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**Research Article**

# Spatial Distribution, Seasonal (Summer and Winter Seasons), and Pollution Assessment of Heavy Metals in Surface Sediments from Aden Coasts, Gulf of Aden, Yemen

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**Abstract** Surface sediments from nine stations within Aden coasts, Gulf of Aden, Yemen, were sampled for seasonal (winter and summer seasons of 2015) and spatial metal contamination analysis variations and background value, Sediment Quality Guidelines, Toxicity guidelines for adverse biological effects, Enrichment factor, Quantification of contamination index, Contamination factor, Degree of contamination, and Pollution load index, was used to quantitatively assess the influences of heavy metal pollution. Heavy metals were analyzed in duplicate using the atomic absorption spectrophotometer. From the samples analyzed the following metal concentrations (range) were obtained (in µg/g): Fe (1332-3663), Mn (76.9-394.6), Zn (32.2-91.6), Pb (13.6-46.0), Ni (4.2-30.3), Cr (12.6-26.6), Co (6.7- 26.4), Cu (3.3-19.83), and Cd (0.60-2.92) in summer; Fe (1061- 3604), Mn (47.8-67.0), Zn (32.6-97.2), Pb (15.2-46.9), Ni (3.9-29.7), Cr (22.2-40.9), Co (9.7-0.7), Cu (8.2-55.3), and Cd (0.8-2.8) in winter. The concentration of Cd in the study area for both seasons was found to exceed the average continental shale, while the concentration of Pb was found to be higher than the average shale in most of the locations. However, most of the concentrations of Co, Zn and Cu were still below the average shale, while metals of Fe, Cr, Mn, Ni were lower than the average continental shale in the all sites. According to SQGs classification, the range value of the metals in Aden coast sediments were non-polluted to medium polluted. Comparing the sediment of the present study with classification system from Hong Kong environmental Protection Department (EPD), the range value of the Cd were slightly contaminated, moderately, and seriously contaminated, while the range value for Cu were moderately contaminated in most of the sites. Pb, Ni values were slightly to moderately contaminated, and Zn concentration showed to be classified as moderately contaminations to uncontaminated. The concentration of Cd were exceeded TEL and ERL values in the most stations for seasons. However, most of the concentrations of Pb, Cu and Ni were still below the TEL and ERL values, while Cr and Zn concentrations were below the TEL value represent concentrations, which are not expected to cause any adverse biological effects. All of studied samples showed valuable anthropogenic sources of all studied metals, except Fe and Cu in sediment is originated predominantly from lithogenous material. Overall average quantification of contamination of metals followed the order Cd>Pb>Co>Zn> Mn>Cr>Cu>Ni>Fe for both seasons. The *Dc* values obtained indicated that the sediments were moderately polluted, except at sites 2, 4, 9 were low degree of contamination for both seasons. The high values of Ni, Cr, Zn, and Mn in Fuqum and Sira island, (Cd and Pb) in al-Ghadir and al-Khaisa may be due to pollutants from untreated waste, marine activities, tourism activities and land based activities from the Crater, Fuqum, little Aden and al-Khaisa cities. A relative increase of metals (Pb, Zn, Ni, Cu, Cr) was found on the labor island probably due to the used the store old, damaged ships, boats, main port activities, transportation, industrial and

municipal waste water. Based on this research, land based activities; shipping activity and the sewage disposal from vessels and residential area (e.g. Crater, little Aden, labor island, al-Khaisa, and Fuqum cities) are the main source of metal pollution in the Aden coasts, Gulf of Aden, Yemen.

**Keywords** Heavy metals; seasonal and spatial variations; pollution assessment; Aden coasts

## 1. Introduction

Sediments are important carriers of heavy metals in the hydrological cycle and because metals are partitioned with the surrounding waters, they reflect the quality of an aquatic system. Heavy metals are one of the most serious pollutants in marine environment; it is mainly due to their persistence and accumulation in organisms [1]. Heavy metals are introduced to the aquatic environment and accumulate in sediments by several pathways via natural and anthropogenic processes [2]. Many researchers have studied the heavy metals in the coast Aden sediments; (Available studies) as Total metals [3-12], Leachable metals [5,9], Bioaccumulation [3,13-14], Bioavailability [3,9,15], Chemical Speciation [7], Heavy metals availability under aerobic and an aerobic conditions [9,16], Geochemical forms of heavy metals [8], Fractionation of trace metals [17], Toxic metals pollution in water, sediment and fish [18], Geochemistry and risk assessment [11], Potential ecological risk assessment [19]. However, no information is available about spatial and seasonal distribution of heavy metal concentration and its pollution assessment in the surface sediments along Aden coasts, Gulf of Aden, Yemen.

In view of that, the present study was designed to understand the seasonal (summer and winter seasons) and spatial distribution pattern of heavy metals (Cd, Pb, Cr, Co, Ni, Cu, Zn, Mn, and Fe) in sediments and also to evaluate the pollution with international standards, Toxicity guidelines for adverse biological effects, Enrichment factor (*EF*), Quantification of contamination index (*QoC*), Contamination Factor (*CF*), Degree of contamination (*Dc*), and Pollution Load Index (*PLI*).

## 2. Materials and Methods

### 2.1. Study area

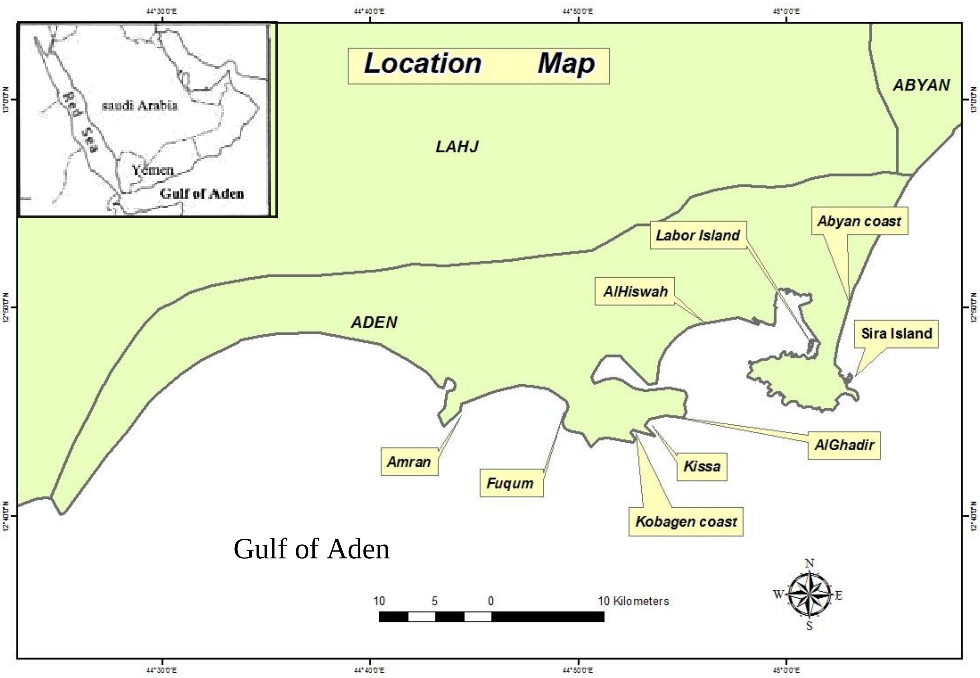



***Figure 1:*** *Study Area and Sampling Sites*

Aden city is located at the southern part of Yemeni coast at Gulf of Aden at the coordination 12° 28' - 12° 57' N and 44° 27' - 45° 07' E. It is located at the south west tip of Yemen and the Arab peninsula. Mid-way between Europe and Far East, Aden lies on major world trading route through the Suez canal. It is one of the largest natural harbors in the world with an area of about 70 km$^2$ of sheltered water surrounded by Jebel Shamsan, khoremakser, and the shore which extends to the hills of Little Aden. Aden contained a series of communities stretching around a well protected bay; these include Crater, Ma'alla, Tawahi, Khormaksar, Shikh-Othman, Al-Mansura, Dar Saad, and Little Aden. Most of the inland and southwest areas of Aden are sparsely occupied. The airport is located in khormaksar, the harbor dominates ma'alla and Tawahi, Al-Hoswah Power station and industrial zone in Madinat Al-Shaab and the oil refinery and oil harbor are in Little Aden [9].

### 2.2. Sampling and sample treatment

Sediment samples were collected seasonally (Summer and Winter, 2015 ), from Nine location along the coastal area of Aden (Figure 1 & Table 1). Samples were transferred to plastic bags and placed in a cooler at 4°C, transported to the laboratory. Sediments were dried at 80 °C in the incubator till fixed weight. The dried sediments were filtered using 100 µm mesh and then enclosed in a new polyethylene bag individually for later chemical analysis.

