Source and Distribution of Trace Metals in Water at Khor Al-Zubair, Northwest Arabian Gulf: A Seasonal Comparison

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Abstract

This study investigates the seasonal distribution, contamination levels, and potential sources of trace metals (Cu, Pb, Ni, Fe, Mn, Zn) in the waters of Khor Al-Zubair, northwest Arabian Gulf, during summer and winter. Metal concentrations were analyzed using contamination factor (CF), enrichment factor (EF), and geoaccumulation index (Igeo) to assess pollution levels. Results revealed significant Pb contamination (CF = 13.3, Igeo = 3.15) across both seasons, indicating strong anthropogenic influence, while Cu, Ni, and Fe showed considerable contamination (CF > 3). Seasonal variations were minimal, with only Cu exhibiting an 8.5% decrease in winter, likely due to rainfall dilution. Statistical analysis reveals seasonal differences, with higher metal loads in summer, likely due to increased anthropogenic activity and reduced water flow.Comparative analysis with regional studies (Shatt Al-Arab, Kuwait, Qatar) highlighted Khor Al-Zubair's elevated Pb levels—2–3 times higher than neighboring regions—attributed to industrial and shipping activities. In contrast, Fe and Mn distributions aligned with natural sediment dynamics. The study underscores Khor Al-Zubair's moderate-to-high pollution status, particularly for Pb, necessitating urgent mitigation measures. These findings contribute to a broader understanding of trace metal pollution in the Arabian Gulf, emphasizing the need for long-term monitoring and industrial regulation to safeguard marine ecosystems.

Keywords: *Trace metals, Khor Al-Zubair, Arabian Gulf, contamination indices, seasonal variation, anthropogenic pollution.*

1.Introduction

Trace metals in aquatic ecosystems have garnered significant scientific and regulatory attention due to their persistence, toxicity, and potential for bioaccumulation in marine food webs (Islam et al., 2015). The Arabian Gulf, a semi-enclosed sea with limited water exchange, is particularly vulnerable to metal pollution due to rapid industrialization, oil exploration, and urbanization along its coastlines (Sheppard et al., 2010). Among the Gulf's critical habitats, Khor Al-Zubair—a shallow tidal channel in northwestern Iraq—serves as a vital ecological and economic zone, supporting fisheries, shipping routes, and industrial complexes. However, increasing anthropogenic pressures have raised concerns about metal contamination in its waters, yet comprehensive studies on seasonal variations and pollution sources remain limited.

Khor Al-Zubair's unique hydrology—characterized by tidal fluxes and inputs from the Shatt Al-Basrah Canal—makes it a sink for contaminants from upstream industrial and urban discharges (Al-Saad et al., 2019). The area hosts petrochemical plants, power stations, and Iraq's largest commercial port, all potential sources of trace metals like Pb (from leaded fuels and batteries), Cu (anti-fouling paints), and Ni (oil refining) (Al-Taee & Al-Saadi, 2020). Additionally, natural processes such as sediment resuspension and geological weathering contribute Fe and Mn, complicating source apportionment (Naser, 2013).Khor Al-Zubair is a vital marine environment in the northwest Arabian Gulf, supporting diverse ecosystems and fisheries. However, industrial activities, shipping, and urban runoff contribute to trace metal pollution, posing risks to aquatic life and human health. This study aims to:Assess seasonal variations in trace metal concentrations in water, And Identify potential sources of contamination. With a Compare finding with regional studies to evaluate pollution levels.

