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Geoindicator of Heavy Metals Contamination in Bottom sediments of Kuwait Bay, Northwestern Arabian Gulf

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COMPREHENSIVE mineralogical and geochemical analyses were conducted on the bottom sediments at the Kuwait Bay, northwest of the Arabian Gulf. The current study aims to measure the contamination level in these sediments to evaluate its environmental impact on marine life. The major and trace elements as well as heavy metals, including V, Cr, Zn, Pb, Ni, Cu, Co and Cd, were measured. in the aggregated clays and bottom sediments. The ranges of the metal enrichment in the lake bottom sediments are as follows: V > Cr > Zn > Ni > Pb > Cu > Co.> Cd. Based on the results, it can be concluded that bottom sediments of Kuwait Bay may be minimal enrichment with metals such as Cu, Co, Cr, Ni, and V., Pb and Bi while minimal enrichment to moderate enrichment in sediments by Cd and Pb. Concentration of Cd, Cr, Cu, Ni, Pb, and Zn were comparison with Sediment Quality Guidelines (SQGs). The mean concentrations of elements Cu, Pb, and Zn were lower than the threshold effect level (TEL) of SQGs values except for Cr and Ni. The concentration of Cr and Ni. were higher than threshold effect concentration (TEL) value of SQGs values. On the other hand, all the heavy metals concentrations are lower than the probable effect level (PEL) of SQGs.

Keywords: trace metals; beach sediments; coastal processes; Kuwait Bay.

1. Introduction

Kuwait Bay (Figure 1) is an important part of Kuwait's marine ecosystem which has been affected significantly by the anthropogenic activities, and various forms of contamination have been appeared. The effluents from the Shatt Al-Arab River, power and desalination plants and as well as industrial operations, all contribute to challenging conditions for marine life in Kuwait Bay.

The bottom sediments in the Arabian Gulf and Kuwaiti marine who are mainly silty clay, clayey silt, sandy mud, silt, muddy sand, and sand (Akoi and Oinumal , 1977, Khalaf and Ala, 1980, and El-Sharkawy et.al., (2025).

The sand and sandy sediments are distributAl-Qattan and Al-Sarawi (2017ed along Kuwait's southern coast, while mud and muddy sediment is dominate the majority of the country's offshore bottom (Al-Bakri and Al-Ghadban, 1984).

Furthermore, the Kuwait Bay environment is divided, based on the textural characteristics of sediments, into two energy zones: (a) a low energy zone, which encompasses the majority of the bay region, and (b) a moderate energy zone, which is confined to the southern offshore part of the bay (Khalaf *et al.*, 1982A&B).

The seawater temperature in Kuwait Bay displays a large variation, where it records the lowest temperature of about 11.9°C in January, while it records the highest temperature of about 36°C in August (Anderelini *et al.*, 1982A; Al-Yamani *et al.*, 2004, Al-Sahli, 2009 and Amos, et.al. 2014). Now, the seawater temperature in Kuwait Bay is increasing more rapidly than the global average, and it is expected to increase by 0.60°C every decade (Al-Rashidi *et al.*, 2009). This increase is closely linked to the human activities in the coastal zone (Al-Rashidi *et al.*, 2007; Lo *et al.*, 1987; Abou-Seida & Al-Sarawi, 1990; Massoud et al., 1996A, 1996B and 2006).

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Kuwait Bay can be generally divided, based on current velocity, into two zones: the eastern zone and the western zone (Al-Ghadban & Salman, 1993, Al-Ghadban et. Al, 1994, 2002).

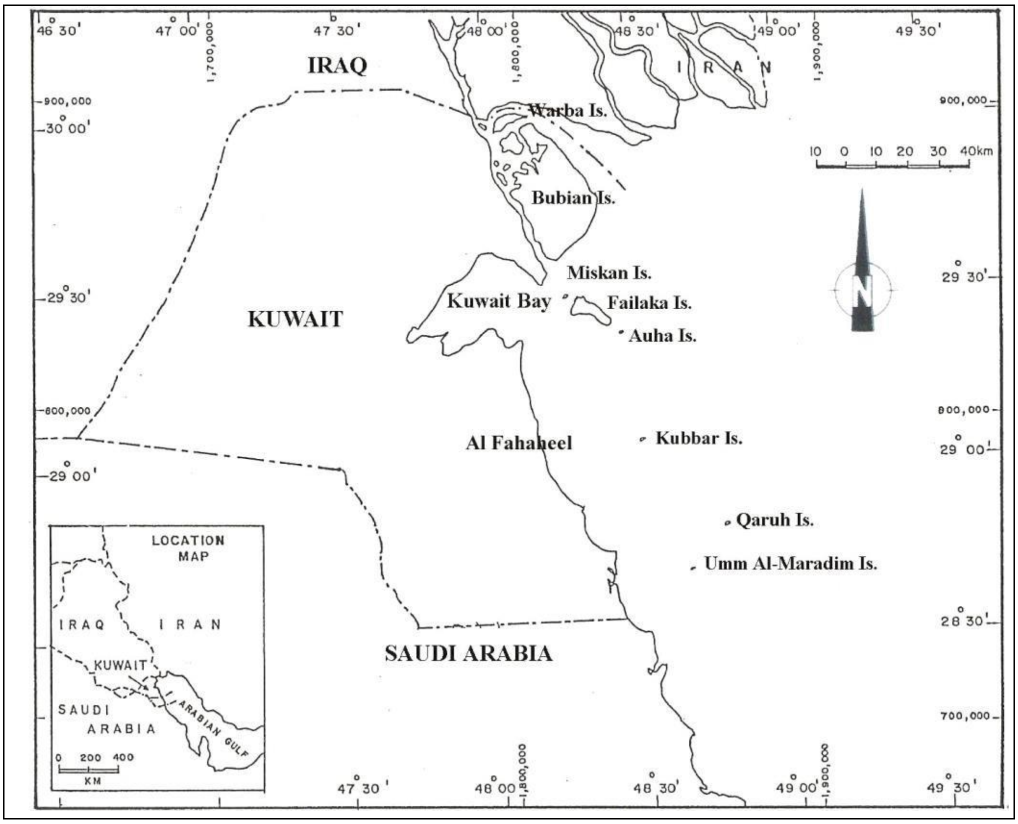


Fig. 1. Map of the research area, Kuwait, and the northwest Arabian Gulf.

The eastern zone is marked by a relatively high current velocity (41.0 cm/s) lower salinity and lower temperature. The western zone features a greater expanse of deep water.

The concentrations of heavy metals in sediments of the southwest coast of Kuwait bay have been the focus of numerous geochemical studies. e.g., (Sugden, 1963, Evans, 1964 and 1966), Anderlini *et al.* (1981&1982B); Sadig ad Zaidi (1985); Basaham and Al-Lahaibi (1993); *Basaham, and El-Sayed (*1998); Metwally *et al.* (1997); Al-Ghadban et. Al., (2002), Al-Sarawi et. Al. (2015&2002); Al-Ghadban & Salman, 1993), Al-Ghadban et al., (1994 &2002), Al-Said et al.; (2018), Al-shemmari1H. & Talebi. (2019) and Neelamani et.al., (2021).

