

Review Article

Assessment of Heavy Metals and Total Petroleum Hydrocarbons in Bottom Sediments of Kuwait Bay

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Abstract

Contaminated marine environments can be explicitly studied using chemical compounds and concentration of pollutants suspended in bottom sediment. Sediments act as repositories for pollutants, and have significant implications as they may pose a potential risk to the environment. In this paper, the geochemistry and provenance of bottom sediments from 17 stations, located along the Kuwait Bay, were studied during June and July 2024. The sediment samples were collected from each station using VanVeen grab sampler and were analysed for physical and chemical parameters for inorganic nutrients, BOD, COD, TOC, TPH and related heavy metals to delineate the extent of pollution levels and their distribution in the Bay. The main sources of pollution along the coast of Kuwait Bay are storm water outlets, emergency sewage discharges, ports, navigation channels, and desalination power plants. Results revealed elevated levels of inorganic nutrients (SiO_2 (3.75 mg/l), NH_3 (2.35 mg/l), NO_3 (1.21 mg/l), NO_2 (1.22 mg/l) and PO_4 (3.25 mg/l)) and TPH (601 mg/kg) in all the investigated sites within the bay. Elevated levels of metals Ni, V and Cr were discovered mostly at station 15 in front of Gazalle outlet and station 17 near the Power station outlet. The metal concentration of Ni (103.4 mg/kg) and V (44.153 mg/kg) exceeded the geo-chemical background levels established for sediment quality guidelines as compared to Cr, Cu and Cd which were found in varying levels (83.5 mg/kg, 40.7 mg/kg and 2.9 mg/kg, respectively), but below the probable effect levels (PEL). While Zn, Fe, Mn were within acceptable limits and Ag, As, Hg, and Pb were found to be very low. The contamination levels are mostly related to the characteristics and homogeneity of the clay presence in the bottom sediments which is highly biogenous. The overall objectives of this study is to determine the distribution, degree of contamination and sources in bottom sediments of Kuwait Bay. The novelty of this study lies in its ability to link pollutant levels to specific anthropogenic activities, offering critical insights into the bay's environmental health. The findings of this study are essential for formulating targeted mitigation strategies to protect Kuwait Bay's marine ecosystem from further degradation.

Keywords

Bottom Sediments, Physical Parameters, Chemical Compounds, Pollutants, Nutrients, Total Petroleum Hydrocarbon (TPH), Heavy Metals

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1. Introduction

Kuwait's marine environment is at constant risk from the effects of pollution that has persisted in the environment due to industrial expansion along with previous pollution events linked to the Gulf War in the region leading to a variety of contaminants being inadvertently or deliberately discharged into the marine environment [3]. With major industrial and economic activities located along the coast of the Kuwait Bay, there is a continuous invasion of different types of pollutants that pose potential threat to the environment. Additionally, environmental incidents such as maritime traffic, oil spills, sewage discharges, etc. contribute significant quantities of pollutants including heavy metals and hydrocarbons which are the main constituents that affect the coastal environment. In this context, bottom sediments can be sensitive indicators for assessing the concentration of heavy metals and hydrocarbon pollution.

A review of previous studies provides a strong indication that the anthropogenic activities are contributing to major pollution impacts on Kuwait's marine environment. According to Al-Abdulghani et al. [2], the effects of pollution resulting from various industrial or recreational activities is clearly visible in the southern and northern areas of Kuwait Bay where the water and sediment quality were assessed to manage and regulate its environmental status. The study concluded that the southern part of the bay is a major source of pollution compared to the northern part due to the reception of pollutants resulting from human activities. The Shuwaikh port which is ecologically significant for its mud flat area for incubating shrimp and feeding ground for shore birds, suffers from coastal erosion and influent pollutants from the Shatt al-Arab river. Bou-Olyan and Al-Sarawi [7] focused on the spatial distribution and monthly variation of pollutants Pb, Hg, PO₄, PAH, and TOC from ten different sites along the Kuwait Waterfront during development. Among the investigated sites, Shuwaikh Industrial Area, Beneid Al-Gar and Al-Shaab beach showed the highest concentration of pollutants due to the discharge of domestic and industrial waste in the intertidal zone of the waterfront project. The Shuwaikh Industrial area located about 5 km to the west of the investigated sites showed high concentration of Pb and Hg, while the introduction of PO₄ was mainly from domestic discharges. Nour et al. [16] investigated the seasonal variations and concentrations of heavy metals in the coastal seawater of Kuwait Bay. The study analysed the presence of various heavy metals over different seasons, providing important insights into the environmental conditions and potential contamination sources affecting the region. Boota and Al-Enezi [6] assessed sediment contamination in Kuwait Bay, focusing on the impact of effluent discharge as a primary pollutant source. The study analysed sediments for trace elements, nutrients, and heavy metals. The concentrations were compared to background levels and USEPA guidelines, revealing low but concerning contamination levels. Al-Qattan and Al-Sarawi [5] assessed

