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Assessment of Seasonal and Spatial Variation of Heavy Metals Concentrations in Shatt Al-Arab River, Basrah, Iraq

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Abstract

Heavy metal contamination in Shatt Al-Arab River poses significant environmental and public health challenges in Basrah Province, Iraq. This study aimed to evaluate the seasonal and spatial variation in total concentrations of heavy metals, including Copper (Cu), Lead (Pb) and Mercury (Hg) at five stations along Shatt Al-Arab River from July 2023 to May 2024. Water samples from surface and bottom layers were analyzed using Inductively Coupled Plasma (ICP) spectrometry. The statistical analysis was performed using one-way ANOVA ($p \leq 0.05$) to assess variations by station, season, and depth between the surface and the maximum depth at each location. Tukey's Honest significant difference was performed to identify group differences. Results revealed temporal and spatial fluctuations in total dissolved solids (TDS), with northern and central stations exhibiting consistent levels, while Al-Fao station (Southern Basrah Province) recorded the highest TDS during summer, and Al-Qurna station (Nourhern Basrah Province) showed the lowest across all seasons. Electrical conductivity and TDS at Al-Fao station exceeded permissible limits, highlighting significant pollution. Reduced river flow, tributary interruption, increased evaporation, and seawater intrusion, exacerbated water quality degradation. Results indicated that Cu was the most abundant element, with a maximum concentration of 0.1 mg/L, while Pb slightly exceeded permissible drinking water limits, and Hg values consistently surpassed safe thresholds. Heavy metal concentrations were higher at greater depths, with seasonal and spatial variability observed. The stations were classified as experiencing low to moderate heavy metal pollution, with industrial activities, oil extraction, diminished freshwater discharge, and seawater intrusion identified as key contributors. This study underscores the urgent need for sustainable water management strategies to mitigate the compounded effects of anthropogenic pressures on Shatt Al-Arab River water quality and ecosystem health.

Keywords: Heavy metals; Surface water; Shatt Al-Arab River; Mercury; Lead; Copper

1. Introduction

Surface waters are open ecosystems that encompass all water bodies on the Earth's surface, including rivers, streams, ponds, lakes, wetlands and oceans close to urban and rural regions (Dimri *et al.,* 2021).

Understanding these complex effects and relationships is crucial because it helps in developing local pollution management strategies and broader environmental policies. The Shatt Al-Arab River is the most important water source for Basrah Province, environmentally and economically. They are directly affected by human activities, such as industry, agriculture and mining practices (Chaoua *et al.,* 2019; Khreebsh & Azeez, 2024), and natural processes similarly, evaporation and the precipitation (Lazar *et al.,* 2024; Abdel-Rahman, 2022).

These activities and processes have a direct influence on the physical, chemical and biological characteristics of surface waters, and rivers play a critical role in sustaining ecosystems and human life by providing water for domestic supply, irrigation, power generation, biodiversity and transportation facilities (Dippong *et al.,* 2024).

Heavy metals are natural elements can accumulate in water bodies, such as rivers, lakes, estuaries, bays and seas, serving as potential reservoirs; most of the metals present in these surface water bodies originate from industrial activities, agricultural runoff and sewage treatment plants (Real *et al.,* 2024). Meanwhile, heavy metals are amongst the most dangerous pollutants due to their high level of toxicity to living organisms, even at low concentrations, are not biodegradable and accumulate in terrestrial and aquatic environments (Azeez, 2021; Onwukeme and Okechukwu, 2021). Heavy metals, including Cadmium, lead, mercury, and their compounds, are amongst the 45 prioritized substances that pose a serious threat to surface waters; the release of heavy metals into water is a serious concern, particularly due to their long-term toxic effects on ecosystems, as they cannot be analysed into nontoxic forms (Piwowarska *et al.,* 2024)

Natural processes and human activities contribute to the gradual release of contaminants, particularly heavy metals, into water over time. The origins of heavy metals in surface water systems can be either natural or anthropogenic (Afzaal *et al.,* 2022). Heavy metals have been classified into two groups; essential and non-essential; essential metals are harmless or relatively harmless at low concentrations, whereas non-essential metals are highly toxic even at low concentrations, such as Cadmium, mercury, Arsenic and Lead (Kim *et al.,* 2019). Metals that are required for plant development and are either innocuous or have a low level of toxicity in tiny doses are categorised as essential; some examples of these metals include Zinc, Copper, Iron and Nickel (Vardhan *et al.,* 2019). Non-essential metals include Cd, Pb and Hg (Piwowarska *et al.,* 2024).

