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Horizontal and Vertical Distribution of Heavy Elements on the Coast of the Shatt al-Arab, Basrah -Iraq

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ABSTRACT

Soil pollution hampers the achievement of the Sustainable Development Goals (SDGs), which include promoting human well-being, ensuring healthy lives, and eradicating poverty. Therefore, this study aimed to determine the pollution levels of heavy elements along the coast of the Shatt al-Arab in Basrah Governorate, southern Iraq. Soil core samples were randomly collected between October 2022 and April 2023 to measure the concentrations of heavy elements—manganese (Mn), lead (Pb), cadmium (Cd), chromium (Cr), zinc (Zn), iron (Fe), and nickel (Ni)—in both exchangeable and residual phases, using a flame atomic absorption spectrometer (AAS). A one-way analysis of variance (ANOVA) was performed using Minitab version 16.1. Additionally, pollution indicators including the geoaccumulation index (I-geo), contamination factor (CF), and enrichment factor (EF) were calculated. The highest concentrations of heavy elements (Ni, Fe, Zn, Cr, Cd, Pb, Mn) in the exchangeable phase were 120.59, 2158.02, 69.63, 262.16, 1.91, 714.13, and 837.83 µg/g dry weight, respectively, while the lowest concentrations were 21.25, 0.81, 7.44, 98.22, 22.45, 446.63, and 7.64µg/ g dry weight, respectively. In the residual phase, the highest concentrations were 109.01, 3005.05, 87.93, 383.5, 1.94, 339.66, and 306.38µg/ g dry weight, respectively, while the lowest were 18.52, 1511.6, 6.12, 39.13, 0.33, 4.53, and 24.8µg/ g dry weight, respectively. Pollution assessment using the calculated indices showed that the annual average of the I-geo values indicated moderate to significant pollution, particularly with Ni, Pb, and Cd. The contamination factor (CF) revealed very high contamination levels, especially for Pb, Ni, and Cd, while the enrichment factor (EF) indicated an extremely severe enrichment for the same elements. Based on the pollution indices, the order of heavy element pollution in the study area was: Pb > Ni > Cd > Cr > Mn > Zn > Fe.

INTRODUCTION

Although some heavy metals are essential to the operation of enzyme systems, excessive concentrations can be toxic. Others, like cadmium and lead, may be hazardous even at low concentrations and have no known biological purpose **(Savci, 2012)**. Due to human activities like mining, smelting, electroplating, energy and fuel production, energy transmission, intensive agriculture, and sludge dumping, heavy elements play a major role in environmental pollution, which is one of the biggest risks to human health and water and soil resources. Exposure to metals results in diseases and health issues. It is well known that heavy metals are the cause of several human illnesses, such as lung and breast cancer, which can result from accidental exposure **(Khalaf *et al.*, 2021; Abduljaleel & Abdulhaleem, 2022)**. Heavy elements bioaccumulate through the food chain and are not degraded by biological organisms **(Alam *et al*., 2019; Taher & Saeed, 2022)**. Using the contamination factor, **Al-Taie *et al.* (2024)** found significant cadmium pollution in Al-Zubair and Al-Shuaiba, located in Basrah. Heavy metal contamination is one of several pollution forms affecting Basrah City.

River pollution refers to the introduction of pollutants such as trash, toxic waste, pesticides, wastewater, and other hazardous residues, which create water contamination. These pollutants originate from either point sources or non-point sources, entering the river system through terrestrial runoff or atmospheric deposition. The presence of these substances alters and degrades the river’s water and sediment properties, affecting physicochemical characteristics (e.g., changes in temperature, pH, dissolved oxygen), biological aspects (e.g., harmful microorganisms), chemical parameters (e.g., accumulation of heavy metals and persistent organic pollutants), and the overall health of the river's flora and fauna **(Bhat *et al.*, 2022; Rasheed *et al.*, 2024)**.

Pollution jeopardizes the health of river users—including humans, animals, and plants—rendering river water, sediments, and aquatic life unsuitable for drinking, irrigation, and daily use **(Ali *et al.*, 2022; Sarkar *et al.*, 2022; Xu *et al*., 2022)**.

The sources and effects of river pollution, whether from anthropogenic or natural activities, have become increasingly dangerous. These pollution sources are generally classified into two categories: point sources (fixed sources) and non-point sources (non-fixed sources) **(Sahoo *et al*., 2021; Sabater *et al.*, 2022; Zakariah *et al*., 2022; Taher & Seed, 2023)**. Point sources typically include the discharge of wastewater from industrial zones or sewage treatment plants. These are often identifiable due to fixed pipelines channeling effluent directly into rivers, commonly located along riverbanks **(Bai *et al*., 2021; Schliemann *et al*., 2021)**. In some densely populated areas lacking effective sewage treatment, communities discharge untreated household waste directly into rivers. This direct input of sewage—containing numerous hazardous heavy metals—causes a sharp decline in water quality, making it unsuitable for domestic, industrial, and agricultural use. Sewage is considered the most common source of water pollution by heavy metals **(Al-Hejuje *et al*., 2017)**.

The current study aimed to determine the concentrations of heavy elements in beach core samples from the Shatt al-Arab shoreline. Additionally, pollution indices will be used to assess and understand the pollution status of the river coast.

