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Table Of Contents

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Residual Selenium Distribution and Risk in Shatt Al-Basrah Sediments: Distribusi Selenium Sisa dan Risiko dalam Sedimen Shatt Al-Basrah

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Abstract

General Background Selenium is a trace element with complex geochemical behavior that can pose ecological and human health concerns when accumulated in aquatic environments. **Specific Background** The Shatt Al-Basrah Channel in southern Iraq is exposed to increasing industrial, agricultural, and urban pressures, yet detailed assessments of selenium behavior in sediment cores remain limited. **Knowledge Gap** Vertical distribution patterns and contamination severity of residual selenium in this channel have not been comprehensively evaluated using combined geochemical indices and health risk indicators. **Aims** This study aimed to quantify residual selenium concentrations, assess vertical and spatial distribution, identify natural and anthropogenic sources, and evaluate ecological and human health risks. **Results** Selenium concentrations ranged from 3.69 to 18.50 ppb, with highest values in surface sediments, particularly at Stations 2 and 3. Enrichment factor, contamination factor, and geoaccumulation index values indicated moderate contamination primarily linked to anthropogenic inputs. **Novelty** The study integrates residual fraction analysis with contamination indices and risk assessment across sediment depths in the Shatt Al-Basrah Channel. **Implications** The findings provide a baseline for future monitoring and support management strategies to reduce selenium inputs and potential long-term ecological and health risks in the northwest Arabian Gulf.

Keywords: Selenium Contamination, Sediment Cores, Shatt Al-Basrah Channel, Ecological Risk, Anthropogenic Sources

Key Findings Highlights:

1. Surface sediments exhibited consistently higher selenium concentrations than deeper layers.
2. Contamination indices indicated moderate enrichment associated with human activities.
3. Residual selenium levels suggest potential long-term ecological and dietary exposure concerns.

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Introduction

The Shatt Al-Basrah Channel in southern Iraq, a place where the Tigris and Euphrates Rivers circulate is a sensitive ecological spot. There are various anthropogenic activities including agricultural runoff, untreated wastewater from households, effluents from oil refineries hence leading to this fragility [1,2]. However, the environment has suffered greatly in the area over the past decades, particularly during the Second Gulf War (1990-2003) when the Shatt Al-Arab system was left exposed to environmental pollutants such as heavy metals and crude oil [3]. These pollutants have been accumulated in bottom sediments over time through trophic transfer and bioaccumulation processes which are toxic for water column species and benthic ecosystems [4].Although a number of studies have been done to study the hydrochemical characteristics of the Shatt Al-Arab River, few studies have been done for comprehensive review of sediment pollution, especially with regard to selenium [2].

Selenium has complicated environmental behaviour; in oxidising circumstances, it prefers to produce selenate (SeO_4^{2-}) compounds, which are very stationary in sediments, by combining with small particles and colloidal materials [5]. Because of its geochemical stability, selenium is a crucial indicator of ongoing pollution. But there are serious ecological and public health issues because of its capacity to bioaccumulate and biomagnify in aquatic food webs [6]. The significance of concurrently monitoring selenium and other potentially harmful elements is highlighted by recent studies that reveal high levels of trace elements such As, Cr, Fe, Mn, Ni, and Pb in southern Iraq [7]. With the aid of contamination indices such as the Contamination Factor (CF) and Geoaccumulation Index (I_geo) the present study aims at: (1) identifying the concentrations of residual selenium (Se) in sediment cores from the Shatt Al-Basrah Channel; (2) assessing its vertical i.e., depth-dependent distribution, in order to infer time accumulation trends; (3) discriminating the contribution of lithogenic i.e., natural and anthropogenic sources to identify the potential sources of Se contamination; and (4) assessing the ecological and health associated risks. This study enhances our understanding of the dynamics of man-made selenium in river systems by addressing these objectives, providing important data for monitoring and innovation throughout the Arabian Gulf.