The selected metals, Cu, Pb, and Hg, are among the most toxic and commonly detected contaminants in aquatic environments in southern Iraq (Hamdan, 2020; Al-Abbawy *et al.,* 2021). Hg and Pb are classified as priority hazardous substances by the WHO (2008) because of their neurotoxicity and bioaccumulative nature, whereas Cu, although essential in trace amounts, becomes harmful at elevated levels. Heavy metal pollution in the Iraqi rivers is primarily linked to industrial, agricultural, and domestic wastewater inputs, especially near urbanized areas. Al-Asadi *et al.* (2020) noted that limited river flow reduced the self-purification capacity and worsened contamination. Al Ani *et al.* (2014) further observed that sediment fissures enhance the accumulation of metals like zinc, iron, and lead, affecting water quality and ecosystem functions.

Despite previous studies on water quality in the Shatt Al-Arab River, few have examined the depth-wise and seasonal dynamics of heavy metal concentrations in both the surface and bottom waters. Additionally, limited attention has been paid to integrating pollution patterns with water use implications in this ecologically stressed region.

Therefore, this study aims to (1) quantify seasonal and spatial variations in Cu, Pb, and Hg concentrations in surface and bottom waters, (2) assess compliance with national and international water quality standards, and (3) evaluate the environmental and anthropogenic factors contributing to the observed pollution patterns.

2. Methodology

2.1 Study Area

Shatt Al-Arab River is the main water source in Basrah Province, serves various functions, including potable water supply, industrial applications and agriculture. This river is in the Basrah Province, Southern Iraq, between latitudes 31° 01° 37″ N and 31° 01° 37″ N and longitudes 47° 44° 44″ E and 48° 46° 04″ E. The width of Shatt Al-Arab River that ranges from approximately 400 m at the center of Basra to about 1700 m at the entrance of the estuary The river's profundity ranges from 8 m to 15 m (Hamdan, 2020). Currently, Shatt Al-Arab receives its water solely from the Tigris River, whereas it previously received water from the tributaries of the Tigris, Euphrates, Karkh and Karun Rivers.

Shatt Al-Arab River experiences two ebb and two flood every 24 h, but they are unequal in duration and amplitude.

During the study period, the maximum and minimum water levels ranged from 0 m to 3.1 m during the study period; the water level rise in Shatt Al-Arab also occurs under the effect of tides, which, in the mouth section of the river, reach 3 m during neap tide and 5 m during springtide (Isaev and Mikhailova, 2009). The average tide range at Al Basrah is 0.5 m. The flow velocities during tidal level variations can reach as high as 2 – 3 m/s.

Water quality in Shatt al-Arab River has worsened in recent years due to the reduced drainage discharge from the Tigris and Euphrates Rivers caused by the construction of numerous dams along the Turkey and Iran Rivers (Al-Asadi and Abdullah, 2015; Mahdi *et al.,* 2023). Reduced freshwater inflows have contributed to increased salinity, particularly in the southern sections near the estuary.

2.2 Study Stations

Five water sampling sites were selected along Shatt Al-Arab (from Qurna in the north to Al-Fao in the south), including stations Al-Qurna (upstream of river), Al-Maqal, Abu Al-Khasib, Al-Seebah and Al-Fao (downstream of river) as shown in Figure 1. A Global Positioning System (GPS) device was used to identify coordinates (Table 1).

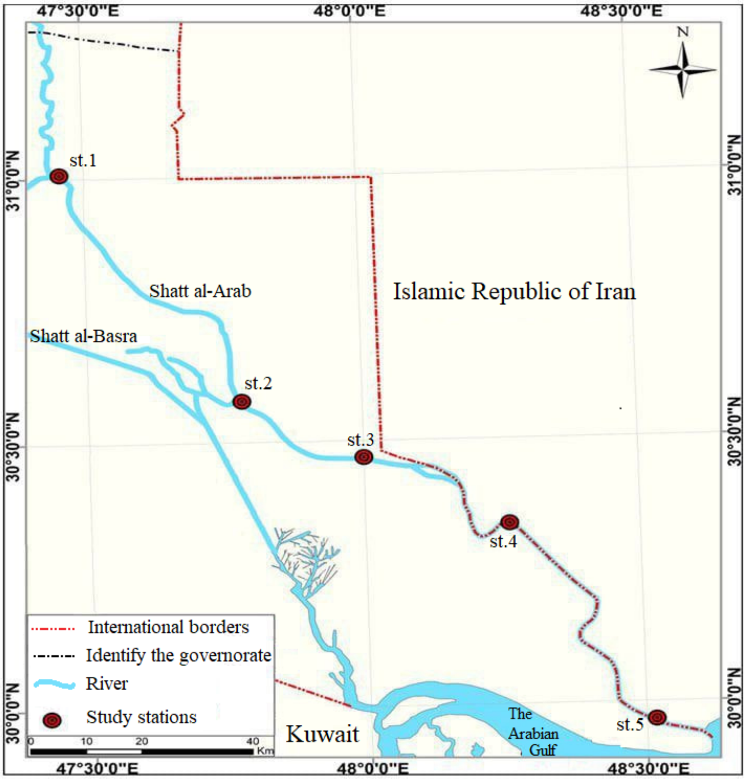

Figure 1. Map of the study stations in Shatt Al-Arab River

Table 1. Geographical coordinates of the study stations using a GPS device

Number station	Station name	Longitude	Latitude
St.1	Al-Qurna	47° 44° 44″	31° 01° 37″
St.2	Al-Maqal	47° 77° 34″	30° 58° 30″
St.3	Abu al-Khasib	47° 98°56″	30° 46° 53″
St.4	Al-Seebah	48° 15° 05″	30° 19° 31″
St.5	Al-Fao	48° 46° 04″	29° 98° 99″

