Assessment of heavy metal contamination in water, sediments, and Mangrove plant of Al-Budhai region, Red Sea Coast, Kingdom of Saudi Arabia

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ABSTRACT
This study investigates the hydrographic parameters and contamination status of zinc (Zn), iron (Fe), copper (Cu), manganese (Mn), lead (Pb), cadmium (Cd), vanadium (V), and nickel (Ni), etc. in surface water, surficial sediments, and mangrove tree tissues (Avicennia marina). Samples were collected from nine sites in Al-Budhai area of Red Sea coast of Jeddah. The trend values of metal contamination factor were Ni(3.23) > Cd(2.99) > Pb(2.86) > Zn(2.69). Translocation factor (TF) of the metals showed Avicennia marina tissues have a dominant role in the phytoremediation process through toxic metal uptake.

1. Introduction
Mangroves are plant communities that play an important role in the coastal plant life system; they are found between the sea and land in areas that are flooded with tidal waters, mainly at high-water level, subject to storms in tropical and semitropical regions [1]. The importance of mangrove environment is due to its high biological diversity that it is safe for many economically important organisms, a huge variety of living groups by providing shelter for many types of marine animals and commercial invertebrates such as birds, fish, shrimp, and crustaceans; it is available in food-rich places and gives protection for a small number of marine creatures [2]. Dead leaves and branches of mangroves are an important source of nutrients that enrich primary productivity in the marine environment. Mangrove trees are used for grazing process. Mangroves themselves provide fuel, pigments, medicine and wood for building homes and boats. The root system of mangrove is known as air roots that stand out above the surface of the earth that surrounds trees; it can protect the coastal land and the formation of sand dunes. Mangrove environments can clean and remove pollutants from marine water [3–4]. The forests of mangroves are adjacent to the coasts of Saudi cities in the east, such as Dammam, Saihat, Qatif, and Safwa all the way to Ras Tanura, and in the west as well, such as the islands of Farsan, Jizan, Qunfudhah, Al-Leith, and Jeddah. It has been noticed that mangrove forests are almost scarce and disappear from the coasts of these cities, due to the urban expansion that affected coastal areas. Avicennia marina and Rhizophora mucronate trees are considered the most dominant types of mangroves, which are found in Red Sea tidal area of Saudi Arabia [5–6]. Mangrove areas are exposed to many problems. Tourism is an important industry, but irresponsible tourism can cause destruction and damage to mangroves. Tourists bring with them trash, sewage, fumes, lights, noise, and other disturbances that can damage these trees and surrounding ecosystems. Many forms of coastal development attract investors, due to its proximity to the sea, construction of ports, docks, hotels, golf courses, marinas, and conference halls. This results in the construction of concrete roads; the pollutants resulting from development processes cause damage to mangroves trees. Officials and governments of many countries have become more aware of protecting the coastal environment, especially mangrove environments, in addition to trying to replant them and take biological care. Mangrove ecosystems are subject to removal, destruction, continuous deterioration, and many risks that have negative impacts and threaten their existence in various places. These risks are mainly from natural hazards and human-induced activities: coastal urbanization, industrialization and emissions are among the consequent problems of wastewater and chemical pollutants, fishing and aquaculture development activities, and tourism [7–11]. One of the factors leading to a decrease in the mangrove area is the filling and expansion of the coastal road, in addition to the construction of marina, which contains a variety of boats and yachts. This causes increased pressure on the coastal resources, and on the coastal ecosystems [8,12]. High level of metal concentrations was recorded in the sediment surface of mangrove wetland [10,13]. Some studies on heavy metal contamination in the mangrove forest ecosystem in the Al-Budhai region in...
the southern corniche of Jeddah city are discussed as follows. Al-Dubai et al. [14] compared the properties and structural components of contemporary sediments of the backreef and forereef areas of the southern corniche of Jeddah, considering the mineralogical point of view. They investigated the mineral patterns of bottom sediments with their features and distributions of the studied areas. Abohassan et al. [2] studied the productivity of perennial biomass in the arid mangrove ecosystems in the Red Sea coast of Saudi Arabia and showed that aboveground biomass of two regions (Yanbu and Shuai’a) was 14.8 t ha$^{-1}$, while belowground fine root was 67.80 t ha$^{-1}$. On the other hand, Eid et al. [15] studied on mangrove forests for the carbon contained in the Red Sea's contiguous areas of Saudi Arabian. El-Juhani [6] is an inventory of mangrove forests in the regions of Jazan, Asir and Makkah. The inventory process of these mangrove forests showed groups consisting mainly of Avicennia marina with a few groups of Rhizophora mucronate. Some researchers have reported about the mangrove forest cultivation and identifying the suitable location around the coastal region of Saudi Arabia [16]. Researchers have used the modern methods, including GIS and remote sensing for identifying the appropriate places for mangrove culture [17]. Elhag et al. [12] studied on species richness and endanger analysis of Avicenna marina in and around coastal areas of Red Sea in Saudi Arabia. Al-Ghanem [3] studied the environmental ecology of Avicenna marina in Al-Qatif District, east Saudi Arabia. Heavy metal pollution and bioaccumulation in mangrove systems were investigated [4,18]. The bioaccumulation of metals in mangrove plants was investigated by Analuddina et al. [19]. Their results showed high levels of copper and mercury in tissues of L. racemosa, while cadmium, zinc, and lead were shown in the tissues of B. gymnorrhiza, B. parviflora, and C. tagal, respectively. The bioaccumulation factors of mangroves revealed a variety of trends, which explain the difference in the ability of metals to cleave and uptake in different tissues of mangrove species. It is not clear how different mangrove vegetation affects the accumulation of metals in coastal sediments although this information is important to assess the role of mangrove species in the remediation of polluted metals in the coastal zone [20]. Recently, multivariate statistical approaches and indices, such as Pearson correlation index (PCI), principal components analysis (PCA), and cluster analysis (CA), are used to identify the origins and relationships of heavy metals to obtain better surface water quality information. To assess sediment contamination, several indicators, such as enrichment factor (EF), contamination factor (CF), geo-accumulation index (Igeo), hazard index (HI), hazard quotient (HQ), and potential environmental hazards and toxicities to human health [21–25], were performed. The main objective of this work was to investigate the distribution of some metal concentrations that includes zinc, iron, copper, manganese, lead, cadmium, vanadium, and nickel in the mangrove ecosystem of seawater, surficial sediments, and mangrove tissues (leaves and roots). Moreover, the studies also emphasized the present status of metal pollution in the sediments and its accumulation within different compartments of mangrove trees.