**Table 1:** Sampling Locations Description [9&19]

| Name of Site | Site No. | Latitude | Longitude | Site description |
|---|---|---|---|---|
| Sira island | 1 | 12° 48' 36" N | 45° 01' 06"E | Population pressure, Sewage effluents, fishing activities, tourism activities and the urban activities, transportation |
| Abyan coast | 2 | 12° 50' 24" N | 45°20' 47" E | Sewage effluents, tourism activities and the urban activities, transportation, |
| Labor island | 3 | 12° 48' 36" N | 45°10' 60" E | Industrial and municipal waste water, used the store old, damaged ships and boats, transportation. |
| al-Hiswah | 4 | 12° 49' 27" N | 44°55' 59" E | Power and desalination plants, runoff, oil spill from the oil pipes, transportation. |
| al-Khissaa | 5 | 12° 44' 45" N | 44°54' 26" E | Sewage effluents, fishing activities, tourism activities and the urban activities |
| al-Ghadir | 6 | 12° 44'16" N | 44°53'16" E | Industrial facilities (near from oil refinery), fishing activities, tourism activities and the urban activities of the coastal cities. |
| Kobagen | 7 | 12° 43' 59" N | 44°52'29" E | Untapped nature, Low Tourism activities. |
| Fuqum | 8 | 12°45' 40" N | 44°49'36" E | Sewage effluents, fishing activities, tourism activities and the urban activities. |
| Amran | 9 | 12° 45' 52" N | 44°44'52"E | Sewage effluents, fishing activities, tourism activities and the urban activities. |

### 2.3. Metal Extraction and Analysis

The sample (0.5g) is digested with a mixture of $HNO_3$, HF and $HClO_4$ (3:2:1) at 80°C. The final solution was diluted to 25 ml with double deionized distilled water [20]. The resulting solution was then stored in polypropylene containers. The final concentrations of metal Fe, Mn, Cu, Zn, Cr, Co, Ni, Pb and Cd in the sediment were determined by aspirating the solution to a standard by atomic absorption spectrophotometer (Vario 6), and the metal contents in the sediments were expressed as µg/g.

### 2.4. Quality Assurance (QA) and Quality Control (QC)

To remove any contamination, all glassware and plastic vessels were washed with diluted nitric acid solution and deionized water and dried. All reagents used were of analytical grade (Merck), a replicate analysis for samples showed a good accuracy. Blanks were treated identically, using the same reagents for testing the precision. In order to check for the quality of the method applied for the analysis of heavy metals, the accuracy of the analytical method was estimated by analyzing sediment standard reference material (IAEA-405) [20]. The recovery of the selected metals ranged from 91 to 108% and the measurements of precision was under 10% RSD.

### 2.5. Assessment Methodology of Sediments Contamination

#### 2.5.1. Sediment Quality Guidelines (SQGs)

To evaluate the level of contamination, sediments were categorized into three classes,: non-polluted, moderately polluted and heavily polluted, based on the SQG of US EPA [21]. Another classification system is the Hong

Kong environmental Protection Department Classification system [22]. In this system 4 classes are used to classify the sediment quality. The first class showed to be classified as uncontaminated sediment (Class A). Whereas, the second class represented (Class B) slightly contaminated sediment. The third and the fourth class were considered as moderately and seriously contaminated (Class C & Class D), respectively, (Table 2).

**2.5.2. Toxicity Guidelines of Heavy Metals**

Incidence of adverse biological effects within range of chemical concentrations in marine and estuarine sediments by Long et al., [23], (Table 2). The chemical concentrations corresponding to the $10^{th}$ and $50^{th}$ percentiles of adverse biological effects were called the effects-range low (ERL) and ERM guidelines, respectively. Another sediment quality guideline which is most widely used to assess the ecotoxicology of sediments is the threshold effects level [TEL] and probable effects level [PEL]. Where ERL and TEL are the concentrations below the adverse effects are expected to occur only rarely, whereas, ERM and PEL represented chemical concentration above the adverse effects are likely to occur.

**2.5.3. Enrichment Factor *(EF)***

Enrichment factor is used to assess the degree of anthropogenic influence on element load in the sediments [24], and also to differentiate between elements originating from the natural or anthropogenic activities [25]. According to Ergin *et al.*, [26] the metal enrichment factor (*EF*) defined in this study as the concentration ration of metal to iron in the sample compared to the ratio in the natural background, average shale standards of metals described by Turekian and Wedepohl [27] were taken as geochemical reference values in the present study (Table 3).

**2.5.4. Quantification of Contamination (*QoC*%)**

The quantification of contamination index (*QoC*) mainly quantifies the anthropogenic concentration of a metal employing the concentration of the background metal to represent the lithogenic metal [28]. This is calculated in accordance with Eq. :

$$QoC\ (\%) = (X - Xe/X) \times 100$$

*Xe:* average concentration of the metal in background [28], (Table 3). The values of this index are mainly expressed as percentage, demonstrating the magnitude of lithogenic and anthropogenic impacts [29].

**2.5.5. Contamination Factor *(CF) and* Degree of contamination *(Dc)***

The contamination factor (*CF*) and the degree of contamination (*Dc*) were used to determine the contamination status of study area. The formula and terminology for describing contamination factor *(CF*) and degree of contamination (*Dc*) [30] are shown in Table (3).

**2.5.6. Assessment according to Pollution Load Index *(PLI)***

The pollution load index (PLI) is another simple method to assess the level of pollution in sediments. In this study, *PLI* is determined the method proposed by Tomlinson *et. al.*, [31], (Table 3).

**3. Results and Discussions**

The concentrations of the nine metals that were analyzed (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) in the surface sediments in the nine sites of Aden coast during winter and summer seasons are listed in Figure 2.

The heavy metal contents of Zn, Cd, Mn, Cu, Cr and Pb are lowest during the summer, possibly because the higher water temperature in the summer and Eh is relatively high, so the heavy metals from sediments are easily released into the water or pore water [32]. In addition, aquatic life (aquatic plants, algae, soft coral animal, microbes, etc.) are actively growing and absorbing heavy metals directly from the water and sediment. The reduction of heavy metals in the water also results in the heavy metals in sediments being released into the water. Benthic disturbance causes the transformation of heavy metals from sediments into water.

**3.1. Distribution of Heavy Metals in the Study Area**

**3.1.1. Cadmium (Cd):**

Cadmium concentration varies between samples analyzed, (Figure 2-A). The highest values for Cd are 2.92 and 2.8 µg/g in summer and winter recorded in the al-Khaisa coast, where the lowest values were exhibited during summer and winter (0.6 and 0.8 µg/g, respectively), were observed in Abyan coast. The reasons for the low concentration of cadmium in the coast of Abyan, may be due to the fact that it is an open coast, which is not used by fishermen for their boats. In addition, the sewerage system stopped directly into the coast in 2003 due to the linking of the sewerage network of the coastal city of Khormaksar with the Al-Arish station for sewage treatment. All these reasons made the coast of Abyan less polluted than other coasts.

The result revealed that the Cd concentration in sampling sites during winter was in the order (Table 4): al-Khaisa>al-Ghadir>Amran>Kobagen>Fuqum>Labor island>Sira>al-Hiswah>Abyan coast.

Distribution of Cd concentration in sampling sites during summer was in the order (Table 4):al-Khaisa>al-Ghadir>Kobagen>Fuqum>Labor island>Sira>Amran>al-Hiswah>Abyan coast.

In the present study high values of Cd in al-Khaisa and al-Ghadir could be ascribed to oil refinery, and the transfer of pollutants from shipwrecks through water currents due to the proximity of the international shipping line, as well as the pollution resulting from the various activities located in the surrounding area of the oil port, tourist, commercial port, fishing activities, tourism activities and the urban activities of the coastal cities (al-Buriqa and al-Khaisa). Although the Amran and Fuqum area off the harbor, water from a fishery refrigerator and some sewage outflow flux into sea. It is assumed that the presence of the area near the strait Bab Al-Mandab, where the water coming from both the Red Sea and the Indian Ocean mixes, especially during the seasonal monsoons, is mainly responsible for elevated tissue Cd concentrations in the molluscs [3]. The sources of Cd release to the surrounding environment come from industrial activities and burning fossil fuels. The enrichment of Cd and human exposures are primarily the result of fossil fuel combustion, phosphate fertilizers, natural sources, iron and steel production, cement production, nonferrous metals production and municipal solid waste incineration [33].

**3.1.2. Lead (Pb):**

The highest concentrations of Pb were found in the al-Ghadir of 46.9 and 46.0 µg/g for winter and summer respectively, while the lowest values were recorded at Fuqum (15.2 µg/g) and al-Hiswah (13.6 µg/g) of winter and summer, respectively, (Figure 2-B). The result revealed that the Pb concentration in sampling sites was in the order (Table 4): al-Ghadir>Labor island>al-Khaisa>Sira>Kobagen>Amran>Abyan coast>al-Hiswah>Fuqum (for winter); al-Ghadir>Labor island>al-Khaisa>Fuqum> Kobagen> Sira>Amran>Abyan coast>al-Hiswah (for summer).