2.3 Water Sample

The water samples were collected at each of the selected stations in four seasons, with the first two samples from the surface at a depth of 10 cm and the second from the river floor at a depth 3-11 m. The samples were collected during the lowest tide based on the lunar calculations. The water samples were collected in 1 L surface-layer plastic bottles. The bottom samples were collected by with a water sampler.

In-situ measurement a water multimeter type Hanna, HI 9813-6 was used to measure pH, electrical conductivity (EC), water temperature (WT), and total dissolved solids (TDS). The total suspended solids (TSS) values were laboratory, and the weighing method was according to APHA (2005) by filtering 100 ml of water sample using a Millipore filter, paper 0.45 um estimated in mg/L.

2.4 Heavy Metal Analysis

The primary objective was to quantify the concentrations of copper (Cu), lead (Pb) and mercury (Hg) in collected water samples. The samples were stored at 4 °C and transported to the laboratory for analysis. Pretreatment included filtration and acidification with concentrated nitric acid to prevent metal precipitation and microbial growth.

• Instrumentation: Inductively coupled plasma (ICP) spectrometry was employed for quantitative analysis of all heavy metals.

• Metals: Cu, Pb, and Hg analyses involved ICP spectrometry with calibration curves established using Cu standards. The concentrations were recorded in mg/L.

Quality Assurance and Control, to maintain analytical accuracy, all instruments were calibrated with certified reference materials prior to the analysis. Concurrent blank and spiked sample analyses were conducted to ensure precision and reliability. The limits of detection (LOD) for Cu, Pb, and Hg were established and observed throughout the study.

2.5 Statistical Analysis

The data were statistically analysed conducting the statistical package, SPSS version 27.0. The mean and standard deviation (SD) of the metal concentrations in the surface and bottom waters were calculated. The results were analyzed using a one-way ANOVA test ($p \leq 0.05$) to show significant variance and coefficient of correlation between all stations and for four seasons. When significant differences were detected, Tukey's Honest Significant Difference (HSD) post-hoc test was performed to identify specific group differences. Pearson's correlation coefficients were calculated to explore inter-metal associations. The significance levels, F-statistics, and confidence intervals were reported for all tests.

3. Results and Discussion

3.1 Physicochemical Parameters of Water

3.1.1 Water Temperature (WT)

Figure 2 shows the seasonal and localized changes in the WT values in the Shatt Al-Arab River. The temperature at the surface and bottom varies between 15.8 °C and 36.4 °C, respectively. The surface and bottom WT were higher in summer, reaching a maximum value of 36.4 – 34.5 °C in July at Al-Fao stations, and decreased in winter, with a minimum value of 15.8 – 16.4 °C in January. The surface WT were higher in summer and lower in winter due to the influence of atmospheric elements, such as radiation, evaporation and winds. The results of the statistical analysis show evident differences in WT between seasons at a level $p < 0.05$.

The largest disparity between surface and bottom temperatures occurred in the summer, while the smallest difference was observed in winter; this pattern suggests that in summer, the distinct temperature stratification in the water may result from climatic and environmental influences., such as the effect of solar radiation, aquatic activity and thermal mixing in the surface and bottom water (Liu *et al.,* 2020; Freitas *et al.,* 2021). The study stations' water temperature variations are influenced by factors such as sampling time, water movement, depth, tide movement, runoff speed, solar radiation impact, geographical location, and human activities near the stations.

3.1.2 Potential of Hydrogen (pH)

Figure 3 illustrates the spatial and temporal changes in pH rates, with the highest rate of 8.9 at Al-Fao station during the summer season and the lowest rate of 7.3 recorded at Al-Seebah station during the spring season in surface water. The bottom water recorded the highest rate of 8.7 at Al-Fao during the summer season and the lowest rate of 7.35 at Al-Seebah station during the spring season. The pH rates in all seasons for all stations were within the alkaline range of 7.3 – 8.9. The pH values at Al-Fao station exceeded the permissible limits mentioned in Table (2). This outcome can be explained by the high regulatory susceptibility of the Shatt Al-Arab waters due to the geology of the area, which is characterized by its high carbonate and bicarbonate contents. The high pH observed during the summer season and at Al-Fao station may be caused by high temperatures, increased evaporation and a decrease in water levels and their vulnerability to the Arabian Gulf salt front (Adlan and Al-Abbawy, 2022). The decrease in pH at Al-Seebah station may result from the high organic matter content in the water, which is influenced by the frequent human and agricultural activities, including numerous orchards.