MATERIALS AND METHOD

Core samples were collected seasonally during the period from July 2022 to April 2023 at four stations along the Shatt al-Arab coast (Qurna, Basrah center, Jaziirah and Abu Al-Khaseeb stations), as shown in the Table (1). Soil in core samples were divided according to depth into three fractions (0-10 , 11-20 and 21-30cm). These soil depths were selected because they represent the zones where most soil organisms thrive and where the roots of most plants cultivated in Basrah—such as vegetables—typically extend. These layers are particularly influenced by the concentration of heavy elements. Core soil samples were placed in polyethylene bags and transported to the laboratory for further analysis.

Table 1. The Shatt al- Arab coast GPS location

Longititude	Latitude	Location
47.948822	30.461771	Abo Al-Kasep
47.775423	30.578563	jaziirah
47.854323	30.505505	Basrah center
47.439616	30.010773	Qurna

Heavy elements extraction

The exchangeable phase extraction

Soil core samples were divided by depth into three fractions: 0–10cm, 11–20cm, and 21–30cm. The samples were dried at room temperature, then sieved through a 63µm mesh. Exchangeable heavy metal ions were extracted from the soil following the method described by **Chester and Voutsinou (1981)**. One gram of the dried soil was placed into a 50 ml polyethylene tube with a tight-fitting cap, and 30ml of 0.5N hydrochloric acid (HCl) was added. The samples were then shaken for 16 hours. After shaking, the samples were centrifuged at 3000 rpm for 20 minutes. The resulting supernatant was filtered using filter paper No. 1 and was stored in plastic vials until analysis by Flame Atomic Absorption Spectrophotometry (FAAS).

The residual phase extraction

The residual heavy metals were extracted following the method of **Sturgeon *et al.* (1982)**. Five milliliters of nitric acid (HNO_3) were added to each residual sample in Teflon (PTFE) beakers and evaporated to near dryness on a hotplate at 70 °C. Subsequently, 5ml of a concentrated mixture of perchloric acid ($HClO_4$) and hydrofluoric acid (HF) in a 1:1 ratio was added. Then, 30ml of 0.5 N hydrochloric acid (HCl) was added to the sample on the hotplate until the volume was reduced to less than 25ml. The extract was filtered, decanted, and diluted to 30ml with deionized distilled water. Samples were stored in tightly sealed polyethylene vials until analysis by Flame Atomic Absorption Spectrophotometry (FAAS).

Heavy elements pollution indices

Geo- accumulation index (I- geo)

To determine the extent of soil pollution by heavy elements, **Mueller (1969)** proposed the use of the geoaccumulation index (I-geo) based on the following equation:

$$\text{I-geo} = \text{Log}_2 \left(Cn / 1.5\ Bn \right)$$

Where, C_n is the concentration of heavy elements in the samples from the current study, B_n is the background concentration of heavy elements in the Earth's crust (average crust values) according to **CBSQG (2003)**, and 1.5 is a constant used to account for possible variations and natural or anthropogenic influences on heavy element concentrations **(Mueller, 1969; Kowalska *et al.*, 2018)**. The I-geo values were classified according to the categories shown in Table (2).

Table 2. Classification of I-geo accumulation index

I-geo value	Soil pollution status
<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

Contamination factor (CF)

Contamination Factor (CF) was used to determine contamination status of soil in the current study. CF was calculated according to the equation described below:

$$CF=Mc/Bc$$

Where, Mc is the measured concentration of the element in the samples, and Bc is the background concentration of the same element. Four contamination categories were defined based on the contamination factor (CF) according to **Hakanson (1980)**, as shown in Table (3).

Table 3. Classification of contamination factor

CF value	**Contamination status**
$CF < 1$	Low contamination
$1 \leq CF \leq 3$	Moderate contamination
$3 < CF \leq 6$	Considerable contamination
$CF > 6$	Very high contamination

Enrichment factor (EF)

To evaluate the magnitude of source material relative to the Earth's crust, the enrichment factor (EF) was calculated using the following equation, as proposed by **Atgin *et al.* (2000)**:

$$EF= (CM / CFe)\ sample / (CM / CFe)\ Earth\ crust$$

Where:

- CM/ CFe sample is the ratio of concentration of trace element CM to that of CFe in the soil sample.
- CM/ CFe Earth crust is the same reference ratio in the Earth crust .

The classification of enrichment factor is shown in Table (4).

Table 4. Classification of enrichment factor

EF value	Enrichment factor Indicates
EF<1	No enrichment
1-3	Minor enrichment
3-5	Moderate enrichment
5-10	Moderate to severe enrichment
10-25	severe enrichment
25 -50	very severe enrichment
EF>50	extremely severe enrichment

Statistical analysis

A completely randomized design (CRD) was used to collect the current study samples. Analysis of variance (one-way ANOVA) was performed using Minitab ver. 16.1. The adjusted least significant difference (RLSD) values were calculated to determine the presence of statistically significant temporal and spatial differences below the probability level ($P \leq 0.05$). The correlation between variables was calculated using Pearson's correlation coefficients**.**

RESULTS

Nickel (Ni)

The mean concentration of nickel in the exchangeable phase showed significant differences among seasons ($P< 0.05$). The highest seasonal mean concentration (120.59µg/ g dry weight) was detected during the autumn season at a depth of 21– 30cm, while the lowest mean concentration (24.54µg/ g dry weight) was recorded during the spring season at a depth of 0–10cm. Among stations, the highest mean concentration (53.54µg/ g dry weight) was observed at the Jazirah station, while the lowest (39.79µg/ g dry weight) was recorded at the Basrah Center station. However, the mean concentration of nickel in the exchangeable phase showed no significant differences ($P > 0.05$) among stations or depths.