Figure (2-B) show that the highest concentration of lead was recorded in al-Ghadir and Labor island, we attribute the reason for the rise of lead in these two coasts: al-Ghadir coast is located near Aden oil refinery and the Labor island coast is located along the highway of vehicles (Bridge line). It is noted that lead concentrations in the study sites decreased in the summer, this is because of the fact that most of the lead in the coast of Aden's source is atmospheric deposition. where summer in Aden is characterized by strong winds that may carry lead compounds to other places far from the coasts, as well as the pollution resulting from the various activities located in the surrounding area (Aden port and oil port), and oil spills from the oil pipes [9]. Pb showed strong affinity for exchangeable and carbonate fractions in the sampling sites, reached to more than 40 % of the total Pb at Sira zone. A significant amount of Pb was presented in the loosely bound fraction *i.e.* exchangeable; this indicates that lead is from anthropogenic source. Saleh [9] showed that the relatively high levels of Pb, Cr, Zn and Co in the sediments of Aden coast are due to the discharges of untreated wastewater of desalination plant, electrical power station, refinery plant, textile industry, oil spills from the oil pipes, as well as domestic wastewater. Attributed high Pb concentrations to several sources, such as boat exhaust systems, spillage of oil, and other petroleum from mechanized boats employed for fishing, and the discharge of sewage effluents into water, in which all of these sources exist in the studied areas [34-35].

**3.1.3. Cobalt (Co):**

The results in Figure (2-C) show that cobalt concentrations in Sira and Amran sites in the winter are higher than those found in the summer for the same coastal. While the other seven coasts showed that concentrations in the summer were higher than those found in the winter. The reason for the summer weather in Aden zone is the rise in temperature and wind intensity. The maximum value of 20.7µg/g was observed in Sira island and the minimum 9.7µg/g in Abyan coast during winter season, while highest and lowest concentration in the summer (26.4 and 6.7µg/g) was observed in al-Hiswah and Amran respectively. This may be because of the presence of the hydroelectric station and the industrial zone of the near al-Hiswah site.

The result revealed that the Co concentration in sampling sites during winter was in the order (Table 4): Sira>al-Khaisa>Kobagen>Fuqum>Labor island >al-Ghadir>al-Hiswah>Amran>Abyan coast.

Distribution of Co concentration in sampling sites during summer was in the order (Table 4): al-Hiswah>Fuqum>al-Khaisa>Labor island=al-Ghadir>Kobagen>Sira> Abyan coast>Amran.

**3.1.4. Nickel (Ni):**

The highest concentrations of nickel for both seasons (30.3 µg/g in summer and 29.7µg/g in winter), were found in the Fuqum coast, while the lowest value was 3.9 µg/g in the Al-Khaisa for both seasons (Figure 2-D).

The result revealed that the Ni concentration in sampling sites during winter was in the order (Table 4): Fuqum>Sira>Labor island>al-Hiswah>al-Ghadir>Abyan coast>Kobagen>Amran>al-Khaisa.

Distribution of Ni concentration in sampling sites during summer was in the order (Table 4):Fuqum>Labor island>al-Ghadir>Sira>al-Hiswah>Abyan coast>Amran> Kobagen> al-Khaisa.

Saleh [9] found 39-72% in coastal Aden sediments, revealed that the non-residual fractions (anthropogenically sources). Non-natural source of Ni in environment from nickel-cadmium batteries, metals electroplating, petroleum industry, ceramics, and as an industrial catalyst, fats hydrogenation and fuel gases [36]. Volcanic activity is the largest natural source of atmospheric nickel, followed by emissions from wind-borne soil particles, forest fires, sea salt spray and biogenic processes [37].

**3.1.5. Cupper (Cu):**

The results showed in Figure (2-E) that the highest value of copper (55.39µg/g) was recorded at Al-Khaisa in the winter, and the lowest value was 3.39 µg/g found in the Amran coast during summer season, when we observed for the winter season, the concentration of copper for all sites was convergent (8.9-18.19µg/g), except for Al-Khaisa site (55.39µg/g). This may be because of the discharges of untreated wastewater from Al-Khaisa city directly to the coast. The concentration of copper for the same site (11.19 µg/g) was similar to the other sites, possibly because of the hot weather of Aden, which increases the use of water and this may reduce the concentration of some elements or push it to the lower layers, where the study was interested only with the surface sediment.

From the result, copper concentration followed the trend (Table 4):

al-Khaisa>Sira>al-Ghadir>Labor island>al-Hiswah>Fuqum>Abyan>Amran> Kobagen (in winter); Labor island>al-Hiswah>al-Ghadir>Sira>Fuqum>al-Khaisa>Abyan>Kobagen> Amran (in summer)

**3.1.6. Chromium (Cr):**

Figure (2-F) show the results obtained for chromium concentrations in sediments samples of the Aden coast, where the results showed that the maximum values of Cr (40.9 and 26.6 µg/g) were observed during winter and summer seasons at Sira and Fuqum respectively, while the lowest levels were recorded in al-Khaisa and Amran (22.2 and 12.6µg/g) during of winter and summer respectively. The results showed a similarity or convergence in the distribution of chromium in all studied sites for both seasons, ranging between (20.2-29.95µg/g), except for Sira and Amran in the winter and summer (40.9 and 12.6µg/g), respectively.

The order of Cr concentration in sampling sites from large to small value was Sira>Kobagen>al-Hiswah>Amran>Fuqum≥Abyan coast>al-Ghadir>Labor island>al-Khaisa (in winter); Fuqum>Labor island>Kobagen>Sira>al-Hiswah>Abyan coast>al-Khaisa>al-Ghadir>Amran (in summer), (Table 4).

**3.1.7. Zinc (Zn):**

The highest value of Zn 91.9 and 97.2 µg/g were recorded in Sira island and Fuqum for winter and summer respectively, where the lowest values were exhibited during summer and winter (32.3 and 32.6 µg/g, respectively), were observed in Fuqum and Abyan coast, respectively, (Figure 2-G) .

From the result, copper concentration followed the trend (Table 4):

Sira>Labor island=al-Khaisa>al-Hiswah>Kobagen>al-Ghadir>Abyan coast>Amran> Fuqum (in winter); Fuqum>Labor island>Sira>Amran>Kobagen>al-Ghadir>al-Hiswah>al-Khaisa>Abyan coast (in summer)

**3.1.8. Manganese (Mn):**

The results of Manganese concentrations in the sediments of the Aden coast (Study Area) as the Figure (2-H) shows that the highest concentrations of manganese were found of the Sira island and Faqum (394.6 µg/g in summer and 367µg/g in winter), respectively, while the lowest values 47.8 and 76.9 µg/g were recorded in the Amran and Al-Khaisa coasts during summer and winter, respectively. The result revealed that the Mn concentration in sampling sites was in the order (Table 4):

Sira>Kobagen>al-Hiswah>Labor island>Fuqum>Abyan coast>al-Ghadir>Amran>al-Khaisa (in winter); Fuqum>al-Hiswah>Sira>Labor island>Kobagen>Abyan coast>al-Ghadir>al-Khaisa>Amran (in summer).

**3.1.9. Iron (Fe):**

The highest concentration of iron 3663µg/g was recorded at Abyan coast for both seasons, while the lowest concentration was found in Kobigan site for seasons (1332µg/g in summer and 1061µg/g in winter), (Figure 2-I). The increase in Fe concentration may be due to previous malpractices, where the construction waste and iron scrap were deposited in Abyan coast.

The result revealed that the Fe concentration in sampling sites during winter was in the order (Table 4): Abyan coast>Sira >Labor island>al-Khaisa>al-Ghadir>al-Hiswah>Fuqum>Amran>Kobagen.

Distribution of Fe concentration in sampling sites during summer was in the order (Table 4): Abyan coast>Fuqum>Labor island>al-Khaisa>Sira>al-Ghadir>al-Hiswah>Amran>Kobagen.

Generally, The high values of some heavy metals (Ni, Cr, Zn, and Mn) in Fuqum and Sira island, (Cd and Pb) in al-Ghadir and al-Khaisa may be due to pollutants from untreated waste, marine activities (fishing boat waste, paints, fishing activities), tourism activities and land based activities from the Crater, Fuqum, little Aden and al-Khaisa cities. Saleh [9] attributed the increase of metal concentrations due to the presence of untreated waste and the pollution resulting from the movement of ships and tankers passing through Bab al-Mandab. Although the Fuqum area off the harbor, water from a fishery refrigerator and some sewage outflow flux into sea [3&9]. It is assumed that the presence of the area near the strait Bab Al-Mandab, where the water coming from both the Red Sea and the Indian Ocean mixes, especially during the seasonal monsoons, is mainly responsible for elevated tissue Cd concentrations in the molluscs [3].

In the Sira coast, a high concentration of most studied metals, especially in the winter, may be due to a decrease in heat in the sea water, which leads to the survival of the pollutants associated with the sediments (adsorbed on the surface of the sediments). However, the Sira location is characterized by a semi-closed, multi-activity (fishing activities, population pressure, busy traffic on the coast from the city of Crater and other cities and tourist activity as it has different restaurants and its unique historical e.g. Sira Fortress and natural location).