the water and bottom sediment quality of the coastal zone of the three refineries: Mina Al-Ahmadi, Shuaiba and Mina Abdullah located along the southern coast of Kuwait. It was found that Al-Ahmadi Refinery was the most polluted among the three refineries, due to the pollution sources, such as industrial effluents and municipal wastewater from the urban system. Furthermore, the degree of sewage contamination in Kuwait's marine environment was assessed by Devlin et al. [8]. They investigated the microbial water quality and concentrations of faecal sterols in sediment. Hot spots for faecal sterols were identified in the sediments in Doha Bay and Sulaibikhat Bay. It is believed that point source for sewage contamination is from illegal connection such as the one sited at Al-Ghazali. The failure of treatment of the sewage network caused a widespread microbial water quality. On a regional level, study conducted by Alshuaib et al. [4] investigated the geochemical fractionation of trace metals within sediments from the Qatar Marine Zone using a five-stage sequential extraction technique. Results showed that the total concentration of trace elements followed the trend: Fe>Mn>Ni>Cr>Zn>As>Cu>Co>Pb>Cd. The study also identified the mobility and bioavailability of metals, with 23.4% of Pb found in the exchangeable phase, 58% of Cd in the carbonate phase, and significant Cr concentrations bound to Fe-Mn oxides. The majority of Fe (84%) was found in the residual fraction, which dominated the fractionation profile for most trace elements except Cd and Mn. In a recent study, Geng et al. [12] analyzed the migration and transformation behavior of heavy metals and its influence under tidal conditions. Junakova et al. [14] assessed the dynamics of sediment characteristics and revealed that the sediment are important for sorption of contaminants.

While most of the reviewed literature confirmed that Kuwait's marine environment despite being exposed to several pollution events, has relatively low level of contamination as compared to other industrial sites in the world that are heavily contaminated. This is due to the influence of strong bottom current circulation, however, sediment contamination potentially pose a threat to marine life if they exceed the global levels of sediment quality criteria. The sediment contamination hotspots associated with point sources of industrial activities, such as Shuwaikh Industrial Zone, Doha, and Sulai-bikhat Bay, exist at a number of locations around the coast of Kuwait Bay. So, these areas need to be assessed and monitored continuously. The aim of this paper is to study the geochemical and environmental quality of Kuwait Bay by collecting water and bottom sediment samples from different stations around the bay and analyzing their physical parameters and chemical compounds for Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), Total Petroleum Hydrocarbon (TPH), inorganic nutrients and heavy metals contents.

Bottom sediment is a key factor for the development of

marine environment. However, its quantity and characteristics can affect the physical, chemical and biological integrity of marine ecosystems [17], hence assessment and evaluation of sediment quality is critical for the purpose of managing the natural resources. The study addresses the current contamination status of Kuwait Bay's sediments and underscores the necessity for continuous monitoring and effective management strategies to mitigate environmental degradation.

2. Materials and Methods

2.1. Study Area and Its Characteristics

Kuwait Bay is a relatively shallow semi-enclosed water body of ~750 km² situated in the northwestern region of the Arabian Gulf with prominent ecological, geological, and

anthropogenic compartments. It is the most significant touristic attraction in the State of Kuwait that hosts multiple industrial, touristic and aesthetic activities. The bay is divided into two zones: northern and southern. The northern section is characterized by a low-energy level with muddy sediment at its bottom, while the southern section has moderate to high-energy level dominated by sand and muddy sediments. A field reconnaissance survey was carried out around Kuwait Bay where several stations in the study area were geologically investigated in terms of lithology of the surficial units and sediment in the Bay. The bottom sediments varied between soft mud - hard rocky mud - coarse to medium calcareous sand and lithified limestone. Most of the bottom sediments were highly broken and fragmented skeletal debris. Based on field survey, site map was prepared and representative sample stations were plotted on the map (Figure 1).

