

# Spatial and Seasonal Variations of Heavy Metals in Water and Sediments at the Northern Red Sea Coast

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**Abstract** The spatial and seasonal variations of heavy metals concentrations (Cd, Cu, Ni, Zn, Pb, Co, Mn, Fe) in water and sediments of different sites at the Northern Red Sea coast during the year 2012 were investigated. The results revealed a small range of variation and regional irregularities. Site III (Hurgaha Harbor) recorded the highest metal concentrations in water and sediments except Co during the different seasons. The annual means of metal concentrations in water were  $0.14 \pm 0.04$  -  $0.42 \pm 0.03$ ,  $0.39 \pm 0.11$  -  $4.71 \pm 0.87$ ,  $0.16 \pm 0.04$  -  $2.15 \pm 0.10$ ,  $0.94 \pm 0.07$  -  $12.07 \pm 2.78$ ,  $0.73 \pm 0.43$  -  $5.84 \pm 0.74$ ,  $0.10 \pm 0.02$  -  $0.42 \pm 0.01$ ,  $0.06 \pm 0.04$  -  $0.39 \pm 0.07$  and  $8.68 \pm 0.80$  -  $36.53 \pm 2.76 \mu\text{g l}^{-1}$  for Cd, Cu, Ni, Zn, Pb, Co, Mn and Fe, respectively, while in sediments were  $1.73 \pm 0.36$  -  $4.40 \pm 1.99$ ,  $8.5 \pm 0.37$  -  $111.3 \pm 23.89$ ,  $16.20 \pm 1.39$  -  $39.00 \pm 1.95$ ,  $19.23 \pm 3.01$  -  $190.33 \pm 13.02$ ,  $16.00 \pm 0.82$  -  $80.33 \pm 4.19$ ,  $10.10 \pm 1.68$  -  $19.23 \pm 2.47$ ,  $106.00 \pm 10.20$  -  $323.33 \pm 46.35$  and  $4172.00 \pm 430.37$  -  $14222.33 \pm 691.02 \mu\text{g g}^{-1}$ , respectively. According to different standard marine water and sediments quality guidelines, heavy metals concentrations at the most of studied sites appeared within the normal range.

**Keywords:** heavy metals, seasonal variations, red sea

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## 1. Introduction

Red Sea is a deep semi-enclosed and narrow basin, lies between  $12 - 30^\circ \text{N}$  and  $32 - 44^\circ \text{E}$ , it is about 1930 km long with an average width of 280 km [1]. It has a maximum depth of 2211 m in the central median trench and an average depth of 490 m. It is connected to the Indian Ocean through Bab El-Mandab strait and extends northward to Sinai Peninsula, which divides it into the shallow Gulf of Suez and deep Aqaba Gulf [2]. The Red Sea is the habitat of more than 1000 invertebrate species, 200 soft and hard corals (3.8% of the world's coral reefs) and over 1200 fish species [3].

Nowadays, The Red Sea environments receive either locally or more widely, a variety of stresses as a result of human activities. The different anthropogenic activities included recreational resorts, urban agglomeration, marine shipping, activities of phosphate industry and fishing ports, as well as limited freshwater and sewage sources [4].

Heavy metals are natural constituents of the marine water environments. The oceans provide a vital sink for many heavy metals and their compounds. Most of these metals are present in seawater in trace concentrations, whereas excessive concentration can affect marine biota and pose risk to consumers of sea food [5]. Although there are some natural sources of these metals, the majority of heavy metals found in nearshore waters are anthropogenic.

Human activities have inevitably increased the levels of metal ions in many of these natural water systems. Heavy

metals such as Cd, Cu, Ni, Zn, Pb, Co, Mn and Fe are regarded as being serious pollutants of aquatic ecosystems because of their environmental persistence, toxicity and ability to be incorporated into food chains and ease of accumulation by various organisms [6].

The toxicity of heavy metals arises from their tendency to bind proteins or other molecules and preventing them from functioning in their metabolic role [7]. Even in small amounts metals can cause considerable damage to organisms [8]. Unlike organic pollutants, the heavy metals couldn't be eliminated from the aquatic system neither by biodegradation nor by chemical means, therefore it persists in the environment and usually present in excess of the recommended threshold limit values [9]. Following the fate of heavy metals after they enter the ecosystem becomes difficult; furthermore, they inflict damage as they move from one ecological trophic layer to another.

Heavy metal pollution in the marine environment is determined by measuring its concentrations in water, sediments and living organisms. Sediments serve as the ultimate sink for many contaminants and as a result, they pose the highest risk to the aquatic life as a source of pollution [10]. The sediments are the main repository and source of heavy metals in the marine environment and that they play a major role in the transport and storage of potentially hazardous metals [11]. In addition, heavy metal concentrations in surface sediments can provide historical information on heavy metal inputs at that location, where surface sediments used as environmental

indicators to reflect the current quality of marine systems for many pollutants [12,13].

Monitoring programs are widely known in many aquatic bodies in the world; usually by investigating the water quality and different pollution parameters in water and sediments. Therefore, monitoring and assessing the

effects of anthropogenic influence is crucial for protection and sustainable maintaining of the fragile aquatic system in the Red Sea. Continuous monitoring data are a useful source of information for the understanding of seasonal physical, chemical and biological changes in marine environments.