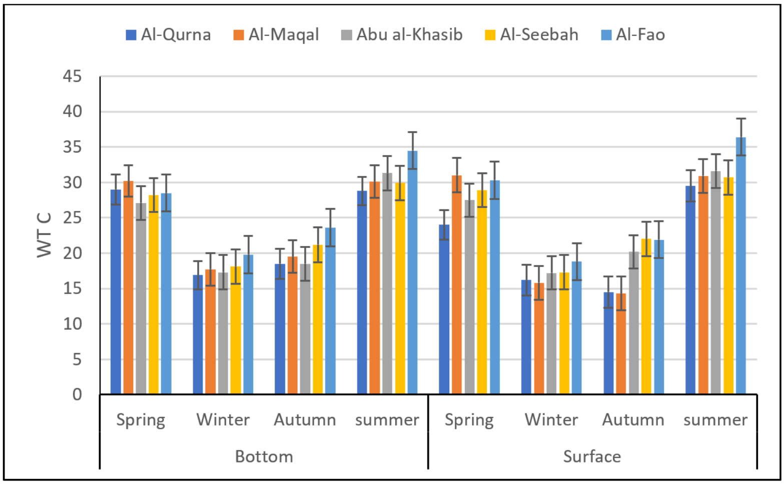

Figure 2. Seasonal Variations in Water Temperature (WT; mean ± SD) at Surface and Near-Bottom Layers across all Sampling Stations in the Shatt Al-Arab River.

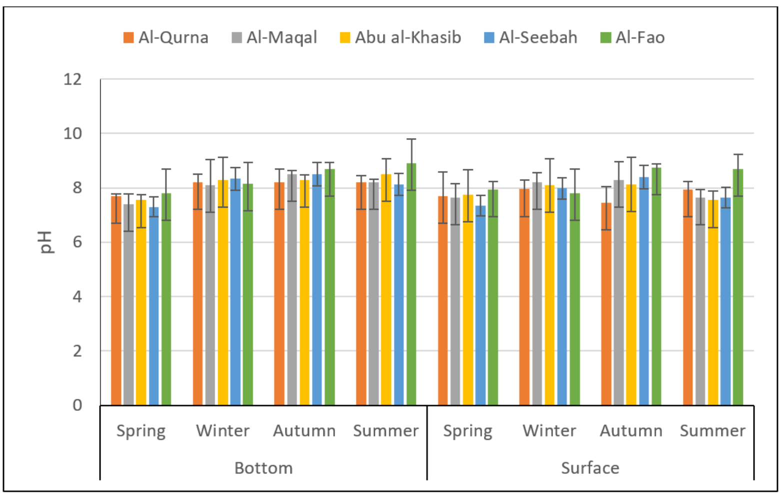

Figure 3. Variabilities of the potential of hydrogen (pH) during the four seasons at all stations in Shatt Al-Arab River

Table 2. Specifications of Iraqi Drinking Water Standard, No. 417, Republic of Iraq (2018)

Item	Value
pH Value	6.5-8.5
EC (ms/cm)	1.5
TDS (mg/L)	1000
TSS	60

3.1.3 Electrical Conductivity (EC)

Figure 4 illustrates the highest EC rate of 28.55 ms/cm during the summer season at Al-Fao Station, whilst the lowest rates of 2.015 – 2.24 ms/cm during the autumn and winter season are recorded at Al-Qurna Station in surface water. The highest rate of 34.8 ms/cm is recorded during the summer season at Al-Fao Station. Meanwhile, the lowest value of 2.18 ms/cm is observed at Al-Qurna during the winter season in the bottom waters. The EC values at all study stations during the seasons of the year are exceeded, and the dry season (summer) and spring are much higher than average because of drought, lack of river flow and erosion of the soil surrounding the channel due to rainstorms.

The high EC in Table 2 during the summer season may be caused by drought and heatwave events, where EC is influenced by several factors, such as the amount of freshwater, temperature, evaporation, rain, the progress in the salt tongue of the Arabian Gulf and the quality of the soil through which water passes. In addition to the presence of power and treatment plants that use large quantities of water for cooling, resulting in a high concentration of salts, the increased evaporation rates and low discharge of the river hindered the river's ability to mitigate (Graham *et al.,* 2024).

