Research Article

Integrated Assessment of Heavy Metal Pollution and Microbial Water Quality in the Coastal Waters of Ras Al Khaimah, Arabian Gulf

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Abstract

Heavy metal contamination in marine ecosystems has become a substantial global environmental concern due to its potential threat to marine life and ecological balance. The primary resources of heavy metals in seawater include anthropogenic activities, discharge of urban and industrial wastewater, and the natural weathering of rocks through physical, chemical, and biological processes. Following a preliminary survey of the Ras Al Khaimah region, five sampling sites were selected for investigation. Seawater samples were collected in triplicate from each site to evaluate the concentrations of selected physicochemical parameters, and microbiological contaminants in the Arabian Gulf. Parameters analyzed included Nitrate-Nitrogen, Nitrite-Nitrogen, Salinity, Phosphate-Phosphorus, Turbidity, Arsenic, Copper, Iron, Lead, Manganese, Mercury, Nickel, Sodium, and Zinc using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). The pH values ranged from 7.51 ± 0.1 to 8.26 ± 0.21 across the sampling locations. Variations in nutrient concentrations were observed among the sites, with the highest Nitrate-Nitrogen concentration recorded at Site 1 and the lowest at Site 3. Heavy metals such as Arsenic, Copper, Iron, Lead, Manganese, Mercury, and Nickel were not detected in any of the collected samples. Microbiological assessment revealed very low levels of *E. coli* and Total Coliform. Overall, the findings indicate that the studied marine area in Ras Al Khaimah is not significantly impacted by heavy metal or microbial pollution, reflecting a satisfactory environmental status. Nevertheless, the results emphasize the importance of implementing targeted preventive measures and maintaining consistent routine monitoring programs to ensure long-term protection and sustainability of the marine ecosystem.

Keywords: Marine water, Biomonitoring, Water quality, Public health, Heavy metals

Abbreviations: SD: Standard Deviation; MW: Marine Water; ND: Not Detected; ppm: Parts per Million; ppt: Parts per Trillion; ADS: Abu Dhabi Specifications.

Introduction

Heavy metal contamination in marine ecosystems has become a major global environmental concern due to its detrimental effects on marine organisms and overall ecological health [1]. Coastal waters are particularly vulnerable to heavy metal inputs arising from anthropogenic activities, including urban expansion, industrial discharge, and wastewater effluents, as well as from the natural weathering of rocks through physical, chemical, and biological processes [2]. Rapid urbanization and industrial development have significantly increased heavy metal pollution along the coastal regions of Saudi Arabia in the Arabian Peninsula [3,4]. Previous assessments of the Arabian Gulf have highlighted the region's environmental vulnerability [5]. The Gulf's arid climate, characterized by high temperatures and elevated evaporation rates, reduces water dilution and slows dispersion processes, thereby enhancing the accumulation and persistence of heavy metals within the marine ecosystem. The presence of heavy metals in coastal waters and sediments poses serious ecological risks due to their toxicity, persistence, and capacity for bioaccumulation, which can

subsequently threaten human health through the food chain [6]. Furthermore, metal contamination has broader socio-economic implications for the region. Seafood resources, particularly fish and shrimp, play a vital role in both domestic consumption and international trade within the Arabian Gulf, making the monitoring and management of heavy metal pollution essential for environmental sustainability and economic stability [5,4].