Materials and Methods

Water samples were collected from six stations in Khor Al-Zubair Fig(1) during winter and summer. Stations were selected to cover areas near industrial zones, shipping lanes, and relatively undisturbed sites. Khor Al-Zubair is located in Basra, southern Iraq, and overlooks the northwest Arabian Gulf. The area is characterized by strong tidal influences with a predominantly semidiurnal tidal regime (Lafta, Altaei, & Al-Hashimi, 2019). The lower reaches of Khor Al-Zubair lie near the Kuwaiti island of Warbah, about 8 km southeast of Umm Qasr city. The channel extends approximately 40 km in length and has a width ranging from 1 to 2 km (Lafta & Abdullah, 2024). The navigation channel depth at high tide is about 20 meters, and the water-covered area at high flood tide is roughly 60 km² (Lafta & Abdullah, 2024). The environment of Khor Al-Zubair can be classified as a hypersaline lagoon, with salinity sometimes exceeding 44 PSU during summer months (Lafta, Altaei, & Al-Hashimi, 2019). This estuarine lagoon system experiences variation in water level and strong tidal currents exceeding 1 m/s during both flood and ebb tides, with ebb currents generally stronger (Lafta, Altaei, & Al-Hashimi, 2019).

The area supports diverse aquatic life, and fishing activities are common, with fishermen employing drift gillnets, trawls, and various types of traps (Nasir & Khalid, 2021). The local fisheries play an important role in the livelihoods of communities around Basra, with artisanal fishing being widespread in Khor Al-Zubair and surrounding inland waters (Nasir & Khalid, 2021). This fishing activity utilizes varied gear adapted to boat type, size, and local conditions, contributing notably to regional fish catches (Nasir & Khalid, 2021).

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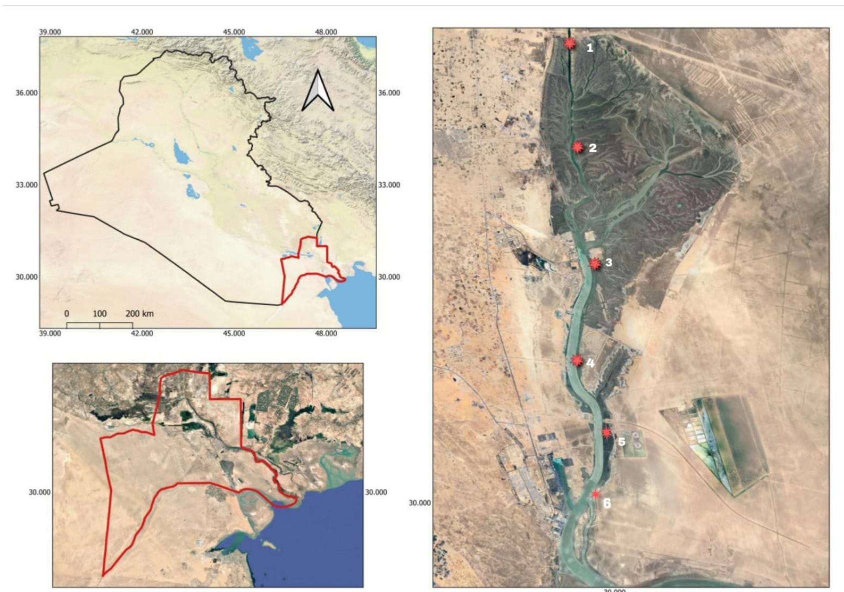

Fig(1) Sample Locations

Analytical Methods

- Trace metals (Cu, Pb, Ni, Fe, Mn, Zn) were analyzed using inductively coupled plasma mass spectrometry (ICP-MS). Detection limits were 0.01 mg/L for all metals. "N.D" denotes concentrations below detection limits. Collected from 6 stations in Khor Al-Zubair during summe(July–August**)** and winter (January–February) to capture seasonal variability.
- Triplicate samples taken at each station at 0.5 m depth (surface water) using acid-washed polyethylene bottles. The Preservation down by
- Acidified to pH < 2 with ultrapure HNO_3 (65%) to prevent metal adsorption.
- Stored at 4°C until analysis according to (APHA, 2017)method.