A relative increase of metals (Pb, Zn, Ni, Cu, Cr ) was found on the labor island probably due to the used the store old, damaged ships, boats, main port activities, transportation, industrial and municipal waste water.

The results of the study show the difference in the distribution of elements between seasons. Most of the concentrations of heavy metals in the winter more than the summer, may be due to differences in temperature, in winter the temperature is lower in the water column and this affects the transfer of metals from water to sediments, while in the case of high temperature increases the release of metals from the surface sediments to the water column, as well as the effects of pH and redox potential conditions with time on the mobilization of some heavy metals, effect of physicochemical characteristics of sediments on the heavy metal forms [9]. Therefore, the potential source and seasonal variation of the heavy metal concentration is the result of the geomorphology of the coast which, associated by reversal winds with northeast and southwest monsoon, change the oceanographic phenomena (tide, waves, and monsoonal circulation), as well as different sources of pollution and human activities.

**3.2. Comparison with the background value**

The average shale background concentration of global sediments [27] is selected as the reference baselines in this study, which are shown in Table 2 and Figures 2. The concentration of cadmium in the study area for both seasons was found to exceed the average continental shale, while the concentration of lead was found to be higher than the average continental shale in all locations, except for the stations of Abyan Coast, al-Hiswah, and Fuqum in the winter and the coast of Abyan, al-Hiswah and Amran in the summer. Cobalt values found less than the average continental shale, except for Abyan coast, al-Hiswah, in the summer and Sira island in winter, while copper concentration of was found to be lower than the average continental shale, except for al-Khissa site, while metals of Fe, Cr, Mn, Ni and Zn were lower than the average continental shale , except Zn at Sira in winter.

The background values of different metals were defined according to international standard: Cd, Pb, and Cr [38-40], Zn and Cu [9,41]; Fe, Mn and Ni [40-41], and Co [9,43], which are shown in Table (2). For Cd, Pb, Co and

Cr the concentrations were exceeded the background values in all sites for both seasons, except Co in site 2 in both seasons, sites 1 and 2 for summer season and Cr in site 9 and Pb in site 4 for summer. The concentrations of Fe and Mn were less than the background value for all sites of the both seasons. For Cu, Ni, and Zn the concentrations were less than the background level in all sites, except coast of al-Khissa for Cu in winter season, Fuqum coast for Ni, Sira island, Labor island (in winter) and al-Ghadir coast (in summer) for Zn. Sira island and al-Hiswah for Co in winter and summer seasons, respectively.

### 3.3. Comparison of current study with previous studies

The comparison between the present concentrations with those reported in the literature concluded that the concentrations observed in the Aden coast were similarity or lower or higher than those recorded in the other studies (Table 5). According to previous studies, the was similar with sediments of Hadramout coast [44] and Red Sea in front of Egypt [45]. The range of most heavy metal value obtained in the present study was higher than those reported for the sediments of Red Sea in front of Yemen [46] and Gulf of Chabahar - Oman Sea [47] and Kanyakumari in India [48] , while was lower than Aden coast, Yemen [5], Gulf of Aden, Yemen [9], Socotra island, Yemen [49], Al-Hodiedah [50], and Red Sea, Egypt [40].

### 3.4. Assessment According to Sediment Quality Guidelines (SQGs)

Numerous sediment quality guidelines are used to protect aquatic biota from the harmful and toxic effects related with sediment bound contaminants [51]. These guidelines evaluate the degree to which the sediment-associated chemical status might adversely affect aquatic organisms and are designed for the interpretation of sediment quality. They are also used to rank and prioritize contaminated areas for further investigation [52]. The National Standard of China (NSC) GB18668-2002 [53], has defined three grades of marine sediment, in which the content of some heavy metals is regarded as parameters used to classify marine sediments quality, (Table 2).

To evaluate the level of contamination, sediments were classified as: non-polluted, moderately polluted and heavily polluted, based on the SQG of US EPA [21], (Table 2 & Figures 2). According to this classification, the range value of the metals in Aden coast sediments were non-polluted and medium polluted. It was observed that the coasts of Sira island and Kobagen, were moderately polluted for Cr in both seasons, al-Hiswah and Amran in winter season, Labor island and Fuqum in summer. The contamination levels of Pb were moderately polluted in the Labor island and al-Ghadir for winter and al-Ghadir for summer. The Ni were moderately polluted in the Fuqum coast in both seasons. The Zn were moderately polluted in the Sira island and Labor island for winter and Fuqum for summer, while Mn value was found to be higher in Sira island, al-Hiswah and al-Ghadir for winter, al-Hiswah and Fuqum for summer. In general, all metals studied have not reached the point of severe pollution (Heavily polluted).

Comparing the sediment of the present study with classification system from Hong Kong environmental Protection Department (EPD) Classification system [22], the range value of the cadmium were slightly contaminated (Class B: 11.1% in winter; 33.3% in summer), moderately (Class C: 11.1% in summer; 33.3% in winter) and seriously contaminated (Class D: 55.6% both seasons), while the range value for Copper were seriously contaminated (at al-Khissa in winter), moderately (at sites 7,9 in winter and site 9 in summer) and moderately contaminated (other sites). Lead values were slightly contaminated (sites 2,4,8 in winter and sites 2,4,9 in summer) and moderately contaminated of other sites. The range value for Nickel were moderately contaminated (sites 8 in winter; 1,3,4,6, and 8 in summer), and slightly contaminated of the other sites. Zinc concentrations showed to be classified as moderately contaminations (Class B: at sites 1,3,5 in winter and site 8 in summer) to uncontaminated (Class A: In other locations), (Table 2 & Figures 2).

### 3.5. Toxicity guidelines of heavy metals for adverse biological effects

Many metals are highly toxic and have chronic effects on living organisms. Elevated concentrations of metals in sediments could cause detrimental effects to benthic organisms as well as other aquatic organisms. Some toxicity guidelines of heavy metals are given in Table (2). Based on the toxicity guidelines, the concentration of Cd were exceeded TEL values in the all stations for seasons, except sites 2 in summer, and Cd values were exceeded ERL values in the all stations for seasons, except sites 2 and 4 in winter, and stations: 1, 2, 4 in summer, were less than the ERL values. Cu values were exceeded TEL values in stations 1 and 5 for winter and station 3 for summer, while station 5 exceeded the ERL for Cu in winter. Stations 3 and 6 exceeded the ERL for Pb in winter. Pb level exceeding TEL for stations 1, 3, 5, 6 in winter and stations 3 and 6 in summer. Ni exceeded the TEL for stations 1, 8 in winter and stations 1, 3, 4, 6, 8 in summer. Cr and Zn concentrations were below the TEL value represent concentrations, which are not expected to cause any adverse biological effects, while during 2004, the concentrations of Pb, Cr, Ni and Zn in the Gulf of Aden sediments were found to be higher than Threshold Effects Level [9].

### 3.6. Enrichment Factor *(EF)*

Enrichment factor (*EF*) is a common method used to study the enrichment degree of metals in sediments and soil. For a better estimation of anthropogenic input of metal in the surface sediments of the Aden coasts, the metal profiles were normalized to Fe. The reason for choosing Fe instead of other elements is its wide distribution in Crust or in the average shale values for metals. In this study, the coefficient of enrichment was determined according to Ergin et al., [26], and natural background values of metals were used described by Turekian and Wedepohl [27], (Table 2). The *EF* values were < 2 indicate that the metal is entirely from crustal materials or natural processes; whereas *EF* values > 2 suggest that the sources are more likely to be anthropogenic [15,24,61]. The enrichment factor (*EF*) of the various in the sediment of Aden coasts are presented in Table (6). Table (6) shows the similarity in the enrichment factor of both seasons, All of studied samples showed valuable anthropogenic additions of all studied metals, except Cu and Fe in sediment is originated predominantly from lithogenous material, and Cr from both lithogenous material and anthropogenic sources, while Saleh [9], using the enrichment factor, found that the Pb, Co, Ni, Zn Cr, Cu, and Mn from anthropogenic sources. For winter season *EF* mean values of metals have the order $EF_{Cd} > EF_{Pb} > EF_{Zn} > EF_{Mn} > EF_{Ni} > EF_{Co} > EF_{Cr} > EF_{Cu} > EF_{Fe}$. *EF* mean values of metals have the order $EF_{Cd} > EF_{Pb} > EF_{Zn} > EF_{Mn} > EF_{Co} > EF_{Ni} > EF_{Cr} > EF_{Cu} > EF_{Fe}$ For summer.

The difference in *EF* values may be due to the difference in the magnitude of input for each metal in the sediment and/or the difference in the removal rate of each metal from the sediments [40]. The results of the present study showed that Aden seashore sediments were highly enriched in Cd and significantly enriched in Lead [19].