Coastal environments worldwide are increasingly exposed to heavy metal contamination because of expanding industrial activities along littoral zones [7]. Heavy metals enter coastal systems through both anthropogenic sources-such as industrial discharge, urban runoff, mining, and wastewater effluents-and natural processes including rock weathering [8,9]. The distribution and behavior of metals in aquatic environments are regulated by complex physicochemical and biological interactions, which are further influenced by human activities and industrial wastewater inputs [10]. In marine coastal areas, a significant proportion of anthropogenic metals originates from terrestrial sources associated with urbanization, industrial development, and other human practices near water bodies [11]. Numerous studies have evaluated heavy metal pollution in coastal regions globally, with a strong focus on sediment analysis as an indicator of contamination [11-22]. More recent investigations along the coastal stretch between Ras Tanura and Ras Abu Ali in the Saudi Arabian Gulf have reported exposure to anthropogenic pollutants, including desalination brine discharge, landfill leachate, sewage effluents, oil residues, and construction-related solid wastes [21-23]. In light of these concerns, the present study aims to: (i) evaluate the levels of heavy metals and microbiological contamination along selected coastal areas of Ras Al Khaimah; (ii) assess the impact of human activities on the coastal marine environment; and (iii) compare pollution levels across five different coastal locations within the emirate. Rapid population growth, urban expansion, industrialization, and agricultural activities have placed increasing qualitative and quantitative pressures on marine water resources. To support ongoing research efforts and address the rising demand for sustainable water management, this study investigates the marine water quality of Ras Al Khaimah by analyzing heavy metals, physicochemical parameters, and microbiological indicators at five selected sites. The findings are expected to provide valuable baseline data on the status of marine water quality in the region, contribute to a better understanding of contamination patterns, and serve as a foundation for future environmental monitoring and management strategies.

Material and Methods

Sample Collection

Five marine water samples were obtained from five different sites within the Emirates of Ras Al Khaimah (labelled MW1, MW2, MW3, MW4, MW5) in the month of august, September 2025. All water samples were collected in sterile glass bottles (1 litre). All samples were stored and transported in a cool box kept below 4°C. Analyses were performed as soon as the samples were carried to the laboratory.

Physico-Chemical Analysis

Marine water samples were analysed for pH, salinity, Nitrate, Nitrite, turbidity, Phosphorous and heavy metal concentration. The pH, salinity was measured with WTW 3430 multimeter, Germany. Nitrate, Nitrite, Sulphate, Phosphorous concentration was measured by using HACH spectrophotometer DR 3900, USA. Heavy metal concentration was measured by using ICP-OES Plasma Quant PQ 9000 (Analytik Jena, Germany) [24]. *E. coli* and Total Coliform were analyzed by using Colilert 18 IDEXX, USA.

Statistical Analysis

The tests were performed in triplicates. Data are expressed as mean. Pair wise comparisons were performed. Experimental error was determined to be triplicate and expressed as Standard Deviation (SD).

Results and Discussion

The objective of this research was to assess the marine water quality of Emirates of Ras Al Khaimah from five different locations by considering physico-chemical parameters to highlight all those factors which are damaging water quality. Microbiological assessment was analysed by *E. coli* and total coliform count. This study provided a valuable data concerning the assessment and awareness of marine water quality of Ras Al Khaimah. Figure 1 showing the location map of study area.

Physicochemical and Microbiological Parameters of Marine Water Samples (Table 1)

Physicochemical Characteristics

The pH of seawater samples collected from the five coastal locations in Ras Al Khaimah ranged from 7.51±0.10 to 8.26±0.21 (Figure 2, Table 1), indicating slightly alkaline conditions typical of marine environments. These values are comparable to those reported near Dammam in the Arabian Gulf (7.91±0.26–8.22±0.38) [25], suggesting that the carbonate buffering system and overall acid–base balance of Gulf waters remain relatively stable across different coastal regions. Salinity values (3.50-3.74% (Figure 3, Table 1)) were consistent with the hypersaline nature of the Arabian Gulf, attributed to high evaporation rates and limited freshwater inflow. Similar elevated salinity and total dissolved solids were observed in the Dammam coastal waters [25], confirming the regional hydrographic characteristics of the Gulf.