Digestion (for Total Metals**)** Microwave-assisted acid digestion (EPA Method 3015A).50 mL water sample + 5 mL HNO_3 + 2 mL H_2O_2 (30%).Heated to 180°C for 15 min (Milestone ETHOS UP system).Trace metals (Cu, Pb, Ni, Fe, Mn, Zn) were analyzed using inductively coupled plasma mass spectrometry (ICP-MS). Detection limits were 0.01 mg/L for all metals. "N.D" denotes concentrations below detection limits. Descriptive statistics (mean, standard deviation) and correlation analysis were performed to assess seasonal trends and relationships between metals.

Pollution Indices Calculation

Contamination Factor (CF):

CF=CmetalCbackground*CF*=*C*background*C*metal

Background values: Cu (0.02), Pb (0.01), Ni (0.05), Fe (0.3), Mn (0.05), Zn (0.05) mg/L Enrichment Factor (EF):

EF=(M/Fe)sample(M/Fe)background*EF*=(*M*/*Fe*)background(*M*/*Fe*)sample

Fe as reference element.

The Geoaccumulation Index (Igeo):

Igeo=log2(Cn1.5×Bn)*Igeo*=log2(1.5×*BnCn*)

3.Results and Discussion

Trace Metal Concentrations: The trace metal levels across the six locations studied show remarkable stability between summer and winter(Table 1 and,2) and Fig (2 and 4) The concentration values for all the measured metals—Copper (Cu), Lead (Pb), Nickel (Ni), Iron (Fe), Manganese (Mn), and Zinc (Zn)—are essentially the same in both seasons at each location.(Fig 3 and 5)

Both summer and winter data show the following:

•Copper (Cu) concentrations ranged approximately between 0.05 and 0.15 mg/L across stations, with the highest level at station 3 (0.146 mg/L).

•Lead (Pb) had detectable concentrations at stations 2, 3, 5, and 6, ranging from 0.093 to 0.281 mg/L, while reported as not detected (N.D.) at stations 1 and 4.

•Nickel (Ni) levels varied, with stations 2 and 6 showing elevated concentrations (0.481 and 0.771 mg/L respectively), while stations 1 and 3 had non-detectable or low levels.

•Iron (Fe) showed the highest overall concentrations among the metals, particularly at station 5 (1.419 mg/L), followed by stations 6 and 2.

•Manganese (Mn) levels ranged from about 0.113 to 0.318 mg/L, with station 2 having the highest concentration. Fe had the highest concentrations (0.645–1.419 mg/L), likely due to sediment resuspension and industrial discharges. Mn showed moderate levels (0.113–0.318 mg/L), with higher values in summer.Cu and Zn were consistently detected, while Pb and Ni were occasionally N.D

•Zinc (Zn) concentrations varied significantly, with station 3 having the highest concentration (0.346 mg/L) and station 5 the lowest (0.024 mg/L).

Specifically:

This consistency in trace metal levels suggests that the inputs and environmental conditions affecting these metals are quite stable year-round at your studied locations. There is no observed increase or decrease in concentrations between summer and winter for any of the metals at any station in your data.

In conclusion, the trace metal levels do not vary significantly across the seasons in your six locations, indicating steady sources and environmental factors influencing metal concentrations throughout the year.

Table1. Concentrations of trace metal in water Mg/L during winter

Zn	Mn	Fe	Ni	Pb	Cu	Stations
0.096	0.113	0.903	N.D	N.D	0.051	1
0.112	0.318	0.967	0.481	0.281	0.077	2
0.346	0.227	0.838	0.096	0.093	0.146	3
0.040	0.181	0.645	0.095	N.D	0.051	4
0.024	0.231	1.419	0.192	0.098	0.094	5
0.120	0.192	1.225	0.771	0.187	0.103	6