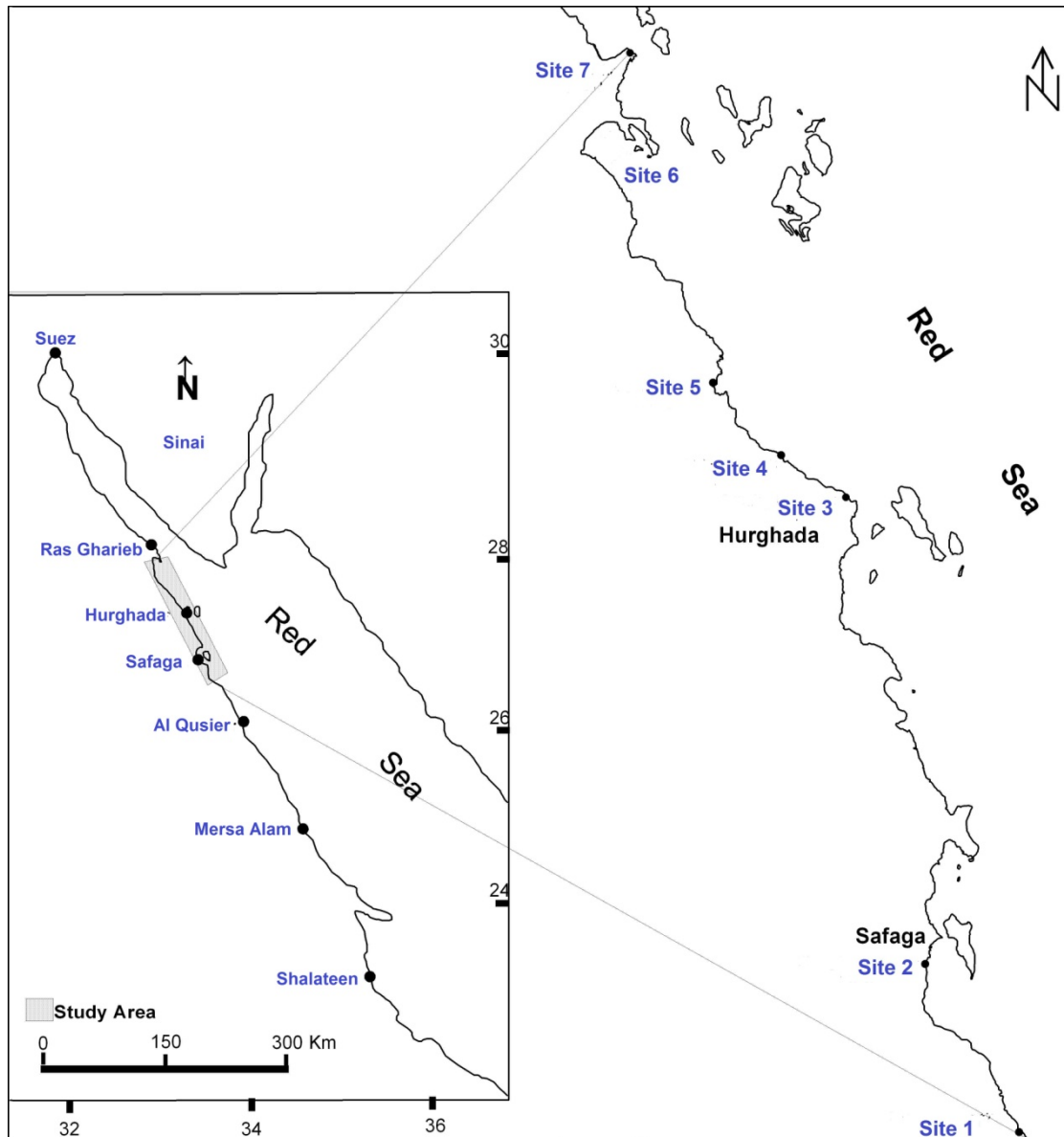


Figure 1. Map of the Red Sea showing the study area and the different sites

## 2. Material and Methods

### 2.1. Study Area

In the present investigation, the study area (Figures 1: 3) included seven sites along the northern part of the Red Sea coast from the Mangrove area (77 km south Hurghada City) to Ras El-behar (80 km north Hurghada City).

**Site I: Mangrove area (k 17)**, it is located at the end of Safaga bay, about 77 km to the south of Hurghada City ( $26^{\circ} 36' 59''$  N and  $34^{\circ} 00' 41''$  E). It is distinguished by mangrove trees (*Avicennia marina*) and tidal zone reach to about 100 m occupied by sand mud and small rocks, the tidal zone followed by deep water which begins with 5 m. There is successful transplantation operation carried out in

this area by Egyptian Environmental Affairs Agency (EEAA).

**Site II: Phosphate harbour**, it is located out of Safaga City at about 60 km south of Hurghada ( $26^{\circ} 41' 46''$  N and  $33^{\circ} 56' 20''$  E). Its activities are limited to exporting of the Egyptian phosphate, packed cement and crude alchortz.

**Site III: Hurghada harbour**, it is located at the center of Hurghada City ( $27^{\circ} 13' 48''$  N and  $33^{\circ} 50' 37''$  E), which represents the main shipyard of Hurghada City. Longtime ago this site was used to repair, maintain and construct fishing ships. Recently, these activities were developed to repair, maintain and construct safari, diving ships and yachts. Ten years ago, the southern part of the shipyard beach was used to drain the brine water of the huge desalination plant of the city [14].