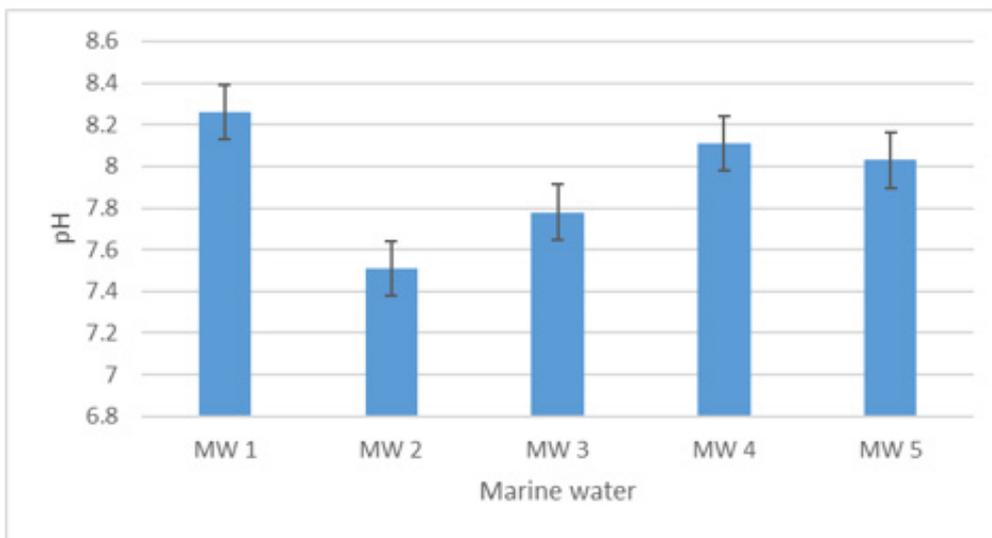**Figure 1:** Location map of study area (Google image).

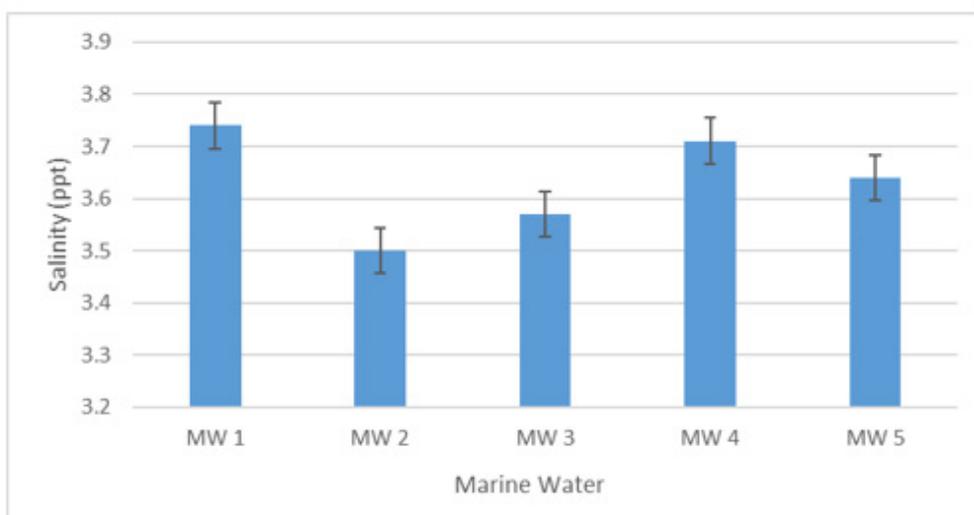**Figure 2:** Showing values of pH in Marine water samples of Ras Al Khaimah.

Figure 3: Showing values of Salinity in Marine water samples of Ras Al Khaimah.

