilizers and pesticides can pollute the soil. Some of these agricultural chemicals contain heavy metals that accumulate in the soil over time [World Health Organization, 2022].

Waste Disposal: Improper disposal of household and industrial waste can cause leaching of heavy metals into the soil. Waste dumps, especially unmanaged ones, can be significant sources of pollution [Siddiqua, A., 2022 p.58514].

Traffic Emissions: Areas with high traffic density might have higher soil pollution due to emissions. Vehicles, especially older ones, emit heavy metals like lead [Kuklová M, 2022 p.183].

Natural Sources: Naturally occurring metals in the soil can sometimes contribute to the mineral content, although CF generally indicates human impacts. Common minerals supporting plant growth in soil include phosphorus, potassium, and nitrogen gas. Other less common minerals include calcium, magnesium, and sulfur [National Geographic Society, 2023].

High CF values are concerning due to their potential impact on human health. When soil is contaminated with heavy metals, they can enter the food chain through crops grown in that soil. Over time, consuming foods containing heavy metal residues can lead to health problems such as:

A. Neurological Disorders: Heavy metals, especially lead, are neurotoxic and can damage the central nervous system, leading to cognitive impairment, especially in children [Chen P, 2016 p.366].

B.Malignant Tumors: Some heavy metals, like chromium and arsenic, have been linked to increased risk of malignant tumors when consumed in large quantities over extended periods [Jyothi, N. R., 2020 p.357].

C.Organ Damage: Heavy metals can accumulate in vital organs like the liver, kidneys, and heart, causing organ damage and disrupting their functions [Oves, M., 2016 p.2].

D. Reproductive Issues: Some heavy metals are known to cause disturbances in endocrine glands, potentially leading to fertility and reproductive issues [McClam, M., 2023 p.161].

Mostly, agricultural practices in the city play a pivotal role. When soil is contaminated, crops absorb these heavy metals through their roots and transfer them to edible parts consumed by humans [Rashid A, 2023 p.1521]. Additionally, irrigation with contaminated water can introduce additional heavy metals into the soil and crops. Similarly, livestock grazing in polluted pastures ingest these pollutants, which accumulate in their meat, milk, or eggs. Besides food, groundwater sources can become contaminated when heavy metals seep from the soil into the aquifers. When consumed directly or used in food preparation, these contaminated waters exacerbate the risk of local populations ingesting heavy metals [Zhai Y, 2022 p.3571].

Basra, the major coastal city in southern Iraq, has faced pollution from various industrial sources. Among these industries, oil and gas have been significant contributors to air, water, and soil pollution due to refineries and extraction sites. Petrochemical facilities associated with oil production emit pollutants that affect both air and water quality. The city's port location poses risks of marine pollution, including oil spills and ship-generated wastes. Manufacturing units, particularly those producing chemicals, metals, and construction materials, release environmental pollutants [Salman, Sonia, & Yeghiazarian, Estabrak. 2022 p.115]. Power generation plants burning fossil fuels emit greenhouse gases and other pollutants. Moreover, inadequate waste management leads to land and water pollution, while agricultural runoff from surrounding areas introduces pesticides and fertilizers into waterways. Previous regional conflicts have also contributed to Basra's environmental degradation. Despite implementing measures to mitigate these pollution sources, their cumulative effects over time have significantly impacted the local environment. The city's history is marked by the aftermath of wars, including concerns about depleted uranium usage during the conflict, potentially affecting soil quality and health [Nashour, Ilham Khuzai, 2013 p.313].

In a recent study conducted in Baghdad, several heavy metals were evaluated using different indices, similar to our study in Basra. It's worth noting that the overall pollution index in Baghdad indicates low pollution from metals like copper, manganese, and zinc. However, it revealed moderate to very high levels of lead and cadmium pollution. This observation might align with our findings due to regional similarities and potential shared pollution sources. Additionally, while certain residential areas in Baghdad showed high levels of soil contamination, especially from lead and cadmium, environmental risks were observed to be moderate to low. The differences and similarities between these studies could stem from unique urban and industrial activities in each city or variations in monitoring periods and seasonal impacts [Al-Dahar, 2023 p.43].

A study from Tikrit also assessed surface soil pollution caused by heavy metals, revealing concentrations of zinc, copper, and lead, among others. Nickel and lead were identified as primary pollutants of human activity. The Pollution Load Index (PLI) indicates significant heavy metal pollution, although health risk assessments indicated minimal risks for both adults and children [Mahmoud Fadel Abd, 2017 p.1]. Interestingly, chromium poses the highest cancer risk. Comparing these results with ours in Basra may help clarify regional patterns of heavy metal pollution and associated health effects.