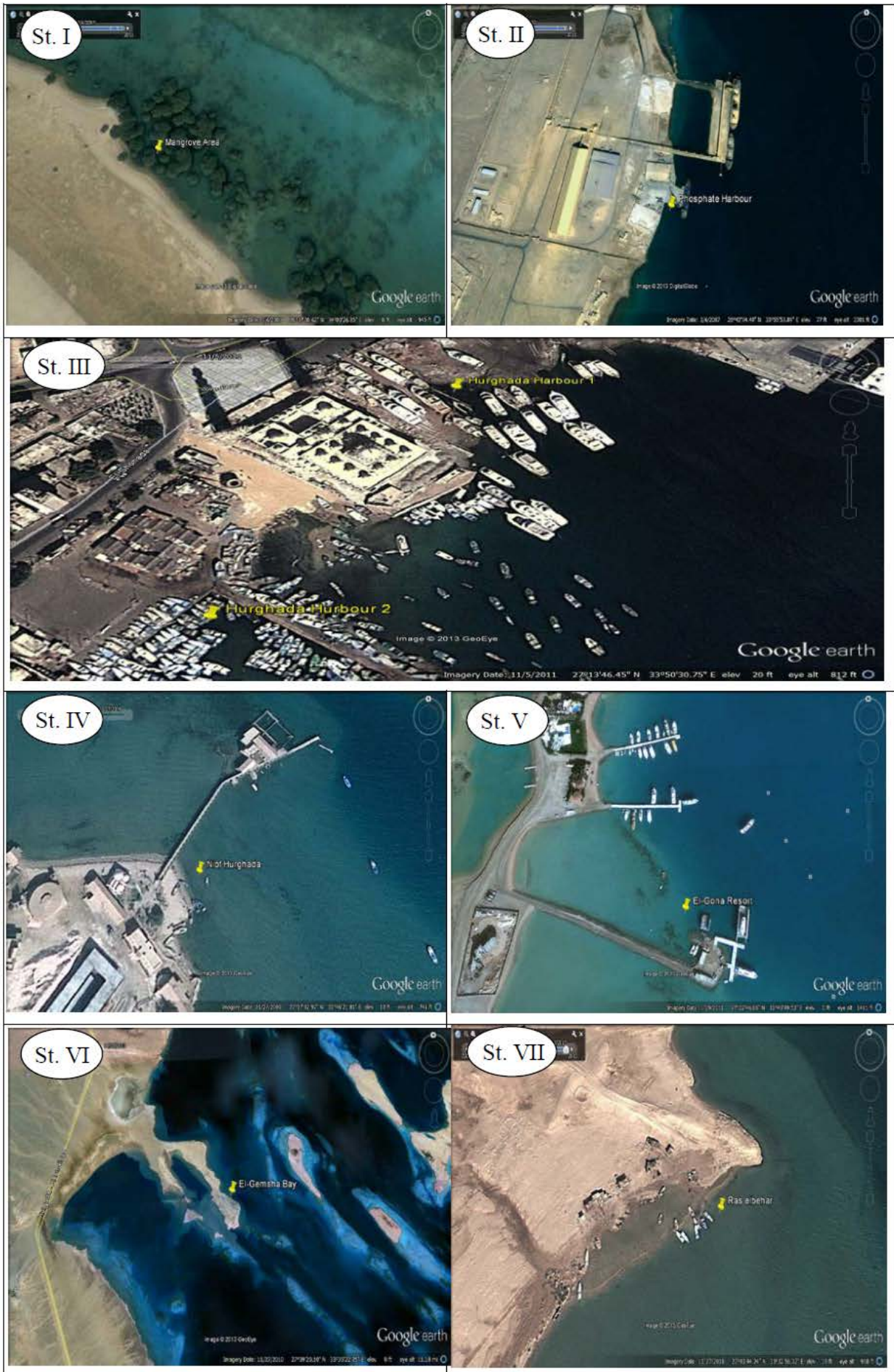


Figure 2 Satellite images for the different sites of the study area





**Figure 3.** Field pictures for the different sites of the study area

**Site IV:** NIOF, it is located in front of the National Institute of Oceanography and Fisheries (NIOF), 5 km north to Hurghada, ( $27^{\circ} 17' 3''$  N and  $33^{\circ} 46' 21''$  E).

Although it isn't located under the direct affects of anthropogenic activities like other studied sites, it is distinguished by highly sedimentation rate.

**Site V: El-Gona resort**, it is located about 22 km north of Hurghada ( $27^{\circ} 22' 39''$  N and  $33^{\circ} 41' 00''$  E), the investigated area included the touristic harbour at which construct safari, touristic diving ships and yachts are found.

**Site VI: Gemsha Bay**, it is located in the northern part of the Red Sea, about 60 km north to Hurghada ( $27^{\circ} 39' 11''$  N and  $33^{\circ} 35' 37''$  E). Gemsha Bay is one of the indentations dissecting the continuity of Red Sea northwestern shoreline. The beach of the investigated area is covered by heavy oil spills as a result of exploration and extraction activities of crude oil and flooding of some oil wells.

**Site VII: Ras Elbehar**, it is located about 80 km north to Hurghada City ( $27^{\circ} 43' 43''$  N and  $33^{\circ} 32' 56''$  E). It is distinguished by tidal zone reach to about 100 m, followed by deep water which begin with 2 m depth and reach to 15 m. Most of the area is covered by sandy mud with dead and destroyed hard corals due to oil production processes and shipping activities.