Nitrate-N (Figure 4, Table 1) and phosphate-P concentrations in the present study were generally low, indicating limited nutrient enrichment and minimal eutrophication risk. This contrasts with some industrialized coastal areas of Saudi Arabia where anthropogenic inputs have been reported to increase pollutant loads [26]. The low turbidity values further support the absence of excessive suspended particulates or major terrestrial runoff during the sampling period (Figure 5).
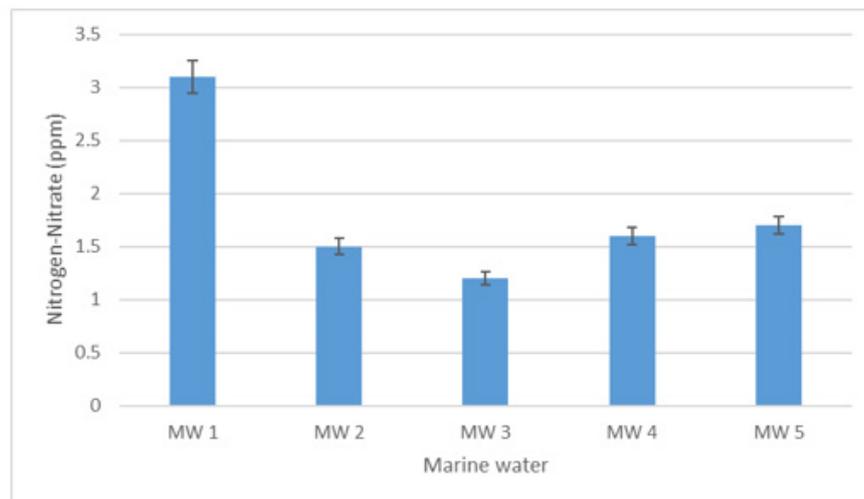

Figure 4: Showing concentration of Nitrate in Marine water samples of Ras Al Khaimah.

Heavy Metal Concentrations in Marine Water

In the present investigation, Arsenic (As), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Mercury (Hg), Nickel (Ni), and Zinc (Zn) (Table 1) were not detected in any of the sampled locations, indicating that their concentrations were below the detection limits of the ICP-OES analysis. Sodium level was analysed and detected (Figure 6, Table 1).
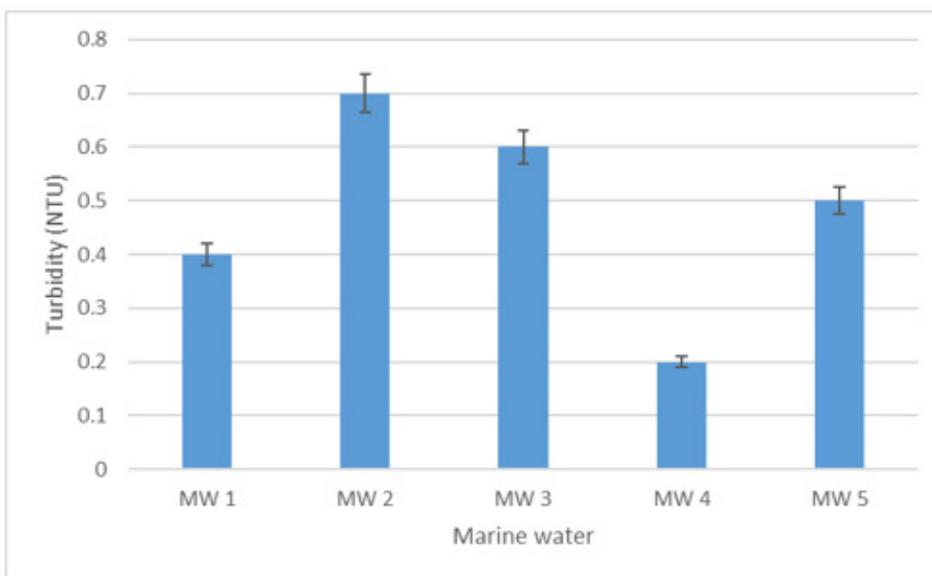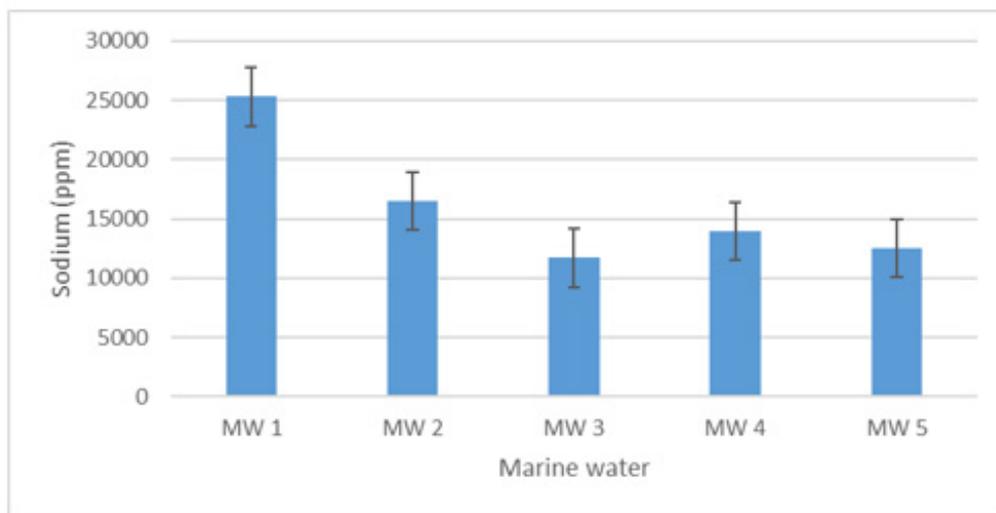