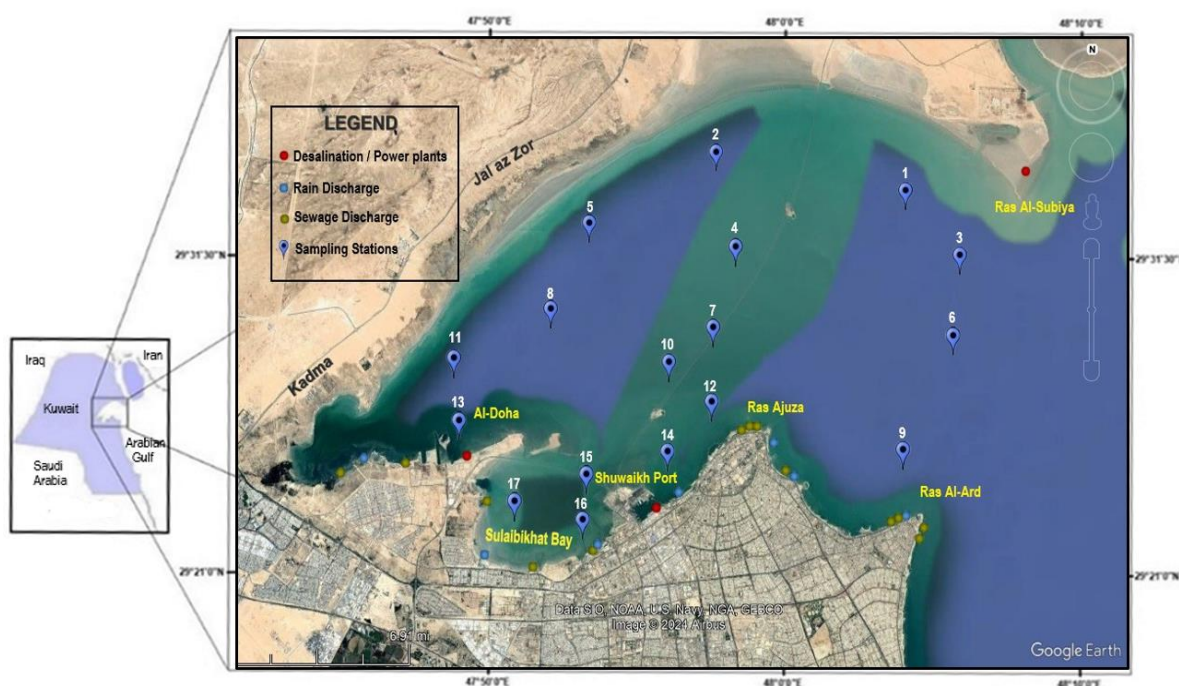


Figure 1. Location map and sample inventory.

2.2. Sampling and Analysis Method

Water and sediment samples were collected from seventeen stations along the coast of Kuwait Bay during the summer of June through July 2024. The water samples were taken within 1 m from surface water layer. Each sample was analysed for pH, Temperature, Salinity, Dissolved Oxygen (DO) and Conductivity. The physical parameters were measured in-situ using a calibrated multi-parameter instrument directly in the field. The sediment sampling was done according to water circulation, depth, sediment biofacies, and hot spots that were identified in previous studies. One sediment sample was col-

lected from each station up to a depth of 15 m using a Van Veen Grab sampler. The collected samples were then subjected to geochemical analyses for assessing the inorganic Nutrients, BOD, COD, TOC, TPH and heavy metals concentration. All sediment samples were air-dried, sieved, and homogenized. The analytical procedure was performed at MEL (Middle East Laboratories), utilizing standard methods recognized globally. The concentration of each metal in the sediment sample was calculated in mg/kg.

Detection Methods

1) Inorganic Nutrients: Ammonia (NH₃), nitrate (NO₃), nitrite (NO₂), and silicate (SiO₂) were measured using HACH DR/2500 methods. Phosphate (PO₄) was ana-

lyzed using a spectrophotometric method.

- 2) Organic Matter: Biochemical Oxygen Demand (BOD) was measured using standard 5-day incubation. Chemical Oxygen Demand (COD) was analyzed using the manganese III digestion method, while Total Organic Carbon (TOC) was determined using the persulfate reagent method.
- 3) Total Petroleum Hydrocarbon: TPH was analyzed using EPA Method 3546 (SW-846).
- 4) Heavy Metals: Acid digestion was performed according to USEPA 6010B using a mixture of nitric acid, perchloric acid, and hydrogen peroxide. Metal concentrations were measured using Inductively Coupled Plasma Mass Spectroscopy (ICP-MS).

To ensure accuracy and reproducibility, the following quality control measures were implemented:

- 1) Instrument Calibration: Instruments (e.g., ICP-MS) were calibrated using certified reference materials (CRMs). Calibration curves were validated with a correlation coefficient ($R^2 > 0.99$).
- 2) Replicates: Analytical measurements were conducted in triplicate to minimize variability. Results were expressed as mean values with standard deviations.
- 3) Blanks: Procedural blanks were analyzed alongside samples to detect contamination during preparation or analysis.
- 4) Recovery Tests: Recovery rates for heavy metals were determined by spiking sediment samples with known concentrations of standard solutions, with acceptable recovery between 85% and 115%.
- 5) Internal Standards: Internal standards were used in ICP-MS analysis to correct the matrix effects and instrumental drift.

3. Results

3.1. Physical Parameters

Water samples were assessed by Kuwait Environmental Public Authority (KEPA) standards and represented five parameters:

3.1.1. pH

The pH values of all samples during the studied period were between 7.29 – 7.65 which is within the desirable levels recommended by KEPA standard (6-9) (Table 1). The maximum value was detected along Station 1 near storm water outlet due to illegal dumping from Al-Subiya industrial site. Some stations showed low pH due to high conductivity.

3.1.2. Temperature

The average temperature was 22.7 °C for all samples in 17 Stations while maximum temperature was 24.5 °C in Station 17 near Doha Power Plant and minimum was 21.3 °C in Station 9 (Table 1).

3.1.3. Salinity

The average salinity of water was 42.65 ppt. for all stations samples while maximum salinity was 45.7 ppt. in Station 17 and minimum was 40.2 ppt. in station 9 (Table 1). The high salinity is due to the concentration of brine in the area. It can be noted that salinity recorded in the area is high compared to the previous studies in Kuwait Bay which is mainly due to the large scale development activities along the coastline. However, some stations such as 1, 5 and 6 showed low salinity due to water input from the outlets.