### 3.7. Quantification of contamination (*QoC*%)

Quantification of contamination (*QoC*, %) values of metals in the sediments of Aden coasts are given in Table 7. According to the quantification of contamination calculations, Fe, Ni, Cu, Mn, Cu, Cr, Zn, and Co, were derived mainly from natural processes and geogenic sources and were related to the exposure of the Earth's crust material, except for cobalt metal in Sira island for winter season, al-Hiswah, al-Khissa, Fuqum for summer season, and Zn in Sira island for winter were related to anthropogenic sources, while the increased values of Cd, and Pb were ascribed to anthropogenic activities in all sites. Overall average quantification of contamination of metals followed the order Cd > Pb > Co > Zn > Mn > Cr > Cu > Ni > Fe for both seasons. The elevated values identified for Cd, and Pb might be related to human activities including sewage effluents, fishing activities, human refuse, shipping, transportation, fuel smuggling, and industrial wastewater [19].

### 3.8. Contamination Factor *(CF)*

The values obtained from the contamination factor (*CF*) shown in Table 3. In the present study, the values of the contamination factor (*CF*) for Cu, Mn, Zn, Ni, and Cr, they were found to be low contamination in all study areas for both seasons, except Zn were moderate contamination at site 1 for winter season, (Table 8). The cadmium values is indicating very high contamination at sites 5,6,7 and 9 for winter and sites 5,6,7 for summer; considerable contamination in the sites 1, 3, 4, 8 for winter and sites 1,3,8,9 in summer; site 2 for winter and sites 2,4 for summer indicate that it is moderate contamination. The lead metal is indicating moderate contamination in the all sites, except sites 2,4,8 for winter and sites 2,4,9 for summer indicate that it is low contamination. The concentration of cobalt were within the low contamination in the all sites, except sites 4,5,8 for summer and site 1 for winter, were within the moderate contamination. This might be related due to industrial waste from power and desalination plants and run-off from Lahij governorate to al-Hiswah site, which including disposal of liquid effluents and terrestrial runoff, as well as atmospheric deposition [9]. In general, The highest *CF* level was obtained for Cd (range:2.33-9.73), which registered a moderate degree to very high of contamination. The *CF* level was significantly high for Cd and Pb which suggests Cd and Pb high pollution due to anthropogenic activities (sewage effluents, fishing activities, damaged ships and boats, human refuse, shipping, transportation, fuel smuggling, and the industrial facilities) [19]. On the basis of the average *CF* values, the sediments may be considered to be contaminated by the metals investigated in the following order: **Cd> Pb> Co**> Zn> Ni >Cu> Cr> Mn for winter season; **Cd> Pb> Co**> Zn> Cu>Ni ≥ Cr> Mn for summer.

According to the contamination factor and quantification of contamination calculations, Ni, Mn, Cr, Cu, Zn, and Co were derived mainly from natural processes and geogenic sources and were related to the exposure of the Earth's crust material, while the increased values of Cd, and Pb were ascribed to anthropogenic activities. Saleh [9], Using the sequential extraction method has revealed that the non-residual fractions (anthropogenically sources) represent 30-73% for the total extractable fractions for Pb, 30-73% for Pb, 21-70% for Co, 38-71 % for Ni, 52-55% for Fe, 31-49 % for Zn, 9-47 % for Cr, 18-40 % for Mn, and 31-35 % for Cu is due to man-mode sources. The elevated values identified for Cd, and Pb might be related to human activities including sewage effluents, fishing activities, human refuse, shipping, transportation, fuel smuggling, and industrial wastewater [19].

### 3.9. Assessment according to Pollution Load Index *(PLI)*

The results of *PLI* are shown in Figure 3-a. The results of our measurements show that the study area for both seasons are not polluted except at sites 1, and 3 (Sira and Labor island) for winter season were unpolluted to moderately. The *PLI* is increasing according to the following order:

Sira>Labor island>al-Ghadir>al-Khissa>Kobigan>al-Hiswah>Fuqum>Amran>Abyan coast for winter; Fuqum>Labor island>al-Ghadir>Sira>Kobigan>al-Hiswah>al-Khissa>Abyan coast>Amran for summer.

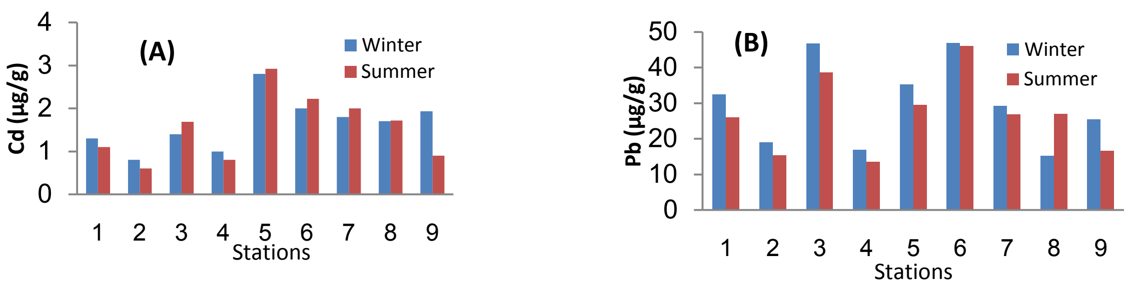
### 3.10. Degree of contamination *(Dc)*

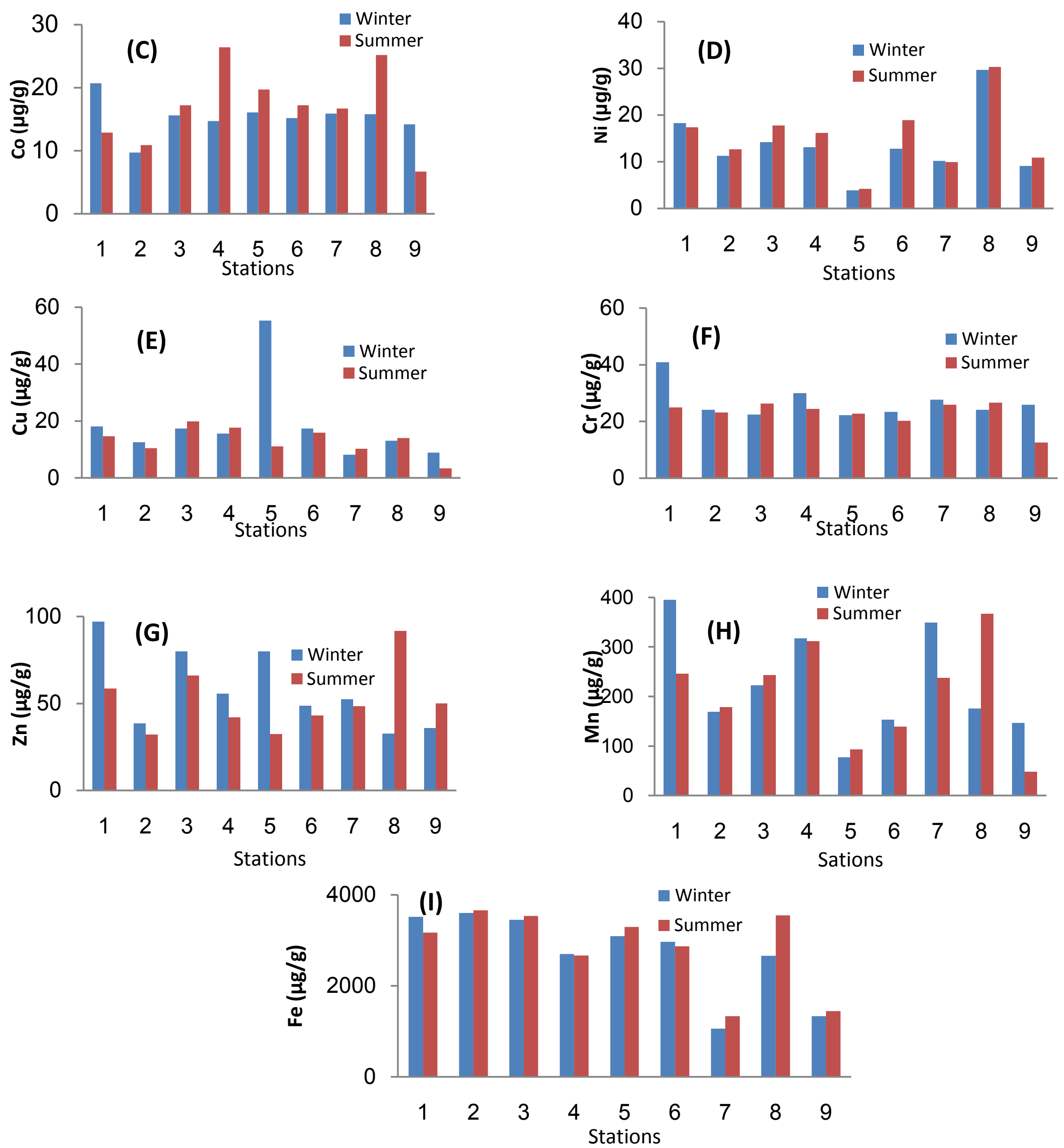
The degree of contamination values of the metals studied and the ranges of *Dc* and their pollution grades and corresponding intensities are given in Figure 3-b. *Dc* values indicate a moderate degree of contamination in all study area, except at sites 2, 4, 9 were low degree of contamination for both seasons. For study area, the degree of contamination of heavy metals represented the decreasing order:

Kobagen>Sira>al-Khissa>al-Ghadir>Fuqum>Amran>Laborisland>al-Hiswah>Abyan coast for winter season; al-Khissa>al-Ghadir>Fuqum>Labor island>Kobagen>Sira island>al-Hiswah >Amran >Abyan coast for summer season.