For environmental and geochemical studies related to marine contamination, marine sediments provide valuable data (Sadig and Zaidi, 1985, Abaychi and Douabul (1986), Basaham, and Al-Lihaibi, 1993, Al-Abdali et al., 1996, and Basaham, and El-Sayed, 1998, Shan et. Al., (2008) and Naser (2013). Consequently, sediments, which have been contaminated by both organic and inorganic substances (Boota, A.A., Al- Enezi, E. (2023), are biologically significant components of the marine environment Balfas et. Al. (2025). They consist of composite minerals made up of biological matter in various states of decomposition, mineral particles, and inorganic components.

Kuwait Bay's seawater is less conducive to marine life as it is particularly susceptible to contamination from sewage discharge and other human activities. The risk of heavy metal contamination in the marine environment has risen with the expansion of industrial activity in coastal areas (Hamdy et.al., (**2022),** Naser (. 2013). Neelamani et.al., (2021).AI-Sarawi, et. al, 2002&2015, Al-Arfaj, and Alam, 1993).

Large quantities of harmful pollutants have been released into coastal environments since the industrial revolution, and bay and estuary sediments serve as significant sinks for heavy metals (Fowler, et. Al., 1993, Basaham & El-Sayed,1998و Turner, 2000;; Fan *et al.,* 2002, and Wang *et al.,* 2010).

The Kuwait Bay's marine ecosystem has been affected significantly by the anthropogenic activities and displaying various forms of contamination. The sediments at the bottom of Sulabikhat Bay, Shuaiba industrial area, Fintas, and Doha contain significant contamination from Cu, Zn, Fe, and V. (Methwally *et al.*, 1997). The mean concentrations of Cu, Fe, Zn, Ni, Pb, V, Cr, and Mn in the bottom sediments of the Bay were 26.98, 24,900, 73.5, 13.97, 5.60, 67.87, 55.60, and 187.40 ppm, respectively (Al-Sarawi *et al.*, 2002; El-Moselhy *et al.*, 2004). The Kuwait's coastline recorded the highest concentration of suspended solids, measuring a maximum value of 47.77 mg/l at Al-Fintas, particularly in Khor Al-Subbiya, north Kuwait Bay, Ras Ushairij, Sulaibikat Bay, Kuwait City, and Al-Bida to Mina Abdullah (Marmoush, 1999). The Kuwait Bay is suffering from several sorts of contamination which affect strongly its marine environment, hence detailed measurement of contamination levels has to be conducted to evaluate its environmental impact.

2. Materials and procedures

2.1. Sampling technique

Bottom sediment samples were taken from 19 stations spread around Kuwait Bay (Figure 2). After being homogenized, the dried samples were placed in plastic bags with labels for further examinations. The following procedures are applied:

- The sediment samples weighted between 0.11 and 0.18 grams and were placed in a beaker.
- Six samples, including a blank digest (5 ml of HNO_3 acid, 2 ml of HCL acid, and 2 ml of HF acid), were prepared together with standard reference materials (SRM).
- After sealing the beakers, the sample was broken down in a Milestone ETHOS UP microwave oven.
- The sample was cooked for 50 minutes at 170°C and held for 30 minutes. Samples were then diluted by sprinkling 30 milliliters of distilled water on them.

2.2. The geo-accumulation index (Igeo)

The geo-accumulation index (Igeo) was originally used with bottom sediment by Muller (1969). It is computed by the following equation:

$$\text{I-geo} = \log 2\, (C_n / (1.5 \times B_n)) \qquad \text{Eq. (1)}$$

where, C_n: is the measured concentration of the element in the tested sediment (surface soils) and B_n: is the geochemical background value of the element in fossil argillaceous sediment (continental crusted average or average shale).

The constant 1.5 is introduced to minimize the effect of possible variations in the background values which may be attributed to lithological variations in the sediments. It is necessary to compare the level of metal in sediments current concentrations with preindustrial reference levels. The geochemical background value of the element for the investigated area did not obtain. Thus, the average abundance of chemical element in the earth's crust (Taylor, 1964) were used as geochemical background value. (Muller, 1981) has distinguished seven classes of geo-accumulation index: these are <0=practically unpolluted, 0–1=unpolluted to moderately polluted, 1–2=moderately polluted, 2–3=moderately to strongly polluted, 3–4=strongly polluted, 4–5=strongly to extremely polluted, and > 5=extremely polluted.

2.3. Enrichment factors

In order to assess the level of contamination and the possible anthropogenic impact, the enrichment factors were used. According to Sutherland, (2000), there are five contamination categories on the basis of the enrichment factor; theses are EF<2 deficiency to minimal enrichment, EF=2–5 moderate enrichment, EF=5–20 significant enrichment, EF=20–40 very high enrichment, EF > 40 extremely high enrichment.

The enrichment factor was calculated using the formula originally introduced by (Buat-Menard & Chesselet, 1979; Liu *et al.*, 2005).

The EF was calculated by the following equation:

$$EF = \frac{\frac{CM}{Cx}(sample)}{\frac{CM}{Cx}(earth\ crust)}$$

Eq. (2)

where, CM is the content of metal studied and CX is the content of immobile element, Al is used as immobile elements in the current calculation.