2. Material and methods

2.1. Study site

The study area is the Al-Budhai lagoon lays between longitude 39.12° to 39.13° E and latitude 21.26° to 21.27° N situated in the southern corniche of Jeddah city of Red Sea, Saudi Arabia (Figure 1). Mangrove forests formed adjacent to the coast with the total area of around 20.0 km$^2$. Mangrove trees are spread along the study area at 5 km next to the Corniche Road in the southern Jeddah city. In the bottom sediments of the Al-Budhai area, 73–94% of calcium carbonate is recorded. More than 70% carbonate minerals, including Mg-calcite, aragonite, dolomite, and calcite were found by the mineralogical study in the studied samples in the bottom surface sediments. It has been noticed in recent years that mangrove forests are almost scarce and disappear from the coasts of Saudi cities, due to the urban expansion that affected coastal areas. Avicennia marina trees are considered the most dominant types of mangroves, which are found in the tidal zone of the Red Sea [6] (Figure 1 and Plate 1). This area has been categorized as the hyper-arid climatic zone with almost 38% salinity of water [26]. The annual average precipitation in between 2.8- and 22.3-mm year$^{-1}$ was recorded considering the subtropical and tropical climatic conditions with erratic rainfall and extreme evaporation rate [27,28]. The oceanography conditions
have very high temperatures over 45°C and wind flow usually showed north to north–northwest direction during all times of the year in this area [29]. The Red Sea is one of the most saline areas across the world. The levels are so high due to the circulation of water and the evaporation and wind patterns. The tidal amplitude in the area is about 50 cm in the northern parts and decreases towards the centre, reaches to zero value near Jeddah. It is also reported that the one-meter high tidal surges with tremendous wind speed are shown in this area.

2.2. Collection, preparation, and analysis of samples

2.2.1. Seawater analysis

Nine surface seawater samples were directly collected from a depth of 30 cm of the surface to avoid floating foreign materials. 1.0 L of polyethylene containers were used, those were washed with acid (2.0 N HCl) and deionized water. Physiochemical parameters of seawater samples, including salinity, pH and dissolved oxygen, were evaluated using CTD (YSI-6000) for each studied site in April 2019. The samples were acidified with concentrated nitric acid and subsequently filtered using a 0.45-μm membrane filter for the determination of metals in the samples. The pre-concentrations of metals in seawater samples were measured [30]. The concentrations of studied metals (Fe, Mn, Cu, Zn, Pb, Cd, Ni, V) were analyzed by using the inductive coupled plasma-optical emission spectrometer (Agilent ICP-OES5100 VDV). The reference material of NASS-5 was used, (NRC- Canada) to perform quality control analyses. The contaminated materials in the glassware used for analysis were removed with a detergent and then rinsed in nitric acid 10%. The limit of detection (in μg L\(^{-1}\)) was 0.055, 0.010, 0.010, 0.009, 0.010, 0.040, 0.050, and 0.020 for iron (Fe), cadmium (Cd), manganese (Mn), zinc (Zn) copper (Cu), lead (Pb), nickel (Ni), and vanadium (V), respectively. The precision of the results represents the coefficient of variation (C.V; within 10%) and was made by determining one sample in three replicate analyses. The data accuracy was carried out by using natural seawater and NASS-5 reference materials. It has given higher recovery values of the studied metals between 90.0 and 95.0%.

2.2.2. Sediment analysis

Nine sampling stations were collected from the 0–20 cm depth of surface sediment, using a plastic tube (PVC) to avoid any foreign contagion. Three sediment samples were collected from each station, then one composite sample was taken. The samples were dried for 48 h at 60°C in a thermostatically controlled oven. Thereafter, the dried sediments were disaggregated using a porcelain mortar with a pestle and subsequently filtered using 2 mm sieve to separate gravel and debris. Each sediment sample was mixed to form homogenized sample and maintained for further analysis. The sediment texture was estimated by Folk [31]. The subsamples were ground by the swing grinding mill and made fine powder and homogenized, and then they passed through a sieve using a 63 μm nylon mesh. The resulting powder samples were ready for total organic matter, calcium carbonate content, and total metal concentration analysis. Total organic matter of sediment was determined at 550 °C in the loss-on-ignition method [32]. Calcium carbonate percentage was determined according to Molina [33]. Total metal concentration was examined using the above-mentioned method [34]. 0.2 g of the fine powder sample was completely digested with a mixed acid solution, containing HNO₃, HClO₄ and HF (3:2:1 v/v) in dry Teflon beaker at 85 °C. The studied metal concentrations were analysed by an inductively coupled plasma-optical emission spectrometer (Agilent ICP-OES5100 VDV).

2.2.3. Determination of heavy metals in mangrove tissues (roots; leaves)

Leaves and aerial roots were sampled from Avicennia marina randomly and manually by hand plucking the leaves and cutting the roots with a knife. Mangrove
tissue samples (leaves and roots) were collected from five individual mature mangrove trees for each site. The total weight of the leaves was about one kg. A combination of roots (Pneumatophore, main root, and branch) was collected for the same mangrove trees, and approximately 2 kg of roots was taken from each site.

For metal analysis, 3 samples were used for each component of the studied sites. Polyethylene bags were used to transport samples to the laboratory. The collected samples were cleaned with deionized water to eliminate the abandoning fine sediments and then dried at 60°C, after which the samples were mixed and homogenized into powder, then sieved and finally kept at room temperature. It was stored in glass containers for laboratory analysis. 0.5 g of ground material (for leaf and aerial roots, with three replicates) was placed into 125 mL digestion tubes. Following the method described by Sparks et al. [35] plant tissues were processed into a concentrated mixed acid solution of HNO₃ and HClO₄ (4:1; v/v) for metal analysis.

The prepared samples were heated at 120°C for 3 h after adding 5 mL of the mixed acid solution in the block digest and finally, 25 mL of the volume was diluted for analysis. The heavy metal concentrations were measured against the certified standard values using an ICP-OES5100 VDV spectrometer. All experiments were triplicated using certified reference materials and samples were examined for accuracy in analytical procedures. 99.5% of recovery rate was exhibited by all studied metals.

### 2.3. Applying of pollution indices

The concentrations of metals in the collected samples can be evaluated by applying different approaches of contamination indices (Contamination factor (Cᵢ), Degree of contamination (Cd), geo-accumulation index (Igeo), Enrichment Factor (EF) and modified degree of contamination (mCd)). The contaminated indicators of toxic metals were calculated based on the background levels in the earth crust [36].

#### 2.3.1. Enrichment factor (EF)

Sinex and Helz [37] is a recommended method to calculate the EF by the evaluation of the impact of anthropogenic on the sediments; in this method, Fe is used as a normalization metal [38,39]. The formula for EF can be expressed as the following equation:

\[
EF = \frac{[C_i/C_{Fe}]}{[C_b/C_{Fe_b}]}
\]

where [Cᵢ/CFe] represent the ratio of studied metal and Fe concentration in the sediment sample, and [Cb/CFe_b] represent the ratio of Fe in the Earth surface and the same metal. EF is the most used method for the evaluation and differentiation of natural and anthropogenic sources of metals in marine sediment samples [40–43].

#### 2.3.2. Geo-accumulation index (Igeo)

The Igeo tool is used to estimate the metal content enrichment and contamination status above the level of background concentration, as reported in previous studies [44–46]. The Igeo can be measured by the following equation:

\[
Igeo = \log_2\left(\frac{C_i}{1.5 * C_b}\right)
\]

where Cᵢ represents the calculated metals in the sediment sample, the geochemical background concentration of studied metals is represented by Cb [47], and 1.5 is considered and used for minimizing the effects of possible variations in the background values in the sediments [48].

#### 2.3.3. Contamination factor (Cᵢ)

The contamination factor, as one of the determining factors, can be evaluated by the contamination/pollution level to measure the possible impact of the human-induced contaminants in marine sediments. Cᵢ of toxic metals was described in the previous works [49–53]. The following equation is to be used for calculating Cᵢ:

\[
C_i = \frac{C_n}{C_b}
\]

where Cᵢ is the concentration of metals in the sediment sample and Cᵢ is the normal metal concentration in the background.