In the residual phase, the highest seasonal mean concentration (109.01µg/ g dry weight) was detected during the autumn season at a depth of 21–30cm, while the lowest mean concentration (18.53µg/ g dry weight) was recorded during the winter season at the same depth. A significant difference ($P< 0.05$) was observed between seasons. Among stations, the highest mean concentration (75.29µg/ g dry weight) was found at the Jazirah station, and the lowest (49.98µg/ g dry weight) at the Basrah Center station; however, differences among stations were not statistically significant (*P*> 0.05). Similarly, no significant differences (*P*> 0.05) were observed among depths (Table 5).

Table 5. Concentration of nickel (µg/g dry wight) in core samples from the Shatt al–Arab coast

depth cm	Season	Mean of season		Qurna		Basrah center		Jaziirah		Abu al- kaseeb	
0-10 CM		Ex	Re	Ex	Re	Ex	Re	Ex	Re	Ex	Re
	Summer	47.56	54.66	8.62	21.56	59.93	37.7	4.31	40.5	117.4	118.87
	Autumn	52.64	85.86	70	89.03	56.85	112.3	65.6	137	18.16	5.232
	Winter	25.37	30.77	7.09	51.55	6.766	32.22	34.5	13.5	53.16	25.777
	Spring	24.54	48.7	8.34	26.73	20.42	44.89	50.1	79.2	19.29	43.945
11-20CM	Summer	67.85	41.37	82.4	19.83	55.74	40.6	29.3	31	103.9	74.012
	Autumn	62.06	102.4	83.1	128.4	61.22	92.16	76.5	125	27.39	64.322
	Winter	34.48	34.23	64.8	44.47	15.14	33.51	15.5	16.4	42.53	42.531
	Spring	36.2	60.58	40.4	38.11	24.21	52.45	61.3	83.7	18.91	68.044
21-30 CM	Summer	39.77	31.55	39.4	2.587	35.44	35.44	3.45	16.4	80.74	71.77
	Autumn	120.6	109	173	114.5	65.6	34.9	227	248	16.62	38.778
	Winter	35.85	18.53	6.44	16.43	56.06	19.33	38.7	10.6	42.21	27.71
	Spring	35.82	79.86	65.4	70.53	20.05	64.26	35.9	102	21.94	82.22
Mean				**43.2**	**51.98**	**39.79**	**49.98**	**53.5**	**75.3**	**46.85**	**55.267**

Nickel (Ni)

The mean concentration of nickel in the exchangeable phase showed significant differences among seasons (*P*< 0.05). The highest seasonal mean concentration (120.59µg/ g dry weight) was observed during the autumn season at a depth of 21– 30cm, while the lowest (24.54µg/ g dry weight) occurred during the spring season at a depth of 0– 10cm. Among stations, the highest mean concentration (53.54µg/ g dry weight) was recorded at the Jazirah station, and the lowest (39.79µg/ g dry weight) at the Basrah Center station. However, the differences among stations and depths were not statistically significant (*P*> 0.05).

In the residual phase, the highest seasonal mean concentration (109.01µg/ g dry weight) was also recorded during autumn at a depth of 21– 30cm, while the lowest (18.53µg/ g dry weight) was observed during winter at the same depth. A significant difference among seasons was detected (*P*< 0.05). The highest mean concentration among stations (75.29µg/ g dry weight) was again found at the Jazirah station, and the lowest

(49.98µg/ g dry weight) at the Basrah Center station. However, differences among stations and depths in the residual phase were not statistically significant (*P*> 0.05) (Table 5).

Table 6. Concentration of iron (µg/g dry weight) in core samples from the Shatt al–Arab coast

Depth cm	Season	Mean of season		Qurna		Basrah center		Jaziirah		Abu aL-Khaseeb	
0-10 CM		Ex	Re	Ex	Re	Ex	Re	Ex	Re	Ex	Re
	Summer	1889.903	2953.95	2668.72	3364.91	406.49	4200.34	3009.08	2815.7	1475.32	1434.85
	Autumn	1431.005	1511.6	1504.98	1580.67	1482.2	1541.72	1548.34	1521.15	1188.5	1402.84
	Winter	727.8263	1693.67	877	640.22	1124.79	896.31	443.07	743.88	466.45	4494.28
	Spring	1675.441	1775.8	2282.563	3793.5	1507.5	1526.98	1409.65	953	1502.05	829.71
11-20CM	Summer	1872.018	2630.67	2684.19	2622.31	385.15	3070.96	3009.08	3473.21	1409.65	1356.19
	Autumn	1429.103	1533.64	1483.67	1590.22	1544.66	1569.65	1543.93	1561.56	1144.15	1413.12
	Winter	578.9975	1621.34	934.93	790.62	480.68	978.63	488.81	685.95	411.57	4030.16
	Spring	2158.02	2023.19	4083.75	4315.5	1513.73	1611.12	1457.76	1371.47	1576.84	794.65
21-30 CM	Summer	1462.023	3005.05	2483.07	3349.44	507.1	3914.13	2807.96	3395.85	1395.9	1360.78
	Autumn	1341.435	1522.62	1220.64	1607.86	1521.88	1518.94	1457.22	1548.34	1166	1415.33
	Winter	568.325	1904.21	964.4	723.55	471.53	989.8	442.06	705.26	395.31	5198.21
	Spring	2100.933	2017.06	4146.75	4464	1457.64	1584.63	1379.87	1334.81	1419.47	684.8
Mean				2111.222	2403.57	1033.61	1950.27	1471.72	1675.85	1129.268	2034.58