3.1.4. DO

The average dissolved oxygen of sea water samples was 4.5 mg/L for all sampled stations while maximum concentration was 7.9 mg/L in Station 6 and minimum was 2.7 mg/L in Station 17 (Table 1). Generally, oxygen solubility decreases as temperature and salinity increases. Low levels of dissolved oxygen were detected at stations 1, 3, 7, 13, 15, 16, and 17. The low DO levels create imbalance between ecosystem and marine life and is detrimental to aquatic ecosystems.

3.1.5. Conductivity

From the results of present investigation, it was observed that electrical conductivity of all Stations ranged from 43.50 – 68.210 µS/cm with max. conductivity observed at station 17 near Doha Power Plant as water temperature is high.

Table 1. Physical parameters of water samples in the study area.

Station	Temp (°C)	DO (mg/l)	pH	Salinity (ppt)	Conductivity (µS/cm)
1	23	3.7	7.65	41.2	58.270
2	22	5.2	7.55	43.7	48.226
3	23.1	3.9	7.45	42.9	67.300
4	24	4.1	7.31	44.2	59.301
5	21.9	4.1	7.45	41.2	55.750

Station	Temp (°C)	DO (mg/l)	pH	Salinity (ppt)	Conductivity (µS/cm)
6	23.5	7.9	7.35	41.9	51.202
7	22.7	3.9	7.29	42.3	61.750
8	22.9	5.2	7.34	43.2	50.224
9	21.3	5.2	7.45	40.2	43.50
10	22.3	4.7	7.41	42.3	60.090
11	22.1	6.1	7.35	43.1	53.830
12	21.9	7.2	7.31	41.2	59.321
13	22.5	3.1	7.29	41.9	61.250
14	23.9	4.2	7.35	42.3	65.182
15	23.9	3.1	7.31	44.9	66.102
16	21.9	3.5	7.34	42.9	59.311
17	24.5	2.7	7.49	45.7	68.210
AVG	22.7	4.5	7.39	42.65	58.16

3.2. Sediment Quality

3.2.1. Inorganic Elements in Bottom Sediments

Certain inorganic elements such as Na, Ca, Mg, Al, Ba, K, were analyzed to assess the level of concentration in the study area (Table 2). The maximum concentration of Na was 73,101 mg/kg in Station 12 while low concentration of 3,810 mg/kg was recorded in Station 16. Maximum concentration of Ca was 482,120 mg/kg in Station 13 whereas the lowest was 9,375 mg/kg in Station 9. Mg was high with 31,200 mg/kg in

station 13 and low with 2,210 mg/kg in Station 6. High Al concentration of 89,501 mg/kg was recorded in Station 3 and the lowest 1,823 mg/kg was recorded in Station 4. Ba concentration was high (41,104 mg/kg) in Station 15 with lowest concentration (20.1 mg/kg) in Station 12. High concentration of K (8,900 mg/kg) was found in Station 11 with lowest concentration (653 mg/kg) in Station 8.

Generally, the concentration of inorganic elements reflect the sediment type (mainly biogenous clay), amount of organic matter that cross the storm water culverts as well as maritime navigation within Kuwait Bay.

Table 2. Inorganic elements in bottom sediments of the study area.

Station	Ca (mg/kg)	K (mg/kg)	Mg (mg/kg)	Na (mg/kg)	Al (mg/kg)	Ba (mg/kg)
1	97121	3109	25171	7191	33161	22.991
2	91220	2100	29001	8521	52121	35.54
3	300129	2750	30700	9521	89501	22.481
4	381000	3100	9700	7321	1823	20.765
5	37100	1300	8100	9850	1920	32.754
6	75123	850	2210	19211	7950	28.958
7	302121	1010	11320	21315	12251	26.126
8	45261	653	7500	25121	8522	27.709
9	9375	1200	4511	19800	9732	22.657
10	89010	2533	23100	21215	10215	20.233
11	79750	8900	24700	23101	8313	30.089

Station	Ca (mg/kg)	K (mg/kg)	Mg (mg/kg)	Na (mg/kg)	Al (mg/kg)	Ba (mg/kg)
12	312521	790	25111	73101	9351	20.1
13	482120	5200	31200	25112	13173	36.787
14	421335	1500	29010	12112	14210	38.44
15	400100	7300	28100	7501	9372	41.104
16	325112	950	18121	3810	7521	39.233
17	465321	1500	10121	12311	13225	35.95

3.2.2. Inorganic Nutrients in Bottom Sediment

The study revealed elevated amount of inorganic nutrients (SiO_2 , NO_2 , NO_3 , PO_4) reflecting high impact of sewage runoff and fertilizers causing eutrophication of water (Table 3). The high level of inorganic nutrients are related to anthropogenic as well as industrial activities in the area. The high level of contamination was found in station 3 (Kuwait Oil Company outlet), station 14 (navigational channel), station 15 (Al-Ghazali outfall), and station 17 (Desalination Plant outlet). These stations are at high risk from land based sources of pollution. The accumulation of inorganic nutrients in these stations will spread the contamination level which will have negative impact on water quality as well as the ecosystem.

Table 3. Inorganic nutrients in bottom sediments of the study area.