## 2.2. Methods

### 2.2.1. Determination of Heavy Metals

#### 2.2.1.1. Sampling

Two liters of sub-surface water samples were collected seasonally from the different sites in previously acid-washed polyethylene bottles. Samples were then transported immediately in icebox to the laboratory where the pH of the samples was adjusted to 3 - 4 [15].

Sediment samples (500 g) were collected from the same sites of water samples using a Van-Veen grab [16]. The samples were kept in self-sealed pre-cleaned plastic bags. The samples were deep-frozen until analysis.

#### 2.2.1.2. Processing of Samples

Water samples were filtered as soon as possible after collection through 0.45  $\mu\text{m}$  membrane filter paper and checked for their pH value (3 - 4). Metals in the filtered seawater were pre-concentrated by complexing the metals with ammonium pyrrolidine dithiocarbamate (APDC), the complexed compound was extracted into methyl isobutyl ketone (MIBK) and back-extracted into an acidic aqueous solution. 5 ml of APDC suspension ( $40 \text{ g l}^{-1}$ ) was added to one liter of sample with continuous shaking for complete chelation (5 min). A volume of 35 ml of MIBK was then added and mixed well by a magnetic stirrer for 5 min for complete extraction. The resulting organic layer was drawn by using a separating funnel, evaporated until dryness and dissolved into 2 ml of concentrated nitric acid, filtrated and completed to 10 ml with distilled water before analysis [17].

Sediment samples were air dried at room temperature. Bulk sediment samples were ground to pass through 250  $\mu\text{m}$  sieve to facilitate sample dissolution before subsequent analysis. Sediment samples were oven dried at  $70^{\circ}\text{C}$  for 12 h [18]. 0.5 g of each sample was weighed into a screw capped teflon beaker and digested with 10 ml of a mixture of concentrated  $\text{HNO}_3$ ,  $\text{HClO}_4$  and HF acids (3: 2: 1) and left overnight (12 h). The samples were then digested at  $120^{\circ}\text{C}$  for 1 - 2 h on a hot plate. The residue of each sample was dissolved into 2 ml of 12 N HCl, diluted to 25 ml with distilled water and filtered using a filter paper [19].

### 2.2.1.3. Samples Analysis

Concentrations of different metals in the final acidic extracts of water and sediments samples were measured using a flame atomic absorption spectrophotometer. This equipment (GBC 932AA) was available at the National Institute of Oceanography and Fisheries, Red Sea branch. Concentrations of heavy metals expressed in  $\mu\text{g l}^{-1}$  for water and  $\mu\text{g g}^{-1}$  for sediments.

### 2.2.2. Marine Water and Sediments Quality Evaluation

The obtained results of heavy metals levels in water and sediments were compared with some standard marine water and sediment quality guidelines to evaluate degree of water and sediment pollution by heavy metals along Egyptian Red Sea coasts. The Australian and New Zealand Guidelines (ANZECC) for Fresh and Marine Water Quality [20, 21] showed permissible limits of heavy metal in marine water for 100%, 95%, 90% and 80% protection of marine species was used for discuss the obtained values of heavy metals in seawater.

While for sediments, Canadian Sediment Quality Guidelines for Protection of Marine Life [22], Sediment Quality Guidelines of the Ontario Ministry of Environment [23] and Guidelines for Marine Sediment Quality of Florida Department of Environmental Protection (FDEP) [24] were used to investigate sediment quality degree of the northern Red Sea. These sediments quality guidelines stated three heavy metal levels for sediments, The threshold effect level (TEL) which defined as the upper limit of sediment contaminant concentrations of no-effects, the probable effect level (PEL) which defined as the lower limit of the range of contaminant concentrations that are usually associated with adverse biological effects and the severe effect level (SEL) at which the sediments considered to be severely impacted.

## 3. Results

### 3.1. Heavy Metals in Water and Sediments

Seasonal variations and annual mean of heavy metals concentrations in water and sediments collected from the different sites of the present study area were recorded (Table 1 - Table 8).

#### 3.1.1 Cadmium

Cadmium concentrations in water through all the study area ranged from  $0.14 \pm 0.04 \mu\text{g l}^{-1}$  (st. VI during winter) to  $0.42 \pm 0.03 \mu\text{g l}^{-1}$  (st. III during spring). While its concentrations in sediments were ranged from  $1.73 \pm 0.36 \mu\text{g g}^{-1}$  at st. V to  $4.40 \pm 1.99 \mu\text{g g}^{-1}$  at st. III during autumn (Table 1). St. III recorded the highest Cd concentration during the different seasons in water and sediments. St. III recorded the highest annual means of Cd in water and sediments ( $0.39 \pm 0.03 \mu\text{g l}^{-1}$  and  $3.86 \pm 0.48 \mu\text{g g}^{-1}$ ), while st. VI recorded the lowest values ( $0.22 \pm 0.06 \mu\text{g l}^{-1}$  and  $2.03 \pm 0.10 \mu\text{g g}^{-1}$ ). Different seasons had a little influence on Cd variation in water and sediments. Except extreme values, no marked differences in Cd concentration were observed in water and sediments of different sites.