Zinc (Zn)

In the exchangeable phase, the highest seasonal mean concentration of zinc (69.64µg/ g dry weight) was detected during the autumn season at a depth of 21– 30cm, while the lowest mean concentration (8.89µg/ g dry weight) was observed during the winter season at a depth of 0– 10cm. Among locations, the highest mean concentration (35.59µg/ g dry weight) was recorded at the Basrah Center station, while the lowest (20.70µg/ g dry weight) was found at the Jazirah station. The mean concentration of zinc in the exchangeable phase showed significant differences among seasons (*P*< 0.05), with no significant differences detected among locations or depths (*P*> 0.05).

In the residual phase, the highest seasonal mean concentration (87.93µg/ g dry weight) was detected during the autumn season at a depth of 11– 20cm, while the lowest (12.01µg/ g dry weight) was recorded during the winter season at a depth of 21– 30cm. The mean concentration of zinc in the residual phase showed significant differences among seasons and among depths (*P*< 0.05). According to location, the highest mean concentration (51.40µg/ g dry weight) was observed at the Basrah Center station, while the lowest (30.63µg/ g dry weight) was recorded at the Qurna station; however, differences among locations were not statistically significant (*P*> 0.05) (Table 7).

Table 7. Concentration of zinc (µg/g dry weight) in core samples from the Shatt al–Arab coast

Depth cm	Season	Mean of season		Qurna		Basrah center		Jaziirah		Abu aL-Khaseeb	
0-10 CM		Ex	Re	Ex	Re	Ex	Re	Ex	Re	Ex	Re
	Summer	32.605	30.749	12.902	46.057	35.375	24.832	28.716	38.566	53.427	13.541
	Autumn	17.029	51.2033	1.926	42.31	5.991	73.491	1.926	70.133	58.273	18.879
	Winter	8.8941	24.8548	9.446	7.685	4.9972	9.446	9.766	34.26	11.367	48.028
	Spring	35.211	30.0395	24.713	2.276	40.363	39.16	15.757	18.712	60.01	60.01
11-20CM	Summer	21.887	27.9453	18.034	51.884	25.387	20.948	23.445	37.595	20.681	1.354
	Autumn	14.728	87.9323	24.8765	56.51	2.354	219.323	25.891	40.583	5.792	35.313
	Winter	34.666	20.092	8.005	8.005	34.901	34.901	73.324	20.492	22.4325	16.97
	Spring	27.14	42.6765	21.678	25.146	50.254	46.912	1.477	23.267	35.151	75.381
21-30 CM	Summer	22.068	32.6003	12.347	37.179	31.075	27.468	23.306	33.433	21.5432	32.3213
	Autumn	69.635	31.8413	104.42	51.137	87.516	29.838	21.184	11.417	65.421	34.973
	Winter	17.263	12.0093	9.606	8.805	34.741	11.527	20.5432	23.5431	4.162	4.162
	Spring	39.656	50.2945	59.181	30.566	74.178	78.989	3.078	19.45	22.186	72.173
Mean				**25.5945**	**30.63**	**35.5944**	**51.4029**	**20.7011**	**30.9543**	**31.7038**	**34.4254**

Chromium (Cr)

In the exchangeable phase, the highest seasonal mean concentration of chromium (262.16µg/ g dry weight) was detected during the summer season at a depth of 0– 10cm, while the lowest mean concentration (21.25µg/ g dry weight) was recorded during the autumn season. Among locations, the highest mean concentration (131.30µg/ g dry weight) was observed at the Jazirah station, while the lowest (95.81µg/ g dry weight) was found at the Abu al-Khaseeb station. However, differences among locations in the exchangeable phase were not statistically significant (*P*> 0.05). The mean concentration of chromium in the exchangeable phase showed significant differences among seasons (*P*< 0.05).

In the residual phase, the highest seasonal mean concentration (445.5µg/ g dry weight) was recorded during the summer season at a depth of 21– 30cm, while the lowest mean concentration (39.13µg/ g dry weight) was observed during the autumn season at a depth of 0– 10cm, showing significant differences among seasons (*P*< 0.05). According to locations, the highest mean concentration (264.71µg/ g dry weight) was detected at the Qurna station, while the lowest (152.28µg/ g dry weight) was recorded at the Abu al-Khaseeb station at a depth of 21– 30cm. Significant differences among locations were observed (*P*< 0.05) (Table 8).