Materials and Methods

Study Area

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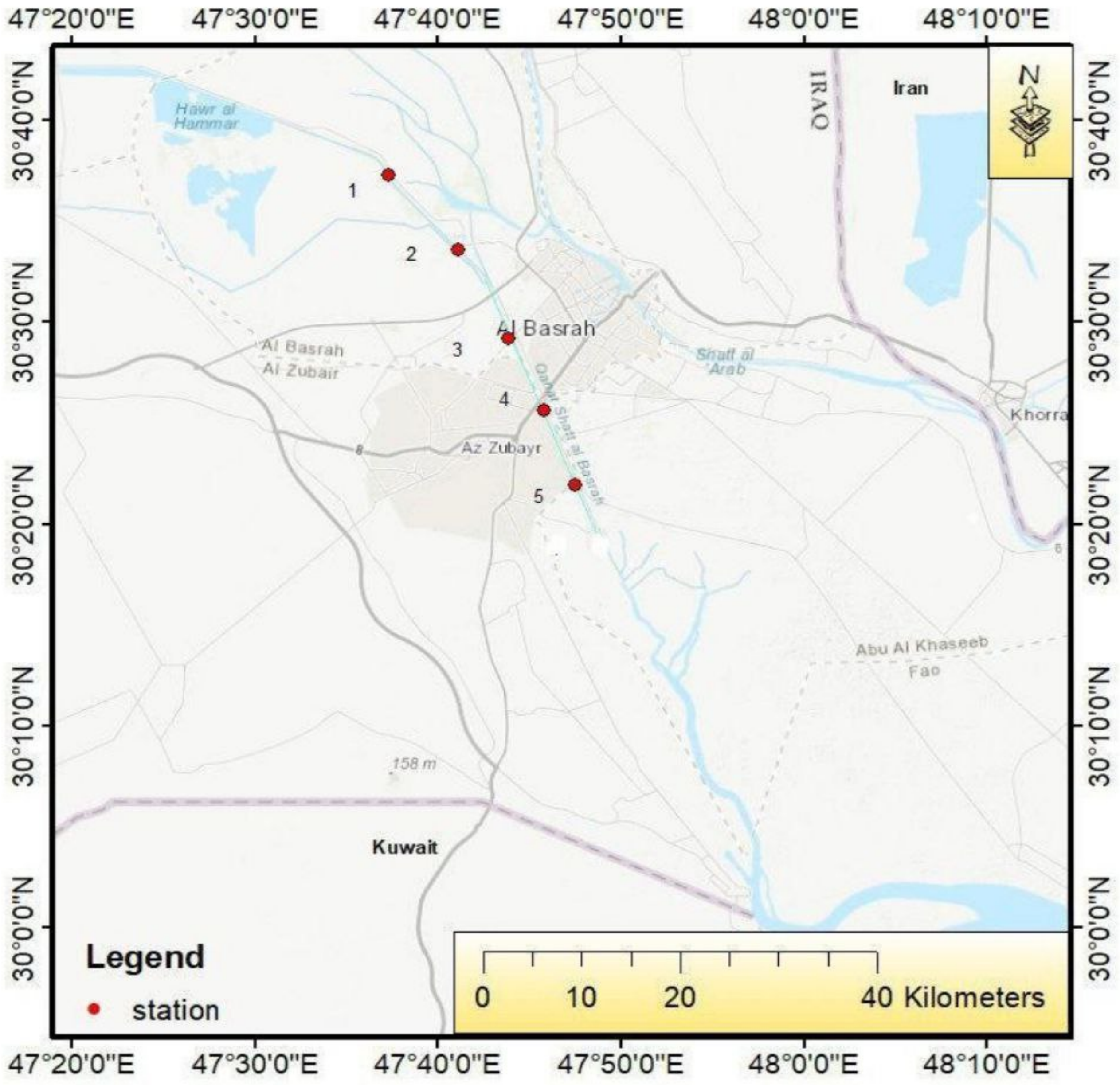

Figure 1. Figure 1 :Sample collection sites in the Shatt al-Basra canal

Methods of Sampling Gathering of SamplesDuring March and April of 2022, 0-30 cm deep sediment cores with a depth profile were collected from all the sample sites. To allow for extensive stratigraphic investigation, each core was divided into 6 depth intervals: those being 0-5, 5-10, 10-15, 15-20, 20-25, and finally 25-30 cm. To increase analysis accuracy and repeatability, each sample was collected in a tripling manner.Methods of Analysis Selenium Determination: Inductively coupled plasma optical emission spectrophotometer (ICP-OES) . This was used to measure the concentration of selenium (Se) Residual Fraction Extraction: Sequential extraction process by Tessier [8] It used to extract residual (inert) fraction of selenium. In order to separate Se embedded in crystalline mineral formations, sediment residues have to be digested using HF and $HClO_4$ acids.