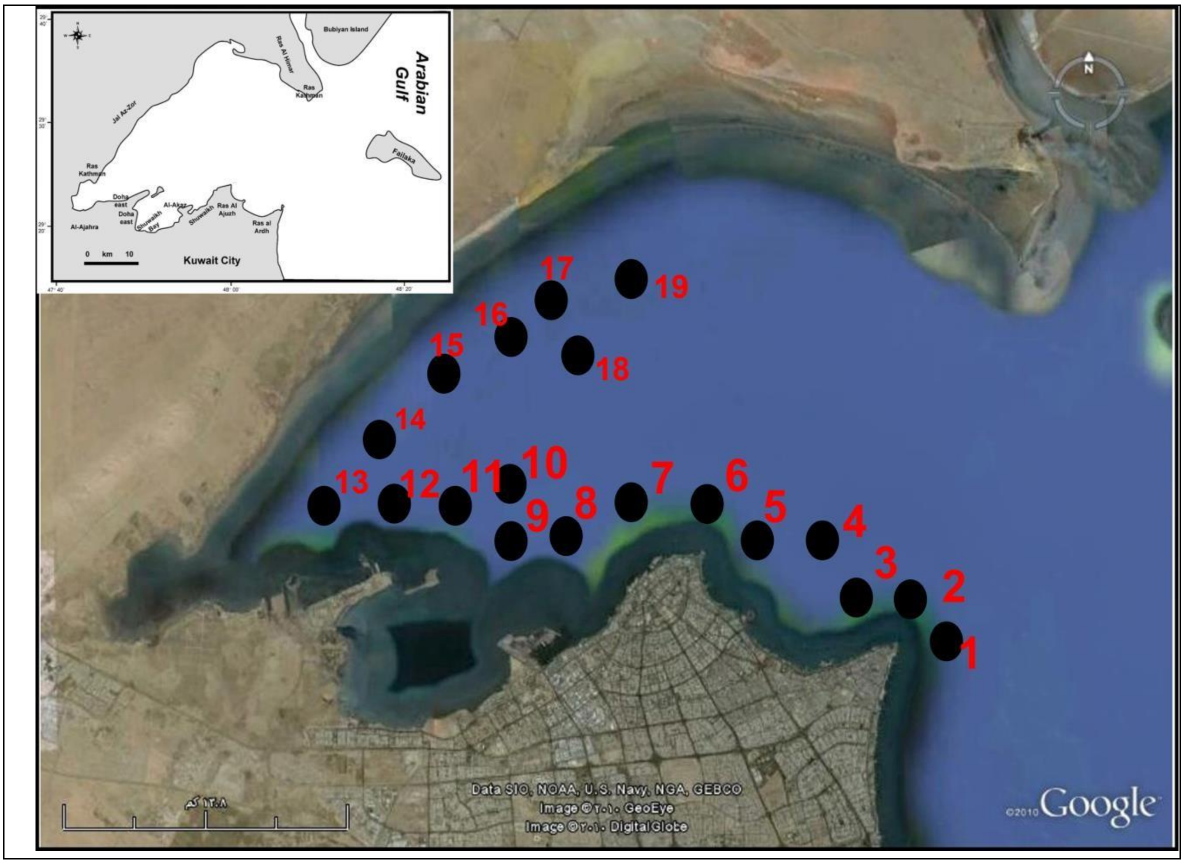


Fig. 2. Kuwait Bay sampling sites (source: Google Earth).

2.4. Sediment Quality Guidelines (SQGs) (MacDonald et al., 1996)

The Sediment Quality Guidelines (SQGs) of Mac-Donald et al. (1996) was applied on heavy metals concentration of the study area. This Sediment Quality Guidelines (SQGs) was based on the calculation of a threshold effects level (TEL) and a probable effects level (PEL). In this respect, the TEL is intended to estimate the concentration of a chemical below which adverse effects only rarely occurred (i.e. a minimal effects range). Also, the PEL is intended to provide an estimate of the concentration above which adverse effects frequently occurred (i.e. probable effects range).

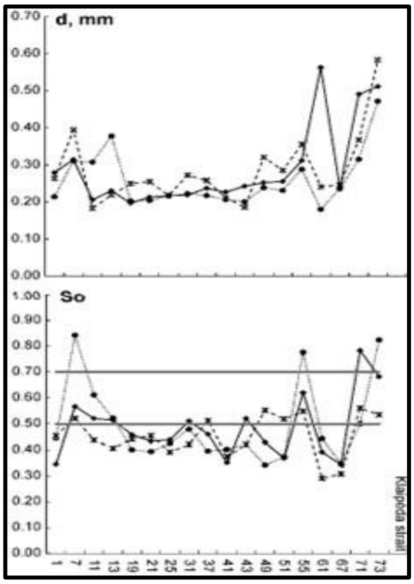
3. The Results

3.1. Sediments texture

Based on the grain size distribution diagram, the sediments are medium- to fine-grained sands (d = 0.26: 0.29 mm, σ = 0.08) make up the sandy beaches of Kuwait Bay (Figure 3a). The surface sediments, in the inner bay, range in particle size from silty sand to sandy silt (El-Sammak A, Al-Ghadban A, and Beg M (2004). There is a medium to coarse sediment percentage in places with fairly well-sorted (0.50 < So > 0.70) or moderately sorted (So > 0.70) sand. However, the inner Kuwait Bay contains fine-grained sediments that contain 14-70% silt (sandy silt and silty sand).

The sediments are texturally categorized using Folk's (1974) nomenclature, and the percentages of sand, silt, and clay fractions of the examined samples were plotted on a triangular diagram (Figure 3b). The diagram shows that the majority of sediments are sand and slightly gravelly sand, with subordinate number of gravelly sand samples.

The saltation is thought to be the primary population of the transportation mechanism, in addition to minor contributions from rolling and suspension populations. Most cumulative probability curves show two parts within the saltation population (Figure 4).



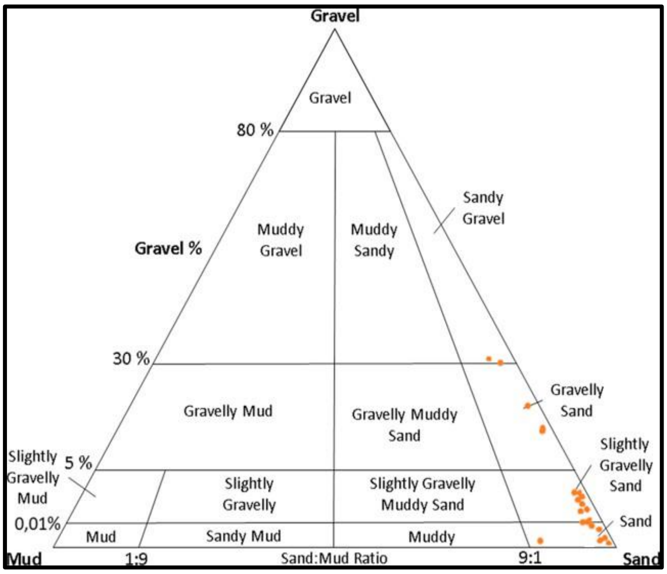


Fig. 3a. Showing the distribution of grain sizes (d, mm) and sorting (So) of the bottom sediments of Kuwait Bay. Figure 3b. Classification of Kuwait Bay's sediment according to Folk 's diagram (1974).

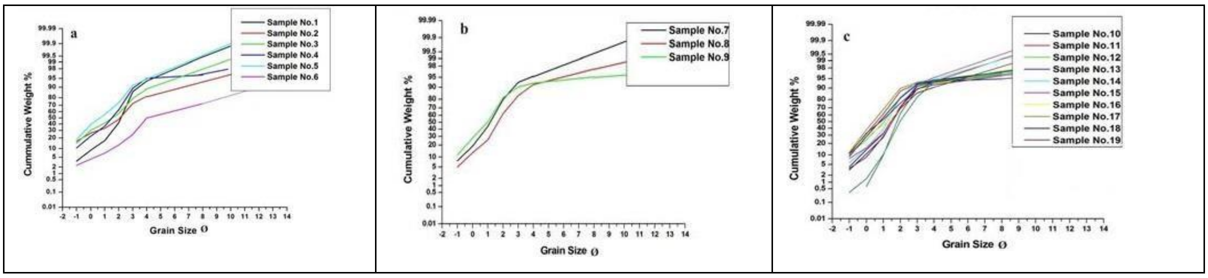


Fig. 4. Showing the probability cumulative curves of the studied samples.

3.2. XRD Investigation

The results of XRD investigation of the various size fractions are displayed in Figures (5a &b). Various fractions of particle size include varying concentrations of different minerals. Feldspars and quartz are the most common minerals detected in the coarsest fractions (250-20Ìm and 20-2Ìm). The two coarsest fractions contain dolomite and calcite because of their partial dissolution during the initial chemical treatment for the removal of carbonate. In the two coarsest fractions, micas and chlorites are the most common phyllosilicate minerals, where all samples contain trace quantities of pyroxenes and amphiboles.

The high percentage of total clays in these two fractions indicates the widespread existence of clay minerals. Furthermore, the coarse clay fraction (2-0.25Ìm) contains notable concentrations of quartz, feldspars, and amphiboles (12–17%).