Table 1. Seasonal variations of cadmium concentrations in water ( $\mu\text{g l}^{-1}$ ) and sediments ( $\mu\text{g g}^{-1}$ ) collected from the different sites

Sites		Cadmium				
		Winter	Spring	Summer	Autumn	Annual mean
St. I	Water ( $\mu\text{g l}^{-1}$ )	$0.28 \pm 0.08$	$0.24 \pm 0.04$	$0.32 \pm 0.04$	$0.33 \pm 0.02$	<b><math>0.29 \pm 0.04</math></b>
St. II		$0.19 \pm 0.01$	$0.27 \pm 0.06$	$0.34 \pm 0.04$	$0.34 \pm 0.05$	<b><math>0.28 \pm 0.07</math></b>
St. III		$0.34 \pm 0.03$	$0.42 \pm 0.03$	$0.41 \pm 0.06$	$0.39 \pm 0.01$	<b><math>0.39 \pm 0.03</math></b>
St. IV		$0.39 \pm 0.03$	$0.29 \pm 0.03$	$0.34 \pm 0.22$	$0.25 \pm 0.01$	<b><math>0.32 \pm 0.06</math></b>
St. V		$0.18 \pm 0.05$	$0.29 \pm 0.01$	$0.28 \pm 0.15$	$0.22 \pm 0.03$	<b><math>0.24 \pm 0.05</math></b>
St. VI		$0.14 \pm 0.04$	$0.27 \pm 0.01$	$0.27 \pm 0.10$	$0.18 \pm 0.06$	<b><math>0.22 \pm 0.06</math></b>
St. VII		$0.25 \pm 0.07$	$0.23 \pm 0.05$	$0.16 \pm 0.04$	$0.27 \pm 0.02$	<b><math>0.23 \pm 0.04</math></b>
St. I	Sediments ( $\mu\text{g g}^{-1}$ )	$2.47 \pm 0.54$	$1.90 \pm 0.14$	$2.16 \pm 0.79$	$2.40 \pm 0.24$	<b><math>2.23 \pm 0.26</math></b>
St. II		$2.57 \pm 0.39$	$2.20 \pm 0.22$	$3.40 \pm 0.59$	$3.90 \pm 0.50$	<b><math>3.02 \pm 0.77</math></b>
St. III		$3.37 \pm 0.37$	$3.57 \pm 0.26$	$4.10 \pm 0.29$	$4.40 \pm 1.99$	<b><math>3.86 \pm 0.48</math></b>
St. IV		$2.37 \pm 0.25$	$2.53 \pm 0.17$	$3.13 \pm 0.45$	$3.40 \pm 0.16$	<b><math>2.86 \pm 0.49</math></b>
St. V		$2.33 \pm 0.17$	$1.80 \pm 0.13$	$2.26 \pm 0.52$	$1.73 \pm 0.36$	<b><math>2.03 \pm 0.31</math></b>
St. VI		$2.03 \pm 0.47$	$1.96 \pm 0.12$	$1.95 \pm 0.68$	$2.17 \pm 0.88$	<b><math>2.03 \pm 0.10</math></b>
St. VII		$2.33 \pm 0.41$	$2.57 \pm 0.37$	$2.53 \pm 0.25$	$2.91 \pm 0.23$	<b><math>2.59 \pm 0.24</math></b>

### 3.2.2. Copper

Copper concentrations range in water of the study area was  $0.39 \pm 0.11 - 4.71 \pm 0.87 \mu\text{g l}^{-1}$ , while in sediments was  $8.5 \pm 0.37 - 111.3 \pm 23.89 \mu\text{g g}^{-1}$  during the different seasons (Table 2). St. III recorded the highest Cu concentration during the different seasons in water ( $3.01 \pm 1.13 - 4.71 \pm 0.87 \mu\text{g l}^{-1}$ ) with an annual mean of  $3.85 \pm 0.70 \mu\text{g l}^{-1}$  and sediments ( $75.33 \pm 6.60 - 111.3 \pm 23.89 \mu\text{g g}^{-1}$ ) with an annual mean of  $90.67 \pm 15.04 \mu\text{g g}^{-1}$ . St. VII (Ras Elbehar) recorded the lowest annual mean of Cu concentration in water ( $0.68 \pm 0.26 \mu\text{g l}^{-1}$ ), but in sediments,

it was recorded at st. IV ( $9.78 \pm 0.95 \mu\text{g g}^{-1}$ ). St. V (El-Gona resort) recorded the second highest annual mean values of Cu in water and sediments ( $1.98 \pm 0.76 \mu\text{g l}^{-1}$  and  $26.01 \pm 3.09 \mu\text{g g}^{-1}$ ). Seasonal variations of Cu concentrations in water of the investigated sites were considerable while in sediments no marked variations were observed during the different seasons. Except st. III and st. V, little differences were observed between Cu concentrations in water and sediments during the different seasons.