3.1.4 Total suspended solids (TSS)

Figure 5 shows that the highest TSS values are recorded at the surface and bottom in the estuary area at Al-Fao station near the Gulf. The highest values at the bottom are observed at Al-Fao station during the summer (1299.5 mg/L); the highest value at the surface at the same station during the summer is 915.6 mg/L. Meanwhile, the lowest values are recorded during the rest of the seasons. The lowest values are recorded at Al-Maqal station during the spring, 23.3 mg/L for the bottom and 13.3 mg/L at the surface. The spatial and temporal variations in the levels of TSS in the Shatt Al-Arab River waters are influenced by the river water source. The TSS values increased during the summer at Al-Fao station, located in the far south of the channel close to the influence of sea water, where the tide infiltrates the channel, especially during the summer. The rest of the stations are affected by natural influences and human activity, such as low water levels in the river and human activities, such as land reclamation, sewage and industrial. Plant growth affects soil stability and reduces sediment transport, and moderate weather conditions minimise sediment erosion in banks and river sides (Li *et al.,* 2024; Luo *et al.,* 2022). Water quality is affected by the TSS values; water is classified as excellent quality if the TSS values are less than 25 mg/L; if the water remains between 26 mg/L and 75 mg/L, the water is classified as good quality; if the suspended solid values in the water exceed these values, then it is considered to be of unsuitable quality for use, whether for human consumption or irrigation (Zamora *et al.,* 2019). Furthermore, the suspended solids are more than the permissible limits at the Al-Fao station, which recorded high values compared with the general average, followed by the Seebah station, which is affected by the infiltration of salt tides during the summer.

The diversion of the Karun River into Iran due to the lack of available water, which has reduced the contribution of the sediment load of the Karun River, which supplied the Abu Al-Khaseeb and Al-Seebah stations with the highest values in the Shatt Al-Arab course 2 decades ago (Al-Mansouri and Al-Mahmoud, 2009).

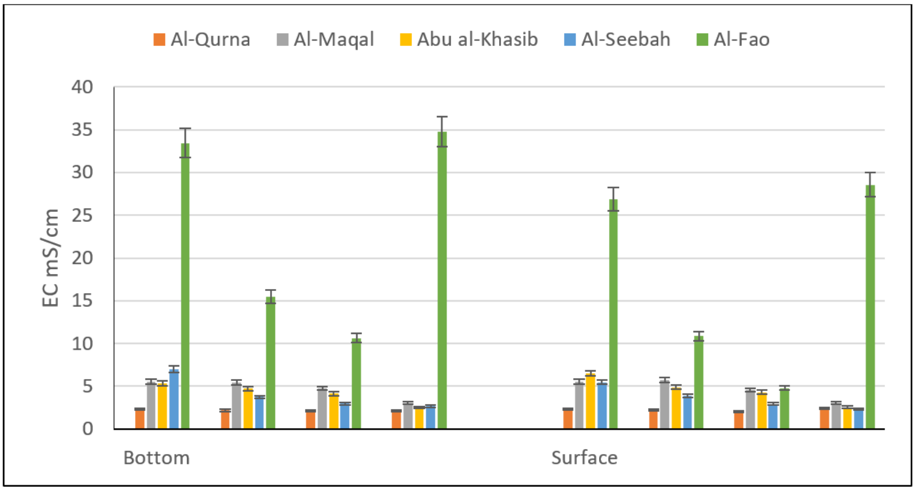

Figure 4. Seasonal and spatial changes in EC values at all stations in Shatt Al-Arab River

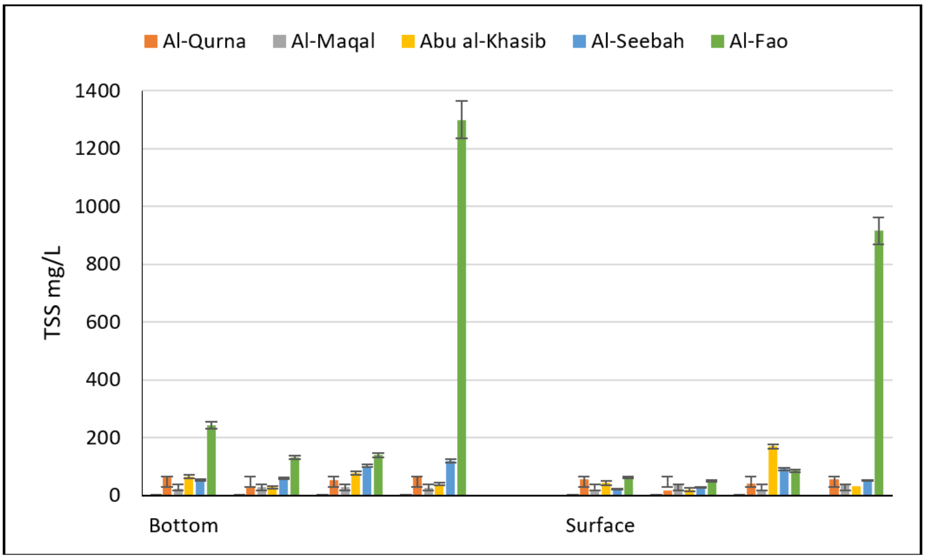

Figure 5. Seasonal and spatial changes in TSS values at all stations in Shatt Al-Arab River