#### 2.3.4. Toxicity risk indicator (TRI)

According to Zhang et al. [54], the calculation of TRI is based on the effects of TEL and PEL to evaluate the toxicity risk of elements in the sediment. PEL represents the probable level of effect of the metal and TEL is the level of threshold condition of the effect [55]. TRI value is to be measured using the following equation for one element:

\[
TRI_n = \sqrt{\frac{(C_n/TEL)^2 + (C_n/PEL)^2}{2}}
\]

The sum of the individual TRIᵢ values for the elements yields to compute the integral toxicity risk indicator of elements in the sediment samples by the following equation:

\[
TRI = \sum_{i=1}^{n} TRI_n
\]

Equation components include TRIᵢ, which is the toxicity risk indicator of an element, Cᵢ is the content of the element in the studied sediments, n is the element number and TRI is the incorporated toxicity risk indicator.

#### 2.3.4. Translocation factor (TF)

The TF index refers to the ability of the plant to translocate metal ions from the roots to the leaf’s parts [59]; it is calculated for each sample separately. This factor
can be applied to assess the possible capacity of mangrove trees to transfer metals from sediment to mangrove tissues. The indices are expressed in the following equations:

$$\text{BCF}_{\text{leaves}} = \frac{C_{\text{leaves}}}{C_{\text{sediments}}}$$

$$\text{BCF}_{\text{roots}} = \frac{C_{\text{roots}}}{C_{\text{sediments}}}$$

$$\text{TF} = \frac{\text{Metal concentration}_{\text{leaves}}}{\text{Metal concentration}_{\text{roots}}}$$

where $C_{\text{leaves}}$, $C_{\text{sediments}}$ and $C_{\text{roots}}$ are the total metal concentration in leaves, sediments, and roots (μg g⁻¹) on a dry weight basis, respectively. BCF_{leaves}: bio-concentration factor of leaves; BCF_{roots}: bio-concentration factor of roots.

### 2.4. Statistical analysis

There are multiple methods in statistical processes to show the hidden information in environmental studies and to understand the degree of correlation of the studied parameters. The present study has focused on the relationship between the various parameters, including sediments and mangrove tissues of seawater in the studied sites. For this purpose, various multivariate statistical methods are used, including descriptive statistics, correlation matrix and cluster analysis. The descriptive statistics of physicochemical characteristics of seawater (salinity, pH, and dissolved oxygen) and dissolved metals, grain size analysis, organic matter, CaCO₃ and metals of sediments, metals in mangrove tissues (roots and leaves) were measured.

### 2.5. Quality control

All contaminants were eliminated by washing glassware and plastic bottles with a 20% HNO₃ solution, rinsing them thoroughly with deionized water and drying them. All reagents used in the analyses were of analytical grade from Merck. As shown in Table 1, the reference material was used to achieve the quality control of the method used during heavy metal analyses. (MESS-3 are the marine sediment reference materials for trace metals). The selected metals’ recovery for spiked samples was used to calculate the accuracy. It was between 91 and 97.9%, while precision was less than 10%.

### 3. Results and discussion

#### 3.1. Seawater Characteristics

Physiochemical parameters of seawater samples, including salinity, pH and dissolved oxygen, were evaluated for each studied site in April 2019. Table 2 represents seawater characteristics in the study area. Generally, slightly spatial variability in salinity during the present work was between 38.31‰ at St. II and 39.20‰ at St. VIII with an average 39.00 ± 0.14 ‰. This is lower than those mentioned in other areas of the Red Sea, where the high levels of salinity were in the range from 40.02 ± 0.11 to 42.32 ± 0.10% at the Northern Red Sea coast [60,61]. The salinity in the study area is relatively higher than the Arabian Sea (35.0–36.5‰) and Gulf of Aden [62] and fell within the range reported by Fallatah et al., [63]. Hydrogen ion concentration is one of the most important parameters that affect the ecosystem in aquatic environment and one of the most significant ionic constituents of natural seawater [64]. The spatial distribution of pH values between the different sites revealed narrow variation (Table 2); it fluctuates from 8.11 at St. I to 8.21 at St. VIII with a regional average 8.17 ± 0.04. These values are analogous with normal oceanic range within 8.1–8.3. The pH values were relatively higher than the Aden Gulf and Arabian Sea within range 7.89–8.03 [62]. The current identified mean and the range of pH values recorded in these studied areas are in good agreement with previously recorded values in different seawaters including the Red Sea [61]. Generally, the pH value of water is affected with some factors, including decomposition of organic matter, dissolved oxygen, photo synthetic activities, and water sewage discharge [65].

The dissolved oxygen (DO) is one of the viral indicators of water quality, if DO decreases, then subsequent negative impact will occur on marine life, whenever temperature increases subsequently DO will decrease and ultimately gas solubility in water will reduce. The results of DO concentration varied between 6.44 mg/l at St. III and 7.04 mgL⁻¹ at St. V with an average 6.77 ± 0.23 mgL⁻¹ (Table 2). Lattemann and Höpner (2008) [66] found the converse effect between temperature in water and the solubility of oxygen. Another research reported that when the salinity increases, then the solubility of DO decreases [67]. (Lawson 2011). The high concentration of dissolved oxygen in seawater can be explained by the exchange process between oxygen in the air and surface waters. In addition, the activity of algae and the process of photosynthesis have an important role in dissolved oxygen concentration levels [68], and sometimes DO concentrations become low due to the respiration of marine life and organic matter decomposition.

| Metal | Found   | Certified |
|-------|---------|-----------|
| Fe    | 39550 ± 0.45 | 43,400 ± 0.11 |
| Mn    | 318.0 ± 0.25  | 324 ± 12.00   |
| Zn    | 155.7 ± 2.3   | 159 ± 8.00    |
| Cu    | 30.8 ± 0.35   | 33.9 ± 1.60   |
| Pb    | 19.40 ± 0.24  | 21.10 ± 0.70  |
| Cd    | 0.22 ± 0.03   | 0.24 ± 0.01   |
| Ni    | 44.20 ± 1.34  | 46.90 ± 2.20  |
| V     | 235.0 ± 2.11  | 243.0 ± 1.00  |
Table 2. Seawater characterization and dissolved trace metal concentration (μg L\(^{-1}\)) in seawater, Al-Budhai area, Saudi Arabia Red Sea Coast.