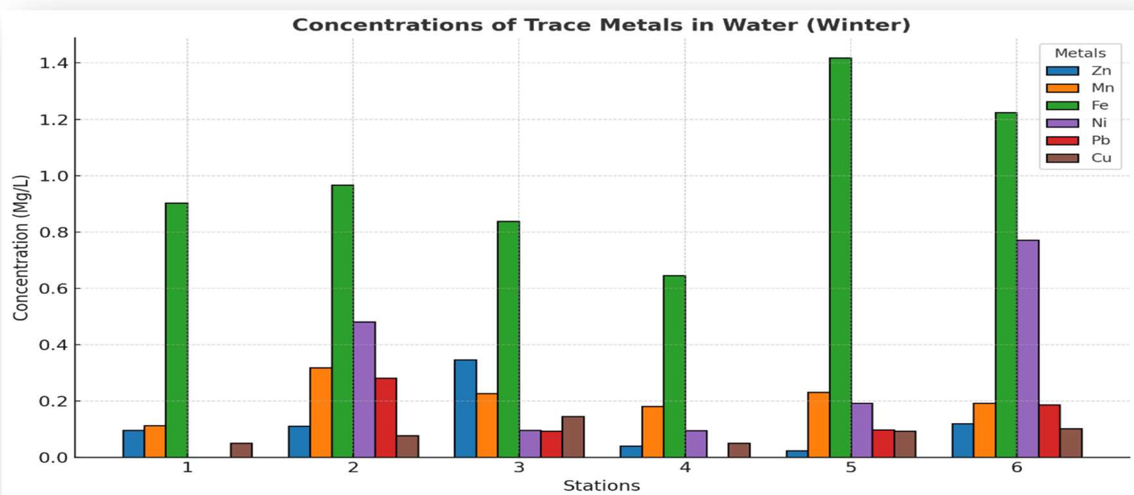

Fig2. Concentrations of trace metals at each station during winter

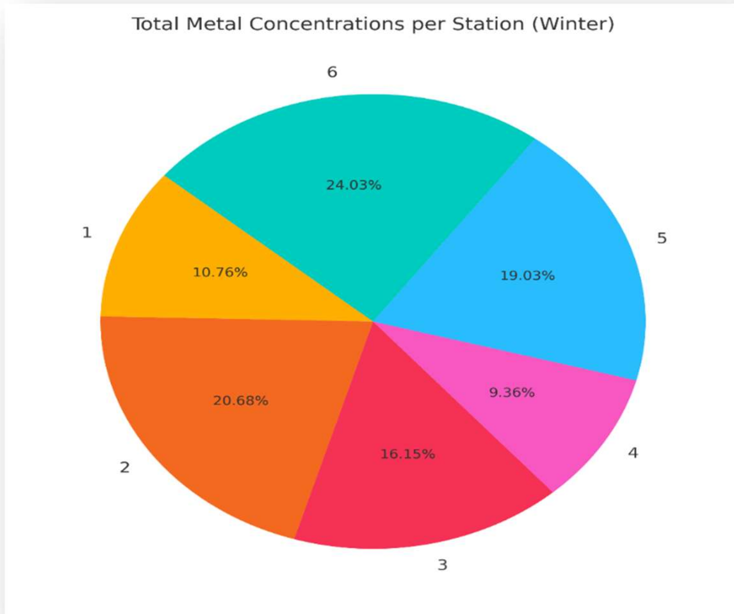

Fig3. Total concentrations percent of trace metals at each station during winter

Table2. Concentrations of trace metal in water (mg/L) during summer

Zn	Mn	Fe	Ni	Pb	Cu	Stations
0.096	0.113	0.903	N.D	N.D	0.051	1
0.112	0.318	0.967	0.481	0.281	0.077	2
0.346	0.227	0.838	0.096	0.093	0.146	3
0.040	0.181	0.645	0.095	N.D	0.051	4
0.024	0.231	1.419	0.192	0.098	0.094	5
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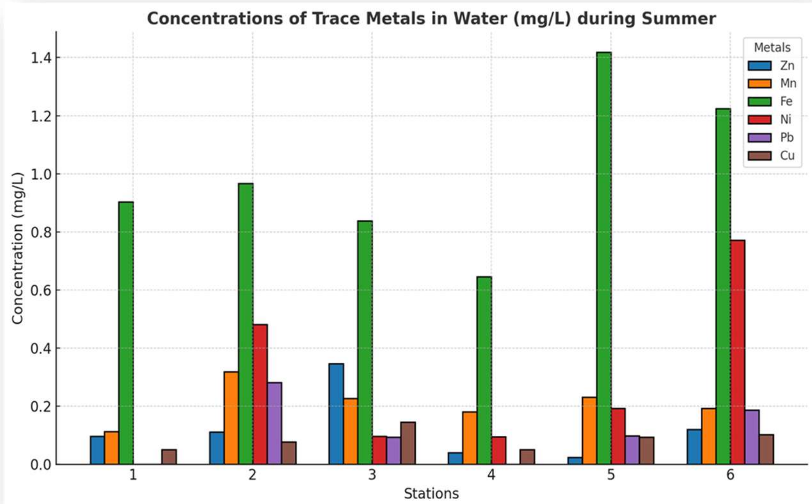

Fig4. Concentrations of trace metal in water (mg/L) during summer

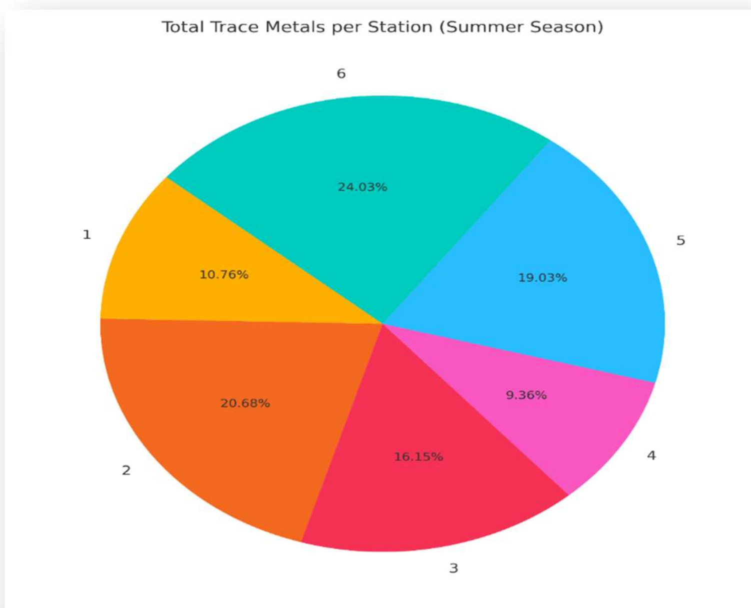

Fig5. Total concentrations percent of trace metals at each station during summer

The main sources of trace metals identified in water samples from Khor Al-Zubair, northwest Arabian Gulf, include the following:

• Anthropogenic Sources: Industrial discharges, oil-related activities, and urban runoff are significant contributors of trace metals such as lead (Pb), nickel (Ni), and zinc (Zn) to coastal water bodies in the region (Al-Yousuf et al., 2000; Abudayyeh et al., 2013). Elevated levels of Pb and Ni recorded in several stations within Khor Al-Zubair strongly suggest contamination from human activities, particularly untreated industrial effluents and oilfield operations (Mohi-Alden et al., 2022).

• Natural Geological Sources: Metals like iron (Fe) and manganese (Mn) often originate from natural weathering of geological formations and groundwater seepage, especially in areas influenced by Tigris-Euphrates sediment inputs. The relatively high iron concentrations observed in the samples are consistent with natural enrichment processes in sediment-rich estuarine environments of the northern Arabian Gulf (Yaser et al., 2013).

