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Trace Metals in Residual Soil from the Oil Fields in Basrah Governorate, Iraq

Fatima J . Ahmed[1*], iD Ayad H. D. Alkafaji[1] and iD Hamid T. Al-Saad[2]

1-Department of Biology, College of Science, University of Basrah, Basrah- Iraq
2-College of Marine Science, University of Basrah, Basrah- Iraq
**Corresponding Author: e-mail: fatima.jassim@uobasrah.edu.iq*

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Abstract - This research investigates the levels of trace metals in residual soil samples collected from eleven locations within the oil fields of Basrah Governorate, Iraq (Seba, Safwan, Majnoon, Ratawi, Bergezia, West Qurna 2, West Qurna 1, Shuaaba, South Rumaila, North Rumaila, and Al Zubair). The primary objective is to assess soil contamination caused by oil extraction activities, using advanced analytical techniques to evaluate heavy metal concentrations and their environmental impact. The measures of trace metals were done by Inconductivity Coupled Plasma (ICP). Metals analyzed include Zn, Cd, Mn, Pb, Fe, Cu and Cr. The study used indicators like Contamination Factor (CF), Enrichment Factor (EF), Geo-Accumulation Index (Igeo), and Pollution Load Index (PLI) to assess the contamination levels. The concentrations of Zn were at their lowest 10.765 ug/g dry weight in South Rumaila field and the highest 60.694 ug/g dry weight in Safwan field. The concentrations of Cd were at their lowest 0.304 ug/g dry weight in Shuaaba field and the highest 1.646 ug/g dry weight in West Qurna 1 field. The concentrations of Mn were at their lowest 71.847ug/g dry weight in Majnoon field and highest 396.628ug/g dry weight in West Qurna 1 field. The concentrations of Pb was lowest 0.480 ug/g dry weight in South Rumaila field and highest 39.288 ug/g dry weight in West Qurna 2 field. The concentrations of Fe was lowest 3372.278ug/g dry weight in South Rumaila field and highest 9279.445 ug/g dry weight in West Qurna 1 field. The concentrations of Cu was lowest 5.272 ug/g dry weight in South Rumaila field and highest 304.929 ug/g dry weight in West Qurna 1 field. The concentrations of Cr was lowest 18.368 ug/g dry weight in Al-Zubair field and highest 76.347ug/g dry weight in West Qurna 1 field. The results showed that Cadmium (Cd) and Copper (Cu) Showed the highest contamination levels, particularly in "West Qurna 1" and "Safwan," indicating significant industrial influence. Lead (Pb) and Zinc (Zn) Moderate contamination was observed in fields like "Safwan" and "West Qurna 2," while other sites showed lower levels. Iron (Fe), Manganese (Mn), and Chromium (Cr) Found within natural thresholds, with minimal contamination across most locations. Pollution Load Index (PLI) Most fields had PLI < 1, indicating low overall pollution, except "West Qurna 1," where PLI > 1 indicates significant contamination..

العناصر النزرة المتبقية في ترب حقول النفط، محافظة البصرة، العراق

فاطمة جاسم احمد[1] و أياد حنتوش الخفاجي[1] و حامد طالب السعد[2]

1- قسم علوم الحياة، كلية العلوم، 2- كلية علوم البحار، جامعة البصرة ، البصرة – العراق

المستخلص - يتناول هذا البحث دراسة مستويات العناصر النزرة في عينات التربة التي تم جمعها من إحدى عشر موقعًا داخل حقول النفط في محافظة البصرة، العراق (السيبة، سفوان، مجنون، ارطاوي، برجسية، غرب القرنة 2، غرب القرنة 1، الشعيبة، الرميلة الجنوبية، الرميلة الشمالية، والزبير). الهدف الأساسي هو تقييم تلوث التربة الناجم عن أنشطة استخراج النفط، باستخدام تقنيات تحليلية متقدمة لتقييم تركيزات المعادن الثقيلة وتأثيرها البيئي تم