| St. | Salinity | pH | DO  | Mn  | Zn  | Cu  | Pb  | Cd  | Ni  | V  |
|-----|----------|----|-----|-----|-----|-----|-----|-----|-----|----|
| I   | 38.92    | 8.11| 6.78| 12.35| 0.77| 3.12| 0.84| 1.57| 0.12| 0.91|
| II  | 38.81    | 8.2 | 6.58| 14.88| 1.05| 3.25| 0.81| 1.62| 0.18| 0.82|
| III | 38.9     | 8.19| 6.44| 15.11| 1.14| 4.42| 1.24| 2.3 | 0.21| 0.95|
| IV  | 39.01    | 8.14| 6.81| 13.44| 0.86| 2.98| 1.35| 2.14| 0.11| 0.86|
| V   | 39.11    | 8.17| 7.04| 12.58| 0.86| 2.98| 1.35| 2.14| 0.11| 0.86|
| VI  | 38.92    | 8.2 | 7.01| 16   | 1.09| 2.77| 1.54| 1.89| 0.2 | 0.71|
| VII | 38.97    | 8.16| 6.68| 14.71| 1.19| 3.38| 1.38| 2.07| 0.25| 0.88|
| VIII| 39.2     | 8.21| 6.58| 12.51| 0.81| 4.1 | 1.18| 1.87| 0.23| 0.75|
| IX  | 39.13    | 8.17| 7.03| 12.61| 0.88| 4.08| 1.28| 2.11| 0.26| 0.97|
| Min | 38.81    | 8.11| 6.44| 12.35| 0.77| 2.77| 0.81| 1.57| 0.12| 0.71|
| Max | 39.20    | 8.21| 7.04| 16.00| 2.01| 4.42| 1.54| 2.30| 0.26| 0.97|
| Ave. | 39.00   | 8.17| 6.77| 13.87| 1.21| 3.54| 1.20| 1.96| 0.19| 0.85|
| ±SD | 0.14     | 0.04| 0.23| 1.42 | 0.44| 0.60| 0.26| 0.26| 0.05| 0.10|

DO in the study area is almost similar to the recorded DO in other regions of Red Sea [69,70]. DO concentration of south part of Gulf of Aqaba, Red Sea, Egypt is 6.6–7 mg L\(^{-1}\) which was reported the same as in the surface water [71]. The minor variations of physicochemical characteristics including salinity, pH, and DO were found by this study. The previous study showed that the salinity of Red Sea water is more than that of the neighbouring Arabian Sea and high values of DO were recorded with well-oxygenated water as well with minor changes of pH values [72].

3.2. Dissolved metal concentration

The status of dissolved metals in a specific area can be recognized by comparing the dissolved metal concentration of studied locations with the limits permitted in previous studies, and with the lowest contents of these soluble metals for water standards. The lowest concentrations in μg L\(^{-1}\) were 50, 20, 10, 10, 10, 7, 20 for iron (Fe), manganese (Mn), copper (Cu), lead (Pb), cadmium (Cd), nickel (Ni) and zinc (Zn) [73], respectively.

Spatial distribution of dissolved trace metal concentrations (Fe, Mn) of the study area is shown in Table 2 and Figure 2. Dissolved Fe content ranged between 12.35 at St. I and 16.00 μg L\(^{-1}\) at St. VI. The concentration of Mn ranged from 0.77 at St. I to 2.01 μg L\(^{-1}\) at St. VIII; the mean values of Fe and Mn were between 13.87 ± 0.23 and 1.21 ± 0.44 μg L\(^{-1}\), respectively. The dissolved Mn and Fe concentrations in the different sites of this studied area revealed narrow variations in both the metals (Figure 2). Moreover, the findings exhibit the significant variations among the values for Fe and Mn, as they increase iron by six to fifteen times.

Generally, dissolved Fe and Mn content of the study area showed lower concentration compared with other regions in the Red Sea. It was lower than the low risk concentration of water quality standards; 50.0 and 20.0 μg L\(^{-1}\) of iron and manganese, respectively [73]. The lower concentrations of iron and manganese may be due to higher salinity (ranged; 38.81–39.20%). But, it can be interpreted by the oxidation process of ferrous to iron hydroxides. This result was observed from previous studies [28,74].

The spatial variation of dissolved Zn and Cu is shown in Table 2 and in Figure 2. In this study, the values of Zn content were in the range from 2.77 at St. VI to 4.42 μg L\(^{-1}\) at St. III with an average 3.54 ± 0.60 μg L\(^{-1}\). Cu concentration ranging between 0.81 at St. II and 1.54 μg L\(^{-1}\) at St. VI with an average 1.20 ± 0.26 μg L\(^{-1}\). These values of zinc and copper in the present study were less compared with those reported by Al-Mur (2020) [28]; it was in the range from 22.0 ± 8.0 to 19.50 ± 6.80 μg L\(^{-1}\).
for Zn, and 1.67 ± 0.60 and 3.20 ± 1.10 μgL⁻¹ for Cu. The previous studies showed a strong relationship between each biological factor and the accumulation of trace metals in plants and microorganisms. Zn is found in the environment, industrial and agricultural wastes, and paints [13,75]. The biosorption mechanism is considered one of the reasons for the deficiency and removal of dissolved Cu from the aquatic environment [76]. The concentration of dissolved Cu and Zn of the study area shows mainly lower levels than the risk concentration for the quality standard of seawater: 10.0 and 20.0 μgL⁻¹ for Cu and Zn, respectively [73].

Table 2 and Figure 2 show the dissolved Pb was shown within the limit of 1.57 at site I and 2.30 μgL⁻¹ at site III, with an average concentration of 1.96 ± 0.26 μgL⁻¹. The lowest Cd content during the period of study was 0.12 μgL⁻¹ at site I, while the highest concentration was 0.26 at site IX with an average 0.19 ± 0.05 μgL⁻¹. The content of dissolved Ni revealed a slight variation, ranging from 0.71 at site VI to 0.97 μgL⁻¹ at site IX with the average value of 0.85 ± 0.10 μgL⁻¹. In general, the values of dissolved Ni are lower than the risk concentration for the water quality standard 7.0 μgL⁻¹ [73].

Vanadium (V) concentrations detected in seawater samples during the period of study showed a slight variation between the locations and were anticipated from 0.46 at site IV and 0.82 μgL⁻¹ at site VII, with an average concentration of 0.63 ± 0.13 μgL⁻¹ (Figure 2 and Table 2). The range 2.08–2.60 μgL⁻¹ of vanadium in Al-Budhai region seawater was lower than the previously reported in the other part around Saudi coast of the Arabian Gulf [77]. Another research reported that the vanadium has been precipitated and subsequently formed as sediment on the seabed by ferric hydroxides and organic matter in the seawater [78]. Schlesinger et al. [79] recorded a good amount of data that the volume-weighted Vanadium concentration within the range of 0.2–5.1 μgL⁻¹ in the moderate and dense areas of human activities. Krachler et al. [81] also found that the atmospheric soil dust is one of the vital sources of Vanadium precipitation; this finding was explored by the investigation of long-term Vanadium accumulation in a Swiss peat bog. Wang and Wilhelmy [82] recommended that the Vanadium concentrations might be reduced by biological activity and showed the relationship between Vanadium concentration and phytoplankton biomass as the positive trend of low Vanadium concentration.

### 3.3. Grain size analysis and organic matter content

Some factors, including texture of the sediment, organic matter, pH and salinity of seawater, are controlled by the pattern and accumulation of heavy metals in the mangrove forests [83]. Fine sediment plays an important role in the attraction of metal ions due to higher surface area and organic complexation [84]. The study area texture (Al-Budhai region) was characterized by high mud content that ranged from 32.50 to 41.60% (38.54 ± 3.34%) which can be attributed to flocculation and eventually settling of finer particles. The results showed that the fine materials, composed of a mixture of bio- and terrestrial materials, were surrounded by the aerial roots of mangrove plants. Table 3 shows the average distribution of sediment texture, total organic matter, and carbonate. The organic matter content ranged from 4.32 to 6.21% (5.22 ± 0.66%); it was lower than those recorded to world average organic matter content for mangrove [85], due to the rate of local organic matter production and subsequent run-off and dissolution in the Red Sea.