3.1.5 Total dissolved solids (TDS)

Figure 6 shows the temporal and spatial changes in TDS values. The changes were evident between stations and during the four seasons. The values at the northern and central stations are in almost the same range. The highest value of 27,045 mg/L is recorded at Al-Fao station during the summer. Salinity increased at Al-Fao station in all seasons, except for the fall, when the lowest value of 4103.25 mg/L is recorded. The lowest salinity ratio is 996.5 – 1039.5 mg/L amongst the stations at Al-Qurna station during all seasons in surface and bottom waters. In general, it appears that the change of salinity and dissolved substances is affected by distance and proximity to the marine estuary more than the seasonal change therefore, the suspended dissolved materials are more than the permissible limits at Al-Fao station, which recorded high values compared with the general average, followed by Al-Seebah station, which is affected by the infiltration of salt tides during the summer.

The increase in salinity during the summer may be linked to heat waves, and extreme weather. These factors lead to higher evaporation rates, reduced river discharge from the Tigris, water scarcity due to interrupted tributaries, and the intrusion of the Arabian Gulf's salt front, further increasing salinity in the Shatt Al-Arab River (Khondoker *et al.,* 2023). The interruption of tributaries and the decrease in river flow, along with increased evaporation losses and seawater infiltration, have contributed to the degradation of hydrological conditions in the region.

3.1.6 Mercury (Hg)

The results in Figure 7 show that the Hg values at the study stations are close to each other between the bottom and the surface, except for some values that are abnormal from the general average. The values typically ranged from 0 mg/L to 0.077 mg/L. During the autumn season, some stations

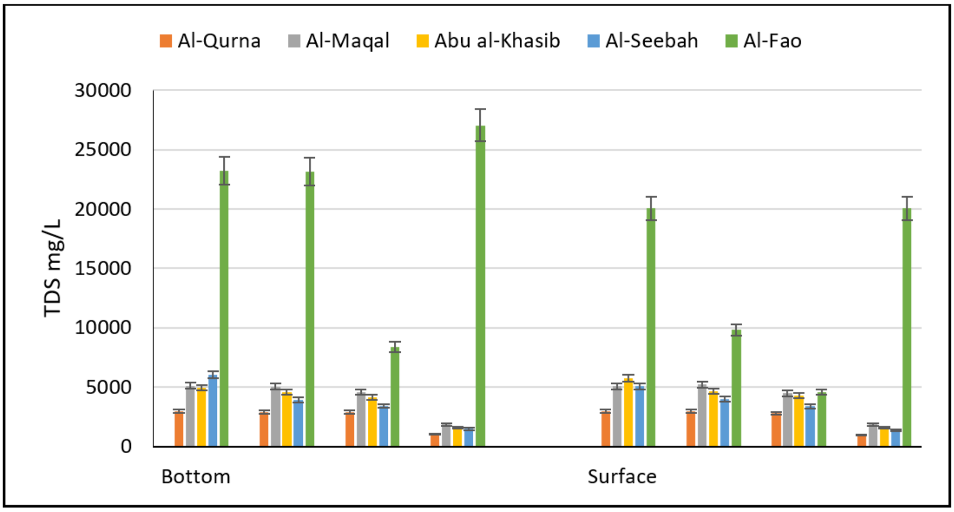

Figure 6. Seasonal and spatial changes in TDS values at all stations in Shatt Al-Arab River