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قياس العناصر النزرة بواسطة (ICP). المعادن التي تم تحليلها تشمل الزنك والكادميوم والمنجنيز والرصاص والحديد والنحاس والكروم. المؤشرات المستخدمة مثل عامل التلوث (CF) وعامل الإثراء (EF) ومؤشر التراكم الجيولوجي (Igeo) ومؤشر حمل التلوث (PLI). وكان تركيز الزنك أقل ما يمكن عند 10.765 ميكروجرام/جرام وزن جاف في حقل الرميلة الجنوبي وأعلى ما يمكن عند 60.694 ميكروجرام/جرام وزن جاف في حقل صفوان. وكان تركيز الكادميوم أقل ما يمكن عند 0.304 ميكروجرام/جرام وزن جاف في حقل الشعيبة وأعلى ما يمكن عند 1.646 ميكروجرام/جرام وزن جاف في حقل غرب القرنة 1. وكان تركيز المنغنيز أقل ما يمكن عند 71.847 ميكروجرام/جرام وزن جاف في حقل مجنون وأعلى ما يمكن عند 396.628 ميكروجرام/جرام وزن جاف في حقل غرب القرنة 1. وكان تركيز الرصاص أقل ما يمكن عند 0.480 ميكروجرام/جرام وزن جاف في حقل الرميلة الجنوبي وأعلى ما يمكن عند 39.288 ميكروجرام/جرام وزن جاف في حقل غرب القرنة 2. كان تركيز الحديد أقل ما يمكن عند 3372.278 ميكروغرام/غرام وزن جاف في حقل الرميلة الجنوبي وأعلى ما يمكن عند 9279.445 ميكروغرام/غرام وزن جاف في حقل غرب القرنة 1. وكان تركيز النحاس أقل ما يمكن عند 5.272 ميكروغرام/غرام وزن جاف في حقل الرميلة الجنوبي وأعلى ما يمكن عند 304.929 ميكروغرام/غرام وزن جاف في حقل غرب القرنة 1. وكان تركيز الكروم أقل ما يمكن عند 18.368 ميكروغرام/غرام وزن جاف في حقل الزبير وأعلى ما يمكن عند 76.347 ميكروغرام/غرام وزن جاف في حقل غرب القرنة 1. وأظهرت النتائج أن الكادميوم (Cd) والنحاس (Cu) أظهرا أعلى مستويات التلوث، وخاصة في "غرب القرنة 1" و"سفوان"، مما يدل على تأثير صناعي كبير. كما لوحظ تلوث معتدل للرصاص (Pb) والزنك (Zn) في حقول مثل "سفوان" و"غرب القرنة 2"، في حين أظهرت مواقع أخرى مستويات أقل. أما الحديد (Fe) والمنغنيز (Mn) والكروم (Cr) فقد وجدت ضمن الحدود الطبيعية، مع الحد الأدنى من التلوث في معظم المواقع. مؤشر حمل التلوث (PLI) كان لدى معظم الحقول مؤشر < 1، مما يدل على انخفاض التلوث الإجمالي، باستثناء "غرب القرنة 1"، حيث يشير مؤشر PLI > 1 إلى تلوث كبير.

الكلمات مفتاحية: البصرة ، حقول نفط البصرة ، المتبقي ، العناصر النزرة ،ICP.