Table 2. Seasonal variations of copper concentrations in water ( $\mu\text{g l}^{-1}$ ) and sediments ( $\mu\text{g g}^{-1}$ ) collected from the different sites

Sites		Copper				
		Winter	Spring	Summer	Autumn	Annual mean
St. I	Water ( $\mu\text{g l}^{-1}$ )	$1.75 \pm 0.83$	$1.23 \pm 0.53$	$0.55 \pm 0.07$	$0.86 \pm 0.26$	<b><math>1.10 \pm 0.52</math></b>
St. II		$1.05 \pm 0.05$	$0.44 \pm 0.15$	$0.94 \pm 0.29$	$1.08 \pm 0.58$	<b><math>0.88 \pm 0.30</math></b>
St. III		$4.71 \pm 0.87$	$3.82 \pm 0.77$	$3.87 \pm 0.33$	$3.01 \pm 1.13$	<b><math>3.85 \pm 0.70</math></b>
St. IV		$1.16 \pm 0.52$	$1.32 \pm 0.35$	$0.94 \pm 0.25$	$0.50 \pm 0.05$	<b><math>0.98 \pm 0.36</math></b>
St. V		$2.52 \pm 0.70$	$2.87 \pm 0.45$	$1.77 \pm 0.80$	$1.18 \pm 0.30$	<b><math>1.98 \pm 0.76</math></b>
St. VI		$0.81 \pm 0.43$	$0.81 \pm 0.58$	$1.08 \pm 0.54$	$0.40 \pm 0.17$	<b><math>0.78 \pm 0.28</math></b>
St. VII		$1.00 \pm 0.09$	$0.58 \pm 0.20$	$0.75 \pm 0.21$	$0.39 \pm 0.11$	<b><math>0.68 \pm 0.26</math></b>
St. I	Sediments ( $\mu\text{g g}^{-1}$ )	$13.80 \pm 3.66$	$11.40 \pm 0.59$	$13.73 \pm 5.14$	$12.5 \pm 2.12$	<b><math>12.87 \pm 1.14</math></b>
St. II		$15.83 \pm 1.65$	$15.67 \pm 1.39$	$16.33 \pm 3.06$	$13.6 \pm 6.65$	<b><math>15.37 \pm 1.19</math></b>
St. III		$89.00 \pm 9.09$	$87.00 \pm 6.53$	$75.33 \pm 6.60$	$111.3 \pm 23.89$	<b><math>90.67 \pm 15.04</math></b>
St. IV		$10.83 \pm 0.54$	$9.77 \pm 0.21$	$10.00 \pm 2.06$	$8.5 \pm 0.37$	<b><math>9.78 \pm 0.95</math></b>
St. V		$24.67 \pm 5.44$	$28.00 \pm 2.16$	$22.33 \pm 6.78$	$29.1 \pm 4.63$	<b><math>26.01 \pm 3.09</math></b>
St. VI		$12.87 \pm 1.80$	$14.00 \pm 2.16$	$11.97 \pm 0.37$	$12.3 \pm 2.74$	<b><math>12.77 \pm 0.90</math></b>
St. VII		$18.67 \pm 2.05$	$14.67 \pm 2.49$	$14.50 \pm 1.06$	$12.4 \pm 4.14$	<b><math>15.05 \pm 2.63</math></b>

### 3.3.3. Nickel

The concentrations of Ni in water samples of the study area ranged from  $0.16 \pm 0.04 \mu\text{g l}^{-1}$  at st. VI (Gemsha bay) during autumn to  $2.15 \pm 0.10 \mu\text{g l}^{-1}$  at st. III during spring. While in sediments, it ranged from  $16.20 \pm 1.39 \mu\text{g g}^{-1}$  at

st. VII during autumn to  $39.00 \pm 1.95 \mu\text{g g}^{-1}$  at st. III during spring (Table 3). No marked differences were observed in Ni concentrations at the study area during different seasons. St. III showed the highest annual mean value of Ni concentrations in water and sediments ( $1.60 \pm 0.45 \mu\text{g}$



$l^{-1}$  and  $37.63 \pm 1.80 \mu\text{g g}^{-1}$ ), while st. VI recorded the lowest values ( $0.40 \pm 0.27 \mu\text{g l}^{-1}$  and  $17.00 \pm 0.45 \mu\text{g g}^{-1}$ ).

**Table 3. Seasonal variations of nickel concentrations in water ( $\mu\text{g l}^{-1}$ ) and sediments ( $\mu\text{g g}^{-1}$ ) collected from the different sites**