Illite is the most common clay mineral found in both clay fractions (2-0.25Ìm and <0.25Ìm), although its percentages slightly vary from 44% to 52%. Smectite is found in both clay fractions, and its quantity is noticeably higher in fraction less than 0.25 Ìm. In both clay fractions, chlorite (+kaolinite) is present in a narrow range of concentrations (16–3%). The 2-0.25Ìm fraction has 30–35% smectite layers along with ordered illite/smectite (I/S).

At random, the <0.25Ìm portion contains interstratified I/S with 50% smectite layers. The average clay mineral concentration, in the studied sea bed sediments of the outer Gulf, is 50% illite, 30% smectite, and 20% chlorite (+ kaolinite) in the <0.25Ìm fraction and 48% illite, 23% smectite, 17% chlorite (+ kaolinite), and 12% other minerals in the 2-0.25 mm fraction.

3.3. Mineralogical study

Optical and scanning electron microscopy (SEM) are used to examine the mineralogical makeup of the hydrosulfates found in the bottom sediments. The sediment (0.05 mm) is represented by light brown (to milky-white) clayey material containing pieces of dark-colored minerals. The most prevalent forms of clay minerals are likely to be kaolinite, montmorillonite, beidellite, and halloysite. The latter two are characteristic of the weathering crusts of the sulfide deposits (halloysite) and the basic rocks of the Kuwait Bay, and probably due to illite admixture.

Gypsum and barite are present as surface coating in the sample, and which appears as individual crystallites, intergrowths, and microaggregates known as "gypsum roses" (Figures 6 A&B).

Barite is less prevalent, and specific peaks of Zn, Mn, and Cu may be seen in some spectra (Figures 6 C). The presence of Mn, Cu, and Zn in polymineral aggregates may be a sign of their high mobility and adsorbed state. Iron compounds and microcrystalline aggregates are created during the oxidative stage of the process and function as sorbents. Clay minerals, particularly montmorillonite and beidellite, which have a high cation exchange capacity, most likely absorb some of these ore metals.

The secondary types consist of clay aggregates and iron hydroxides in the form of concretions (Figures 6D). Apatite, zircon, and pyrite grains are examples of accessory minerals as well as ilmenite and titanium oxide (rutile/anatase).

Acicular epsomite, which is hydrated magnesium sulfate ($MgSO_4 \cdot 7H_2O$), is found and it represents a typical sulfate mineral (Figures 6E).

A manganese-bearing mineral and chromium-bearing mineral inclusions in the shape of a vein with submicron diameters are present in the sample. Iron compounds; iron sulfates, or jarosite, are examples oxides and hydroxides are also present. Native iron was discovered, which is shown as a rounded structure with balls smaller than a micron and measuring around 20 µm (Figures 6F).

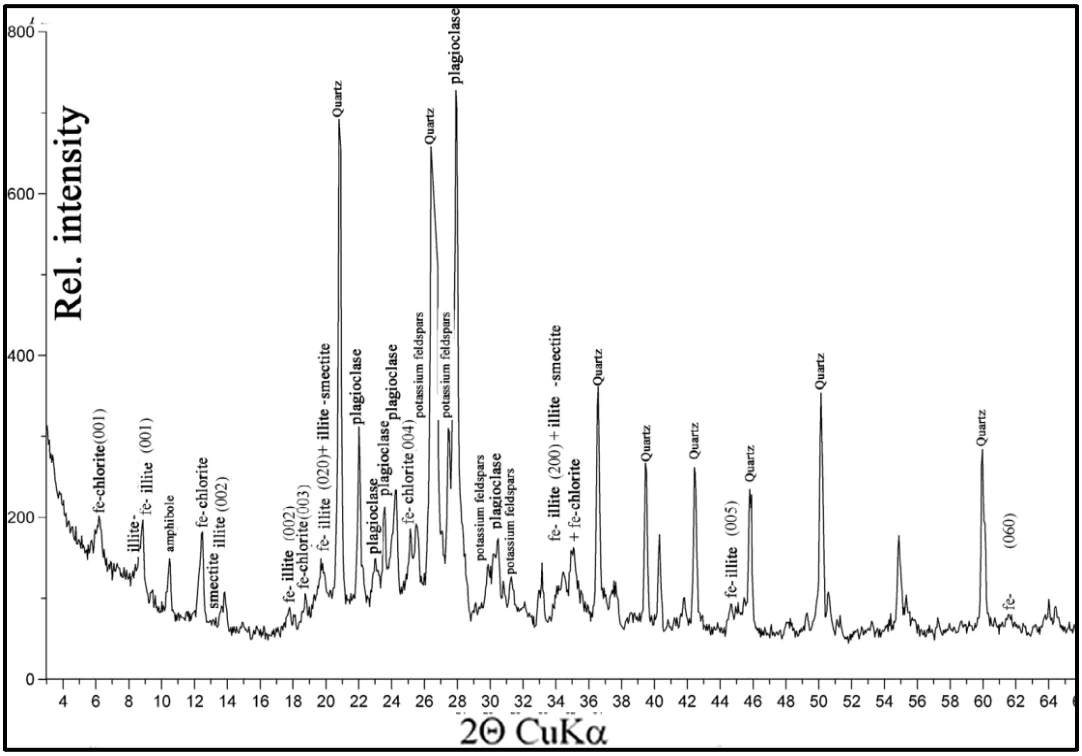


Fig. 5a. Diffractogram of undirected drag sample No. 18, bottom sediment of Kuwait Bay.