Figure 5: Showing Turbidity in Marine water samples of Ras Al Khaimah.

Figure 6: Showing concentration of Sodium in Marine water samples of Ras Al Khaimah.

Table 1: Physicochemical and microbiological parameters of five marine water samples of Ras Al Khaimah, United Arab Emirates compared with ADS standard reference limit.

Parameter	MW 1	MW 2	MW 3	MW 4	MW 5	Specification Limit* ADS 81/2017
pH	8.26±0.21	7.51±0.10	7.78±0.12	8.11±0.0	8.03±0.21	-
Nitrate-Nitrogen (ppm)	3.1	1.5	1.2	1.6	1.7	-
Nitrite-Nitrogen (ppm)	ND	0.01	ND	ND	ND	-
Salinity (ppt)	3.74	3.5	3.57	3.71	3.64	-
Phosphate-Phosphorus (ppm)	0.07	0.1	0.08	ND	ND	-
Turbidity (NTU)	0.4	0.7	0.6	0.2	0.5	-
Arsenic (ppm)	ND	ND	ND	ND	ND	-
Copper (ppm)	ND	ND	ND	ND	ND	0.003
Iron (ppm)	ND	ND	ND	ND	ND	-
Lead (ppm)	ND	ND	ND	ND	ND	0.0022
Manganese (ppm)	ND	ND	ND	ND	ND	-
Mercury (ppm)	ND	ND	ND	ND	ND	0.0001
Nickel (ppm)	ND	ND	ND	ND	ND	0.007
Sodium (ppm)	25300	16500	11720	13950	12530	-
Zinc (ppm)	ND	ND	ND	ND	ND	0.015
E. coli (MPN/100mL)	ND	52	ND	402	266	-
Total Coliform (MPN/100mL)	263	4786	10	776	3654	-

Note: *Specification Limit: ADS 81/2017-Ambient Marine Water and Sediments Specifications.

This finding differs significantly from the study conducted near Dammam, Saudi Arabia, where measurable concentrations of multiple metals were reported in seawater, with the order of abundance: Sr>Cu>Se>Zn>As>Mn >Fe>Ni>Mo>Hg>Co>Cr>Ag>Cd>Pb and Be [25]. Moreover, that study concluded that concentrations of As, Hg, Cd, Cr, Cu, Fe, and Sr were alarmingly high in the Dammam area [25]. In contrast to our study [2,26-31] stated that Zn (30.78 lg/L) and Cu 100.396 lg/L) were higher compared to Gulf of Suez, Iranian Oman Sea coast and, Gulf of Aqaba and Yellow River Estuary. In contrast, the absence of detectable heavy metals in Ras Al Khaimah coastal