### 3.4. Metal distribution in the sediments

Toxic metals can accumulate and turn into mangroves (leaves and roots) when they grow in contaminated

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**Table 3.** Sediment's characterization and total metal concentration of mangrove sediment in Al-Budhai area, Saudi Arabia Red Sea Coast.

| St. | Sand | Silt + Clay | OM% | CaCO₃% | Fe | Mn | Zn | Cu | Pb | Cd | Ni | V |
|-----|------|-------------|-----|-------|----|----|----|----|----|----|----|----|---|
| I   | 5.1  | 32.5        | 6.21| 39.8  | 3847| 2472.2| 90.80| 41.30| 28.30| 0.70| 15.30| 9.95|   |
| II  | 64.30| 35.7        | 5.22| 45.3  | 3742| 241.6| 94.20| 43.38| 28.63| 0.70| 18.93| 8.12|   |
| III | 59.40| 40.6        | 4.97| 42.6  | 4007| 2384.1| 91.20| 42.65| 28.43| 1.03| 16.83| 8.87|   |
| IV  | 61.60| 38.4        | 5.08| 43.5  | 3891| 237.8| 87.60| 40.33| 25.65| 1.06| 15.59| 10.95|   |
| V   | 58.40| 41.6        | 4.65| 40.2  | 4152| 242.8| 89.60| 40.18| 30.28| 1.07| 18.85| 9.08|   |
| VI  | 58.80| 41.2        | 5.07| 38.9  | 4117| 243.2| 84.40| 39.58| 31.28| 0.69| 16.27| 8.16|   |
| VII | 61.90| 38.1        | 4.32| 38.4  | 3964| 239.7| 78.80| 38.70| 29.63| 0.73| 18.04| 11.57|   |
| VIII| 59.80| 40.2        | 6.1 | 40.1  | 3956| 244.5| 77.40| 40.13| 32.73| 1.05| 17.58| 12.8|   |
| IX  | 58.50| 41.5        | 5.28| 41.5  | 3886| 250.1| 79.40| 37.35| 31.03| 1.34| 15.40| 10.74|   |
| Min | 56.10| 32.50       | 4.32| 38.4  | 3742| 237.8| 77.40| 37.35| 25.65| 0.69| 15.30| 8.12|   |
| Max | 64.30| 41.60       | 6.21| 45.3  | 4152| 250.1| 94.20| 43.38| 32.73| 1.34| 18.93| 12.8|   |
| Ave. | 59.93| 38.54       | 5.22| 41.27 | 3952| 243 | 85.91| 40.39| 29.49| 0.95| 17.00| 10.11|   |
| ±SD | 2.70 | 3.34        | 0.66| 2.45  | 141 | 4.4 | 6.37 | 2.04 | 2.34 | 0.24 | 1.45 | 1.7 |   |
| ERL | -    | -           | 150 | 218   | 1.2 | 20.9| Ba  | 820  | 95   | 45   | 0.3 | 68  | 130 |   |

ERL ERM according to NOAA, 2012. Screening Quick Reference Tables. National Oceanic and Atmospheric Administration. http://archi-ve.orr.noaa.gov/book_shelf/122_NEW-SQuiRTs.pdf

Ba: Background level according to crust.
sediments with metal. A variety of toxic heavy metals, including copper, zinc, cadmium, nickel, and lead, are mainly related to the environmental condition and the growth of phytoplankton. Human activities and the degradation of geological minerals are responsible for the emergence and increase of metals in seawater [86].

Iron (Fe) and Manganese (Mn) concentrations in surficial sediment of the study area showed narrow variation from one site to another, as presented in Table 3. The lowest concentration was observed at St. II (3742 μgg⁻¹) for Fe and at St. IV (237.8 μgg⁻¹) for Mn, while the highest concentration was recorded at St. V (4152 μgg⁻¹) and at St. IX (250.10 μgg⁻¹) for Fe and Mn, respectively (Table 3). The mean concentration was 3952 ± 141 μgg⁻¹ for Fe and 243 ± 4.4 μgg⁻¹ for Mn, which were very low relative to the typical average concentration of these metals in the shale (47000,820 μgg⁻¹ for Fe and Mn, respectively).

Zinc (Zn) and Copper (Cu) are important metals for nutrition of all living things in water and sediments, which are required by plants, animals, and humans, and they are among the necessary elements at low content, as the concentration higher than the permissible limits is considered to have toxic impact on the environment [87].

In high concentrations, copper may damage and destroy the liver and kidneys in the case of excessive consumption [88]. Cu and Zn levels found in our study range from 37.4 to −43.4 μgg⁻¹ with an average 40.4 ± 2.04 μgg⁻¹ for Cu and from 77.40 to −94.20 μgg⁻¹ with an average 85.91 ± 6.37 μgg⁻¹ displaying a narrow spatial distribution pattern. The results of Cu and Zn concentrations often show similar level or lower than those reported in the shale material; it is noted that the estimated copper values fall in a direction close to the average value of shale material (45 μgg⁻¹) and decreasing seven folds for Cu and five folds for Zn in comparison with the ERM values (Table 3).

Cadmium (Cd) and lead (Pb) can be considered most dangerous; studies have shown that cadmium (Cd) and lead (Pb) are elements that have a harmful effect on environment and on the ecological systems, as it is present in low levels in the natural environment. Its propagation in the environment mainly occurs through human activities [89–91]. Cadmium is naturally found in the environment at low concentration. It is highly toxic at exposure to very low levels. The sources of cadmium are from air, water, and food [92]. Long-term exposure causes high blood pressure, affecting the heart muscle [93]. Other heavy metal, the Pb as highly toxic can also be absorbed in inorganic forms. The average range values were from 0.69 to 1.34 μgg⁻¹ (0.95 ± 0.24 μgg⁻¹) for Cd, and from 25.65 to −32.73 μgg⁻¹ (29.49 ± 2.34 μgg⁻¹) for Pb (Table 3). The spatial variation of Cd and Pb values recorded higher concentration than the mean values of shale material (0.3 and 20 μgg⁻¹ for Cd and Pb, respectively) of this study. Cd and Pb concentrations were higher from 3 to 2 folds than those in the shale material. The high Pb amount in the samples may be due to the vehicle emissions and atmospheric deposits on the coastal path of the Red Sea [94]. Nickel is an important metal for plants, but it has the opposite effect and becomes toxic at elevated levels [39]. The toxic effects of nickel include inhibition of the germination process and reduced growth of roots and shoots [95].

Spatial variations of total concentration of Ni and V in the sediments of the study area are given in Table 3. The range and average concentrations (μgg⁻¹) were 15.30–18.93 (17.00 ± 1.45) for Ni and 8.12–12.80 (10.11 ± 1.70) for V. Ni revealed low values when compared with some studies in sediment quality guidelines (SQGs). Comparing the data of this study with the values of both ERL and ERM, it was found that Ni at 100% of sampling sites is below the ERL value (20.9 μgg⁻¹), which indicates that Ni is not likely to have adverse effects on organisms that live in the sediment. Generally, the results of V concentration show no marked trend in its regional distribution over the study sites.

3.5. Applying of pollution indicators

The concentrations of metals in the collected samples can be evaluated by applying different approaches of contamination indices (Contamination factor (Cf), Degree of contamination (Cd) geo-accumulation index (Igeo), Enrichment Factor (EF) and modified degree of contamination (mCd)). The contaminated indicators of toxic metals were calculated based on the background levels in the earth crust [36].