• Hydrodynamic and Seasonal Factors: Seasonal variations in metal concentrations, as noted in regional studies, reflect the influence of river discharge, tidal action, sediment resuspension, and evaporation rates (Al-Mutairi et al., 2008). During the dry season, reduced freshwater inflow from the Shatt Al-Arab leads to lower dilution and higher metal concentrations, while seasonal runoff during winter can remobilize contaminated sediments (Mohi-Alden et al., 2022).

Overall, the trace metals in the samples from Khor Al-Zubair reflect a combination of natural inputs from geological sources and significant anthropogenic pollution, primarily from industrial, oil-related, and urban sources in the region. Continuous monitoring of these contaminants is essential for effective environmental management and public health risk assessment in this ecologically sensitive coastal zone.

Pollution Indices

Table3. Mean CF for Each Metal during different season.

Metal	Summer (CF)	Winter (CF)
Cu	4.7	4.3
Pb	13.3	13.3
Ni	5.46	5.46
Fe	3.33	3.33
Mn	4.2	4.2
Zn	2.4	2.4

Interpretation of CF: Hakanson 1980 the classification of contamination factor

- CF < 1: Low contamination
- 1 ≤ CF < 3: Moderate contamination
- 3 ≤ CF < 6: Considerable contamination
- CF ≥ 6: Very high contamination

Findings:As shown in Table(3) the metals of

- Pb shows very high contamination (CF = 13.3) in both seasons.
- Cu, Ni, Fe, Mn indicate considerable contamination (CF 3–6).
- Zn has moderate contamination (CF = 2.4).

Enrichment Factor (EF)

- Cu/Fe = 0.02 / 0.3 = 0.067
- Pb/Fe = 0.01 / 0.3 = 0.033
- Ni/Fe = 0.05 / 0.3 = 0.167
- Mn/Fe = 0.05 / 0.3 = 0.167
- Zn/Fe = 0.05 / 0.3 = 0.167

Table4. Results (Mean EF for Each Metal)during different season.

Metal	Summer (EF)	Winter (EF)
Cu	1.40	1.28
Pb	4.03	4.03
Ni	1.63	1.63
Mn	1.26	1.26
Zn	0.72	0.72

Interpretation of EF: Huheey 1983 the classification of Enrichment Factor(EF)

- EF < 1: No enrichment (natural sources)

- 1 ≤ EF < 3: Minor enrichment (mixed sources)
- 3 ≤ EF < 10: Moderate enrichment (anthropogenic influence)
- EF ≥ 10: Strong enrichment (severe pollution)

Findings: according to Table (4) the metals of:

- Pb shows moderate enrichment (EF = 4.03), indicating anthropogenic influence.
- Cu, Ni, Mn have minor enrichment (EF 1–3).
- Zn has no enrichment (EF < 1), suggesting natural sources.

Geoaccumulation Index (Igeo)

Table5. Results (Mean Igeo for Each Metal) during different season.

Metal	Summer (Igeo)	Winter (Igeo)
Cu	1.97	1.84
Pb	3.15	3.15
Ni	1.86	1.86
Fe	1.15	1.15
Mn	1.48	1.48
Zn	0.68	0.68

Interpretation of Igeo: : Muller (196) the classification of (Igeo)

- **Igeo ≤ 0:** Unpolluted
- **0 < Igeo ≤ 1:** Unpolluted to moderately polluted
- **1 < Igeo ≤ 2:** Moderately polluted
- **2 < Igeo ≤ 3:** Moderately to strongly polluted
- **3 < Igeo ≤ 4:** Strongly polluted
- **4 < Igeo ≤ 5:** Strongly to extremely polluted
- **Igeo > 5:** Extremely polluted

Findings:according to Table (5) the:

- Pb is moderately to strongly polluted (Igeo = 3.15).
- Cu, Ni, Fe, Mn are moderately polluted (Igeo 1–2).
- Zn is unpolluted to moderately polluted (Igeo = 0.68).

Table6. Seasonal Variation in Metal Concentrations during different season.