Sites		Nickel				
		Winter	Spring	Summer	Autumn	Annual mean
St. I	Water ( $\mu\text{g l}^{-1}$ )	$1.30 \pm 0.08$	$1.34 \pm 0.17$	$1.10 \pm 0.15$	$1.25 \pm 0.10$	<b><math>1.25 \pm 0.11</math></b>
St. II		$1.04 \pm 0.20$	$0.95 \pm 0.10$	$1.02 \pm 0.21$	$1.21 \pm 0.27$	<b><math>1.05 \pm 0.11</math></b>
St. III		$1.74 \pm 0.11$	$2.15 \pm 0.10$	$1.42 \pm 0.09$	$1.09 \pm 0.30$	<b><math>1.60 \pm 0.45</math></b>
St. IV		$0.87 \pm 0.23$	$1.04 \pm 0.05$	$0.57 \pm 0.14$	$0.62 \pm 0.46$	<b><math>0.78 \pm 0.22</math></b>
St. V		$0.66 \pm 0.22$	$0.67 \pm 0.26$	$0.91 \pm 0.22$	$0.54 \pm 0.20$	<b><math>0.70 \pm 0.16</math></b>
St. VI		$0.24 \pm 0.14$	$0.77 \pm 0.17$	$0.44 \pm 0.08$	$0.16 \pm 0.04$	<b><math>0.40 \pm 0.27</math></b>
St. VII		$1.33 \pm 0.12$	$1.72 \pm 0.23$	$1.25 \pm 0.05$	$1.11 \pm 0.38$	<b><math>1.35 \pm 0.26</math></b>
St. I	Sediments ( $\mu\text{g g}^{-1}$ )	$28.33 \pm 6.65$	$27.00 \pm 3.56$	$27.33 \pm 3.40$	$25.40 \pm 2.32$	<b><math>27.02 \pm 1.22</math></b>
St. II		$26.00 \pm 4.55$	$27.00 \pm 3.56$	$24.57 \pm 2.95$	$20.83 \pm 1.33$	<b><math>24.60 \pm 2.70</math></b>
St. III		$39.00 \pm 1.41$	$39.00 \pm 1.95$	$37.33 \pm 1.70$	$35.20 \pm 1.99$	<b><math>37.63 \pm 1.80</math></b>
St. IV		$22.67 \pm 6.55$	$19.67 \pm 3.30$	$19.54 \pm 2.43$	$20.17 \pm 0.26$	<b><math>20.51 \pm 1.46</math></b>
St. V		$24.00 \pm 2.45$	$23.33 \pm 2.05$	$22.10 \pm 3.47$	$20.88 \pm 3.25$	<b><math>22.58 \pm 1.38</math></b>
St. VI		$17.33 \pm 4.50$	$17.00 \pm 2.94$	$17.30 \pm 2.42$	$16.37 \pm 3.76$	<b><math>17.00 \pm 0.45</math></b>
St. VII		$18.67 \pm 3.30$	$17.00 \pm 4.32$	$18.90 \pm 2.81$	$16.20 \pm 1.39$	<b><math>17.69 \pm 1.31</math></b>

**3.3.4. Zinc**

According to the seasonal variations of Zn concentrations in water and sediments (Table 4), Zn concentrations in water of the study area were ranged from  $0.94 \pm 0.07 \mu\text{g l}^{-1}$  at st. II during spring to  $12.07 \pm 2.78 \mu\text{g l}^{-1}$  at st. during summer. While in sediments, it

ranged from  $19.23 \pm 3.01 \mu\text{g g}^{-1}$  at st. VI during summer to  $190.33 \pm 13.02 \mu\text{g g}^{-1}$  at st. III during autumn. Seasonal variations of Zn concentrations in water was noticed while did not strongly observed in sediments. Minor differences were observed between the annual mean values of Zn concentrations along the different sites except st. III.

**Table 4. Seasonal variations of zinc concentrations in water ( $\mu\text{g l}^{-1}$ ) and sediments ( $\mu\text{g g}^{-1}$ ) collected from the different sites**

Sites		Zinc				
		Winter	Spring	Summer	Autumn	Annual mean
St. I	Water ( $\mu\text{g l}^{-1}$ )	$2.74 \pm 0.46$	$1.79 \pm 0.54$	$1.74 \pm 0.54$	$1.19 \pm 0.10$	<b><math>1.87 \pm 0.64</math></b>
St. II		$2.27 \pm 0.10$	$0.94 \pm 0.07$	$1.93 \pm 0.21$	$1.57 \pm 0.16$	<b><math>1.68 \pm 0.57</math></b>
St. III		$11.71 \pm 4.71$	$10.59 \pm 3.27$	$12.07 \pm 2.78$	$11.07 \pm 1.49$	<b><math>11.36 \pm 0.66</math></b>
St. IV		$3.75 \pm 1.27$	$1.54 \pm 0.06$	$2.08 \pm 0.12$	$1.07 \pm 0.12$	<b><math>2.11 \pm 1.17</math></b>
St. V		$2.01 \pm 0.15$	$2.23 \pm 0.34$	$2.44 \pm 0.56$	$1.60 \pm 0.34$	<b><math>2.07 \pm 0.36</math></b>
St. VI		$2.20 \pm 0.34$	$1.54 \pm 0.30$	$2.55 \pm 0.43$	$1.25 \pm 0.14$	<b><math>1.88 \pm 0.60</math></b>
St. VII		$3.73 \pm 0.97$	$4.45 \pm 0.70$	$2.26 \pm 0.60$	$2.04 \pm 0.63$	<b><math>3.12 \pm 1.16</math></b>
St. I	Sediments ( $\mu\text{g g}^{-1}$ )	$26.33 \pm 3.30$	$29.67 \pm 5.56$	$25.33 \pm 5.31$	$33.24 \pm 0.96$	<b><math>28.64 \pm 3.58</math></b>
St. II		$39.33 \pm 4.50$	$39.67 \pm 3.40$	$40.33 \pm 6.24$	$34.38 \pm 5.51$	<b><math>38.43 \pm 2.73</math></b>
St. III		$151.00 \pm 36.48$	$137.00 \pm 28.25$	$105.67 \pm 34.59$	$190.33 \pm 13.02$	<b><math>146.00 \pm 35.11</math></b>
St. IV		$25.83 \pm 4.40$	$31.67 \pm 2.05$	$26.33 \pm 5.31$	$25.81 \pm 2.58$	<b><math>27.41 \pm 2.85</math></b>
St. V		$36.33 \pm 4.78$	$30.00 \pm 5.35$	$37.33 \pm 7.72$	$38.00 \pm 4.97$	<b><math>35.42 \pm 3.68</math></b>
St. VI		$25.33 \pm 2.87$	$21.13 \pm 2.31$	$19.23 \pm 3.01$	$26.03 \pm 5.01$	<b><math>22.93 \pm 3.28</math></b>
St. VII		$26.33 \pm 4.03$	$28.33 \pm 3.86$	$25.67 \pm 2.05$	$29.75 \pm 7.16$	<b><math>27.52 \pm 1.87</math></b>