## 4. Conclusion

The baseline data for spatial distribution and seasonal variation (summer and winter) of heavy metals and their controlling factors found in this study will be useful for pollution monitoring program along the Aden coast, Gulf of Aden, Yemen.






*Figures 2A-2I: Seasonal (Winter and Summer) and Spatial Variability of Heavy Metals Con-centration in Aden coasts, Gulf of Aden*

**Table 2:** Statistical summary of the metal contents in study area (Average, Max., Min., SD) and *Concentrations of metals in shale's and according to various guidelines and comparing with sediment quality guidelines (SQG)*

| Metal | | Cd | Co | Cr | Cu | Fe | Mn | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|
| Average | (winter) | 1.64 | 15.32 | 26.74 | 18.49 | 2708 | 222.7 | 13.62 | 29.70 | 57.83 |
| Maximum | | 2.8 | 20.7 | 40.9 | 55.3 | 3604 | 394.6 | 29.70 | 46.9 | 97.2 |
| Minimum | | 0.8 | 9.7 | 22.2 | 8.2 | 1061 | 76.9 | 3.90 | 15.2 | 32.6 |
| SD | | 0.60 | 2.82 | 5.88 | 14.27 | 923. | 106.9 | 7.19 | 11.87 | 22.71 |
| Average | (summer) | 1.55 | 16.99 | 23.00 | 13.02 | 2835 | 207.0 | 15.37 | 26.60 | 51.57 |
| Maximum | | 2.92 | 26.40 | 26.60 | 19.83 | 3663 | 367.0 | 30.30 | 46.00 | 91.60 |
| Minimum | | 0.60 | 6.70 | 12.60 | 3.30 | 1332 | 47.8 | 4.20 | 13.60 | 32.20 |
| SD | | 0.76 | 6.36 | 4.39 | 4.91 | 882 | 102.5 | 7.31 | 10.75 | 18.65 |
| B value | | 0.38 | 13 | 17 | 20 | 5% | 450 | 20 | 14 | 70 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Average shale | 0.3 | 19 | 90 | 45 | 47200 | 850 | 68 | 20 | 95 |
| Non polluted | - | - | <25 | <25 | <17000 | <300 | <20 | <40 | <90 |
| Moderately polluted | - | - | 25-75 | 25-50 | 17000-25000 | 300-500 | 20-50 | 40-60 | 90-200 |
| Heavily polluted | >6 | - | >75 | >50 | >250000 | >500 | >50 | >60 | >200 |
| Class A | <0.1 | - | <25 | <10 | - | - | <15 | <25 | <70 |
| Class B | 0.1-1.0 | - | 25-50 | 10-41 | - | - | 15-35 | 25-65 | 70-150 |
| Class C | 1-1.5 | - | 50-80 | 55-64 | - | - | 35-40 | 65-75 | 150-200 |
| Class D | >1.5 | - | >80 | >64 | - | - | >40 | >75 | >200 |
| ERL | 1.2 | - | 81 | 34 | - | - | 20.9 | 46.7 | 150 |
| ERM | 9.6 | - | 370 | 270 | - | - | 51.6 | 218 | 410 |
| TEL | 0.68 | - | 52.3 | 18.7 | - | - | 15.5 | 30.2 | 124 |
| AET | - | - | 2600 | 310 | - | - | >140 | 150 | 340 |
| PEL | 4.2 | - | 140 | 108 | - | - | 43 | 112 | 270 |

SD: Standard deviation, TEL: Threshold Effect Level, PEL: Probable Effect Level, ERL: Effects rang low, ERM: Effects range median, AET: Apparent Effects Threshold; B value: Background value: Cd, Pb, and Cr [38][39] [40], Zn and Cu [41] [9] ; Fe, Mn and Ni [42] [40], and Co [9] [43].

**Table 3**: Sediment quality indices and their classification systems

| **Index** | **Equation** | **Classification** | **References** |
|---|---|---|---|
| *EF* | $EF = \frac{(Metal / Fe)_{Sample}}{(Metal / Fe)_{Background}}$ | *EF* values < 2 indicate that the metal is entirely from crustal materials or natural processes<br>*EF*: 2 - 5 (moderate enrichment)<br>*EF*: 5 - 20 (significant enrichment)<br>*EF*: 20 - 40 (very high enrichment)<br>*EF* > 40 (extremely high enrichment) | [26] |
| *QoC%* | $QoC\ (\%) = (X - Xe/X) \times 100$ | *QoC* (%) = 0 (geogenic source)<br>*QoC* (%) > 0 (anthropogenic magnitude) | [28-29] |
| *CF* | $CF = C_a / C_b$ | CF < 1 (low CF)<br>1 ≤ CF < 3 (moderate CF)<br>3 ≤ CF < 6 (considerable CF)<br>CF ≥ 6 (very high CF | [30&54] |
| *Dc* | $Dc == \sum_{i=1}^{8} C_f^i$ | *Dc* < 8 (low Dc)<br>8 ≤ *Dc* < 16 (moderate Dc)<br>16≤ *Dc* < 32 (considerable Dc)<br>*Dc* ≥ 32 (very high Dc) indicating alarming anthropogenic contamination | [30&55] |
| *PLI* | $PLI = \sqrt[n]{Cf1\ X\ Cf2\ X \ldots\ldots X\ Cfn}$ | PLI = 0 (background concentration)<br>0 < *PLI* ≤ 1 (unpolluted)<br>1 < *PLI* ≤ 2 (unpolluted to moderately)<br>2 < *PLI* ≤ 3 (moderately polluted) | [31] |

| | | |
|---|---|---|
| | $3 < PLI \leq 4$ | (moderately to highly polluted) |
| | $4 < PLI \leq 5$ | (highly polluted) |
| | $PLI > 5$ | (very highly polluted) |

**Table 4:** Sequential orders of heavy metals in sampling sites

| Sites | Seasons | Metals in decreasing orders |
|---|---|---|
| Sira island | winter | Fe> Mn>Zn>Cr> Pb> Co> Ni> Cu> Cd |
| | summer | Fe> Mn>Zn>Pb> Cr> Ni> Cu> Co> Cd |
| Abyan coast | winter | Fe> Mn>Zn>Pb> Cr> Cu>Ni> Co> Cd |
| | summer | Fe> Mn>Zn>Cr> Pb> Ni> Co> Cu> Cd |
| Labor island | winter | Fe> Mn>Zn>Pb> Cr> Cu> Co> Ni> Cd |
| | summer | Fe> Mn>Zn>Pb> Cr> Cu> Ni> Co> Cd |
| al-Hiswah | winter | Fe> Mn>Zn>Cr> Pb> Cu> Co> Ni> Cd |
| | summer | Fe> Mn>Zn>Co> Cr> Cu> Ni> Pb> Cd |
| al-Khissaa | winter | Fe> Zn>Mn>Cu> Pb> Cr> Co> Ni> Cd |
| | summer | Fe> Mn>Zn>Pb> Cr> Co> Cu> Ni> Cd |
| al-Ghadir | winter | Fe> Mn>Zn>Pb> Cr> Cu> Co> Ni> Cd |
| | summer | Fe> Mn>Pb>Zn> Cr> Ni> Co> Cu> Cd |
| Kobagen | winter | Fe> Mn>Pb>Cr> Zn> Co> Ni> Cu> Cd |
| | summer | Fe> Mn>Zn>Pb> Cr> Co> Cu> Ni> Cd |
| Fuqum | winter | Fe> Mn>Zn>Ni> Cr> Co> Pb> Cu> Cd |
| | summer | Fe> Mn>Zn>Ni> Pb> Cr> Co> Cu> Cd |
| Amran | winter | Fe> Mn>Zn>Cr> Pb> Co> Ni> Cu> Cd |
| | summer | Fe> Zn>Mn>Pb> Cr> Ni> Co> Cu> Cd |