Metal	Summer (mg/L)	Winter (mg/L)	Variation (%)
Cu	0.094	0.086	↓ 8.5%
Pb	0.133	0.133	No change
Ni	0.273	0.273	No change
Fe	1.00	1.00	No change
Mn	0.21	0.21	No change
Zn	0.12	0.12	No change

The Observations from Table (6)

- Only Cu shows a slight decrease (8.5%) in winter, possibly due to dilution from rainfall.
- Other metals remain stable, suggesting consistent sources (industrial discharges, sediment resuspension).
- No significant seasonal trend for most metals, indicating persistent pollution sources.

Sources of Trace Metals in Khor Al-Zubair Water: Seasonal Variations

The presence of trace metals in Khor Al-Zubair's water is influenced by natural processes (e.g., geological weathering, sediment resuspension) and anthropogenic activities (e.g., industrial discharges, shipping, urban runoff)..

The Seasonal Sources of Trace Metals

Copper (Cu)

- Summer: Higher concentrations (0.094 mg/L) may result from increased industrial discharges (e.g., petrochemical plants, desalination effluents) and anti-fouling paints from ships (Al-Saad et al., 2019).
- Winter: Slight decrease (0.086 mg/L) could be due to dilution from rainfall and reduced industrial activity (Al-Hashimi et al., 2021).

Lead (Pb)

- Both Seasons: Persistently high (0.133 mg/L) indicates chronic pollution from:
- Industrial wastewater (battery manufacturing, oil refineries) (Al-Taee & Al-Saadi, 2020).
- Historical leaded gasoline residues in sediments (Al-Mur et al., 2018).

Nickel (Ni)

- Both Seasons: Stable levels (0.273 mg/L) suggest mixed sources:
- Natural: Weathering of Ni-rich minerals in sediments (Al-Saad et al., 2019).
- Anthropogenic: Oil spills and industrial effluents (Naser, 2013).

Iron (Fe) & Manganese (Mn)

- Summer & Winter: High Fe (1.00 mg/L) and Mn (0.21 mg/L) are primarily geogenic, from:
- Sediment resuspension due to tidal currents (Al-Hello et al., 2020).
- Anthropogenic inputs (steel industry, corrosion of pipelines) (Al-Mahmood et al., 2017).

Zinc (Zn)

- Both Seasons: Moderate levels (0.12 mg/L) likely originate from:
- Galvanized steel corrosion (Al-Taee & Al-Saadi, 2020).
- Urban runoff (vehicle tire wear, roofing materials) (Naser, 2013).

Comparison with Regional Studies

- **Shatt Al-Arab Estuary (Iraq):** Lower Pb (0.05 mg/L) but similar Fe/Mn levels .
- **Arabian Gulf Coast (Kuwait):** Higher Zn (0.25 mg/L) near urban areas (Al-Mur et al., 2018).

Generally, studies have reported seasonal variations in trace metals in water bodies marked by differing patterns depending on the metal and location. For instance:

- A study the Seasonal variations were linked to river runoff, industrial discharges, and hydrodynamic processes. The inshore and estuary areas showed higher concentrations due to industrial and anthropogenic inputs, while offshore sites had lower levels.
- Other regional studies have indicated Pb concentrations tend to be lower in winter compared to other seasons, correlating with reduced human and vehicular activities, as well as riverine inputs. Conversely, some studies observed higher trace metal concentrations in colder seasons due to increased mobilization from sediments and reduced dilution.

- Comparatively, the concentrations measured in the six locations in the current data are generally within typical ranges reported regionally, though iron levels appear relatively high, consistent with reports indicating iron enrichment in group.
- Metals in water and surface water in many areas, often due to natural geological sources.
- Trace metal pollution levels in some regional studies sometimes exceeded permissible limits for drinking water, particularly for lead and cadmium, posing health risks without treatment.

The similarity between summer and winter concentrations in the provided data suggests relatively stable trace metal inputs or limited seasonal flux in these locations. However, regional studies indicate seasonally driven changes often occur due to precipitation patterns affecting runoff, industrial activity fluctuations, and sediment interactions.