Introduction

Trace metals are essential components of soil composition and are categorized according to their availability for plant absorption. In contaminated regions, particularly those associated with oil production, trace metals can significantly impact ecosystems and human health (Kadhum *et al.*, 2024). The Basrah governorate in southern Iraq is particularly noted for its oil extraction activities (Al-Halfy *et al.*, 2021)**.** Recent research in the field of environmental science has highlighted an increasing concern regarding soil contamination caused by oil production, particularly in oil fields. The south of Iraq, residues from abandoned oil reservoirs are contributing to environmental degradation, with significant ramifications for the residual soil in Basrah region (Muslim *et al.*, 2022). There is currently insufficient information on the levels of trace metals present in these contaminated areas. In response to this gap, advanced analytical methods are being employed to evaluate various essential elements found in the region (AI-Saad *et al.*, 2022). The presence of trace metals is known to affect the morphological, physicochemical, and biological processes that are vital for maintaining soil fertility. Contaminants, including petroleum hydrocarbons and harmful metals, arise from extensive crude oil extraction activities, resulting in persistent environmental issues that demand urgent remediation efforts (Al-Bayati *et al.*, 2021). Soil contamination represents a significant environmental concern globally, affecting nations including Iraq and others in the Middle East (Al-Shammari *et al.*, 2022). It is widely believed that the Basrah Governorate in southern Iraq is experiencing heightened levels of environmental contamination (Assi, 2023). This region grapples with severe pollution issues, particularly associated with Shatt Al-Arab River, the atmosphere, and marine environments (Ali *et al.*, 2020). The intricate relationships among ecosystem components such as soil, water, plants, and organisms involve global cycles, health risks, and biogeochemical patterns that require monitoring, modeling, and management to safeguard public health and mitigate the presence of toxic trace metals in food chains (Gupta, 2020). Activities like industrial production, agriculture, and urban development elevate the concentrations of certain trace metals in the environment (Vithanage *et al.*, 2022). While trace metals are naturally occurring in soils, waters, and on the Earth's surface, their levels have been notably augmented by historical and current industrial practices. Urban environments are primary contributors to trace metal pollution, with soil serving as the ultimate repository for these contaminants (Istanbullu *et al.*, 2023). The Aim of the Study determine the concentration, sources, and origins residual trace metals in the soil of 11 oil fields in Basrah Province, southern Iraq.

Materials and Methods

Study Area:

Soil samples were collected from eleven fields (Seba, Safwan, Majnoon, Ratawi, Bergezia, West Qurna 2, West Qurna 1, Shuaaba, South Rumaila, North Rumaila and Al Zubair) in the oil fields at Basrah city as shown in Figure (1).

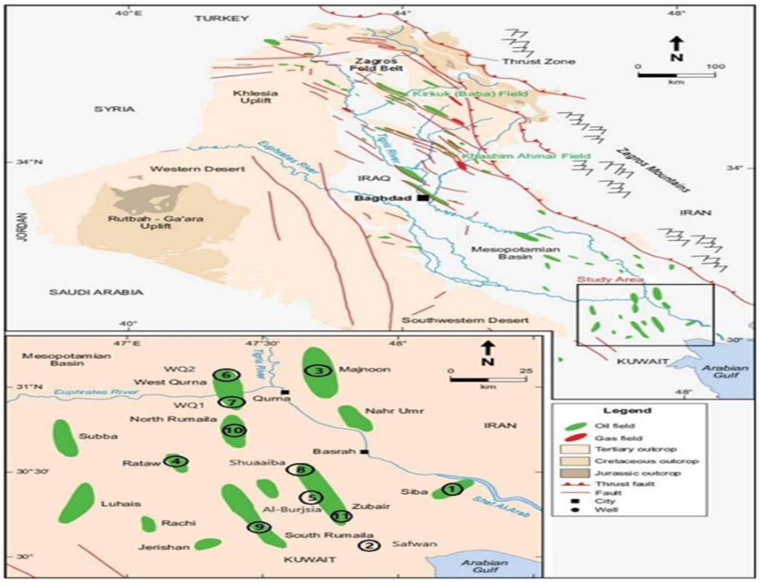

Figure 1. Maps of the study area

Heavy Metals Analysis:

The Residual:

The residual heavy metals were extracted according to Sturgen *et al.* (1982). Concentrated HCl and HNO_3 (1:1) were added to each sample and evaporated to near dryness on a hotplate at 80°C, then a mixture of concentrated $HClO_4$ and HF (1:1) were added. After heating to near dryness, 20 ml of 0.5 HCl were added and cooled for 10 min. The extraction was decanted into 25 ml plastic volumetric flask. This step was repeated twice and all supernatant were combined. Samples were stored in tight stopper polyethylene vials to be ready for analysis by inductively Coupled Plasma (ICP).

Determination of Contamination Factor (CF):

Contamination Factor was used to determine the contamination status of soil in this study. CF was calculated by the equation described below:

$$CF = Mc/Bc$$

Where;

Mc : The measured concentration of the metal.

Bc: the background concentration of the same metal.