**Table 5:** Comparison of heavy metal concentrations (µg/g) of Aden coast sediments with the International and National coastal sediments

| Locality | Cd | Co | Cr | Cu | Fe | Mn | Ni | Pb | Zn | References |
|---|---|---|---|---|---|---|---|---|---|---|
| Aden,Yemen " Summer" | 0.60-2.92 | 6.7-26.4 | 12.6-26.6 | 3.3-19.83 | 1332-3663 | 76.9-394.6 | 4.2-30.3 | 13.6-46.0 | 32.2-91.6 | Present study |
| Aden, Yemen Winter | 0.8-2.8 | 9.7-0.7 | 22.2-40.9 | 8.2-55.3 | 1061-3604 | 47.8-67.0 | 3.9-29.7 | 15.2-46.9 | 32.6-97.2 | |
| Aden coasts | 0.93-3.3 | 18.4-42.4 | 135-389 | 11-120.6 | 285 - 1205 | 548-2250 | 13.6-30 | ND-1350 | 62.3-381 | [5] |
| Gulf of Aden | - | 13.75-33.64 | 17-233.9 | 8.09-111 | 2140-2769 | 138.23-658.87 | 16.17-48.07 | 14.8-138.06 | 21.85–263.49 | [9] |
| Hadhramout, Yemen | 1.02-2.80 | - | 3.85-16.6 | 13.8-51.2 | 1255-3141 | 27.98-87.4 | 22.7-38.7 | 10.21-19.3 | 18.5-84.95 | [44] |
| Socotra, Yemen | 1.8-6.61 | 7.84-89.83 | | 59.84-300.7 | | | | | | [49] |
| Red Sea, Yemen | 0.2-0.7 | 6.3-15 | 6.8-7.6 | 3.6-7.9 | 540-840 | 44.3-70.2 | 2.5-6.8 | 2.4-4.6 | 7.6-9.6 | [46] |
| Al-Hodiedah, Yemen | 7.33-10.17 | 24- 32 | | | | | 13.39-20.5 | 61.45-65.16 | | [50] |
| Red Sea, Egypt | 2.48-8.14 | | 1.39-75.3 | 5.36-48.87 | 1549.8-4729.8 | 54.9-966.4 | 9.5-67.04 | 10.78-70.37 | 30.11-99.8 | [40] |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Oman Sea (winter) | 0.4-0.87 | 19.18–47.16 | 21.85-46.79 | 14.22-53.46 | 43.16-84.42 | 11.74-26.45 | 13.88-28.23 | 16.2-43.21 | [47] |
| " (summer) | 0.21-0.53 | 19.03-51.43 | 16.97-54.76 | 12.77-52.13 | 46.9-89.14 | 8.32-28.68 | 10.72-25.63 | 18.77-40.14 | |
| Red Sea, Egypt (winter) | 1.89-3.98 | 4.38-12.75 | 3.2-12.16 | 2.14-4.56 | 33.19-70.2 | 25.9-49.63 | 18.5-42.15 | 25.48-58.06 | [45] |
| " (Summer) | 1.29-3.23 | 2.48-9.03 | 2.79-8.65 | 1.24-3.28 | 12.9-64.2 | 16.84-34.3 | 12.1-36.52 | 27.42-51.78 | |
| Kanyakumari, India | 0.35-0.50 | | 17.32-17.27 | 2011.7-4370.6 | | | 5.89-11.23 | 10.47-18.76 | [48] |

**Table 6:** Enrichment factor (*EF*) of heavy metals in sampling sites

| a) Winter-*EF* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sites | **Zn** | **Pb** | **Ni** | **Mn** | **Fe** | **Cu** | **Cr** | **Co** | **Cd** |
| Sira island | **13.68** | **21.73** | **3.60** | **6.21** | 0.07 | 0.25 | 1.69 | **2.35** | **57.94** |
| Abyan coast | **5.27** | **12.39** | **2.17** | **2.59** | 0.08 | 0.29 | 1.61 | **2.57** | **34.78** |
| Labor island | **11.45** | **31.82** | **2.85** | **3.56** | 0.07 | 0.16 | 1.19 | **3.14** | **63.59** |
| al- Hiswah | **10.20** | **14.81** | **3.36** | **6.50** | 0.06 | 0.41 | 1.73 | **2.07** | **58.09** |
| al-Khissa | **12.77** | 26.84 | 0.87 | 1.38 | 0.07 | 0.70 | **4.30** | **9.37** | **141.92** |
| al-Ghadir | **8.13** | **37.17** | **2.98** | **2.85** | 0.06 | 0.16 | 1.38 | **4.44** | **105.68** |
| Kobagen | 1.40 | **3.71** | **6.64** | **18.18** | 0.02 | 0.11 | 0.40 | 0.76 | **15.25** |
| Fuqum | **6.07** | **13.44** | **7.73** | **3.65** | 0.06 | 0.38 | 0.61 | **4.03** | **100.24** |
| Amran | **13.31** | **44.92** | **4.71** | **2.13** | 0.03 | 0.16 | **2.15** | **4.33** | **226.66** |
| Minimum | 1.40 | **3.71** | 0.87 | 1.38 | 0.02 | 0.11 | 0.40 | 0.76 | **15.25** |
| Maximum | **13.68** | **44.92** | **7.73** | **18.18** | 0.08 | 0.70 | **4.30** | **9.37** | **226.66** |
| Mean | **9.14** | **22.98** | **3.88** | **5.23** | 0.06 | 0.29 | 1.67 | **3.67** | **89.35** |
| **b) Summer-*EF*** | | | | | | | | | |
| Sites | **Zn** | **Pb** | **Ni** | **Mn** | **Fe** | **Cu** | **Cr** | **Co** | **Cd** |
| Sira island | **9.17** | **19.29** | **3.80** | **4.29** | 0.07 | 0.25 | 1.09 | **2.35** | **54.42** |
| Abyan coast | **4.35** | **9.88** | **2.40** | **2.69** | 0.08 | 0.30 | 1.38 | **2.73** | **25.66** |
| Labor island | **9.22** | **25.64** | **3.48** | **3.80** | 0.08 | 0.23 | 1.12 | **3.17** | **74.84** |
| al- Hiswah | **7.80** | **12.00** | **4.20** | **6.47** | 0.06 | 0.58 | 1.14 | **3.79** | **47.05** |
| al-Khissa | **4.85** | **21.05** | 0.88 | 1.56 | 0.07 | 0.17 | **4.10** | **9.47** | **138.88** |
| al-Ghadir | **7.41** | **37.64** | **4.55** | **2.68** | 0.06 | 0.15 | 0.81 | **5.53** | **121.10** |
| Kobagen | 1.02 | **2.68** | **5.15** | **9.85** | 0.03 | 0.12 | 0.47 | 1.15 | **13.33** |
| Fuqum | **12.78** | **17.83** | **5.91** | **5.72** | 0.08 | 0.23 | 0.66 | **3.07** | **75.99** |
| Amran | **17.19** | **27.05** | **5.22** | 0.68 | 0.03 | 0.09 | 0.87 | **6.27** | **97.78** |
| Minimum | 1.02 | **2.68** | 0.88 | 0.68 | 0.03 | 0.09 | 0.47 | 1.15 | **13.33** |
| Maximum | **17.19** | **37.64** | **5.91** | **9.85** | 0.08 | 0.58 | **4.10** | **9.47** | **138.88** |
| Mean | **8.20** | **19.23** | **3.95** | **4.19** | 0.06 | 0.24 | 1.29 | **4.17** | **72.12** |