Station	SiO_2 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	NO_2 (mg/l)	PO_4 (mg/l)
1	1.75	0.21	0.03	0.02	0.22
2	2.20	0.52	0.02	0.01	0.11
3	3.11	1.43	0.07	1.22	1.22
4	0.25	0.71	0.03	1.12	0.15
5	0.31	0.05	0.06	0.03	0.10
6	0.15	0.03	0.07	0.09	0.05
7	0.23	0.07	0.03	0.03	0.71
8	0.25	0.09	0.04	0.02	0.35
9	0.15	0.05	0.07	0.06	0.87

Station	SiO_2 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	NO_2 (mg/l)	PO_4 (mg/l)
10	0.22	0.04	0.12	0.07	0.45
11	0.15	0.06	0.22	0.05	0.21
12	0.16	0.09	0.07	0.02	0.75
13	0.21	1.25	0.92	0.03	3.25
14	2.56	1.75	1.21	0.12	2.11
15	1.75	2.35	0.08	0.12	1.24
16	3.25	1.20	0.09	0.22	2.32
17	3.75	2.15	1.21	0.92	2.57

3.2.3. Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Total Organic Content in Sediment Samples

The BOD in samples varied from 150 mg/kg to 1322 mg/kg (Table 4). It is obvious from the data that the area is highly contaminated and needs more dissolved oxygen to protect the ecosystem. Station 17 exhibited highest BOD reflecting high contamination with pollutants. The COD was ranging between 201 mg/kg and 1920 mg/kg with highest recorded value at Station 17 which is within Doha Power Station outlet (Table 4). The high COD will have great impact on the ecosystem of the area. The organic content in sediment samples varied from 4.2 mg/kg to 22 mg/kg with an average 12.01 mg/kg reflecting high industrial pollution in some stations near industrial outlet where pesticides and organic matter are found (Table 4). The organic matter can be toxic to ecosystem of the wide tidal flat within the boundary of the study area.

Table 4. Distribution of TOC, BOD and COD in the sediments of the study area.

Station	TOC mg/kg	BOD mg/kg	COD mg/kg
1	12	750	710

Station	TOC mg/kg	BOD mg/kg	COD mg/kg
2	14	250	410
3	8	450	830
4	10	250	650
5	12	180	510
6	9	150	201
7	15	800	950
8	6.1	120	320
9	4.2	160	250
10	7.5	280	750
11	5.5	310	712
12	10	170	650
13	18	950	1312
14	17	820	320
15	22	1300	1723
16	19	1250	1521
17	15	1322	1920

3.2.4. Total Petroleum Hydrocarbon (TPH)

The Total Petroleum Hydrocarbons (TPH) concentrations across 17 sampled stations in Kuwait Bay exhibited significant variability, as depicted in Table 5. TPH levels ranged from approximately 304 µg/g to over 600 µg/g (dry weight), indicating a heterogeneous distribution of hydrocarbon contamination across the bay.

The level of TPH was highest in sediments at Station 15 with 601 µg/g, followed by stations 13, 14, 16 and 17 with varying values of 512 µg/g, 510 µg/g, 458 µg/g and 494 µg/g, respectively (Table 5). These elevated levels suggest significant hydrocarbon input from the nearby industrial activities, sewage discharges, thermal desalination plants, harbour activities or oil-related operations. The spatial distribution patterns of TPH indicated that they are mostly from the southern interior bay which is bounded by land mass subjected to anthropogenic influence. Figure 1 shows station 15 located in front of Al-Ghazali storm drain which is known to contain a number of illegal connections and discharges. It is thought that Al-Ghazali storm drain may account for a considerable amount of this pollution. While station 13 located at Doha Bay also indicated significant sewage pollution. Station 14 is near the Shuwaikh Port where industrial and maritime activities are most common. Further spills from handling of hazardous materials and vessel collisions have also been reported in this area. Station 16 which is near the Sabah hospital area is believed to have contamination most likely originating from

the wastewater discharged from the hospital complex while station 17 is subject to contamination from brine rejection of the Doha desalination plant. Other stations such as 1 to 12 may be more isolated from direct pollution sources, nevertheless, the TPH concentration was exceeding the reference value for sediment quality as proposed by Massoud et al. [15]. The high level of TPH in these sensitive areas need to be assessed regularly to ensure the safety of habitat and human health risk that could be associated with these multiple stressors.

Compliance with guideline limits

TPH values reported in the sediment samples of several stations around the coast of Kuwait Bay were found to be significantly high due to the impact of anthropogenic activities. Although Kuwait EPA has no sediment guidelines in place for the TPH, nevertheless, three levels of TPH pollution were suggested by Massoud et al. [15]. These are slightly polluted areas (15-50 µg/g), moderately polluted areas (50-200 µg/g), and heavily polluted areas (>200 µg/g). The Australian SQGs specifies the default guideline value for TPH concentration in sediment to be below 280 mg/kg for unpolluted environments.

Based on the findings of this study, the TPH concentrations of Kuwait Bay sediments are significantly higher than the intervention level across the study area which is the level that requires attention. The TPH levels in the sediment of the study area ranged between 304-601 mg/kg (Table 5) which is comparatively higher than the values reported in the previous

study by Jasser et al. [13] where TPH concentration was within the range of 72.44 - 252.79 ppm (moderately to heavily polluted). This indicates that the sources of pollution are increasing at an alarming rate. El-Sammak et al. [10] indi-

cated that the sediment quality in the northern region of Kuwait's marine environment is less compared to the southern region which is characterised by high contents of TPH.