Table 1. Hakanson 1980 the classification of contamination factor.

CF	Indicate of Contamination Factor
CF<1	low contamination
1≤CF≤ 3	moderate contamination
3≤CF<6	considerable contamination
CF>6	very high contamination

Determination of Enrichment Factor (EF):

To evaluate source material found in the Earth's crust (Huheey, 1983), EF was calculated by the equation described below:

$$\mathbf{EF = (CM / CFe)\ sample / (CM / CFe) Earth's\ crust}$$

Where;

CM / CFe: The sample ratio of concentration of trace metal

CM / CFe Earth's crust: is the same reference ratio in the Earth's crust; the reference value of Fe is 5.2% was selected as the reference element, due to its crustal dominance and its high immobility (Huheey, 1983).

Table 2. Huheey 1983 the classification of enrichment factor (EF).

EF	Indicates of Enrichment Factor
EF <1	no enrichment
EF = 1-3	minor enrichment
EF = 3-5	moderate enrichment
EF = 5-10	moderate to severe enrichment
EF = 10-25	severe enrichment
EF 25-50	very severe enrichment
EF >50	extremely severe enrichment

Determination of Geo Accumulation Index (Igeo):

Geo accumulation index (Igeo) values were calculated of different metals, (Igeo) was calculated by the equation that is introduced by (Muller, 1969) as described below:

$$\mathbf{I\text{-}geo = \log_2 (Cn / 1.5\ Bn)}$$

Where;

Cn: The measured concentration of element n in the soil.

Bn: The geo accumulation background for the element n.

Table 3. Muller 1969 the classification of (Igeo).

Igeo	Soil Pollution Case
<1	practically unpolluted- Background sample
1-2	unpolluted to moderately polluted
2-3	moderately polluted to polluted
3-4	strongly polluted
4-5	strongly to extremely polluted
>5	extremely polluted

Pollution Load Index (PLI):

Soil pollution load index was calculated using the equation:

$$PLI = \sqrt[n]{(CF1 \times CF2 \times CF3 \times CFn)}$$

Table 4. Tomlinson *et al.* (1980) the classification of (PLI).

PLI	The Indicates
value > 1	Pollution
value < 1	no pollution

Results and Discussion

Results of the study are shown in Table (5) and Figure (2). The concentrations of Zn was lowest 10.765 ug/g dry weight in South Rumaila field and the highest 60.694 ug/g dry weight in Safwan field as shown in (Table 5 and Fig. 2). The concentrations of Cd was lowest 0.304 ug/g dry weight in Shuaaba field and the highest 1.646 ug/g dry weight in West Qurna 1 field (Table 5 and Fig. 2). The concentrations of Mn was at its lowest 71.847ug/g dry weight in Majnoon field and highest 396.628ug/g dry weight in West Qurna 1 field (Table 5 and Fig. 2). The concentrations of Pb was lowest 0.480 ug/g dry weight in South Rumaila field and highest 39.288 ug/g dry weight in West Qurna 2 field (Table 5 and Fig. 2). The concentrations of Fe was lowest 3372.278ug/g dry weight in South Rumaila field and highest 9279.445 ug/g dry weight in West Qurna 1 field (Table 5 and Fig. 2).

Table 5. Concentration of residual trace metals (ug/g) dry weight

Fields	**Zn**	**Cd**	**Mn**	**Pb**	**Fe**	**Cu**	**Cr**
Seba	45.231	1.114	383.322	2.584	6773.00	14.850	55.341
Majnoon	40.530	0.575	71.847	3.647	5152.388	6.664	22.623
Ratawi	33.939	0.577	164.053	4.973	5219.880	7.209	34.407
Bergezia	28.675	0.339	83.706	5.731	3630.297	8.506	22.028
Safwan	60.694	1.396	330.052	6.561	9198.399	30.500	72.947
South Rumaila	10.765	0.314	89.808	0.480	3372.278	5.272	47.158
Shuaaba	36.782	0.304	73.543	5.614	3475.508	14.816	16.046
West Qurna 1	60.318	1.646	396.628	4.813	9279.445	304.929	76.347
North Rumaila	38.474	0.474	129.609	3.568	4851.255	6.336	33.069
AlZubair	58.917	0.767	100.023	13.916	4388.155	53.486	18.368
West Qurna 2	20.510	0.804	184.068	39.288	7086.898	29.794	41.333