Table 8. Concentration of chromium (µg/g dry weight) in core samples from the Shatt al–Arab coast

Depth cm	Season	Mean of season		Qurna		Basrah center		Jaziirah		Abu aL-Khaseeb	
0-10 CM		Ex	Re	Ex	Re	Ex	Re	Ex	Re	Ex	Re
	Summer	262.1605	346.99	399	467.4	185.862	131.24	285	537.7	178.78	251.62
	Autumn	37.44875	39.125	48.582	103.68	46.558	22.99	46.558	16.14	8.097	13.69
	Winter	77.73835	75.1025	59.88	15.93	136.975	13.66	106.97	36.41	7.1324	234.41
	Spring	90.0315	190.1675	7.245	108.67	172.35	278.57	94.356	225.13	86.175	148.3
11-20CM	Summer	254.626	383.5275	324.9	608	86.483	196.48	292.6	459.8	314.521	269.83
	Autumn	21.25475	50.7425	10.121	89.01	4.049	17.12	40.485	33.75	30.364	63.09
	Winter	57.872	110.38	68.113	236.69	92.065	7.59	69.793	162.34	1.517	34.9
	Spring	98.955	269.7025	54.875	352.58	148.301	298.61	84.424	253.27	108.22	174.35
21-30 CM	Summer	235.9405	445.54	273.6	549.1	166.897	410.41	283.1	590.9	220.165	231.75
	Autumn	55.66725	58.69	8.097	116.89	12.146	39.62	113.36	20.05	89.067	58.2
	Winter	94.4805	98.62	171.41	96.34	99.55	142.62	90.276	100.9	16.69	54.62
	Spring	87.6485	333.0825	36.224	432.27	150.305	370.75	67.87	236.72	96.195	292.59
Mean				**121.84**	**264.71**	**108.462**	**160.81**	**131.23**	**222.76**	**96.4103**	**152.28**

Cadmium (Cd)

In the exchangeable phase, the highest seasonal mean concentration of cadmium (2.32µg/ g dry weight) was detected during the spring season at a depth of 0– 10cm, while the lowest mean concentration (0.86µg/ g dry weight) was observed during the winter season at a depth of 11– 20cm. According to location, the highest mean concentration (2.17µg/ g dry weight) was recorded at the Abu al-Khaseeb station, while the lowest (0.80µg/ g dry weight) was found at the Jazirah station. The mean concentration of cadmium in the exchangeable phase showed significant differences among locations (*P*< 0.05), but no significant differences among seasons (*P* > 0.05).

In the residual phase, the highest mean concentration (1.94 µg/g dry weight) was observed during the summer season, while the lowest (0.62µg/ g dry weight) was recorded during the winter season at a depth of 11– 20cm. Regarding locations, the highest mean concentration (2.00µg/ g dry weight) was detected at the Qurna station, while the lowest (0.55µg/ g dry weight) was observed at the Jazirah station. The results showed significant differences among seasons and among locations (*P*< 0.05) (Table 9).

Table 9. Concentration of cadmium (μg/g dry weight) in core samples from the Shatt al–Arab coast

Depth cm	Season	Mean of season		Qurna		Basrah center		Jaziirah		Abu aL-Khaseeb	
0-10 CM		Ex	Re	Ex	Re	Ex	Re	Ex	Re	Ex	Re
	Summer	2.10925	1.7821	1.2341	3.86968	4.0185	1.63717	2.5302	0.29767	0.6542	1.32405
	Autumn	1.41443	1.6683	2.2214	3.52646	0.2897	0.94039	0.2897	0.70529	2.8569	1.50108
	Winter	1.62748	0.7394	1.3395	0.29767	2.0837	0.59533	0.7442	0.74417	2.3425	1.32041
	Spring	2.31843	1.071	1.3241	0.32014	4.9457	1.3848	0.4321	0.20507	2.5718	2.37394
11-20CM	Summer	1.92125	0.9889	1.5461	0.29767	3.2743	1.63717	0.3214	0.65021	2.5432	1.37065
	Autumn	1.44572	1.3669	2.4146	3.80791	0.0966	0.70529	0.70529	0.47019	2.5664	0.48422
	Winter	0.8558	0.6138	1.3395	0.74417	0.7442	0.61223	0.5953	0.59533	0.7442	0.50342
	Spring	1.3543	1.6716	1.3421	0.54275	0.9891	1.97829	0.5142	0.60457	2.5718	3.56091
21-30 CM	Summer	1.94378	1.9389	1.3201	3.86968	2.8278	2.38134	1.1907	1.30395	2.4365	0.20057
	Autumn	1.90928	1.4642	2.6148	3.76156	1.1509	1.88078	0.8692	0.11755	3.0022	0.09684
	Winter	1.00463	1.0384	1.1907	1.48834	2.2325	0.6234	0.4465	1.63717	0.1488	0.40465
	Spring	1.7335	1.067	0.2714	1.46543	2.1761	1.97829	0.9256	0.51424	3.5609	0.31013
Mean				**1.5132**	**1.99929**	**2.0691**	**1.36287**	**0.79703**	**0.65378**	**2.1666**	**1.12091**

Lead (Pb)

In the exchangeable phase, the highest seasonal mean concentration of lead (714.13μg/ g dry weight) was detected during the autumn season at a depth of 21– 30cm, while the lowest mean concentration (15.93μg/ g dry weight) was observed during the winter season at a depth of 0– 10cm. According to location, the highest mean concentration (426.60μg/ g dry weight) was recorded at the Basrah Center station, while the lowest (27.58μg/ g dry weight) was found at the Abu al-Khaseeb station. The mean concentration of lead in the exchangeable phase showed significant differences among locations and among seasons ($P< 0.05$).