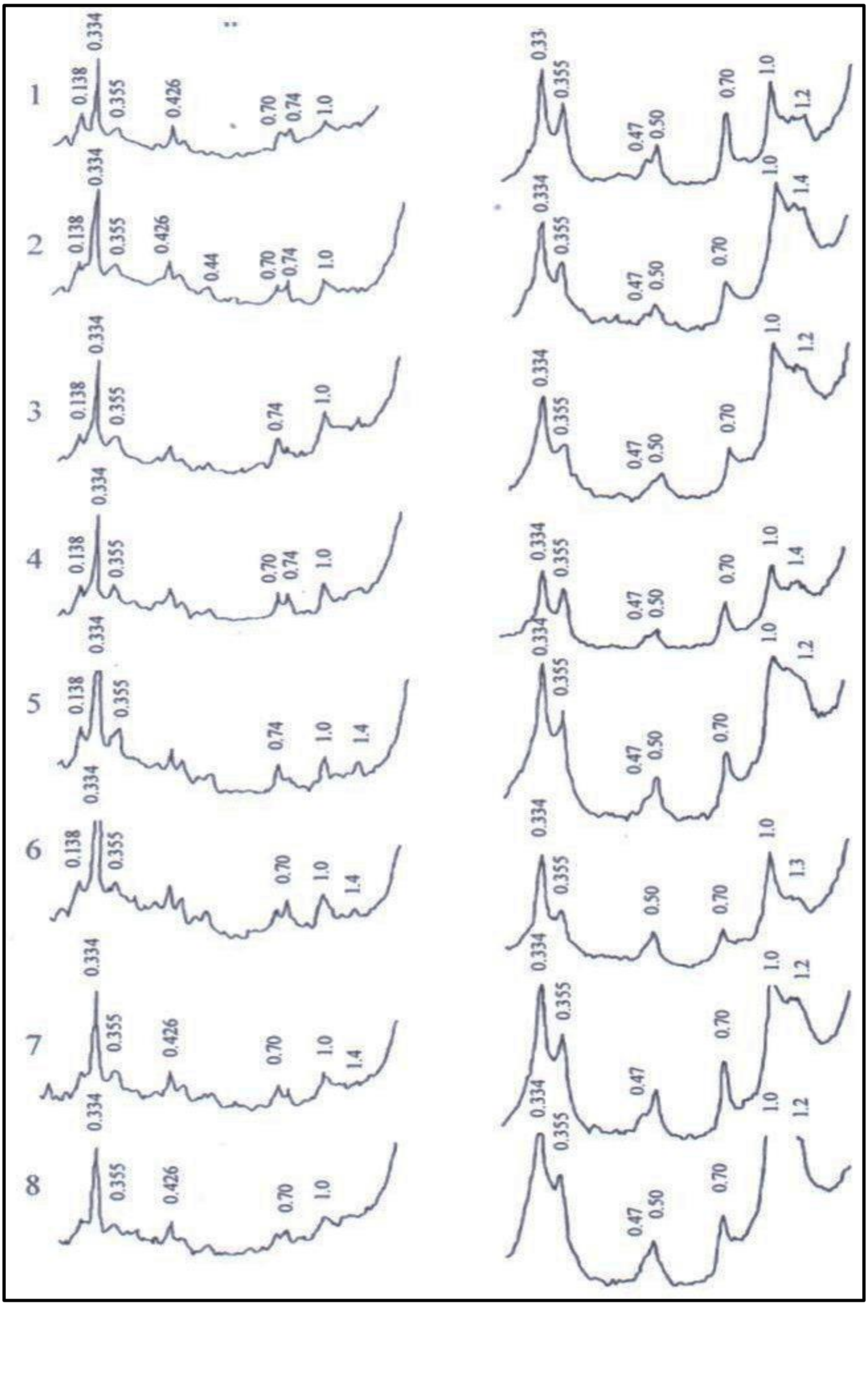
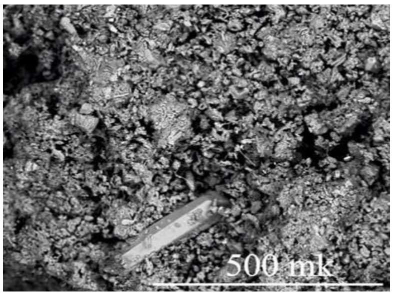
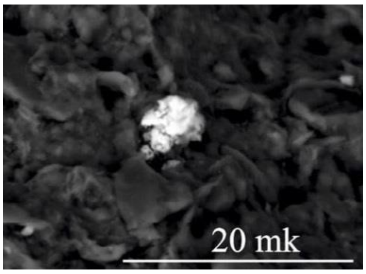


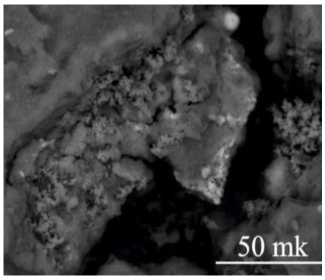
Fig. 5b. The fine bottom-sediment component's X-ray diffraction patterns (air-dry samples).



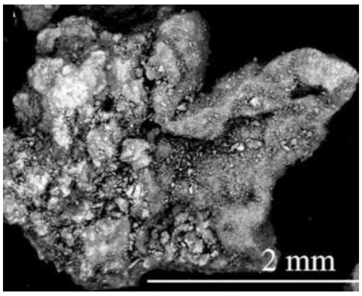
A: Aggregates of gypsum and inclusions of barite (white mineral) .



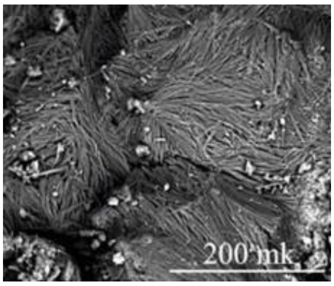
B: inclusions of barite (white mineral)



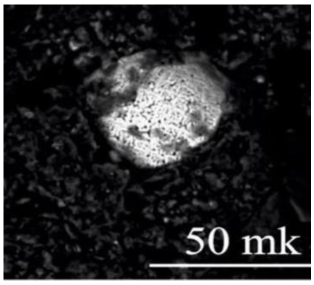
C: Polymineral aggregates: Mn, Cu and Zn



D: Native iron (a) oxyhydro xides :white on the surface of the aggregates



E: Acicular aggregates of epsomite.



F: Native iron (a) oxyhydroxides: white on the surface of the aggregates

Fig. 6. SEM picture of individual grains and microcrystalline aggregates.

3.4. Chemical analysis

3.4.1. Major elements

Table (1) lists the percentage of major elements of the studied samples along with the minimum, maximum, average, background concentration in the crust and I-geo. Figure (7) showing the concentration distribution of the major elements in the Kuwait Bay Careful investigation of the figure reveals Si is the most prevailing element in the bottom sediments and recording an average percentage of about 40.13%. With respect to I-geo categories, all calculated values of major elements are <0 which are practically unpolluted (Table 1). Moreover, SiO_2 and CaO are more abundant in the coarse fraction (250–20 Ìm) than in the fine fraction (<0.25 Ìm), indicating the widespread presence of non-clay minerals.

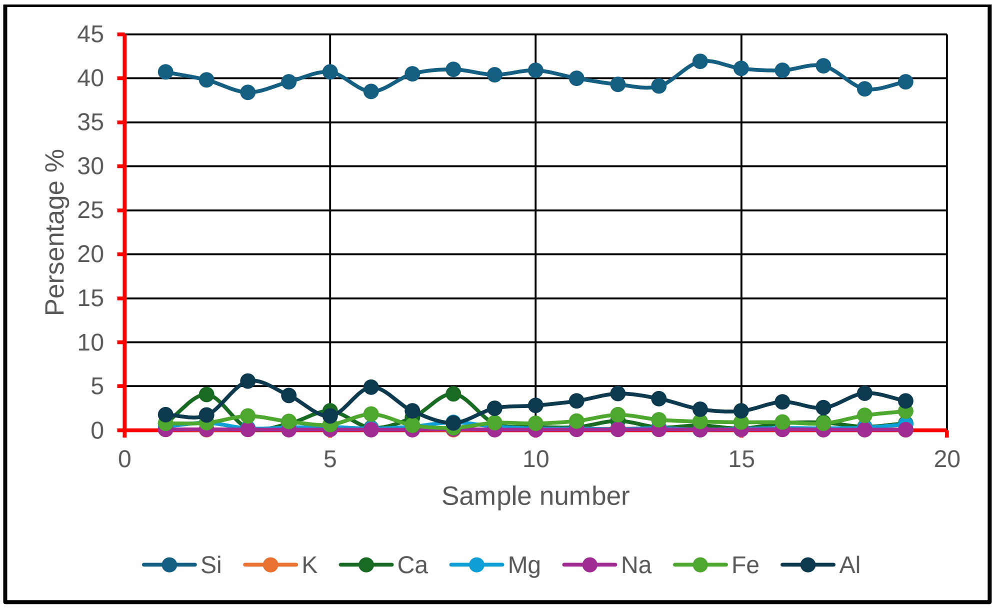


Fig. 7. The concentration distribution of major elements in the Kuwait Bay.