In a previous study, it was revealed that Lake Jazmourian, a dry lake in southeastern Iran, showed varying levels of rare metal pollution, particularly lead, nickel, and aluminum [Shirani, M., 2020 p. 4775]. The study employed various pollution indices on this lake, revealing elevated levels of enrichment factors and risks at specific sites. It's worth noting that climate change played a significant role in reshaping local water and sediment pollution issues in the area. Drawing parallels with the results obtained in the study area provides a sharp comparison, emphasizing the broader impacts of metal pollution in diverse regional contexts.

Table (4) and Figure (2) present the results of calculating the Enrichment Factor (EF) for the elements under study at the six sites in the city of Basra. In this study, iron (Fe) was used as a reference metal for calculating the Enrichment Factor (EF). The logical basis behind using iron as a two-fold reference metal is as follows: First, iron is ubiquitously present in soils and sediments with limited variation due to its natural occurrence. Second, compared to other trace metals, iron concentrations in sediments and soils are typically less affected by human activities. Hence, its stable baseline concentration serves as a reliable standard to measure the relative enrichment factor of other metals, and consequently, its enrichment factor for itself will always be 1 [Chester, R., 1967 p. 250].

In our study, we calculated the Enrichment Factor (EF) for various heavy metals across the six sites to understand their relative enrichment concerning the reference metal, iron (Fe). It's worth noting that arsenic (Az) exhibited

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the highest average EF value, approximately 0.674, indicating a clear enrichment in the samples compared to the background. On the other hand, manganese showed the lowest enrichment ratio with an average EF value of about 0.210, confirming diverse patterns of pollution and deposition in the studied areas. One of the notable findings was the pronounced enrichment of several metals reflected in the maximum EF value of 1.0, indicating significant pollution sources affecting specific sites. Examining the variations among the selected sites in Basra, "Site-4" showed the highest average EF value of around 0.251. These results offer insightful perspectives on the relative distribution and potential sources of these metals in the study area.

In our comprehensive analysis of the Enrichment Factor (EF) values for heavy metals across multiple sites, we utilized the Kruskal-Wallis test, a non-parametric method suitable for datasets with non-normal distributions or unequal variations among groups. The consistently obtained results indicated a p-value of approximately 0.4232 for each heavy metal, including Co, Cu, Cr, Pb, Az, Zn, and Mn. This outcome signifies no statistically significant differences in EF values among the sites for any of the examined metals. This uniformity across the sites suggests a potential overall similarity in pollution or deposition patterns for each metal, indicating shared sources or mechanisms contributing to the EF values in the study areas.

Table 4. Enrichment Factor (EF) in surface soil samples in Basra City.

Element / Location	Co	Cu	Cr	Pb	Az	Zn	Mn
Location 1	0.135	0.118	0.233	0.289	0.772	0.108	0.075
Location 2	0.128	0.139	0.304	0.161	0.577	0.133	0.086
Location 3	0.14	0.139	0.236	0.345	0.615	0.121	0.074
Location 4	0.109	0.124	0.188	0.378	0.784	0.109	0.064
Location 5	0.129	0.137	0.306	0.155	0.379	0.125	0.088
Location 6	0.143	0.143	0.234	0.378	0.59	0.131	0.084

Source: Laboratory analyzes were conducted at the Environmental Research Center, Soil Analysis Department, Baghdad, 2023

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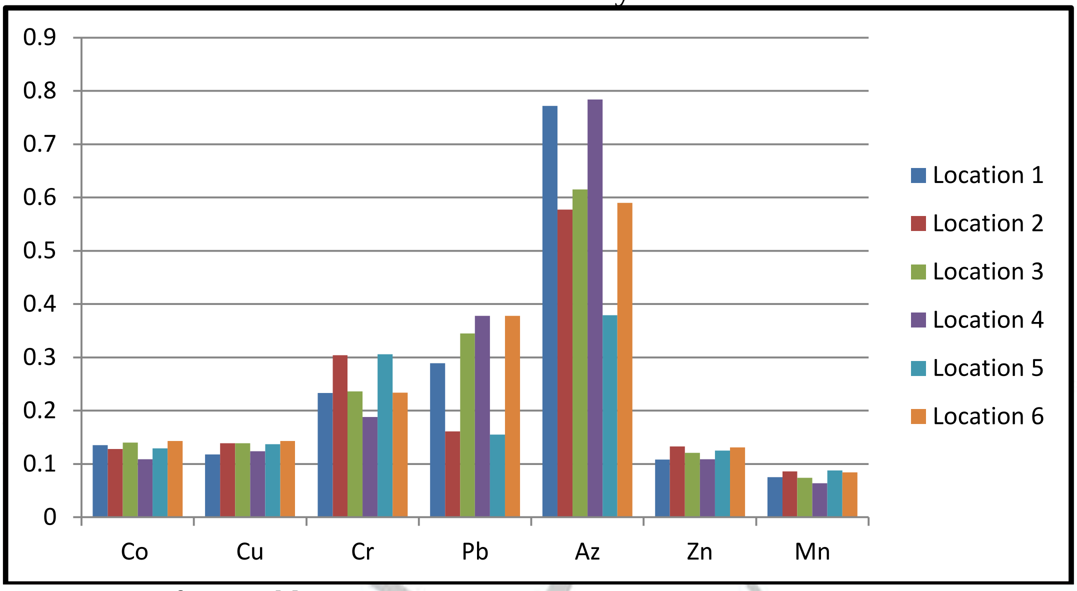
Figure 2. Enrichment Factor (EF) values for heavy metals in the surface soil of Basra City.