In the residual phase, the highest seasonal mean concentration (339.66μg/ g dry weight) was detected during the summer season at a depth of 0–10cm, while the lowest (10.24μg/ g dry weight) was recorded during the winter season at a depth of 0– 10cm. The results showed significant differences among seasons ($P< 0.05$). According to locations, the highest mean concentration (217.86μg/ g dry weight) was observed at the Basrah Center station, while the lowest (28.57μg/ g dry weight) was found at the Abu al-Khaseeb station. Significant differences among locations were also recorded ($P< 0.05$) (Table 10).

Table 10. Concentration of lead (µg/g dry weight) in core samples from the Shatt al–Arab coast

Depth cm	Season	Mean of season		Qurna		Basrah center		Jaziirah		Abu AL-Khaseeb	
0-10 CM		Ex	Re	Ex	Re	Ex	Re	Ex	Re	Ex	Re
	Summer	238.6216	339.6605	32.5564	264.167	834.22	792.74	66.42	184.162	21.29	117.578
	Autumn	295.6725	28.27025	190.12	23.673	760.47	41.033	228.14	26.829	3.96	21.546
	Winter	15.9315	10.238525	7.55	12.839	32.766	9.818	4.53	0.755	18.88	17.5421
	Spring	39.67635	32.013825	33.7654	22.4563	34.95	28.086	66.9	58.789	23.09	18.724
11-20CM	Summer	281.6933	262.29405	84.53	24.5532	992.46	792.74	31.543	172.086	18.24	59.802
	Autumn	508.7575	24.85675	513.31	25.251	1330.8	37.876	190.12	34.72	0.79	1.58
	Winter	49.0208	18.248675	30.96	12.839	5.29	5.287	31.443	32.4367	128.39	22.432
	Spring	40.573575	36.456875	31.6543	27.7655	37.45	16.852	63.86	91.224	29.33	9.986
21-30 CM	Summer	289.8375	278.89143	51.32	26.4567	861.87	815.78	230.96	258.129	15.2	15.2
	Autumn	714.125	26.8595	950.58	28.407	190.12	42.611	1711.1	22.095	4.75	14.325
	Winter	25.3158	21.87885	30.96	21.146	3.78	12.839	32.543	31.8764	33.98	21.654
	Spring	40.458825	64.177625	32.9853	26.9875	34.95	18.724	60.82	188.53	33.08	22.469
Mean				**165.858**	**43.0451**	**426.59**	**217.86**	**226.53**	**91.8027**	**27.582**	**28.5698**

Manganese (Mn)

In the exchangeable phase, the highest seasonal mean concentration of manganese (796.03µg/ g dry weight) was detected during the autumn season at a depth of 0– 10cm, while the lowest mean concentration (98.22µg/ g dry weight) was recorded during the winter season at a depth of 21– 30cm. According to location, the highest mean concentration (563.39µg/ g dry weight) was observed at the Basrah Center station, while the lowest (267.65µg/ g dry weight) was found at the Abu al-Khaseeb station. Results showed significant differences among locations and among seasons ($P< 0.05$).

In the residual phase, the highest seasonal mean concentration (306.38µg/ g dry weight) was detected during the autumn season at a depth of 11– 20cm, while the lowest mean concentration (24.09µg/ g dry weight) was recorded during the winter season at a depth of 11– 20cm. Significant differences among seasons were observed ($P< 0.05$). According to location, the highest mean concentration (206.62µg/ g dry weight) was recorded at the Jazirah station, while the lowest (111.39µg/ g dry weight) was found at the Basrah Center station. Results also showed significant differences among locations ($P< 0.05$) (Table 11).

Table 11. Concentration of manganese (µg/g dry weight) in core samples from the Shatt al–Arab coast

Depth cm	Season	Mean of season		Qurna		Basrah center		Jaziirah		Abu aL-Khaseeb	
0-10 CM		**Ex**	**Re**	**Ex**	**Re**	**Ex**	**Re**	**Ex**	**Re**	**Ex**	**Re**
	Summer	352.45	149.0945	390.54	207.398	19.39	66.004	491.52	174.48	508.35	148.495
	Autumn	796.028	283.375	606.14	299.066	1739.2	359.254	499.37	347.54	339.4	127.636
	Winter	142.723	52.78775	29.72	8.759	218.97	1.564	71.01	121.06	251.19	79.768
	Spring	358.556	124.604	432.44	46.771	276.86	130.665	429.4	165.32	295.53	155.656
11-20CM	**Summer**	274.078	144.606	436.33	223.237	20.96	59.435	484.34	162.35	154.68	133.398
	Autumn	837.83	306.3845	612.16	416.397	1821.85	253.398	582.03	358.32	335.28	197.426
	Winter	99.1625	24.08675	23.46	15.328	15.64	11.574	159.54	39.102	198.01	30.343
	Spring	359.338	171.0938	441.18	194.529	338.34	132.569	464.54	193.29	193.291	163.986
21-30 CM	**Summer**	246.153	125.2175	370.49	182.649	58.5	40.041	439.79	147.51	115.83	130.675
	Autumn	802.36	282.5555	344.48	391.339	1904.51	104.919	664.68	489.7	295.77	144.264
	Winter	98.2225	92.12475	28.15	7.195	16.89	7.508	157.66	112.93	190.19	240.869
	Spring	384.538	174.9485	432.8	185.221	329.58	169.698	441.52	167.8	334.25	177.076
Mean				**345.66**	**181.491**	**563.391**	**111.386**	**407.12**	**206.62**	**267.648**	**144.133**