The existence of the aforementioned minerals as well as the feldspars from which they are created accounts for the prevalence of clay minerals in the Gulf sediments.

On contrary, both fractions maintain a constant weight % of MnO, and TiO_2, and the fine fraction (<0.25Ìm) exhibiting vast abundance of phyllosilicate minerals indicating enrichment in the alkalis (Na and K), and Mg.

All silicate minerals have terrigenous origins, where they are resulted from the weathering of parent rocks of the nearby beaches and the streams of drainage basins. These rocks contain pyroxenes, amphiboles, and chlorites as accessory minerals and micas as main minerals.

3.4.2. Heavy Metals

Table (2) displays the total concentrations of heavy metals along with minimum, maximum, average, STDEV, average concentration in the crust, and enrichment factors (EF). The results show that the mean concentrations of metals in sediments of study area followed the order: V > Cr > Zn > Ni > Pb > Cu > Co.> Cd. Careful inspection of Figure (8) reveal that the V and Cr are the most abundant heavy metals in the bottom sediments of the Kuwait Bay.

All sampling locations had extremely low concentrations of the hazardous elements Cd (0.19- 0.42 mg/kg) and Pb (0.19- 0.42 mg/kg) (Table 2 &Figure 8). Iron and manganese, along with copper and zinc, exhibit similar distribution patterns in each reservoir, indicating (1) that they originate from the same sources in the drainage areas and (2) that they occur in the sediments in similar inorganic/organic forms while preferentially associating with the same mineral and organic compounds.

According (Muller& 1969, and Muller, 1981) classes of geo-accumulation index, the calculated I-geo of the heavy metals, the bottom sediments Kuwait Bay is of unpolluted (Table 2 &Figure 8).

Based on the results of enrichment factors (Table 2 & Figure 9), it can be concluded that bottom sediments of Kuwait Bay may be minimal enrichment with metals such as Cu, Co, Cr, Ni, and V., Pb and Bi while minimal enrichment to moderate enrichment in sediments by Cd and Pb.

The comparison concentration of Cd, Cr, Cu, Ni, Pb, and Zn with Sediment Quality Guidelines (SQGs) of Mac-Donald et al (1966), the mean concentrations of elements Cu, Pb, and Zn were lower than the threshold effect level (TEL) of SQGs values except for Cr and Ni (Table 2 & Figure 9). The concentration of Cr and Ni. were higher than threshold effect concentration (TEL) value of SQGs values. On the other hand, all the heavy metals concentrations are lower than the probable effect level (PEL) of SQGs.

The pH values are ranging from 7.43 to 8.82, indicating alkaline nature of the sediments. The total organic carbon (TOC) percent is ranging from 0.18 to 0.72%, the nitrogen is ranging 280 to 840 ppm, and phosphorus is ranging from 250 to 470 ppm.

4. Discussion

The identification of trace elements in Kuwait Bay's sediments raises the possibility that contaminants from power plants, desalination facilities, industry, and the Shatt Al-Arab influx could endanger marine life. According (Muller, 1981) classes of geo-accumulation index, the calculated I-geo of the heavy metals (class 0-1), the bottom sediments Kuwait Bay is of unpolluted.

The results of the study show that the main components of the bay's sediment are TOC, TN, salinity, and trace elements (Al, V, Ni, Cr, Fe, Pb, Zn, and Cu). The biology of the sediments in Kuwait Bay is significantly shaped by these organic chemicals and trace elements.

Based on the results of enrichment factors, the bottom sediments of Kuwait Bay have minimal enrichment with metals such as Cu, Co, Cr, Ni, and V., Pb and Bi (EF = <2), while minimal enrichment to moderate enrichment in sediments by Cd and Pb (EF = 2-5).

The elements with the highest concentrations in this context were chromium (Cr) and vanadium (V). High amounts of vanadium are thought to be caused by seepage from power plants and oil slicks from the northwest region of the Gulf.

Increasing industrial and developmental activity are probably the source of chromium. Major pollution consequences are caused by land usage and human activities.

Table 2. Heavy metals content in sediment of the Kuwait Bay (mg/kg).

Sample #	Cu	Cd	Co	Cr	Ni	Pb	V	Zn
1	3.61	0.42	0	59.9	23	29.9	65	39.3
2	3.6	0.42	0	62.7	26.9	29.9	68.4	38.2
3	17.3	0.32	1.9	70.6	32.2	24.5	74.2	43.8
4	4.51	0.33	0.10	60.6	27.1	22.3	66.9	41.7
5	9.47	0.27	2.30	64.5	28.8	20.9	66.6	38.8
6	15.1	0.3	0	55.7	21.7	22.8	62.3	33.5
7	6.04	0.38	0.50	57.2	26.4	24.2	62.8	40.1
8	21.3	0.42	0	60.5	26.6	24.3	67.5	47
9	15	0.36	1.10	60.6	27.4	25.1	66.7	54.5
10	14.8	0.33	0	54	19.6	25.2	63.5	50.4
11	19.8	0.36	0	55.2	22.3	27.2	63.3	32.6
12	12.1	0.29	0	54.3	20.6	23.8	59.3	45.9
13	20.75	0.37	0.20	52.7	22.6	33	59.1	68.2
14	17.95	0.19	5.50	55.8	30.8	0	57.2	42.6
15	18.61	0.39	1.20	60.5	28.2	28.5	68.5	62
16	20.22	0.4	0	61	26.2	28.5	68.3	36.2
17	16.95	0	0.2	12.4	3.7	0	15.8	11.2
18	20.75	0.32	0	53.9	21.1	22.4	59.6	31.2
19	17.95	0.19	4.9	51.3	26.7	0	53.2	25.2
Minimum	**3.6**	**0**	**0**	**12.4**	**3.7**	**0**	**15.8**	**11.2**
Maximum	**21.3**	**0.42**	**5.5**	**70.6**	**32.2**	**33**	**74.2**	**68.2**
STDEV	**6.14**	**0.10**	**1.65**	**11.54**	**6.09**	**10.13**	**12.09**	**12.74**
Average	**13.94**	**0.29**	**1.13**	**52.63**	**22.90**	**20.71**	**57.74**	**39.75**
Average concentration in crust	**55**	**0.2**	**25**	**100**	**75**	**12.5**	**135**	**70**
I-geo index	**-2.5**	**-0.0037**	**-5.04**	**-1.51**	**-2.19**	**0.14**	**-1.81**	**-1.40**
Average Enrichment Factors (EF)	**0.26**	**1.59**	**0.037**	**0.55**	**0.32**	**1.73**	**0.45**	**0.58**