The concentrations of Cu was lowest 5.272 ug/g dry weight in South Rumaila field and highest 304.929 ug/g dry weight in West Qurna 1 field (Table 5 and Fig. 2). The concentrations of Cr was lowest 18.368 ug/g dry weight in Al-Zubair field and highest 76.347ug/g dry weight in West Qurna 1 field (Table 5 and Fig. 2). Metal toxicity is commonly associated with acute poisoning incidents; however, it is important to note that chronic exposure to low levels of metals over a lifetime has been linked to various non-communicable diseases and adverse health conditions in humans (Folorunso *et al.*., 2021). Research from epidemiological studies and animal models indicates a higher occurrence and frequency of diseases and health issues in both humans and animals exposed to elevated levels of trace metals (Al-Hadlaq *et al.*, 2022).

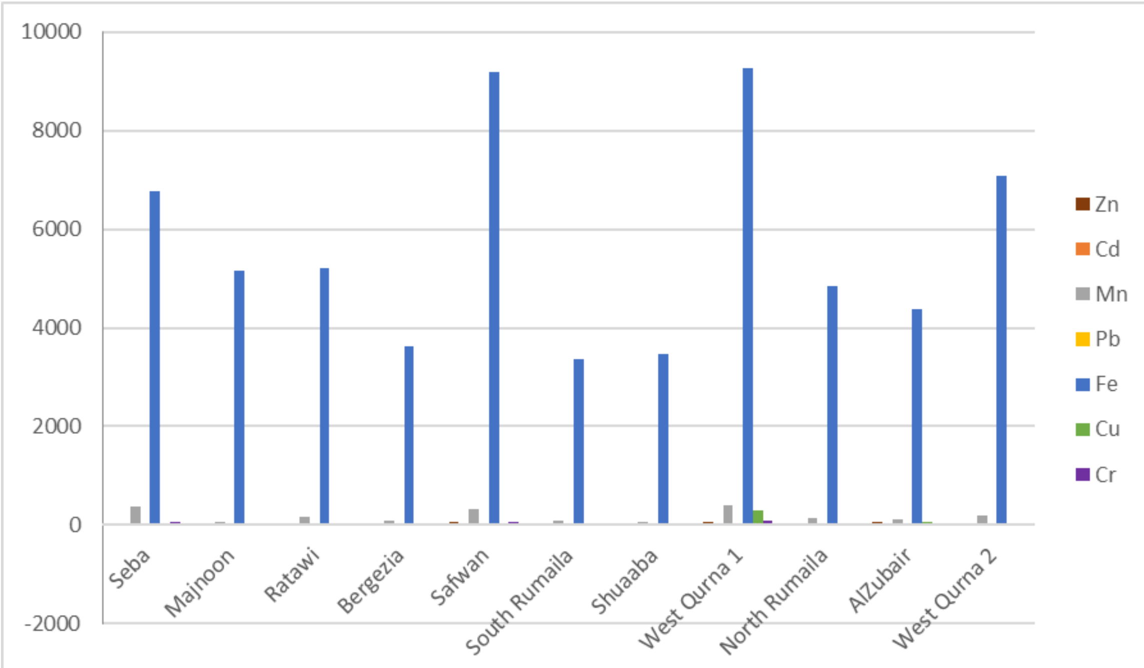

Figure 2. Concentration of Residual Trace Metals (ug/g) dry weight

The precise mechanisms by which exposure to these trace metals contributes to the onset and advancement of these diseases are not fully elaborated, particularly regarding the toxic actions of these metals. Additionally, recent advancements in understanding the health effects associated with metals have revealed that numerous metals can lead to similar health problems, and some may amplify the negative impacts caused by others (Anyanwu *et al.*, 2024). This information is poised to be significant for a variety of stakeholders, including policymakers, regulators, and industries, as it informs risk assessments, guides the management of metal exposures, aids in the formulation of health standards, and supports the development of environmentally sustainable practices aimed at protecting both environmental and public health (Di *et al.*, 2024).