Heavy elements indices

I-geo index

Overall, according to the I-geo index, the soils of Basrah Province are classified as unpolluted with respect to iron (Fe), manganese (Mn), and zinc (Zn). The highest annual average I-geo value for total nickel (Ni) in the core samples was 2.70, recorded at the Jazirah station at a depth of 21– 30cm, indicating that the soil was moderately polluted to polluted with Ni. In contrast, the lowest I-geo value was −3.60 for iron (Fe), observed at the Basrah Center station at a depth of 0– 10cm, indicating practically unpolluted soil (Table 12).

Table 12. Annual geoaccumulation index (I- geo) of heavy elements in core sample of study stations

Depths	station	Mn igeo	Pb igeo	Cd igeo	Cr igeo	Zn igeo	Fe igeo	Ni igeo
0-10cm	Qurnah	-1.97	0.72	1.39	0.30	-2.44	-3.22	0.60
	Basrah center	-0.95	1.64	1.15	0.39	-2.05	-3.60	1.22
	jazeera	-0.45	0.58	-0.62	0.56	-1.79	-3.49	1.33
	Abu - Alkaseeb	-0.58	-1.07	1.03	0.01	-1.25	-3.30	1.07
11-20cm	Qurnah	-0.94	0.83	-0.30	1.07	-2.12	-2.94	1.17
	Basrah center	-1.68	1.84	0.21	-0.23	-1.14	-3.50	1.32
	jazeera	-0.38	0.69	-0.28	0.78	-1.70	-3.39	1.33
	Abu - Alkaseeb	-0.93	-0.80	0.89	0.04	-2.32	-3.35	1.50
21-30cm	Qurnah	-1.17	0.92	0.47	1.17	-1.59	-2.93	0.18
	Basrah center	-1.64	1.34	1.23	0.72	-1.11	-3.43	1.25
	jazeera	-0.25	1.98	0.16	0.94	-2.28	-3.44	1.38
	Abu - Alkaseeb	-0.81	-0.91	-0.46	0.47	-1.94	-3.31	1.36

Note: i- geo value < 1: practically unpolluted, 1-2: unpolluted to moderately polluted, 2-3: moderately polluted to polluted.

Contamination factor (CF)

Overall, according to the CF (Contamination Factor) index, the soils of Basrah Province are classified as low contamination with respect to iron (Fe) and zinc (Zn). The highest annual average CF value was recorded for lead (Pb) at 22.35 in the Basrah Center station at a depth of 11–20cm, indicating very high contamination with lead. In contrast, the lowest CF value was 0.14 for total iron (Fe), also recorded at the Basrah Center station, indicating low contamination with iron (Table 13).

Table 13. Annual contamination index (CF) of heavy elements in core sample of study stations

Depths	station	Mn CF	Pb CF	Cd CF	Cr CF	Zn CF	Fe CF	Ni CF
0-10cm	Qurnah	0.86	3.87	3.56	3.03	-2.44	0.18	2.98
	Basrah center	1.53	17.37	4.01	2.47	-2.05	0.14	4.03
	jazeera	1.25	4.42	1.39	3.37	-1.79	0.16	4.62
	Abu - Alkaseeb	1.04	1.41	3.30	2.30	-1.25	0.16	4.37
11-20cm	Qurnah	1.28	4.95	2.33	4.22	-2.12	0.23	4.55
	Basrah center	1.44	22.35	2.38	2.13	-1.14	0.14	4.08
	jazeera	1.33	4.16	1.36	3.49	-1.70	0.17	4.77
	Abu - Alkaseeb	0.84	1.72	3.48	2.49	-2.32	0.15	4.57
21-30cm	Qurnah	1.06	7.85	3.33	4.21	-1.59	0.24	4.88
	Basrah center	1.43	13.75	3.70	3.48	-1.11	0.15	3.60
	jazeera	1.42	17.55	1.78	3.76	-2.28	0.16	7.42
	Abu - Alkaseeb	0.89	1.18	1.88	2.65	-1.94	0.16	4.15

Note: $CF < 1$: low contamination, $1 \leq CF \leq 3$: moderate contamination, $3 < CF \leq 6$: considerable contamination ,$CF > 6$: very high contamination.

Enrichment factor (EF)

The highest annual average enrichment factor (EF) for total lead (Pb) in the core samples was 136.20, recorded at the Basrah Center station at a depth of 11– 20cm, indicating extremely severe enrichment with lead. In contrast, the lowest EF value was 1.53 for total zinc (Zn), observed at the Jazirah station at a depth of 21– 30cm, indicating minor enrichment (Table 14).