3.5.1. Enrichment factor (EF)

The values of enrichment factor, calculated in the present study, were discussed as reported by Birch [96] and divided according to Sutherland [97] in Table 4. The results revealed that Zn, Cu and Pb are significant enrichment factors (EF range; 9.72–12.51 for Zn; 10.08–12.16 for Cu; EF range, 15.56–19.53 for Pb), the EF values of Cd ranged from very high enrichment to extremely high enrichment (EF range 26.37–54.25 for Cd), as shown in Figure 3. On the other hand, Mn and Ni are moderate enrichment factors (EF range, 3.25–3.592 for Mn: ER range 2.74–3.51 for Ni). Generally, Vanadium (V) showed EF lower than one (minimal enrichment). Anthropogenic sources of Cd, Pb, Zn, Cu, and Ni, which have an enrichment factor of more than 10, are believed to have a wide range of potential effects of the aquatic system derived from human activities [96–99]. The direct and indirect sources are mainly responsible for heavy metals in the studied sediments. The urban run-off is another source of accumulation of heavy metals in surface sediments of this area since log period. As a result of the increase in biological activity and the
Table 4. Enrichment Factor (EF) and Toxic Risk Indicator (TRI) for contamination levels in sediments.

| Enrichment Factor (EF) | Toxic Risk Indicator (TRI) |
|------------------------|----------------------------|
|                        | Sutherland [97]            |
|                        | Kükrer et al. [101]        |
| EF Value               | EF Level                   |
| 2.0 < EF < 5.0         | Minimum enrichment         |
| 5.0 < EF < 20.0        | Moderate enrichment        |
| 20.0 < EF < 40.0       | Very high enrichment       |
| EF ≥ 40                | Extremely high enrichment  |
| TRI Value              | TRI Level                  |
| 5 < TRI ≤ 10          | Low toxic risk             |
| 10 < TRI ≤ 15         | Moderate toxic risk        |
| 15 < TRI ≤ 20         | Considerable toxic risk    |
| TRI > 20              | Very high toxic risk       |

growth process of plants and mangroves, the absorption of elements from the surrounding environment and the study area, and because of the decomposition of these plants after the fall of leaves and dead roots, trace metals transported down to the sediments; this will lead to an increase in the metals.

3.5.2. Geo-accumulation index (Igeo)

The scope of the geo accumulation index (Igeo) has been used in many studies to determine the state of pollution. Seven cases have been identified from seven categories [44,100]: very strongly polluted (Igeo ≥ 5); strongly to very strongly polluted (4 < Igeo < 5); strongly polluted (3 < Igeo < 4); moderately to strongly polluted (2 < Igeo < 3); moderately polluted (1 < Igeo < 2); unpolluted to moderately polluted (0 < Igeo < 1) and unpolluted (Igeo ≤ 0). The values of Igeo of the studied metals are shown in Figure 3. Among the investigated metals, the values of Igeo revealed the decreasing order of cadmium (Cd) > lead (Pb) > zinc (Zn) > copper (Cu) > nickel (Ni) > manganese (Mn) > iron (Fe) > vanadium (V). The range and average values of Igeo of the studied sediments are presented in Figure 3. The interpretation of Igeo was according to Müller [44], which is lower than one for Mn, Fe, Zn, Pb, Cu, V, and Ni (unpolluted metals), while Cd was within the range (1 < Igeo < 2) as moderately polluted.

3.5.3. Contamination factor (CF)

According to Hökanson [49], CF was divided into the following groups: low CF (CF < 1); moderate CF (1 ≤ CF < 3); high CF (3 ≤ CF < 6); very high CF (CF ≥ 6). The range and average values of the obtained CF results are 0.079–0.088 (0.084), 0.280–294 (0.286), 0.815–0.992 (0.904), 0.830–0.964 (0.898), 1.283–1.637 (1.475), 2.300–4.467 (3.151), 0.225–0.278 (0.250), and 0.062–0.098 (0.078) for Fe, Mn, Zn, Cu, Pb, Cd, Ni, and V, respectively (Figure 4). The trend values of contamination factor are less than one for all the studied metals except Pb (average, 1.5) and Cd (average, 3.2).
3.5.4. Toxicity risk indicator (TRI)

According to Kükrer et al. [101], toxicity risk indicator can be divided into five categories (Table 4). TRI threshold values of sediments contain some living biota, according to the eco-toxicological laboratory experiments. The different indices of contaminations can be used for different approaches to provide the broader perception and a wider insight into the ecological risk assessment of the metals. The TRI calculations of the sediment samples (Figure 5) ranged from 17.23 to −19.10, with an average of 15.15. The eco-toxic risk level of the mangrove sediments is at considerable level ($15 < \text{TRI} \leq 20$). The highest metal contribution to TRI was recorded by the following order: copper ($6.43$) > nickel ($3.23$) > cadmium ($2.99$) > lead ($2.86$) > zinc ($2.69$). According to Kükrer et al., the calculated values...
of TRI index, which are generally ranged from 17 to 19 \((15 < \text{TRI} \leq 20)\), indicate that the sediment of the examined area is considerably contaminated.

### 3.6. Toxic metal concentrations in mangrove tissue samples

The metal concentrations of Mn, Fe, Zn, Pb, Cu, Cd, V, and Ni \((\mu g g^{-1} \text{ dry weight})\), presented in Table 5, were determined in tissue samples of mangrove trees (leaves and roots, *Avicennia Marina*) collected from Al-Budhai area in the Red Sea coast of Jeddah.

The average concentrations of Mn, Fe, Zn, Pb, Cu, Ni, Cd, and V \((\mu g g^{-1} \text{ dry weight})\) in mangrove leave samples were 89.76 \(\pm\) 4.36, 560.45 \(\pm\) 95.36, 94.96 \(\pm\) 11.05, 30.64 \(\pm\) 3.21, 69.81 \(\pm\) 5.46, 1.45 \(\pm\) 0.57, 19.37 \(\pm\) 2.17, and 8.05 \(\pm\) 1.28, respectively.

The mean values of metal concentration of the studied mangrove leaves are significantly diverse and a decreasing trend was found as Fe \(>\) Mn \(\approx\) Zn \(>\) Cu \(>\) Pb \(>\) Ni \(>\) V \(>\) Cd, whereas the mean concentration of these metals in mangrove root samples were in the following order: Fe \(>\) Zn \(\approx\) Cu \(>\) Mn \(>\) Pb \(>\) Ni \(>\) V \(>\) Cd. It is clear from Table 5 and Figure 6 that the contaminations of metals in mangrove tissue samples were not evenly distributed among the studied locations. Diverse metal concentrations were found in the study areas because of natural phenomenon, human induced activities and pollution rate. The study by Almahasheer et al. [102] explained the ecological importance and vital role of grey mangroves through the absorption and accumulation of metals in mangrove tissues. Therefore, attention must be paid to these plants because of their vital role in cleaning coastal areas of these toxic metals.

Table 6 shows a comparison of heavy metal concentrations in the current study with the previous works [18,103–109]. A noticeable difference was found between the current concentrations of the metals by comparing them with the concentration in the previous studies. It was found, in comparison to the permissible limits, that Zn increased twice, Cu increased seven times, Pb increased fifteen times, and Cd increased from forty to hundred folds [109] (Table 6). The explored metal concentrations in the mangrove tissues in the Al-Budhai area of Jeddah coast were relatively higher than the other locations due to the human-induced activities in this vicinity of studied sites. Some common tools are used to calculate bioaccumulation indices, as suggested by several researchers [105, 110–111].