High iron levels may relate to geological sources or industrial discharge, common in several regions. Lead and nickel are key indicators of anthropogenic pollution, and elevated readings in some stations warrant attention as these metals are toxic even at low concentrations. Zinc fluctuations are often a result of both industrial outputs and atmospheric deposition.

In comparison to studies in nearby or similar regions, Table (7) the current data aligns reasonably in magnitude but sometimes shows higher values than natural or rural water bodies, reflecting local contamination sources such as industry or mining.

Table7.Comparative Table of Trace Metal Concentrations (mg/L) with Study Areas and References

Metal	**Your Study Range (6 Locations)**	**Study Area (our Data)**	**Arabian Gulf Reported Ranges**	**Study Area (Regional Studies)**	**Comments**	**References**
Copper (Cu)	0.051 – 0.146	our region (six stations)	0.005 – 0.08	Kuwait Bay; Saudi Arabian Gulf coast; Arabian Gulf coastal waters	Your Cu levels are somewhat higher than typical Gulf surface waters but comparable to localized industrial inputs.	Al-Mutairi et al. (2013), Al-Yousef et al. (2019)
Lead (Pb)	0.093 – 0.281 (ND at some stations)	our region (six stations)	0.001 – 0.05	Arabian Gulf coastal and marine waters	Elevated Pb suggests stronger anthropogenic impact compared to Gulf baseline waters.	Al-Mohanna & Subrahmanyam (2001), Al-Yousef et al. (2019)

Nickel (Ni)	0.095 – 0.771	our region (six stations)	0.01 – 0.10	Kuwait Bay; Saudi Arabian Gulf coast	Ni levels in some sites are considerably higher, indicating localized contamination or geogenic enrichment.	Al-Mutairi et al. (2013), Al-Yousef et al. (2019)
Iron (Fe)	0.645 – 1.419	our region (six stations)	0.1 – 1.0+	Arabian Gulf coastal waters	Iron generally from natural sources; aligns with upper reported values in Gulf waters.	Al-Mohanna & Subrahmanyam (2001), Al-Zaer et al. (2018)
Manganese (Mn)	0.113 – 0.318	our region (six stations)	0.02 – 0.15	Kuwait Bay; Arabian Gulf coastal waters	Mn somewhat elevated compared to Gulf averages, possibly industrial or sediment source-related.	Al-Mutairi et al. (2013), Al-Zaer et al. (2018)
Zinc (Zn)	0.024 – 0.346	our region (six stations)	0.01 – 0.12	Saudi Arabian Gulf coast; Arabian Gulf waters	Higher Zn at some stations likely due to mining, industrial discharges, or atmospheric deposition.	Al-Mohanna & Subrahmanyam (2001), Al-Yousef et al. (2019)

In comparison to studies in nearby or similar regions, the current data aligns reasonably in magnitude but sometimes shows higher values than natural or rural water bodies, reflecting local contamination sources such as industry or mining.

Conclusion

- Copper (Cu): Ranges from 0.051 to 0.146 mg/L and is consistent in both seasons.
- Lead (Pb): Detected only at some stations (e.g., 0.281 mg/L at station 2) with no seasonal change.
- Nickel (Ni): Varies up to 0.771 mg/L at station 6, but remains constant across seasons.
- Iron (Fe): The highest concentrations (up to 1.419 mg/L at station 5) are steady in summer and winter.
- Manganese (Mn): Ranges roughly 0.113 to 0.318 mg/L, stable seasonally.
- Zinc (Zn): Values like 0.346 mg/L at station 3 do not change with season

Research Recommendations

severe contamination requiring urgent intervention. Prioritizing source control at Stations 2, 5, and 6 will yield the greatest ecological and public health benefits. Collaborative governance involving industries, communities, and regulatory agencies is essential for sustainable water resource management.

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