Quality Assurance (procedural blanks, certified reference materials, CRMs) To ensure the precision and accuracy of analysis, Three geochemical indicators were computed in order to evaluate the degree of Se contamination:

1-The enrichment factor (EF) was measured according to Sutherland(2000) [9]: **EF= (Se/Fe) sediment /(Se/Fe) background**

Vol. 2 No. 3 (2025): Desember
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Where the typical crustal value, or background Se/Fe ratio, is 0.2.

Where : Enrichment Factor (EF) < 1: No enrichment , 1–3: Minor (natural sources) and EF= 3–10: Moderate (anthropogenic influence),

2. The Contamination factor (CF) is calculated by means of the equation of Hakanson (1980) [10]:

CF = Se concentration in sample / Se concentration in background

The background value of selenium in crust erths is 0.4 ppm . Contamination Factor (CF) can be described less than < 1 which refer to Low contamination , while if their value was located between 1 to 3 that refer to Moderate contamination , and 3 to 6 refer to high contamination and very high contamination if its value up than 6.

3- Geo accumulation index (Igeo) values were calculated of different elements, (Igeo) was calculated by the equation that introduced by (Muller, 1969) [11] as described below:

I-geo = log2 (Cn / 1.5 Bn)

Where: Cn: The measured concentration of element n in the sediment .

Bn: Background for the element in the sediment.

The Geo accumulation index was originally proposed by Muller (1969) and categorized into six classes, these classes are described as follows:

Type of class	**I-geo**	**Sediments pollution case**
Class 1	**<0**	**practically unpolluted- Background sample**
Class 2	**1-2**	**unpolluted to moderately polluted**
Class 3	**2-3**	**moderately polluted to polluted**
Class 4	**3-4**	**strongly polluted**
Class 5	**4-5**	**strongly to extremely polluted**
Class 6	**>5**	**extremely polluted**

Table 1.

Results and Discussion

The other levels of the concentration of selenium in sediments in the Shatt Al-Basrah Channel were determined in five stations and six levels of depths (0-5 cm to 25-30 cm) adding up to Table 1. The determined concentrations of Se had a range of 3.69 to 18.50 ppb, and they were also characterized by the apparent spatial and vertical heterogeneity.

The heterogeneity of Se concentrations showed the spatial and vertical heterogeneity with effective diffusion coefficients varying from 3.69 to 18.50 ppb.

Overall, the highest Se concentrations in Station 2 ranged from 18.14 ppb in surface sediments (0-5 cm) to 9.22 ppb at the deepest layer (25-30 cm), suggesting local sources or sediment properties being favourable for Se accumulation. Similarly, Station 3 had high Se contents close to the surface (mean 18.08 ppb at 0-5 cm) then a sharp decline in Se content 9with depth to 4.31 ppb at a depth of 25-30 cm. Station 1 was the lowest at all depths with Se decreasing from 12.14 ppb at the surface to 6.38 ppb in the deeper layers. Stations 4 and 5 had intermediate levels with Station 5 slightly higher than Station 4 in the intermediate depths (10-25 cm) as can be seen in Figure 2.

All sites showed a reduction in the concentration of selenium with depth. The vertical distribution shows recent input of anthropogenic selenium or an increase in the concentrations within the upper sediment layers and is likely linked to current industrial and agricultural runoff within the region.

Deeper sediments, which represent older deposits, showed reduced selenium levels, indicating historical lower selenium loading or the effects of diagenetic processes reducing Se availability in older sediments. This trend is consistent with previous studies assessing trace metal distribution in coastal and estuarine sediments, where surface sediments typically reflect recent contamination while deeper layers correspond to historical baseline levels [12,13 ,14].

Selenium is an essential trace element but can become toxic at elevated concentrations to aquatic organisms and ecosystems [15 ,14] The range of selenium concentrations found (up to ~18 ppb) in this study is relatively low compared to toxic levels reported in some contaminated sites but highlights the importance of monitoring in this region, particularly given the increasing industrial activities disrupting the Basra shoreline .Sediment selenium concentrations observed here can relate to bioavailability and potential biomagnification risks in the aquatic food web, as selenium is mobilized from sediments under changing redox conditions [16]. The spatial variability also underscores the influence of local sources and sediment characteristics on selenium distribution.