Metal translocation factor (TF) is assessed by metal transport from roots to leaves [56–58]. This indicator is an important tool to evaluate the feasibility of a plant...
Table 6. Comparison between the present data of metal concentrations (μg g⁻¹) in mangrove tissues (leaves and Roots) of the study area with those recorded in the other studies.

|       | Fe          | Mn          | Zn          | Cu          | Pb          | Cd          | Ni          | V           | References               |
|-------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|--------------------------|
| Leaves | 433.3–674.9 | 82.5–94.5   | 78.8–111.13 | 60.5–76.1   | 27.3–34.8   | 0.76–2.15   | 16.8–22.9   | 6.3–9.8     | Present Study            |
| 262–555 | 23.2–101.6 | 6.6–16.9    | 2.18–3.16   | 7.9–8.72    | 0.11–0.20   | 1.1–2.1     | 14.7–21     | 6.3–9.8     | Almahasheer et al. [102]  |
| 39.54–375.4 | 4.14–65.9  | 0.0–4.23    | 4.17–6.83   | 0.22–0.57   | 0.00–0.01   | 6.74        |             |             | Ubong and Obunwo [104]   |
| 264–458 | 9.40–17.70 | 15.4–21.38  | 3.0–4.12    | 0.06–0.14   | 0.05–0.10   | 4.1–6.0     |             |             | Abohassan [18]           |
| 5500–10,500 | 308–510   | 146.0–220   | 1.7–3.2     | 0.22–0.73   | 0.00–0.01   | 6.74        |             |             | Al Hagibi et al. [106]   |

| Roots  | 459.3–696.4 | 81.6–101.8  | 96–115.7    | 36.4–46.1   | 1.59–2.64   | 20.3–25.1   | 6.2–8.5     |             | Present Study            |
| 115.1  | 4           | 1.63        | 3.73        | ND–0.30     | 0.07        | 4.7         |             |             | Abohassan [18]           |

Figure 6. Trace metal concentrations in mangrove plant tissues (roots and leaves).

for phyto-remediation purposes. If a mangrove tree has a BCFroots value > 1 and TF value < 1, it can be used for phyto-stabilization, whereas if the BCFleaves value is > 1, it can be used for phyto-extraction [112]. Plants having phyto-stabilization and metal-tolerance capacity could be potentially useful for phytoremediation.

The values of phytoremediation indices, Biological Accumulation Factor (BAFleaves), Biological Concentration Factor (BCFroots) and translocation Factor (TF) for the studied metals in Avicennia Marina collected from Al-Budhai area, Saudi Arabia Red Sea Coast are presented in Table 7. It was found from the calculation of the transfer factor (TF) values of the studied metals that the tissues of mangrove plants (Avicennia Marina) have a high capacity in the phytoremediation process, and it was observed that the order of metals as was follows: Fe 0.83–1.38 (1.03 ± 0.21) > Mn 0.81–1.13 (0.97 ± 0.11) > Zn 0.68–1.08 (0.87 ± 0.14) ≈ Ni 0.72–1.11 (0.88 ± 0.14) ≈ V 0.71–1.11 (0.88 ± 0.14) > Cd 0.30–1.35 (0.80 ± 0.40) > Pb 0.59–0.95 (0.75 ± 0.15) > Cu 0.54–0.77 (0.69 ± 0.09).

As shown in Figure 7 and Table 7 differences were recorded in the calculated TF values of the studied elements. The differences may be due to the physiological conditions of the plant where uptake depends on the element content in the sediment and the physiological demand of the plant [91,113]. Fe, Mn, Zn, and V revealed the highest TF, and have a direct influence on concentrations in mangrove leaves. The TF values of metals in the present study were shown different; this may be due to the movement of metals and the behaviour of transporting them from the sediment to the parts of mangrove tree as well as the physical and chemical properties of the sediment [91].

Table 7. Biological Accumulation Factor (BAFleaves), Biological Concentration Factor (BCFroots) and Translocation Factor (TF) in Avicennia Marina collected from Al-Budhai area, Red Sea.

|       | BAFleaves | BCFroots | TF         |
|-------|-----------|----------|------------|
| Fe    | 0.11–0.17 | 0.11–0.19 | 0.83–1.38  |
| Mn    | 0.34–40   | 0.34–42  | 0.81–1.13  |
| Zn    | 0.37±0.02 | 0.38±0.3  | 0.97±0.11  |
| Cu    | 0.22±0.14 | 0.25±0.01 | 0.87±0.14  |
| Pb    | 0.22–0.30 | 0.31–0.45 | 0.59–0.95  |
| Cd    | 0.26±0.04 | 0.36±0.05 | 0.75±0.15  |
| Ni    | 0.25–0.99 | 0.41–1.02 | 0.30–1.35  |
| V     | 0.28–0.41 | 0.27–0.57 | 0.71–1.11  |
|       | 0.33±0.04 | 0.40±0.10 | 0.88±0.14  |
3.7. Correlation matrix

In general, correlation analysis between two variables is commonly performed in finding the relationship between two different parameters. This type of analysis has been largely carried out in environmental studies and research [114]. To understand the relationship between the obtained data of the various studied parameters, dissolved trace metals in seawater, total metal concentrations in sediments and seawater and sediment characteristics (grain size analysis, organic matter, CaCO$_3$) were subjected to statistical studies using the Pearson correlation analysis; the results revealed negative and positive correlations (Table 8). The total dissolved metals in seawater (Cu, Pb, and V) and total Fe in the sediments showed a significant positive correlation with Mud ($r = 0.819$, $0.765$, $0.692$, and $0.687$, respectively at $n = 9$, $P \leq .05$): the correlation coefficients of metals in seawater and sediment showed correlations between several metal pairs ($P \leq .05$), high significant positive correlations between total Cu and total Zn in sediments ($r = 0.822$ at $n = 9$, $P \leq .05$), positive correlations between dissolved Cu and total Fe in sediments ($r = 0.837$ at $n = 9$, $P \leq .05$), seawater salinity shows a positive correlation with Cd and V ($r = 0.726$ and $0.696$, respectively at $n = 9$, $P < .05$), while there is a negative correlation with total Zn in the sediments ($r = 0.684$ at $n = 9$, $P \leq .05$). A significant negative correlation ($r = -0.747$; $P \leq .05$) was obtained between Mn in seawater and total Zn in the sediments. While a significant positive correlation ($r = 0.744$ and $0.733$; $P \leq .05$) recorded between dissolved Mn and dissolved Cd in seawater and total Pb in sediments. Generally, the previous studies recorded by Lu et al. [115] showed that if the correlation coefficient is positive between the studied metals, then these metals are from the same source, interdependence, and similar behaviour during transport. On the contrary, if the correlation was negative between the studied parameters, they originated from various sources.