Table (6) shows the levels of contamination by heavy elements (Zn, Cd, Mn, Pb, Fe, Cu and Cr) in soil based on the Contamination Factor (CF). The level of contamination is determined by comparing the concentration of the element in the sample with its natural concentration in the soil Table (1).

Most Contaminated Elements:

Cadmium (Cd):

Showed the highest levels of contamination, especially in fields like West Qurna 1 ,Seba and Safwan, where contamination levels reached severe thresholds (CF > 6).

Copper (Cu):

Recorded severe contamination in West Qurna 1 (CF = 11.728), pointing to significant human activity, likely due to equipment leakage or oil field operations.

Elements with Moderate or Natural Contamination:

Lead (Pb):

Showed moderate contamination in West Qurna 2 (CF = 2.619), while other stations exhibited natural or acceptable concentrations.

Zinc (Zn):

Most stations showed natural or slight contamination levels, with the highest value in Safwan (CF = 0.919).

Iron (Fe) and Manganese (Mn):

These elements did not show significant contamination, with all values remaining within natural thresholds.

Chromium (Cr):

Exhibited natural concentrations across all stations, indicating minimal human impact.

Table 6. The Contamination Factor (CF) of trace metals

Fields	CF_Zn	CF_Cd	CF_Mn	CF_Pb	CF_Fe	CF_Cu	CF_Cr
Seba	0.685	7.427	0.362	0.172	0.130	0.571	0.553
Majnoon	0.614	3.833	0.068	0.243	0.099	0.256	0.226
Ratawi	0.514	3.847	0.155	0.332	0.100	0.277	0.344
Bergezia	0.434	2.260	0.079	0.382	0.070	0.327	0.220
Safwan	0.919	9.307	0.312	0.437	0.177	1.173	0.729
South Rumaila	0.163	2.093	0.085	0.032	0.065	0.203	0.472
Shuaaba	0.557	2.027	0.069	0.375	0.067	0.570	0.160
West Qurna 1	0.914	10.973	0.375	0.321	0.179	11.728	0.763
North Rumaila	0.583	3.160	0.122	0.238	0.093	0.244	0.331
AlZubair	0.892	5.113	0.095	0.928	0.084	2.057	0.184
West Qurna 2	0.311	5.360	0.174	2.619	0.136	1.146	0.413

Table (7) shows the Enrichment Factors (EF) of heavy elements (Zn, Cd, Mn, Pb, Fe, Cu and Cr) in soils. EF is a tool for assessing the degree of soil contamination resulting from human activity compared to the natural background. (EF) determines the extent of anthropogenic influence by normalizing metal concentrations against a reference element (Fe) (Table 2). "West Qurna 1", "Al-Zubair" and "West Qurna 2" show the most significant enrichment for Cu , Cd and Pb, indicating potential hotspots of pollution.

Table 7. Enrichment Factor (EF) of trace metals

Fields	EF_Zn	EF_Cd	EF_Mn	EF_Pb	CF_Fe	EF_Cu	EF_Cr
Seba	5.261	57.018	2.781	1.322	0.130	4.385	4.248
Majnoon	6.197	38.687	0.685	2.453	0.099	2.586	2.283
Ratawi	5.122	38.320	1.544	3.302	0.100	2.762	3.427
Bergezia	6.223	32.372	1.133	5.472	0.070	4.686	3.155
Safwan	5.198	52.612	1.763	2.472	0.177	6.631	4.123
South Rumaila	2.515	32.278	1.308	0.493	0.065	3.126	7.271
Shuaaba	8.338	30.322	1.040	5.599	0.067	8.525	2.400
West Qurna 1	5.121	61.492	2.100	1.798	0.179	65.721	4.278
North Rumaila	6.248	33.871	1.313	2.549	0.093	2.612	3.544
Al-Zubair	10.578	60.593	1.120	10.993	0.084	24.377	2.176
West Qurna 2	2.280	39.328	1.276	19.218	0.136	8.408	3.032

Table (8) Geochemical Index (I-geo). I-geo assesses pollution levels by comparing metal concentrations to background values, considering natural variability (Table 3). West Qurna 1 and Safwan exhibit moderate to heavy contamination with cadmium (Cd) and copper (Cu), indicating significant anthropogenic influence. Other metals in these fields show minimal contamination. Zinc (Zn), manganese (Mn), and chromium (Cr) display low Igeo values in most fields, indicating no significant contamination.