Stations	Depth cm	Concentrations ppb	Range ppb	Mean Se ppb
Station 1	0-5	12.43 , 12.64 , 11.35	11.35 - 12.64	12.14 ppb

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	5-10	10.49 , 10.50 , 10.96	10.49 - 10.96	10.65 ppb
	10-15	9.64 , 8.94 , 9.54	8.94 - 9.64	9.37 ppb
	15-20	9.10 , 8.52 , 8.42	8.42 - 9.10	8.68 ppb
	20-25	7.64 , 7.54 , 6.89	7.54 - 8.69	7.35 ppb
	25-30	6.20 , 6.50 , 6.46	6.20 - 6.50	6.38 ppb
Station 2	0-5	18.50 , 18.46 , 17.46	17.46 - 18.50	18.14 ppb
	5-10	16.46 , 16.52 , 15.42	15.42 - 16.52	16.13 ppb
	10-15	14.53 , 14.63 , 14.52	14.52 - 14.63	14.56 ppb
	15-20	11.30 , 11.28 , 11.06	11.06 - 11.30	11.21 ppb
	20-25	10.28 , 10.24 , 9.68	9.68 - 10.28	10.06 ppb
	25-30	9.38 , 9.32 , 8.98	8.98 - 9.38	9.22 ppb
Station 3	0-5	18.24 , 18.33 , 17.68	17.68 - 18.33	18.08 ppb
	5-10	14.54 , 14.52 , 14.63	14.52 - 14.63	14.56 ppb
	10-15	12.63 , 12.62 , 12.64	12.62 - 12.64	12.63 ppb
	15-20	10.48 , 10.42 , 10.68	10.42 - 10.68	10.52 ppb
	20-25	8.54 , 8.54 , 8.52	8.52 - 8.54	8.53 ppb
	25-30	4.63 , 4.62 , 3.69	4.39 - 4.63	4.31 ppb
Station 4	0-5	13.40 , 13.64 , 13.60	13.40 - 13.64	13.54 ppb
	5-10	12.42 , 12.43 , 11.98	11.98 - 12.43	12.27 ppb
	10-15	10.93 , 10.84 , 10.97	10.84 - 10.97	10.91 ppb
	15-20	10.03 , 10.02 , 10.01	10.01 - 10.03	10.02 ppb
	20-25	8.45 , 8.40 , 8.43	8.40 - 8.45	8.42 ppb
	25-30	8.20 , 8.22 , 8.24	8.20 - 8.24	8.22 ppb
Station 5	0-5	13.53 , 13.63 , 13.62	13.33 - 13.63	13.59 ppb
	5-10	13.20 , 13.21 , 13.42	13.20 - 13.42	13.27 ppb
	10-15	10.29 , 12.10 , 12.22	10.29 - 12.22	11.53 ppb
	15-20	10.94 , 11.54 , 11.03	10.94 - 11.54	11.17 ppb
	20-25	9.69 , 10.63 , 10.62	9.69 - 10.63	10.31 ppb
	25-30	7.65 , 7.54 , 7.43	7.43 - 7.65	7.54 ppb

Table 2. Table (1): Concentration of Selenium (ppb) in the Residual Fraction of Sediments from the Basra Shore Channel

Sources and Distribution of Selenium in Sediments

Natural Sources

Selenium (Se) naturally occurs in sediments due to: Geogenic weathering of Se-rich bedrock (e.g., shales, phosphorites) .Anoxic conditions in aquatic systems, where Se binds to organic matter and Fe/Mn oxides [5]

In the Shatt al-Basrah channel, background Se levels (6–12 ppb in deeper layers) align with uncontaminated estuarine sediments globally (5–15 ppb) [17]. However, surface enrichment (up to 18.5 ppb) suggests additional anthropogenic inputs.

Anthropogenic Sources

Industrial Discharges such as Oil refineries and petrochemical plants in Basrah release Se via wastewater (Se is a byproduct of crude oil processing) [18]. Phosphate fertilizers from agricultural runoff contribute Se (average 5–100 mg/kg in fertilizers).Urban and Agricultural Inputs like Sewage effluents (Se concentrations up to 50 ppb in untreated wastewater) [19]. Irrigation drainage from Se-rich soils (common in arid regions like southern Iraq) [20].Atmospheric Deposition such as Coal combustion from regional power plants emits particulate Se [21].