3.8. Cluster analysis (CA)

CA was applied to discover the unified groups between the physical and chemical variables, and trace metals in water and sediment profile for all the studied samples and the results are described in Figure 8. CA was classified into two groups based on metal concentrations. Group A included Fe-w, Zn-S, Cu-s, Ni-s, sand and CaCO$_3$. Group B was further separated into three groups: Group B1 included Cu-w, Pb-w, Fe-s, DO, and silt Clay (Mud) was redistributed between iron content and Mud in the sediments with changing dissolved oxygen level in the seawater, effects of seawater dissolved oxygen variability on dissolved copper and lead and group B2 included Mn-s, Pb-s, V-w, pH, and OM revealed the important role of organic matter and pH values on the distribution of Mn, Pb, and V. The important factors of pH and OM affect bioavailability, leaching and toxicity of metals in sediments. Clay, iron, and manganese oxides are an important component, and group B3 included V-s, Ni-w, Zn-w, Cd-w, Mn-w, Cd-s and salinity. Group B3 revealed the important role of water salinity in the distribution of metals because it has a complex composition of various organic and inorganic substances Metals (Mn, Fe, Cu, Zn, Cd, Pb, Ni, and V) with properties of surface seawater and surficial sediments were clustered due to anthropogenic source. As shown in Figure 8, the results of cluster analysis (CA)
Table 8. Correlation coefficient between trace metals, physicochemical characteristics of seawater and sediment characteristics of the study area.

| S‰ | pH  | DO  | Fe  | Mn  | Zn  | Cu  | Pb  | Cd  | Ni  | V   | Sand | Mud | OM  | CaCO₃ | FeS  | MnS | ZnS  | CuS | PbS | CdS | NiS | Vs  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-------|------|-----|------|-----|-----|-----|-----|-----|
|     |     |     |     |     |     |     |     |     |     |     |      |     |     |       |      |     |      |     |     |     |     |     |
| S‰ | 1   |     |     |     |     |     |     |     |     |     |      |     |     |       |      |     |      |     |     |     |     |     |
| pH  | .084 | 1   |     |     |     |     |     |     |     |     |      |     |     |       |      |     |      |     |     |     |     |     |
| DO  | .347 | −.239 | 1   |     |     |     |     |     |     |     |      |     |     |       |      |     |      |     |     |     |     |     |
| Fe  | −.693 | .452 | −.251 | 1   |     |     |     |     |     |     |      |     |     |       |      |     |      |     |     |     |     |     |
| Mn  | .327 | .213 | −.520 | −.178 | .585 | 1   |     |     |     |     |      |     |     |       |      |     |      |     |     |     |     |     |
| Zn  | .367 | .294 | .444 | .306 | .178 | −.039 | 1   |     |     |     |      |     |     |       |      |     |      |     |     |     |     |     |
| Cu  | .349 | .152 | .073 | .098 | .489 | .688 | 1   |     |     |     |      |     |     |       |      |     |      |     |     |     |     |     |
| Pb  | .267 | .480 | −.171 | .255 | .744 | .554 | .421 | .385 | 1   |     |      |     |     |       |      |     |      |     |     |     |     |     |
| Cd  | −.033 | −.364 | −.083 | −.265 | −.080 | .405 | −.201 | .300 | .113 | 1   |     |     |     |       |      |     |      |     |     |     |     |     |
| Ni  | .144 | .735 | .019 | .472 | .540 | .201 | .642 | .345 | .576 | −.130 | 1   |     |     |       |      |     |      |     |     |     |     |     |
| V   | −.329 | −.390 | −.432 | .451 | .050 | .060 | −.155 | −.033 | .291 | −.290 | −.161 | 1   |     |     |       |      |     |      |     |     |     |     |     |
| sand | .537 | .586 | .321 | .132 | .427 | .287 | .819 | .765 | .471 | −.097 | .692 | .058 | 1   |     |     |      |     |     |     |     |     |
| Mud | .168 | −.128 | −.161 | −.497 | .305 | .161 | −.577 | −.626 | −.220 | −.106 | −.128 | −.410 | −.435 | 1   |     |      |     |     |     |     |     |
| OM  | −.350 | .140 | −.360 | .085 | −.152 | .314 | −.556 | −.063 | −.126 | .073 | −.363 | .563 | −.167 | .038 | 1   |     |     |     |     |     |     |
| CaCO₃| −.726 | .703 | .168 | −.031 | −.224 | .833 | −.558 | −.023 | −.192 | .552 | −.393 | .687 | −.436 | −.623 | 1   |     |     |     |     |     |     |
| FeS | .393 | −.122 | .486 | −.545 | .349 | −.051 | −.150 | −.358 | .071 | .278 | .105 | −.581 | −.047 | .546 | −.280 | −.156 | 1   |     |     |     |     |     |     |
| MnS | −.684 | −.191 | −.184 | .184 | −.747 | −.272 | −.538 | −.244 | −.745 | .121 | −.415 | .084 | −.430 | −.002 | .583 | −.220 | −.304 | 1   |     |     |     |     |     |
| ZnS | −.618 | −.191 | −.184 | .184 | −.747 | −.272 | −.538 | −.244 | −.745 | .121 | −.415 | .084 | −.430 | −.002 | .583 | −.220 | −.304 | 1   |     |     |     |     |     |
| CuS | −.646 | .133 | −.654 | .280 | −.362 | −.005 | −.630 | −.332 | −.501 | −.061 | −.233 | .295 | −.454 | .186 | .596 | −.324 | −.447 | .822 | 1   |     |     |     |     |
| PbS | .528 | .595 | .207 | −.092 | .733 | .013 | .383 | −.023 | .440 | −.146 | .710 | −.264 | .484 | .169 | −.542 | .393 | .544 | −.617 | −.425 | 1   |     |     |     |
| CdS | −.726 | .077 | .233 | −.526 | .426 | .657 | .247 | .634 | .311 | .349 | .101 | −.201 | .614 | −.004 | .185 | .106 | .252 | −.320 | −.420 | .139 | 1   |     |     |     |
| Nis | −.658 | −.511 | −.268 | .193 | .056 | −.208 | −.025 | −.005 | −.034 | −.156 | .046 | .539 | .118 | −.413 | .099 | .161 | −.348 | .147 | .331 | .237 | −.229 | 1   |     |     |     |
| Vs  | .906 | −.153 | −.142 | −.547 | .603 | .456 | .074 | .122 | .452 | −.026 | −.125 | −.021 | .039 | −.253 | −.311 | −.117 | .131 | −.762 | −.509 | .209 | .364 | −.160 | 1   |

*Correlation is significant at the 0.05 level (two-tailed).
*aCorrelation is significant at the 0.01 level (two-tailed).
were compatible with those obtained from the Pearson correlation analysis, thus reflecting that these metals originated from a common source.

4. Conclusions

Generally, total average metal concentrations throughout the studied area were recorded in the following order: iron > manganese > zinc > copper > lead > nickel > vanadium > cadmium. This study found that the studied metal concentrations were low compared with those of ERL and ERM. However, the amounts of Cd and Cu at most stations exceeded the ERL, indicating that occasional adverse biological effects could be expected. Four indices (EF, Igeo, Cf and TRI) were used depending on mathematical equation and the crust metal background. The mean TRI values of studied metals have been found as descending sequences of Cu > Ni > Cd > Pb > Zn. The findings of the present study illustrated the environmental important and vital role of mangrove plan tissues (Avicennia Marina) through toxic metal uptake as good phyto-accumulators for metals in their roots and leaves. The current study concluded that A. Marina distinguished by the ability to remove and clean contaminated sediments from heavy metals.

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