Table 8. The geochemical accumulation coefficient (I-geo) of trace metals concentration

Fields	Igeo_Zn	Igeo_Cd	Igeo_Mn	Igeo_Pb	Igeo_Fe	Igeo_Cu	Igeo_Cr
Seba	-1.130	2.307	-2.049	-3.122	-3.525	-1.393	-1.435
Majnoon	-1.288	1.353	-4.465	-2.625	-3.920	-2.549	-2.729
Ratawi	-1.544	1.358	-3.274	-2.177	-3.901	-2.435	-2.124
Bergezia	-1.787	0.591	-4.244	-1.973	-4.425	-2.196	-2.767
Safwan	-0.705	2.633	-2.265	-1.777	-3.084	-0.354	-1.040
South Rumaila	-3.201	0.480	-4.143	-5.550	-4.531	-2.887	-1.669
Shuaaba	-1.428	0.434	-4.431	-2.002	-4.488	-1.396	-3.224
West Qurna 1	-0.714	2.870	-2.000	-2.224	-3.071	2.621	-0.974
North Rumaila	-1.363	1.074	-3.614	-2.656	-4.007	-2.621	-2.181
Al-Zubair	-0.748	1.769	-3.987	-0.693	-4.151	0.455	-3.029
West Qurna 2	-2.271	1.837	-3.107	0.804	-3.460	-0.388	-1.859

Table (9) shows the Pollution Load Index (PLI) for different fields, summarizing the overall contamination levels by multiple metals in the soil. PLI is a valuable metric used to assess the cumulative pollution status of an area based on contamination factors (CF) of individual metals (Table 4). Most fields have PLI values less than 1, indicating low levels of overall pollution. "West Qurna 2" (0.649) and "Safwan" (0.780) show slightly higher PLI values compared to other fields, suggesting moderate pollution. The field "West Qurna 1" has the highest PLI value (1.098), indicating that it is the most polluted area among all fields in the study.

As shown in Table (10), in general, the difference in the concentration of heavy elements for the present study with other studies is attributed to the difference in the quality of the selected soils in addition to the volume of household and health waste and the amount of industrial pollutants and others.

Table 9. Pollution Load Index (PLI) of trace metals for this study

Fields	PLI
Seba	0.538
Majnoon	0.300
Ratawi	0.284
Bergezia	0.284
Safwan	0.780
South Rumaila	0.178
Shuaaba	0.291
West Qurna 1	1.098
North Rumaila	0.327
Al-Zubair	0.536
West Qurna 2	0.649

Table 10. Trace metals concentrations (µg/g dry weight) in the present study as compared with the other previous studies.

Location	Zn	Cd	Mn	Pb	Fe	Cu	Cr	References
Khor Al-Zubair	27.41-58.48	-	353.7-570.6	-	6676.0-7398.3	7.56-27.73	-	Al-Saad *et al.*, 2006
Southern Iraq	-	-	506.3-408.6	-	-	38.3-16.63	-	Al-Saad *et al.*, 2007
Northern Iraq	-	9.79-19.65	91.65-111.5	-	-	6.18-14.42	-	Raheem, 2009
Southern Iraq	39.89	5	361.29	25	298.14	17.71	-	Khalaf, 2011
Shatt Al-Arab River	-	5.8	-	40.13	4170.89	30.15	-	Al-Qarooni, 2011
Basrah Oil Fields	10.765-60.694	0.304-1.646	71-847-396.628	0.480-39.288	3372.278-9279.445	5.272-304.929	16.046-76.347	Present study

Conclusions:

"West Qurna 1" and "Safwan" are the most polluted fields, especially with cadmium and copper. Most fields show low to moderate contamination, with evident anthropogenic impacts in some areas.

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