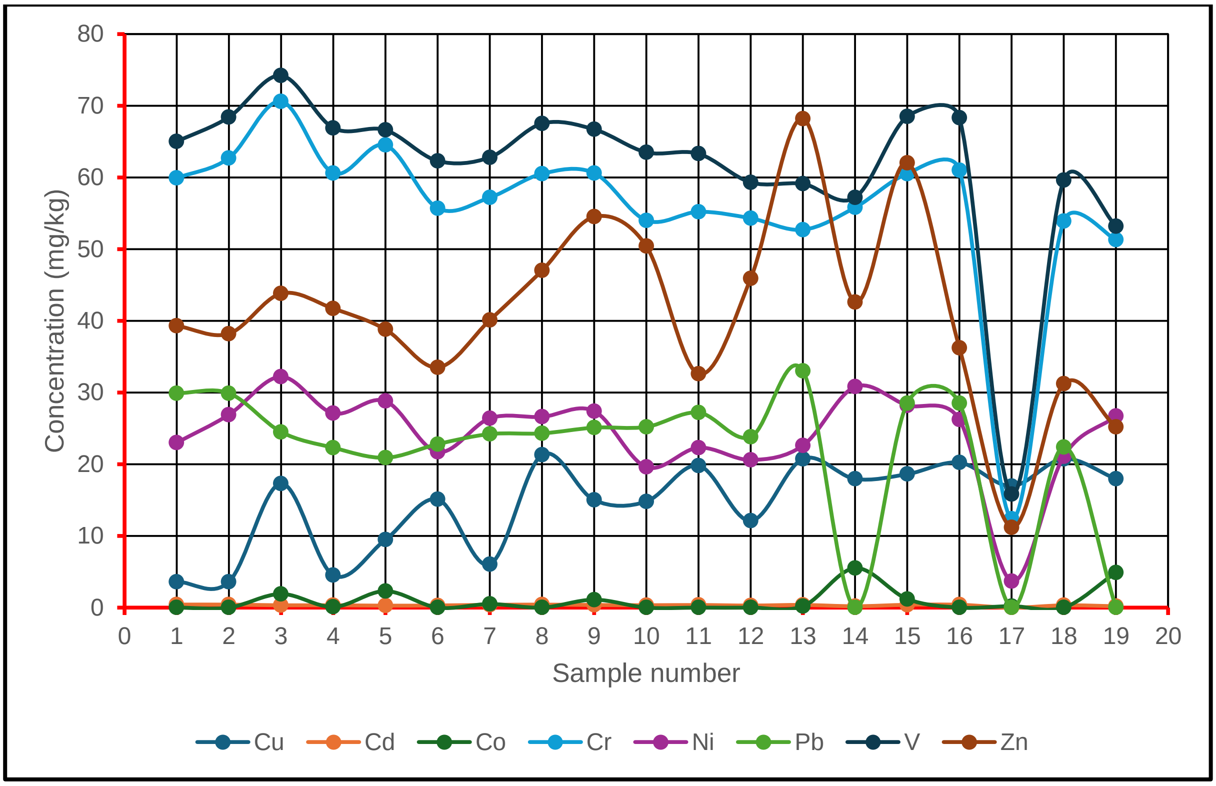


Fig. 8. The distribution of heavy metals concentration (mg/kg) in the bottom samples, Kuwait Bay.

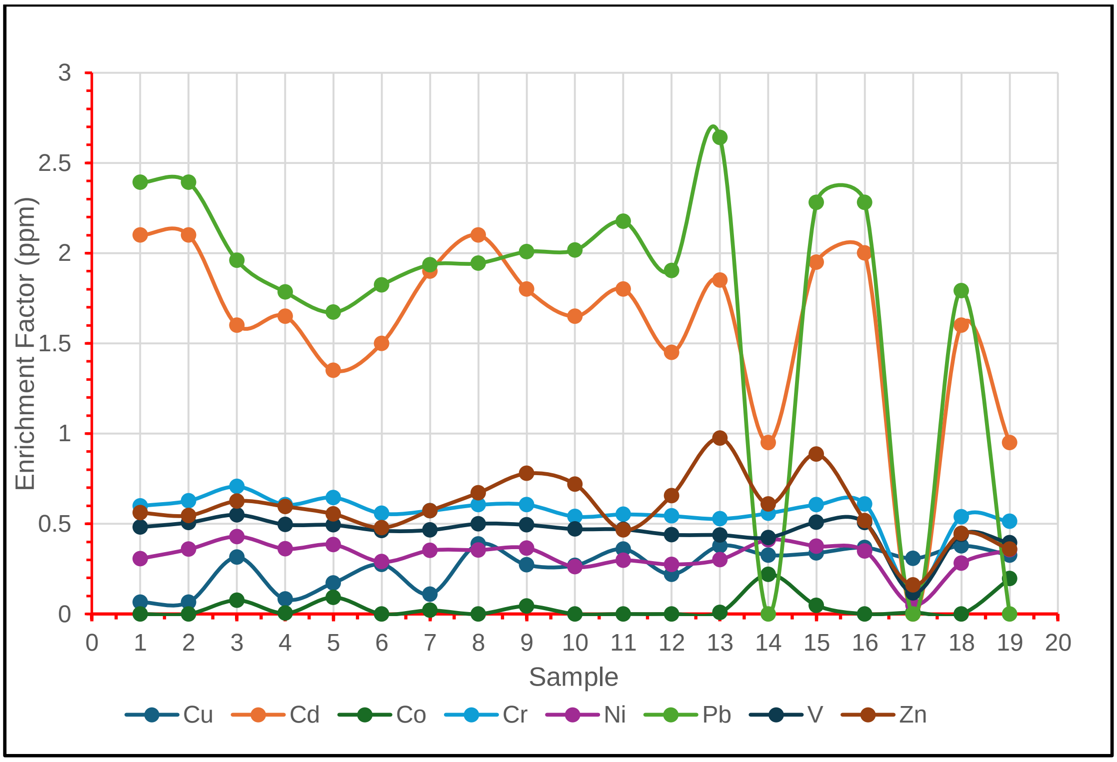


Fig. 9. Enrichment factors of measured metals in sediment samples.

Table 3. Results of pH, organic carbon, nitrogen, phosphorus, and C/N ratio.

Sample No.	pH	Organic Carbon (ppm)	Nitrogen ppm	Phosphorus (ppm)	C/N ratio
1	8.82	1800	280	250	6.428
2	8.68	2400	280	250	8.571
3	8.70	2900	420	300	3.320
4	8.75	2900	420	340	3.320
5	8.64	3000	420	340	7.142
6	8.55	3600	420	300	8.571
7	8.49	3600	420	340	9.047
8	8.36	4100	420	300	8.571
9	8.28	4100	560	380	9.761
10	8.05	5700	840	430	9.464
11	7.83	5700	840	430	10.178
12	8.31	6800	700	430	8.095
13	7.98	6900	840	380	9.857
14	8.04	7100	840	340	8.452
15	8.12	7200	700	300	8.571
16	7.72	6000	700	380	8.571
17	8.27	5300	560	430	8.142
18	7.85	5100	560	470	7.571
19	7.43	4100	420	510	9.107

High quantities of iron found in sediment samples have the potential to significantly impact the dynamics of sedimentation (O'Brien et al., 2012).

Fonseca et al., (2009, 2011 & 2017) and Beg (2011&2025), detected higher values of these metallic elements in the sediments in similar systems to the Kuwait Bay but under a Mediterranean climate. They attributed these high levels to: (1) the increasing annual rates of temperatures and precipitation, which subsequently increasing the weathering rate rock and soil and finally leaching of metallic element from the basin to be deposited in marine sediments; (2) the Fe-oxides enrichment of latosols, which reducing trace elements from the environment; and (3) the predominance of kaolinite clay mineral in sediments. Despite having a lower cationic exchange capacity, kaolinite is a clay mineral that strongly adsorbs metallic elements through its siliceous tetrahedral surfaces (*Meunier, Alian, 2005).*

Downstream, some heavy metals from weathered rocks and soils are mobilized and dispersed. They can also often be immobilized by adsorption onto mineral and organic particles when they leach into the reservoirs as suspended load or are adsorbed and concentrated by lower trophic levels of algae or other organisms.