Table 5. Total Petroleum Hydrocarbon (TPH) distribution in bottom sediments of the study area.

Station	Coordinates	TPH (mg/kg)	Reference
1	29°30'21"N 48°05'29"E	373	
2	29°31'28"N 47°58'00"E	425	
3	29°28'23"N 48°07'36"E	380	
4	29°28'26"N 47°58'53"E	378	
5	29°29'03"N 47°53'07"E	346	
6	29°25'54"N 48°07'19"E	388	
7	29°25'58"N 47°58'03"E	386	<i>Massoud et al. 1996</i>
8	29°26'22"N 47°51'43"E	398	15-50 µg/g Slightly polluted areas
9	29°22'31"N 48°05'21"E	335	50-200 µg/g Moderately polluted areas
10	29°24'51"N 47°56'23"E	418	>200 µg/g Heavily polluted areas
11	29°24'44"N 47°48'05"E	421	<i>Australian SQGs (DGV)</i>
12	29°23'38"N 47°58'04"E	304	280 mg/kg (dw)
13	29°22'54"N 47°48'24"E	512	
14	29°22'12"N 47°56'24"E	510	
15	29°21'24"N 47°53'23"E	601	
16	29°20'06"N 47°53'16"E	458	
17	29°20'27"N 47°50'41"E	494	

3.2.5. Heavy Metals

The concentration of heavy metals Fe, Mn, Zn, Ni, Cr, V, Ba, Cu, Co, Sb, Ag, Be, As, Hg, Cd and Pb were sampled from 17 locations and presented in Table 6. Chemical analysis revealed variations in the concentration of V and Cr within the sampled locations. While the concentration of Ni was observed to be exceedingly high in all the stations with maximum enrichment at station 15, the concentration of Cu and Cd however, showed slight increase in levels when compared to

ERL (Effect Range Low) reference values for sediment quality. Other metals such as Zn, Fe, Mn, were within the permissible limit while Ag, Hg, As and Pb were found to be very low in all sampled sites.

The sediment mineral concentrations in the study area were compared with the Internationally permissible sediment quality guidelines (SQGs), which are widely used to determine metal toxicity in sediments. The sources of Ni, and V could be attributed to different anthropogenic inputs. The findings of the metal concentration are elucidated in Table 6.

Table 6. Concentration of heavy metals in sediment samples.

Station	Ba	V	Cr	Ni	Zn	Fe	Mn	Cu	Co	Ag	Be	As	Sb	Hg	Cd	Pb
1	22.991	35.087	62.5	93.3	45.3	13745	367	2.7	11.571	<0.3	<0.04	2.5	0.4	<0.002	0.2	<0.7
2	35.54	41.577	75.8	93.2	48.5	14315	398.7	7.5	12.341	<0.3	0.107	2.3	<0.2	0.002	1.3	<0.7

Station	Ba	V	Cr	Ni	Zn	Fe	Mn	Cu	Co	Ag	Be	As	Sb	Hg	Cd	Pb
3	22.481	27.9	49.2	72.8	3.4	11054	319.8	1.8	8.076	<0.3	5.904	1.9	0.7	0.04	2.9	2.9
4	20.765	24.794	60.2	81.4	66	12377	362.7	9.4	10.347	<0.3	1.235	2.7	<0.2	0.02	0.8	<0.7
5	32.754	40.356	79.8	88.9	53	14362	397.4	5.75	12.895	<0.3	0.392	2.5	<0.2	0.014	0.9	<0.7
6	28.958	38.722	67.6	87.4	52.5	13872	373.3	6.9	11.102	<0.3	0.257	2.1	<0.2	<0.002	<0.08	<0.7
7	26.126	36.571	67.6	95.8	69.4	13583	376	40.7	15.657	<0.3	0.341	0.9	1.9	<0.002	<0.08	<0.7
8	27.709	33.467	63.6	80.8	44.1	11972	326.3	1.9	8.952	<0.3	0.385	2.5	<0.2	<0.002	<0.08	<0.7
9	22.657	29.941	60.4	91.2	71	13439	347.3	17.5	12.634	<0.3	<0.04	2.2	<0.2	<0.002	<0.08	<0.7
10	20.233	27.81	47.1	56.6	40	8982	247.7	1.4	8.48	<0.3	<0.04	2.6	<0.2	<0.002	<0.08	<0.7
11	30.089	38.161	70.8	83.8	48.9	13817	361.7	5	11.729	<0.3	<0.04	2.1	0.8	<0.002	<0.08	<0.7
12	20.1	20.3	53.5	68.1	73	10379	305.2	5.4	9.413	<0.3	0.236	1.7	1.1	<0.002	<0.08	<0.7
13	36.787	39.647	83.3	89	47	14154	382.8	4.7	11.83	<0.3	0.12	2.2	<0.2	<0.002	<0.08	<0.7
14	38.44	42.577	79.7	98.2	49.7	14795	401.5	5.9	12.623	<0.3	0.256	0.9	<0.2	<0.002	<0.08	2.4
15	41.104	44.153	83.5	103.4	51	15275	412.6	4.3	12.939	0.091	2.9	<0.2	<0.002	<0.08	<0.7	<0.7
16	39.233	40.668	76.6	87.8	59.6	14568	404.4	6.8	13.966	0.237	1.5	<0.2	<0.002	<0.08	<0.7	<0.7
17	35.95	40.124	77.4	87.5	56.1	14465	404.5	6.275	13.431	0.122	1.3	<0.2	<0.002	<0.08	<0.7	<0.7
Range	20.1 -41.104	20.3 -44.153	47.1 - 83.5	56.6 - 103.4	3.4 - 73	8982 - 15275	247.7- 412.6	1.4 - 40.7	8.076 -15.657	0.091- <0.3	<0.04- 5.904	0.9 - 2.7	<0.002- 1.9	<0.002- 0.014	<0.08- 2.9	<0.7-2 .9
CCME, 1999	N.A	N.A	ISQG 52.3 PEL 160	N.A	ISQG 124 PEL 271	N.A	N.A	ISQG 18.7 PEL 108	N.A	N.A	N.A	ISQG 7.24 PEL 41.6	N.A	ISQG 0.13 PEL 0.70	ISQG 0.7 PEL 4.2	ISQG 30.2 PEL 112
NOAA -SQUIR T	N.A	N.A	ERL 81 ERM 370	ERL 20.9 ERM 51.6	ERL 150 ERM 410	N.A	N.A	ERL 34 ERM 270	N.A	ERL 1 ERM 3.7	N.A	ERL 8.2 ERM 70	N.A	ERL 0.15 ERM 0.7	ERL 1.2 ERM 9.6	ERL 46.7 ERM 218
AlAbdali et al., 1996	N.A	20-30	N.A	70-80	30-60	10,00- 20,000	300-6 00	15-30	N.A	N.A	N.A	N.A	N.A	N.A	1.2-2.0	15-30