Source: Data from Table 4 .

Table (5) presents data related to the Pollution Load Index (PLI). The Pollution Load Index (PLI) was calculated for each site based on the values of the Contamination Factor (CF) for various heavy metals included in the study. PLI values provide an accurate insight into the degree of pollution at each site. Sites with PLI values greater than 1 indicate higher pollution levels, while sites with PLI values less than 1 indicate lower pollution levels.

In our comprehensive assessment of pollution levels across different sites, the Pollution Load Index (PLI) served as a pivotal gauge, shedding light on the overall pollution degree. Sites exhibited diverse PLI values, indicating varying levels of pollution. It is noteworthy that Site-3, Site-4, and Site-6 showed a high degree of pollution, with PLI values of 1.578, 1.903, and 1.589 respectively. On the other hand, Site-5 displayed the lowest pollution level with a PLI index of 0.936. Meanwhile, Site-1 and Site-2 exhibited moderate pollution levels. These data confirm the heterogeneous nature of pollution across the studied sites, emphasizing the importance of targeted environmental interventions. These results highlight differences in pollution levels across the surveyed sites, which could significantly impact environmental management and remediation efforts.

Table 5. Pollution Load Index (PLI) in surface soil samples in Basra City.

ZDSA	Pollution Load Index (PLI)	Pollution Level
Location 1	1.466	Medium
Location 2	1.051	Medium
Location 3	1.578	High
Location 4	1.903	High
Location 5	0.936	Low
Location 6	1.589	High

Source: Laboratory analyzes were conducted at the Environmental Research Center, Soil Analysis Department, Baghdad, 2023.

Figure (3) illustrates a scatter plot representing the values of the Pollution Load Index (PLI) across different study sites, connected by a red line to depict the trend. The vertical axis represents PLI values, which serve as a measure of pollution, while the horizontal axis lists the distinguished study sites. The graph shows that some sites exhibit higher PLI values than others, indicating varying degrees of pollution. The connecting line also provides insight into fluctuations in pollution levels across the sequence of sites. This visual representation allows for a comprehensive understanding of the pollution landscape across the studied areas, highlighting areas of interest.

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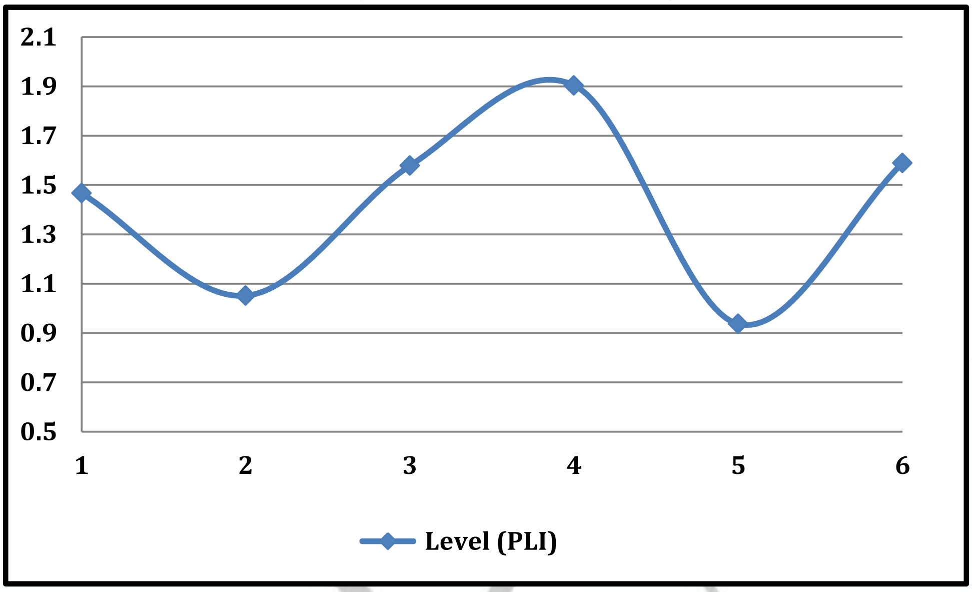
Figure 3. Scatter plot of Pollution Load Index (PLI) values for the soil in Basra City with the connecting line.