Sites with a higher heavy mineral composition and a lower volume of bay sediment had higher Mn concentrations. Additionally, compounds containing cations of divalent metals like Cu, Zn, Mn, Sr, and Pb are frequently found in carbonate rocks. Coarser quartz particles are associated with finer but heavier particles related to heavy minerals, while finer light mineral fractions like quartz, feldspar, and muscovite mica are typically washed away.

The comparison concentration of Cd, Cr, Cu, Ni, Pb, and Zn with Sediment Quality Guidelines (SQGs) of Mac-Donald et al (1966), the mean concentrations of elements Cu, Pb, and Zn were lower than the threshold effect level (TEL) of SQGs values except for Cr and Ni. The concentration of Cr and Ni were higher than threshold effect concentration (TEL: Cr=52.3 ppm & Ni= 15.9 ppm) value of SQGs values which are 52.63ppm 22.9ppm, respectively. On the other hand, all the heavy metals concentrations are lower than the probable effect level (PEL) of SQGs.

The nitrogen and organic carbon have a strong positive correlation (r = +0.90), indicating that the fine sediments that have deposited are nitrogenous organic matter. Because of their reduced permeability to tidal water flushing, fine sediments hold reactive iron more effectively, according to the good positive correlation linear relationship between Fe and Al (r= + 0.78) (Figure 10). Lead has a weak positive correlation with nickel(r=0.36), and the copper has a weak negative correlation with lead (r= -0.18) (Figure 11).

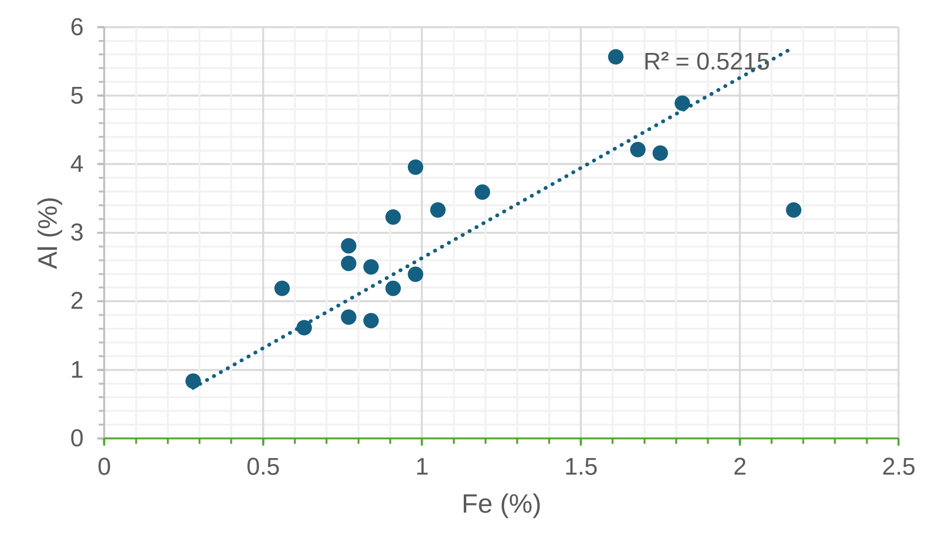


Fig. 10. Plot of Fe% against Al % (r= + 0.78).

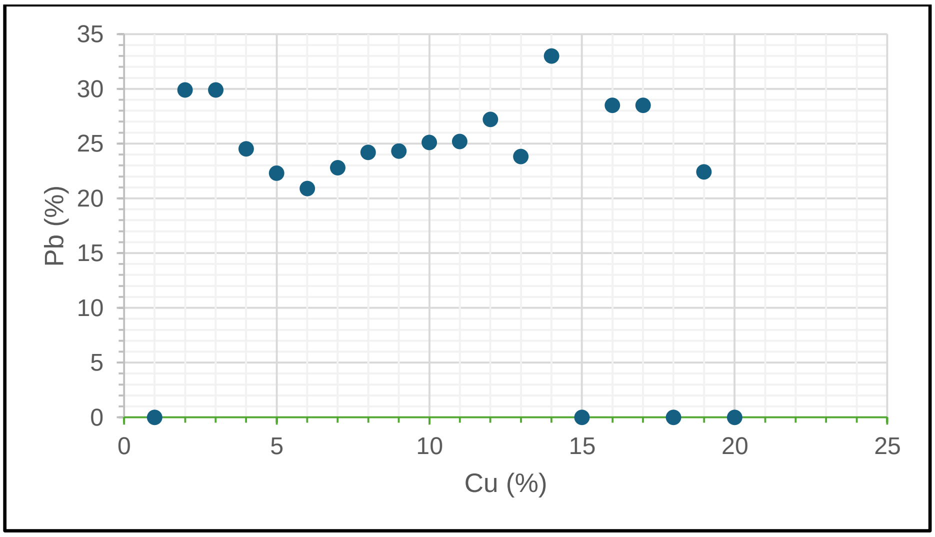


Fig. 11. Plot of Cu% against Pb% (r = -0.18).

5. Conclusions

The current study aims to measure the contamination level in the bottom sediments at the Kuwait Bay, northwest of the Arabian Gulf to evaluate its environmental impact on marine life. The ranges of the metal enrichment in the lake bottom sediments are as follows: V > Cr > Zn > Ni > Pb > Cu > Co.> Cd. It can be concluded that bottom sediments of Kuwait Bay have minimal enrichment with metals such as Cu, Co, Cr, Ni, and V, Pb and Bi while minimal enrichment to moderate enrichment in sediments by Cd and Pb. Comparison with Sediment Quality Guidelines (SQGs) reveals that the mean concentrations of elements Cu, Pb, and Zn were lower than the threshold effect level (TEL) of SQGs values except for Cr and Ni. The concentration of Cr and Ni. were higher than threshold effect concentration (TEL) value of SQGs values. On the other hand, all the heavy metals concentrations are lower than the probable effect level (PEL) of SQGs.

Frequent releases of fuel oil, crude oil, and land-based wastewaters into the Gulf appear to be the main cause of the pollution of Kuwait's bay sediments. Also, the degree of contamination varies with the distance from the sources. Chemical influent from Shatt Al-Arab and direct influxes of untreated sewage are other causes of contamination.

Along with other hydrodynamic factors (currents, tides, and waves), the distribution of illite (or other clay minerals in general) reflects the distribution of salinity. The sediment budget of the bay is provided by the erosion of the surrounding region.

The most prevalent clay mineral is illite. There are a number of ways that illite can form, including precipitation from solution, overgrowth on smectite-illite crystallites, or pseudomorphs that replace micas.

Although nickel concentrations are higher in these areas as well, they are more frequently found in coarser sediments as opposed to fines.

The low degree of metal desorption in estuary circumstances indicates a higher concentration of lead in sediments. According to analytical studies, turbulent circumstances at the estuary's mouth result in a very little amount of fine sediments.

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