Spatial and Vertical Distribution

Surface sediments (0–5 cm): Highest Se levels (Stations 2 and 3: 17–18.5 ppb) correlate with industrial proximity. Subsurface (15-30cm): Decreasing concentrations. At Station 3, a recorded 4.3 ppb at (25-30cm) reflects historical deposition trends. At Station 5, may suggest episodic contamination events, such as dredging activities or accidental discharges, as possible origins where anomalous mid-depth peaks of Se were recorded (12.22) ppb at (10-15 cm). The calculated values of the enrichment factor (EF) exceeding 3 (Table 3) are further evidence for the occurrence of anthropogenic enrichment especially in areas affected by urban or industrial activities.

Selenium Distribution in Sediments

Residual concentrations of selenium (Se) at all the sampling stations and sediment depth intervals are shown in Table 1. Here are some obvious patterns:

Station 1: Selenium concentrations varied between 6.20 and 12.64 ppb, and high selenium concentrations were found in the surface layer (0-5 cm; mean = 12.14 ppb).

Station 2: Surface sediments had significantly higher concentrations of Se (17.46 to 18.50 ppb), representing possible anthropogenic inputs in the area.

Station 5: Showed a strong fluctuating behavior of Se concentrations (7.43-13.63 ppb), which might have been a mixture of

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natural geochemical effects and localized anthropogenic inputs.

Human Health Implications of Selenium Contamination

Exposure Pathways

Dietary Intake (Primary Risk)

1-Fish and shellfish consumption: Se gets bioaccumulated in food chains of the aquatic environments. Local species (e.g., Liza abu, Metapenaeusaffinis) may have 0.5-2.0 ug/g Se [22], and this exceeds WHO's safe limit (0.3 ug/g wet weight) [23].

2- Crop irrigation: Se laden water contaminate Rice and Vegetables [20].

Direct Exposure

1-Dermal contact (e.g. fishermen handling sediments).

2- Suspended Se particles can be inhaled during droughts

Toxicity Mechanisms

1- Deficiency (< 40 µg/day): Linked to Keshan disease (cardiomyopathy) [24].

2- Excess (> 400 µg/day): Causes selenosis, with symptoms:

3- Acute: Hair loss, nail brittleness, neurological disorders [25].

4-Chronic: Liver cirrhosis, teratogenicity [26].

Parameter	**Findings**	**Health Risk**
Sediment Se (0–5 cm)	12–18.5 ppb (EF > 3)	Moderate contamination
Estimated dietary Se*	200–600 µg/day (fishermen)	Exceeds WHO limit (55 µg/day)
Bioaccumulation factor	10–100 (fish muscle)	High biomagnification potential

Table 3. Table 2 : Risk Assessment for Basrah Residents
Assumes daily fish intake of 100–200 g [22].

Case Studies and Regional Comparisons

Arabian Gulf: Se levels in fish from Kuwait Bay (2.1 µg/g) caused selenosis cases .suggesting similar risks in Shatt al-Basrah. (Tables 3) and (Figure 2)

Interpretation:

EF > 1.5 suggests anthropogenic enrichment (e.g., industrial discharges).

CF > 1 indicates moderate contamination, particularly at Stations 2 and 3.

Igeo values (0–1) classify sediments as "uncontaminated to moderately contaminated."

Comparison with Regional Studies

Previous studies in the Arabian Gulf report Se concentrations of 5–15 ppb in uncontaminated sediments [17]. Our findings exceed these levels, aligning with trends of increasing Se pollution due to urbanization and industrial growth [18]

Human Health Implications

The presence of high concentrations of selenium in sediments can result in a variety of pathways that are a potential health risk to the local population. One of the most important pathways is the bioaccumulation of selenium in aquatic organisms (fish, shellfish, etc.) which are important sources of nutrients for the local population. Hence, selenium consumption in humans may be elevated as a result of contaminated seafood consumption. Furthermore, selenium above the need for the organism can trigger toxic effects, which is known as selenosis and that causes neurological, gastrointestinal and dermatological disorders [25].

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