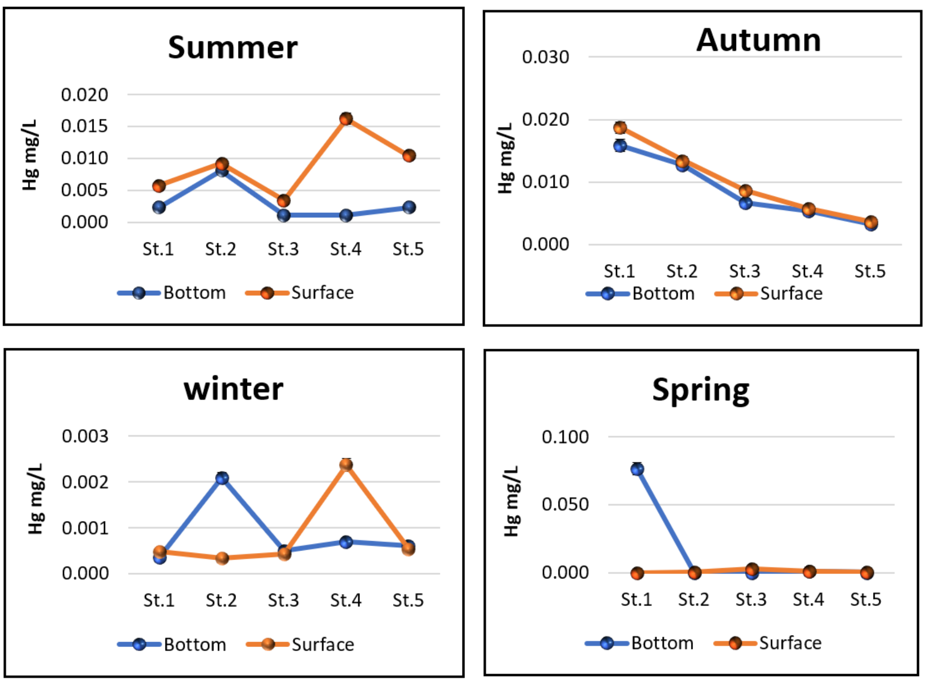

Figure 7. Seasonal and spatial changes in Hg values at all stations in Shatt Al-Arab River

recorded values above the average, which can be attributed to local conditions in the areas near these sites which is affected by industrial concentrations and the oil industry, as well as the impact of intensive human activities. The Hg values are higher than the permissible limits for drinking water, whilst Pb concentrations are slightly higher than the established limits. Majority of the study stations are classified as low and moderate pollution by heavy metals (Table 3).

3.1.7 Lead (Pb)

Pb is one of the most widespread environmental pollutants, absorbed into the human body, where it can lead to dysfunction in the nervous, skeletal and reproductive systems and negative effects on the blood, kidneys and cardiovascular system (Collin *et al.,* 2022). Furthermore, Pb is transferred from soil and water to plants through bioaccumulation, a dynamic process in which Pb is absorbed from terrestrial and aquatic ecosystems and then transported to higher levels of the food chain by biomagnification, reaching humans through food sources (Bețianu *et al.,* 2024). Pb reacts with air and water to form Pb sulphate, Pb carbonate or Pb oxide. This element is removed from the atmosphere by rain, transported to soil and washed into rivers. The primary sources of Pb pollution include factories that use Pb compounds, vehicle exhausts and the burning of fossil fuels (Collin *et al.,* 2022). Bețianu *et al.* (2024) reported that climate change influences atmospheric chemistry and mercury deposition patterns. Major changes are expected in vegetation density and foliage density, along with decreased Hg oxidation due to higher temperatures. This phenomenon could affect ecosystems particularly vulnerable to global warming, including the Shatt al-Arab region. A particular scientific challenge in the near future is the methylation of Hg, which bioaccumulates more highly in freshwater systems than in marine systems.

Figure (8) show that the Pb values at the study stations are close to each other between the bottom and the surface, except for some values that deviated from the general average in Table 3. Meanwhile, the Pb values at the surface ranged from 0 mg/L to 0.014 mg/L. During the autumn season, some stations (Al-Qurna) recorded values above the average, which can be attributed to the local conditions in the areas near these sites.

3.1.8 Copper (Cu)

Figure 9 show that the concentration of Cu at the bottom is higher than the general average, with a recorded value of 0.099 mg/L during the spring and ranged between 0 mg/L and 0.076 mg/L during the summer at Seihan station and between 0 mg/L and 0.098 mg/L during the fall at Al-Qurna station. In terms of surface water, the values are lower than the average during the spring, summer and fall for most stations, ranging from 0 mg/L to 0.049 mg/L during the spring at Abu Al-Khaseeb station. The high values at some stations are due to sewage, household and municipal waste being discharged directly into Shatt Al-Arab or through the river branches connected to it. Meanwhile, the higher-than-average values in surface water during the spring are due to soil erosion that occurs during the rainy season.

This study illustrated records of Cu that exhibited locational and seasonal changes due to factors surrounding the stream. The Cu levels are low, and their distribution between stations depends on the volume of water flow and the movement of water

Table 3. Permissible limit of heavy metal concentration in water according to the WHO standards in mg/L

Heavy metal	Permissible limit (mg/L)
Cu	0.2
Pb	0.010
Hg	0.006

Source: WHO, 2008

currents. The depth measurements recorded higher levels of Cu concentration compared with the surface due to the presence of sediments, which are the primary source of heavy metals. Given that the volume of the water mass decreases with the decrease in discharge during the summer and autumn, the Cu concentration reached the highest level, whilst winter records the lowest concentration due to the rise in water levels that reduce the levels of heavy metals in the water mass. In this study, the Cu values at the bottom are higher than the surface for all seasons and for all stations.