Source: Data from Table 5 .

The results of our study on heavy metal pollution in the surface soil of Basra City, as evaluated through Pollution Load Index (PLI) calculations, present intriguing similarities and differences when compared to a related study conducted in the Miyan Ab Plain, Khuzestan City [Jorfi, S, 2017 p.585]. Both studies utilized PLI as a primary indicator to measure the degree of pollution at various sampling sites, demonstrating that PLI values greater than 1 indicate higher pollution levels, whereas values less than 1 indicate lower pollution. This classification shares common ground with the findings in the Miyan Ab Plain, where PLI values were used to identify moderately polluted areas (24% of the region) alongside unpolluted areas (76%). Nevertheless, while our results carry similarities, they also shed light on local variations in the pollution landscape. These divergences may be attributed to distinct geographical, industrial, or agricultural dynamics unique to each area, a critical factor deserving close examination.

In a parallel study conducted on the industrial city of Jubail, Eastern Saudi Arabia, surface soil samples exhibited extensive pollution, notably with lead (Pb) concentrations reaching up to 2270 times the baseline values in certain areas. These findings confirm the potential risks associated with industrial activities and their far-reaching effects on the environment. In our study, similar high levels of certain metals indicate potential common sources or pollution processes. This correlation emphasizes the urgent need for regular monitoring, stricter regulations on industrial emissions, and effective remediation strategies to ensure environmental safety and public health.

Comparing our findings with a study conducted in Jubail, Eastern Saudi Arabia, it becomes evident that industrial activities are a major source of environmental pollution. Both studies indicate PLI values significantly higher than 1, signifying conspicuous pollution, while our study revealed a peak PLI of 2.34 at Site 4. The investigation in Jubail indicated globally high values across all areas, suggesting broader industrial pollution. These parallels underscore the urgent need for regular environmental assessments, tightening controls on industrial emissions, and proactive mitigation efforts to alleviate environmental impacts.

A previous study revealed diverse levels of heavy metal pollution in the agricultural soil of Liwa, a major food-producing area in the United Arab Emirates [Al-Taani AA, 2021 p.53]. This offers a comparative context for evaluating pollution in our sites, particularly concerning metals such as manganese, zinc, and chromium. Insights from the study about pollution sources, such as agricultural chemicals and airborne dust, provide valuable context for our research. Specifically, shedding light on the non-crustal origins of some heavy metal enrichment processes. Therefore, their methodologies, especially the use of the geoaccumulation index and environmental risk assessment, can be adopted or adapted for a comprehensive understanding of pollution in our sites. Furthermore, distinguishing between low and high environmentally hazardous metals provides a precise approach that could be beneficial for analyzing our study and its recommendations.

Assessing the accumulation of heavy metals in the surface soil of Basra City holds utmost significance. Environmental health in the region and the well-being of its inhabitants are closely linked to soil quality. The use of advanced environmental pollution indicators, such as pollution and enrichment factors and the Pollution Load Index, enables a multifaceted and precise assessment of pollution levels. These indicators not only determine the extent of pollution but also shed light on potential sources and impacts. With the growth of urban development and industrial activities in Basra City, such analyses have become vital in making crucial decisions to ensure mechanisms for environmental sustainability and public health safety.

Accumulation of heavy metals in the surface soil of Basra City can be attributed to various human activities. Advanced environmental pollution indicators - Pollution Factor, Enrichment Factor, and Pollution Load Index - provide precise insights into this phenomenon. These indicators reveal "industrial discharges, vehicular emissions, improper waste disposal, and intensive use of agricultural chemicals as major contributing factors. Additionally, urban sprawl and increased transportation within the study area exacerbate the situation. By employing these advanced measures, we can identify pollution sources, assess their proportions, and develop strategies to mitigate the negative environmental impacts in the region. Moreover, the presence of oil and the hot humid climate can influence the nature and concentrations of heavy metals in the surface soil of a region like Basra. This is influenced by the following factors:

Oil Activities: Oil exploration and extraction affect concentrations of heavy metals in the surface soil, as evidenced by a study conducted on samples near drilling sites. The research indicated increased pollution levels, especially concerning copper, chromium, zinc, and nickel, around these sites. Risk assessments identified carcinogenic and non-carcinogenic threats from metals such as Cr, As, Pb, emphasizing environmental and health risks associated with oil activities, highlighting the need for remedial measures, especially in agricultural areas. Oil spills exacerbate the problem by releasing trace metals from crude oil into the environment [Aradhi, K.K, 2023 p.10614].