ERL - Effect Range Low

ERM - Effect Range Median

ISQG - Interim Sediment Quality Guidelines

PEL - Probable Effect Level

N.A - Not Available

Nickel (Ni) represented the maximum abundance of the studied metals during the present study. This enrichment of Ni may be related to a variety of processes occurring in the investigated areas. The above inference is well supported by high values of Ni observed in all the stations. The Total nickel in the investigated areas, ranged from 56.6 -103.4 mg/kg, which represented contamination in all studied stations with significant enrichment reported at station 15.

Vanadium (V) was detected in the bottom sediments of all stations. Total Vanadium concentration was in the range of

20.3 - 44.153 mg/kg. The concentration of V was reportedly high at Station 15 above the background level established by AlAbdali et al. [1] while low concentrations were observed at Stations 3, 4, 9, 10 and 12.

Copper (Cu): The concentration of Cu was in the range between 1.4 - 40.7 mg/kg. According to the Canadian guidelines for Cu, the ISQG permissible level corresponds to the concentration limit of 18.7 mg/kg which is by far exceeding at station 7 (40.7 mg/kg). However, the maximum concentration is far below the PEL value for Cu. It can be seen that occur-

rence of contamination cannot be precisely predicted from concentration data alone; the assessment considers concentration ranges below and between ISQG and PEL confirming that adverse effects are more likely to be observed when concentrations of Cu exceed the PELs [11]. According to the calculated value for Cu concentration in Station 7, the metal enrichment in sediment is below the probable effect level (PEL).

Chromium (Cr): The total Cr concentration was in the range of 47.1 - 83.5 mg/kg. With most stations showing values that exceed the permissible range of the risk appraisal established in ISQG. However, considering the PEL (Probable Effect Level) the detected level for the metal enrichment is below the limit.

Cadmium (Cd): The detected Cd in the collected sediments represented concentrations in the range <0.08 - 2.9 mg/kg. Among all the sampled stations, 2 and 3 showed slightly high level 1.3 and 2.9 mg/kg, respectively which exceed the permissible range of the established ISQG. Moreover, it is slightly higher than the NOAA established ERL level. However, considering the probable effect level (PEL), the metal enrichment is below the limit.

The total concentration of Fe, Zn and Mn in sampled stations were in the range 8,982-15,275 mg/kg, 3.4-73 mg/kg and 247.7- 412.6 mg/kg, respectively. These metals were within the accep limits while Ag, As, Hg, and Pb were found to be very low.