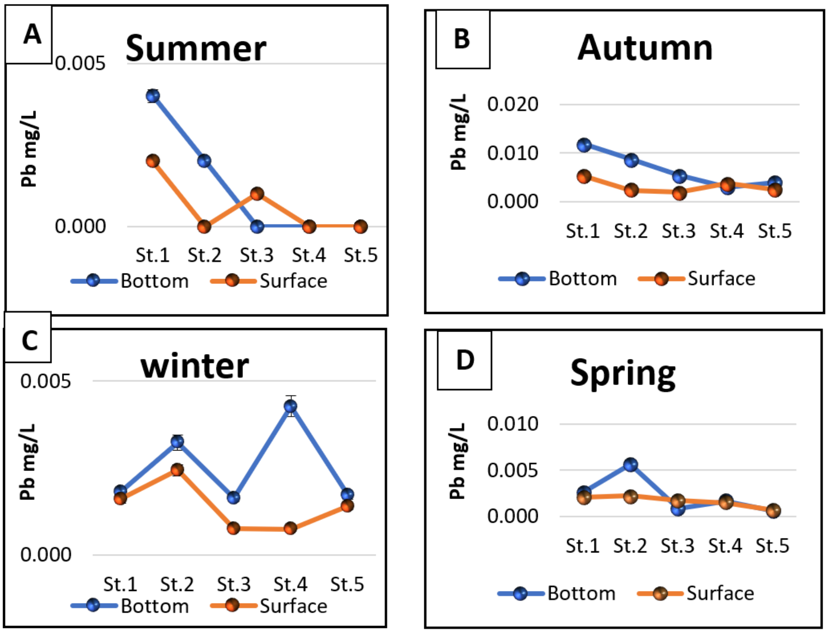

Figure 8. Seasonal and spatial changes in Pb values at all stations in Shatt Al-Arab River

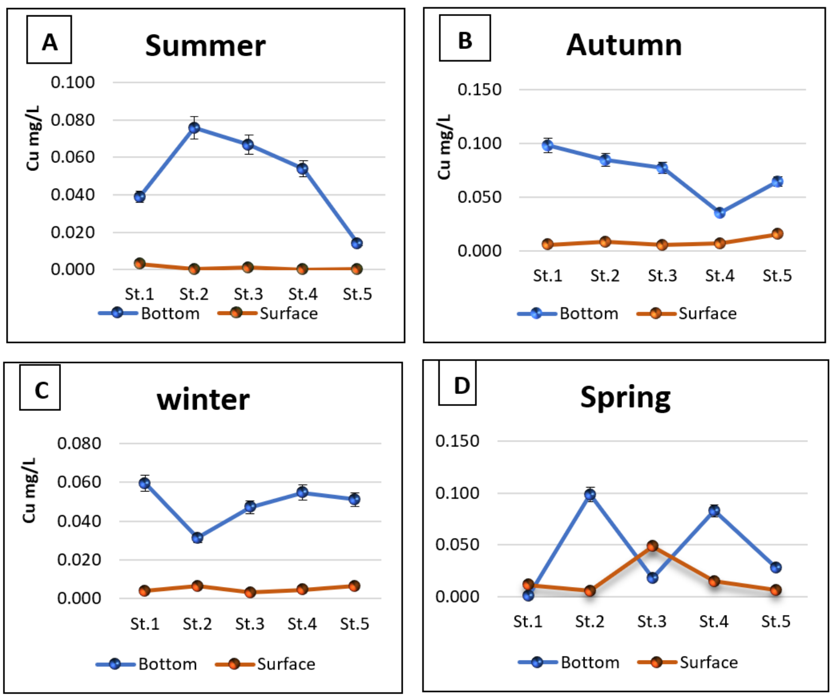

Figure 9. Seasonal and spatial changes in Cu values at all stations in Shatt Al-Arab River

This agrees with the effects on chlorophyll and protein content observed for plants under salinity stress (Al-Nabhan *et al.,* 2024). Higher concentrations of heavy metals adversely affect aquatic plant physiology and indicate a greater risk of other environmental stressors within sensitive ecosystems, such as the Shatt Al-Arab River.

The elevated concentrations of Hg and Pb detected in several locations, particularly at Al-Fao and Abu Al-Khasib stations, raise serious public health concerns. According to WHO (2008) guidelines, Hg concentrations exceeding 0.006 mg/L pose neurodevelopmental risks, particularly to children and pregnant women (Collin *et al.,* 2022). Pb is similarly associated with cognitive impairment and cardiovascular damage, even at low concentrations (Bețianu *et al.,* 2024). The river is a vital source of water for domestic, agricultural, and industrial use in Basrah Province, and contamination at this scale could affect both food safety and potable water supplies. Risk assessment frameworks such as Hazard Quotient (HQ) analysis are recommended for future studies to estimate actual human exposure and support policy interventions.

4. Conclusion

This study highlights the seasonal and spatial variability of heavy metals in the Shatt Al-Arab River, revealing higher concentrations during low-discharge periods and in bottom waters. Industrial discharges, oil-related activities, and reduced freshwater inflows emerged as key pollution sources. While seasonal hydrological changes may contribute to metal mobility and bioavailability, anthropogenic activities remain the dominant driver. The concentrations of Hg and Pb exceed safe thresholds, posing ecological and public health risks. This underscores the urgent need for integrated water quality monitoring, pollution control, and sustainable watershed management to safeguard human and ecosystem health in southern Iraq.

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