Sewage Water Discharge: Sewage water produced during oil extraction often contains high concentrations of heavy metals. If not properly treated, this can lead to surface soil contamination [Laura Castanaris, 2021].

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In hot climates, accelerated weathering processes of rocks and soil release heavy metals into the surface soil. Both wet and arid conditions affect this release. While moisture enhances leaching, leading to metal accumulation in water collecting areas, arid climates, characterized by dryness and temperature fluctuations, intensify evaporation, pushing heavy metals upwards, especially in sandy soil. A study conducted on Saudi Arabian soil highlighted this upward transport, leading to potential airborne pollution and public health hazards. These results emphasize the significant role climatic conditions play in the surface concentration of heavy metals [Lima, A. T., 2014 p.639].

Biological Activity: Hot and humid climates often support diverse biological ecosystems. The decomposition of organisms can release stored metals into the soil. Soil organisms, including microorganisms, use organic matter in the soil as food. When breaking down organic matter, they release excess nutrients like nitrogen, phosphorus, and sulfur into the soil in forms usable by plants. This release process is called mineralization [Bot, A, 2005].

Regarding the quantitative approach in the current study, both pollution indicators (such as CF, EF, PLI) and statistical analyses are of clear importance in environmental assessments. Pollution indicators provide direct measures of pollution levels, facilitating easy site comparisons and setting treatment standards. However, their limitations lie in not determining the possibility that observed differences are random and relying on specific predetermined reference values. On the other hand, statistical analyses determine the likelihood that significant differences are not due to random variations, strengthening results derived from pollution indicators. Nevertheless, they come with assumptions and might be challenging for non-statisticians to interpret. Additionally, their effectiveness can be affected by small sample sizes, as is the case in our dataset where each site has only one observation, making the indicators more valuable in such outcomes. However, in studies with large datasets per site, the intertwining of statistical methods with pollution indicators leads to a comprehensive understanding. While pollution indicators provide measures of pollution, statistical tests verify the significance of these observations. For our specific study and considering the dataset structure, pollution indicators offer more insights. In general, harnessing both approaches, especially when datasets are extensive and comply with the fundamental requirements of statistical tests, is beneficial.

Conclusions:

Our study shed light on the comprehensive assessment of heavy metal concentrations in surface soil samples at six locations in Basra City, revealing the extent of pollution in the area. The conclusions are as follows:

1. Site 4 consistently exhibited the most striking figures, containing the highest concentrations of several metals, including iron, cobalt, chromium, lead, zinc, and manganese.
2. The use of the Contamination Factor (CF) also revealed clear contamination of several heavy metals at Site 4 when compared to baseline environmental levels.
3. This observation was reinforced when evaluating the Pollution Load Index (PLI), with Site 4 showing concerning levels of pollution, while other sites exhibited more moderate pollution.
4. The Enrichment Factor (EF), which used iron as a reference metal due to its stability in the soil and minimal human impact, provided insights into the relative enrichment of other metals across the sites.
5. Lead at Sites 4 and 6 showed significantly high enrichment levels.

We believe our study on heavy metal pollution in Basra City underscores the urgent need for targeted interventions, especially in identified hotspots like Site 4. Comparing our findings with related studies highlights the global relevance of indicators like PLI, emphasizing the nuanced nature of environmental pollution across different landscapes.

Recommendations

1. Due to the evident pollution levels observed, especially at sites 3-4-6 in Basra City, immediate remedial actions should be taken.
2. Local authorities should initiate comprehensive interventions to remediate soil and remove toxins in highly polluted areas.

3. Regular monitoring should be conducted at all sites to track changes in heavy metal concentrations and assess how effective the implemented measures are.
4. Further research into potential sources of pollution, whether in industrial activities or agricultural practices, should be urged to implement preventive measures.
5. Collaborating with regions that have conducted similar studies, such as the Miānāb Plain in Khuzestan Province, could provide valuable insights and best practices for mitigating pollution sources.
6. Community awareness campaigns should be launched to educate the public about the implications of heavy metal pollution and how citizens can help reduce their environmental footprint.

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