waters suggests comparatively lower anthropogenic pressure and better environmental quality. Similarly, sediment studies along the Al-Khobar coastline reported severe to very severe enrichment of Cu, V, Sr, Cr, Zn, Hg, Mo, and Se due to anthropogenic activities such as oil spills, desalination discharge, and industrial effluents [26]. The contrast between those findings and the present study highlights the relatively unpolluted status of Ras Al Khaimah marine waters. Another similar study reported by *Al-Taani et al.*, he stated that Be and Se were relatively low in concentration in water and sediment samples. Mo concentration was found higher compared to in the Gulf of Aqaba. In another contrast study *Lattemann and Hoepner*, revealed that Mo is probably entered due to corrosion and discharged from desalination plants in Saudi Arabia. The difference in contamination levels may be attributed to varying degrees of industrialization, petrochemical activities, landfilling, and sewage discharge. Previous studies have emphasized that coastal regions subjected to intense urbanization and industrial activities exhibit higher metal enrichment factors [29], whereas the Ras Al Khaimah sites examined in this study appear less impacted.

Microbiological Quality

Microbiological assessment revealed low concentrations of *E. coli* and Total Coliforms in most sampling locations, although certain sites showed relatively higher counts. The absence of heavy metals coupled with limited microbial contamination suggests that fecal inputs, where present, are localized rather than widespread. Although the Dammam study [25] primarily focused on physicochemical and heavy metal parameters, it linked elevated metal concentrations to anthropogenic activities such as sewage discharge and industrial effluents. In the present study, the minimal microbial and metal contamination indicates that such pollution sources are either absent or effectively managed in the surveyed areas. Our microbiology results are like [32], which revealed that very low concentration of Total coliforms, Faecal coliforms were found and no Salmonella in microbiological monitoring of sea water.

Environmental Implications and Comparative Assessment

Comparative evaluation with studies from Al-Khobar and Dammam indicates that while certain Saudi Arabian Gulf coastal areas exhibit moderate to severe heavy metal enrichment [29], the Ras Al Khaimah coastal waters investigated in this study remain within safe environmental limits. The absence of detectable heavy metals contrasts sharply with reports of elevated As, Hg, Cd, Cu, and Sr in other Gulf regions [25]. These differences underscore the spatial variability of heavy metal pollution within the Arabian Gulf and emphasize the importance of localized monitoring. The relatively good environmental status observed in Ras Al Khaimah may reflect lower industrial intensity, better waste management practices, or favorable hydrodynamic conditions that enhance dilution and dispersion [33-35].

Overall Assessment

The results demonstrate that the coastal waters of Ras Al Khaimah are not currently affected by significant heavy metal contamination, unlike some industrialized sectors of the Arabian Gulf reported in previous studies. Nevertheless, given the Gulf's vulnerability to pollutant accumulation due to high evaporation and limited water exchange, continuous routine monitoring is essential to prevent future deterioration. The findings provide valuable baseline data for Ras Al Khaimah and support the implementation of proactive environmental management strategies to maintain the ecological health and sustainability of the coastal marine ecosystem.

Conclusion

This study assessed the marine water quality of five coastal locations in Ras Al Khaimah through physicochemical, heavy metal, and microbiological analyses. The results showed slightly alkaline pH, normal salinity, low nutrient levels, and acceptable turbidity. Heavy metals (As, Cu, Fe, Pb, Mn, Hg, Ni, and Zn) were not detected in any samples, and microbiological indicators (*E. coli* and Total Coliforms) were present at very low concentrations. Overall, the findings indicate that the studied coastal waters are not significantly affected by pollution and remain in a satisfactory environmental condition. Continuous routine monitoring is recommended to ensure long-term protection and sustainable management of the marine ecosystem.

Ethics Approval and Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Availability of Data and Materials

The relevant data and materials are available in the present study.

Competing Interests

The authors declare that they have no competing interests. All procedures followed were in accordance with the ethical standards (institutional and national).

Authors' Contributions

VB performed all the experiments. VB analysed the data and wrote the manuscript.

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