**Table 7:** Quantification of Contamination (QoC% ) of Heavy Metals in Aden Coast Sediments

| Sites | a) QoC% - Winter | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Zn** | **Pb** | Ni | Mn | Fe | Cu | Cr | **Co** | **Cd** |
| Sira island | **2.32** | **62.50** | (73.09) | (53.58) | (92.52) | (59.78) | (54.56) | **8.95** | **333.33** |
| Abyan coast | (59.58) | (5.00) | (83.38) | (80.14) | (92.33) | (72.22) | (73.22) | (48.95) | **166.67** |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Labor island | (16.00) | **133.50** | (79.12) | (73.85) | (92.66) | (61.56) | (75.11) | (17.89) | **366.67** |
| Al-Hiswah | (44.40) | (15.00) | (86.90) | (62.68) | (94.26) | (84.40) | (70.05) | (22.63) | **233.33** |
| Al-Khissa | (20.20) | **76.50** | (96.10) | (23.10) | (93.42) | (44.70) | (77.80) | (15.26) | **833.33** |
| Al-Ghadir | (51.30) | **134.50** | (87.20) | (82.00) | (93.69) | (82.60) | (76.60) | (20.00) | **566.67** |
| Kobagen | (47.50) | **46.00** | (89.80) | (58.96) | (97.74) | (91.80) | (72.30) | (16.32) | **500.00** |
| Fuqum | (67.40) | (24.00) | (70.30) | (79.35) | (94.35) | (86.90) | (75.90) | (16.84) | **466.67** |
| Amran | (64.10) | **27.50** | (90.90) | (82.73) | (97.16) | (91.10) | (74.10) | (25.26) | **543.33** |
| Minimum | (67.40) | (24.00) | (96.10) | (82.73) | (97.74) | (91.80) | (77.80) | (48.95) | **166.67** |
| Maximum | **2.32** | **134.50** | (70.30) | (23.10) | (92.33) | (44.70) | (54.56) | **8.95** | **833.33** |
| Mean | (40.91) | **48.50** | (84.09) | (66.27) | (94.24) | (75.01) | (72.18) | (19.36) | **445.56** |
| Sites | b) QoC% - Summer | | | | | | | | |
| | Zn | **Pb** | Ni | Mn | Fe | Cu | Cr | **Co** | **Cd** |
| Sira island | (38.21)* | **30.00** | (74.41) | (71.07) | (93.26) | (67.56) | (72.22) | (32.11) | **266.67** |
| Abyan coast | (66.11) | (23.00) | (81.32) | (79.02) | (92.21) | (76.67) | (74.22) | (42.63) | **100.00** |
| Labor island | (30.63) | **93.00** | (73.82) | (71.42) | (92.47) | (55.93) | (70.78) | (9.47) | **463.33** |
| al-Hiswah | (58.00) | (32.00) | (83.80) | (63.32) | (94.33) | (82.30) | (75.60) | **38.95** | **166.67** |
| al-Khissa | (67.70) | **47.50** | (95.80) | (6.90) | (92.99) | (88.90) | (77.20) | **3.68** | **873.33** |
| al-Ghadir | (57.00) | **130.00** | (81.10) | (83.62) | (93.89) | (84.08) | (79.80) | (9.47) | **640.00** |
| Kobagen | (51.70) | **34.00** | (90.08) | (72.08) | (97.17) | (89.80) | (74.10) | (12.11) | **566.67** |
| Fuqum | (8.40) | **34.50** | (69.70) | (56.82) | (92.46) | (86.00) | (73.40) | **32.63** | **473.33** |
| Amran | (49.90) | (17.00) | (89.10) | (94.38) | (96.93) | (96.70) | (87.40) | (64.74) | **200.00** |
| Minimum | (67.70) | (32.00) | (95.80) | (94.38) | (97.17) | (96.70) | (87.40) | (64.74) | **100.00** |
| Maximum | (8.40) | **130.00** | (69.70) | (6.90) | (92.21) | (55.93) | (70.78) | **38.95** | **873.33** |
| Mean | (47.52) | **33.00** | (82.13) | (66.51) | (93.97) | (80.88) | (76.08) | (10.58) | **416.67** |

***(Values are in brackets ): geogenic source**

**Table 8:** Contamination Factor (*CF*) of heavy metals in sampling sites

| Sites | Winter | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Zn | Pb | Ni | Mn | Cu | Cr | Co | Cd |
| Sira island | 1.02 | 1.63 | 0.27 | 0.46 | 0.40 | 0.45 | 1.09 | 4.33 |
| Abyan coast | 0.40 | 0.95 | 0.17 | 0.20 | 0.28 | 0.27 | 0.51 | 2.67 |
| Labor island | 0.84 | 2.34 | 0.21 | 0.26 | 0.38 | 0.25 | 0.82 | 4.67 |
| al- Hiswah | 0.59 | 0.85 | 0.19 | 0.37 | 0.35 | 0.33 | 0.77 | 3.33 |
| al-Khissa | 0.84 | 1.77 | 0.06 | 0.09 | 1.23 | 0.25 | 0.85 | 9.33 |
| al-Ghadir | 0.51 | 2.35 | 0.19 | 0.18 | 0.39 | 0.26 | 0.80 | 6.67 |
| Kobagen | 0.55 | 1.46 | 0.15 | 0.41 | 0.18 | 0.31 | 0.84 | 6.00 |
| Fuqum | 0.34 | 0.76 | 0.44 | 0.21 | 0.29 | 0.27 | 0.83 | 5.67 |
| Amran | 0.38 | 1.28 | 1.00 | 0.17 | 0.20 | 0.29 | 0.75 | 6.43 |
| Sites | Summer | | | | | | | |
| | Zn | Pb | Ni | Mn | Cu | Cr | Co | Cd |
| Sira island | 0.62 | 1.30 | 0.26 | 0.29 | 0.32 | 0.28 | 0.68 | 3.67 |
| Abyan coast | 0.34 | 0.77 | 0.19 | 0.21 | 0.23 | 0.26 | 0.57 | 2.00 |
| Labor island | 0.69 | 1.93 | 0.26 | 0.29 | 0.44 | 0.29 | 0.91 | 5.63 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| al- Hiswah | 0.44 | 0.68 | 0.24 | 0.37 | 0.39 | 0.27 | 1.39 | 2.67 |
| al-Khissa | 0.34 | 1.48 | 0.06 | 0.11 | 0.25 | 0.25 | 1.04 | 9.73 |
| al-Ghadir | 0.45 | 2.30 | 0.28 | 0.16 | 0.35 | 0.22 | 0.91 | 7.40 |
| Kobagen | 0.51 | 1.34 | 0.15 | 0.28 | 0.23 | 0.29 | 0.88 | 6.67 |
| Fuqum | 0.96 | 1.35 | 0.45 | 0.43 | 0.31 | 0.30 | 1.33 | 5.73 |
| Amran | 0.53 | 0.83 | 1.00 | 0.06 | 0.07 | 0.14 | 0.35 | 3.00 |

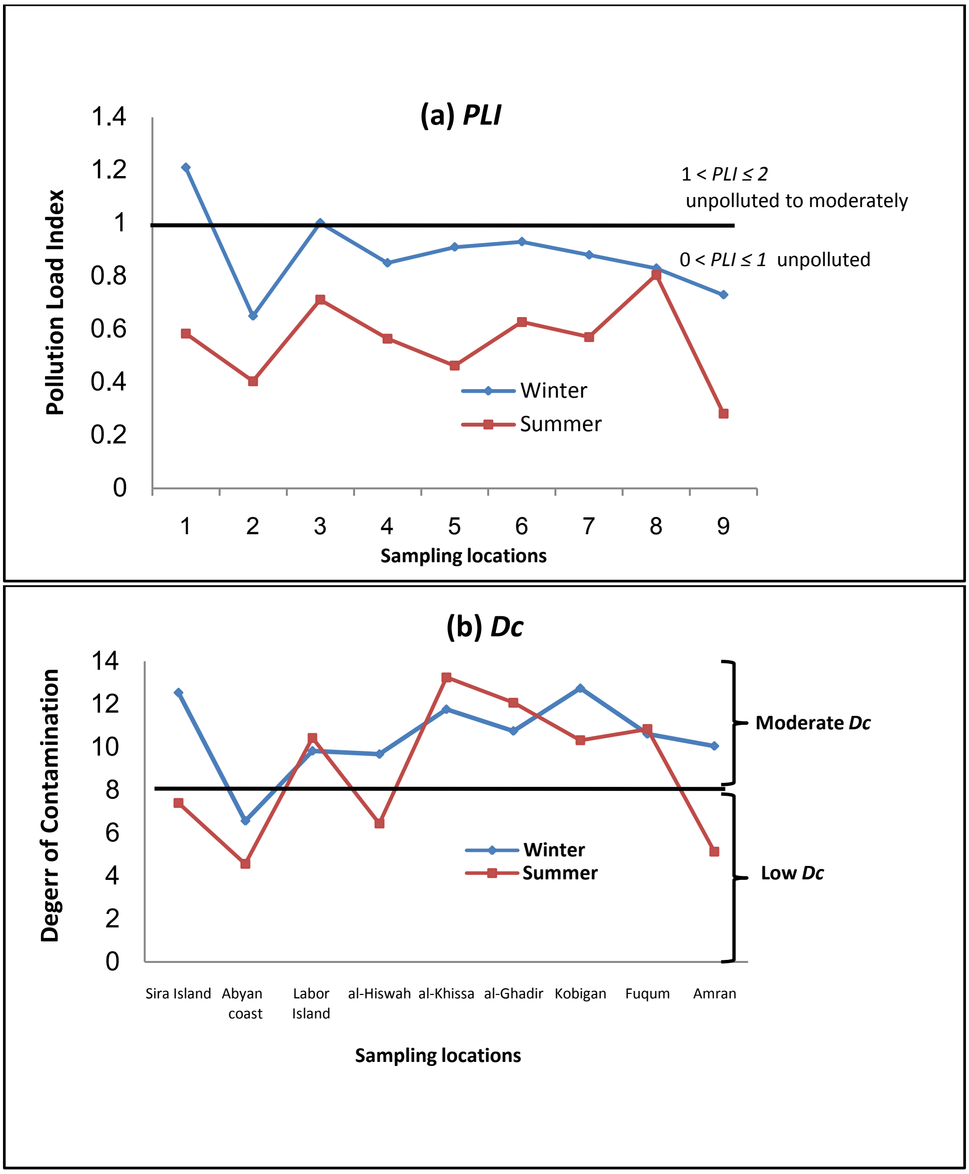



*Figure 3: Pollution Load Index (PLI) and Contamination Degree (Dc) of Heavy Metals in Aden Coast Sediments for Winter and Summer Seasons*

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