4. Discussion

4.1. Spatial Distribution and Potential Contamination Sources

The spatial distribution of TPH concentrations and inorganic nutrients in Kuwait Bay reveals a pattern of contamination that corresponds to areas of industrial, maritime activity and sewage discharge. The elevated TPH levels in all sampled areas around Kuwait Bay indicate significant contamination likely linked to anthropogenic inputs which is much higher in comparison to the previous studies by Masoud et al. [15] and Al-Abdali et al. [1]. Most of the inorganic nutrients were found above the permissible limit mainly in the hotspots around the Desalination outlets, navigation channel and Al-Ghazali storm outlet. For metal concentration, Ni was exceedingly high in all the stations within the bay, while V and Cr showed variations within the sampled locations. Both TPH and metal concentration of Ni, V and Cr were highest at station 15, south east of Sulaibikhat Bay, adjacent to Al-Ghazali outfall. Nickel is possibly leached from heat exchangers and treatment chemicals from desalination plants which could be generated in the discharged brine [9]. The presence of V concentrations in marine sediment indicate direct input of oil pollutants from the facilities at Shuwaikh Port through discharge of oily waste sludge into the marine

environment. Furthermore, Cu concentration was found to be above ERL at station 7 which represents the south part of the Jaber Bridge Causeway. It is reported that the construction of the bridge has largely impeded the bay's hydrodynamic characteristics, causing the anthropogenic sources originating from the land mass of the southern interior bay to increase the accumulation of organic matter into the stagnant waters in the bay [18]. Cd was also reported to be relatively above the ERL limit at stations 2 and 3 located far north and north east of the bay close to Subiya plant. The values are relatively higher compared to previous study by El-Anbaawy et al. [9]. Conversely, the lowest concentrations of metals Ag, As, Hg, Pb was seen across the study area. Trace metals depending on their solubility may be dissolved or get accumulated in the sediments which serve as indicator for assessing the distribution and impacts of anthropogenic inputs from land-based sources around Kuwait Bay.

4.2. Environmental Implications

The high concentrations of TPH, inorganic nutrients and metals observed in certain areas of Kuwait Bay could have serious implications for the marine ecosystem. Hydrocarbons are known to be toxic to marine organisms, particularly benthic species that inhabit the sediment. Prolonged exposure to high levels of hydrocarbons and heavy metals can lead to contamination of water. The pollutants in sediments can bioaccumulate in the food chain, potentially affecting a wide range of species, including those of commercial importance. Sediment pollution can potentially impact humans in the food chain. The findings of this study highlight the need for ongoing monitoring and the implementation of effective pollution control measures to protect the bay's marine environment.

5. Conclusions and Recommendation

This study provides a comprehensive assessment of TPH, nutrients and metal concentrations in marine sediments from Kuwait Bay. The results indicate significant spatial variability in hydrocarbon contamination, with all sites exhibiting alarmingly high levels of TPH. While metal concentration of Ni was found exceedingly high in all sediment samples, V and Cr concentrations were above the established baseline range in most of the sampled stations. Furthermore, Cu and Cd were reportedly high at station 7 and stations 2 & 3, respectively, but the concentrations were below the probable effect levels (PEL). However, continual effluent discharge could escalate these levels, potentially impacting marine fauna. These findings underscore the urgent need for targeted environmental management and remediation efforts, particularly in areas with the highest contamination levels. Continued monitoring is essential to track the effectiveness of these measures and to ensure the long-term sustainability of Kuwait Bay's marine ecosystem.

The study also highlights the importance of managing both

point and non-point sources of pollution in the region to prevent further degradation of marine sediments and the broader ecosystem. The following recommendations are proposed to mitigate the adverse impacts of Kuwait Bay by.

- 1) Regular monitoring of the water quality and sediments along the coastal line as it is one of the most important recreational areas in Kuwait.
- 2) Preparing an Environment Impact Assessment (EIA) for any intended project along the coastline to avoid negative impacts of the projects on the marine environment.
- 3) To oblige power stations located near the sea to treat the brine water before discharging it.
- 4) Regulate the monitoring and treatment of wastewater discharged into the sea by governmental and private agencies and setting penalties for its violation due to negative impact on the surrounding environment.
- 5) Oblige the Ministry of Public Works (MPW) to comply with Kuwait Environmental Public Authority (KEPA) regulations to control the discharge of untreated sewage into the sea.
- 6) Temporarily isolate polluted places and not use them for swimming or fishing until they are safe for public use.
- 7) Encouraging research on further studies of marine sediments and sea water to ensure their quality level.
- 8) Preservation and protection of the coastal area when planning future townships.

Abbreviations

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
DO	Dissolved Oxygen
USEPA	U.S. Environmental Protection Agency
KEPA	Kuwait Environmental Public Authority
MPW	Ministry of Public Works
ICP/MS	Inductively Coupled Plasma Mass Spectroscopy
MEL	Middle Eastern Laboratories
mg/kg	Milligram Per Kilogram
mg/L	Milligram Per Liter
ppt	Parts Per Thousand
°C	Degree Centigrade
µS/cm	Microsiemens Per Centimeter
SQGs	Sediment Quality Guidelines
DGV	Default Guideline Values for Toxicant
dw	Dry Weight
µg/g	Microgram Per Gram
ERL	Effect Range Low
ERM	Effect Range Median
ISQG	Interim Sediment Quality Guidelines
PEL	Probable Effect Level
N. A	Not Available
EIA	Environmental Impact Assessment

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Author Contributions

Reem Al-Jber: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Visualization, Writing – original draft

Mohammad Al-Sarawi: Data curation, Formal Analysis, Supervision, Validation, Writing – review & editing

Ethics Approval and Consent to Participate

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Conflict of Interest

The authors declare no conflicts of interest.

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Research Fields

Reem Al-Jber: Environmental Geology, Geochemistry, Marine sediments, Water quality, Coastal pollution

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