Table 14. Annual enrichment factor index (EF) of heavy elements in core sample of study stations

Depths	Station	Mn EF	Pb EF	Cd EF	Cr EF	Zn EF	Ni EF
0-10cm	Qurnah	4.68	19.93	18.79	13.67	1.77	22.22
	Basrah center	11.88	90.27	33.89	20.42	3.17	30.90
	jazeera	8.74	25.52	10.86	20.88	3.61	36.71
	Abu - Alkaseeb	7.24	9.86	27.10	15.21	4.60	28.96
11-20cm	Qurnah	6.06	32.82	17.05	21.33	1.93	31.56
	Basrah center	9.34	136.20	15.85	15.00	6.11	29.35
	jazeera	8.74	22.36	13.15	22.85	4.98	33.17
	Abu - Alkaseeb	6.19	10.37	23.15	18.76	3.10	32.89
21-30cm	Qurnah	4.87	56.11	22.91	19.91	3.53	28.55
	Basrah center	9.39	67.36	25.61	24.23	5.58	27.91
	jazeera	10.21	104.64	15.57	23.20	1.53	55.49
	Abu - Alkaseeb	6.30	7.35	15.52	20.92	3.95	30.17

Note: EF< 1: no enrichment, 1-3: minor enrichment, 3-5: moderate inrechment, 5-10: moderate to severe enrichment, 10-25: severe enrichment, 25-50: very severe enrichment, EF >50 :extremely severe enrichment.

DISCUSSION

Numerous factors contribute to the high levels of pollutants observed in the study area. These include the overuse of chemical pesticides and fertilizers in agricultural operations, as well as the accumulation of household waste and untreated sewage discharged directly into the Shatt al-Arab without prior treatment **(Al-Hejuje *et al*., 2018)**. Additionally, industrial activities, heavy traffic, and emissions from fossil fuel combustion for power generation have significantly contributed to soil contamination **(Al-Halfy *et al*., 2021)**. The use of fossil fuels for transportation and the burning of waste have particularly increased the concentrations of cadmium (Cd) and lead (Pb) in the soil, with further leaching of these elements toward the beach due to rainfall, polluted river flow, and coastal discharge.

This study recorded increased concentrations of heavy elements during the hotter seasons (summer and autumn) and decreased concentrations during winter, which may be linked to temperature variations **(Al-Hejuje, 2014)**. High temperatures enhance the solubility, mobility, and availability of heavy elements in the soil, promoting their uptake by plants or binding with other soil components. Conversely, frequent rainfall in winter likely leads to the leaching of heavy elements from the riverbanks, reducing their concentrations.

A comparison between the exchangeable and residual phases showed that concentrations of certain heavy elements—particularly Pb, Mn, and Ni—were higher in the exchangeable phase during summer and autumn. In the Basrah Center station, lead and manganese concentrations exhibited the highest values, while nickel concentrations peaked at the Jazirah station. The lowest concentrations of lead and manganese were recorded at the Abu al-Khaseeb station during winter, while nickel value was the lowest at the Basrah Center station during the same season.

According to the I-geo index, the soil was generally uncontaminated with iron (Fe) and zinc (Zn), while nickel (Ni) and manganese (Mn) ranged from uncontaminated to moderately polluted. Chromium (Cr) showed a range from uncontaminated to strong pollution, and cadmium (Cd) and lead (Pb) levels ranged from non-polluted to highly contaminated.

The CF index results indicated low contamination for iron, moderate contamination for zinc, and considerable contamination for manganese and lead. Very high contamination levels were observed for nickel, chromium, and cadmium.

The EF index showed severe enrichment for zinc, very severe enrichment for manganese and chromium, and extremely severe enrichment for nickel, lead, and cadmium in the core samples.

Understanding the distribution and concentration of heavy elements in soil is crucial for identifying pollution sources and assessing potential impacts on plants and ecosystems **(Al-Khuzaie, 2015; Al-Atbee, 2018)**.

The results highlight consistently high concentrations of lead (Pb) across all stations, associated with heavy traffic and the historical use of leaded gasoline. The accumulation of Pb in soil represents a significant ecological risk due to its detrimental effects on biological activity in aquatic environments **(Kabata-Pendias, 2011)**.

The annual CF values confirmed that lead exhibited extremely high contamination, and EF values indicated extremely severe enrichment. Meanwhile, the I-geo index results registered nickel (Ni) as moderately polluted to polluted.

The high levels of cadmium pollution are attributed to increased human activities and the continued discharge of untreated pollutants, resulting in extremely severe enrichment **(Al-Saad *et al.*, 2021)**. Variations in heavy element concentrations across studies suggest that local pollution sources, economic development, and environmental management practices strongly influence contamination levels.

CONCLUSION

This study revealed that the majority of soils in the Basrah Governorate exhibit very high levels of contamination and extremely severe enrichment with lead (Pb). In addition, the soils were found to be moderately to severely polluted by cadmium (Cd) and nickel (Ni). The distribution of heavy metal contaminants across the study stations varied, ranging from low to medium to high levels of pollution. These findings highlight the urgent need for monitoring programs and pollution control measures to mitigate the environmental and ecological risks associated with heavy metal accumulation in the region.

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