St. III recorded the highest values of Zn concentrations in water and sediments of the study area during the different seasons with an annual mean of  $11.36 \pm 0.66 \mu\text{g l}^{-1}$  for water and  $146 \pm 35.11 \mu\text{g g}^{-1}$  for sediments. While st. II recorded the lowest annual mean of zinc in water ( $1.68 \pm 0.57 \mu\text{g l}^{-1}$ ), while in sediments, st. VI recorded the lowest value ( $22.93 \pm 3.28 \mu\text{g g}^{-1}$ ).

**3.3.5. Lead**

Lead concentration in water samples from the study area ranged from  $0.73 \pm 0.43 \mu\text{g l}^{-1}$  at st. VI during spring

to  $5.84 \pm 0.74 \mu\text{g l}^{-1}$  at st. III during summer, while in sediments ranged from  $16.00 \pm 0.82 \mu\text{g g}^{-1}$  during summer to  $80.33 \pm 4.19 \mu\text{g g}^{-1}$  during winter at the same sites of water, which also showed the lowest and the highest annual mean of Pb concentrations in water and sediments (Table 5). Pb concentrations varied at different seasons in seawater of the study area but it was not obviously clear for sediments. On the other hand, Pb concentrations in the sediments showed marked variations between the surveyed sites but it was limited in water except at st. III.

Table 5. Seasonal variations of lead concentrations in water ( $\mu\text{g l}^{-1}$ ) and sediments ( $\mu\text{g g}^{-1}$ ) collected from the different sites

Sites		Lead				
		Winter	Spring	Summer	Autumn	Annual mean
St. I	Water ( $\mu\text{g l}^{-1}$ )	$2.70 \pm 0.65$	$1.69 \pm 0.35$	$2.70 \pm 0.33$	$3.30 \pm 0.31$	<b><math>2.60 \pm 0.67</math></b>
St. II		$3.10 \pm 0.67$	$2.05 \pm 0.05$	$2.40 \pm 0.50$	$1.34 \pm 0.58$	<b><math>2.22 \pm 0.73</math></b>
St. III		$3.33 \pm 0.44$	$3.78 \pm 1.05$	$5.84 \pm 0.74$	$4.06 \pm 1.74$	<b><math>4.25 \pm 1.10</math></b>
St. IV		$2.07 \pm 0.23$	$1.97 \pm 0.25$	$2.49 \pm 0.64$	$2.13 \pm 0.11$	<b><math>2.17 \pm 0.23</math></b>
St. V		$1.69 \pm 1.55$	$2.10 \pm 0.82$	$1.78 \pm 0.40$	$2.98 \pm 0.15$	<b><math>2.14 \pm 0.59</math></b>
St. VI		$2.69 \pm 0.68$	$0.73 \pm 0.43$	$1.78 \pm 0.37$	$2.33 \pm 1.69$	<b><math>1.88 \pm 0.86</math></b>
St. VII		$3.46 \pm 0.69$	$1.29 \pm 0.18$	$1.61 \pm 0.79$	$2.84 \pm 0.21$	<b><math>2.30 \pm 1.02</math></b>
St. I	Sediments ( $\mu\text{g g}^{-1}$ )	$45.33 \pm 8.58$	$43.00 \pm 9.27$	$38.70 \pm 7.36$	$44.60 \pm 3.97$	<b><math>42.91 \pm 2.97</math></b>
St. II		$40.33 \pm 4.64$	$47.67 \pm 6.02$	$47.33 \pm 3.68$	$46.88 \pm 1.91$	<b><math>45.55 \pm 3.49</math></b>
St. III		$80.33 \pm 4.19$	$69.00 \pm 4.32$	$68.33 \pm 5.79$	$73.59 \pm 4.22$	<b><math>72.82 \pm 5.53</math></b>
St. IV		$24.33 \pm 7.13$	$29.33 \pm 2.05$	$18.00 \pm 2.94$	$20.37 \pm 4.96$	<b><math>23.01 \pm 4.96</math></b>
St. V		$31.67 \pm 2.05$	$37.33 \pm 2.87$	$35.00 \pm 5.89$	$38.77 \pm 3.98$	<b><math>35.69 \pm 3.10</math></b>
St. VI		$21.67 \pm 2.05$	$19.67 \pm 2.49$	$16.00 \pm 0.82$	$18.03 \pm 3.27$	<b><math>18.84 \pm 2.41</math></b>
St. VII		$26.67 \pm 5.56$	$22.33 \pm 4.11$	$21.00 \pm 6.68$	$22.84 \pm 5.05$	<b><math>23.21 \pm 2.43</math></b>

### 3.3.6. Cobalt

As shown in Table 6, Co concentrations varied at different seasons in water of the study area but not for sediments. In seawater, Co concentrations reported the range of  $0.10 \pm 0.02 \mu\text{g l}^{-1}$  (st. VI during summer) -  $0.42 \pm 0.01 \mu\text{g l}^{-1}$  (st. I during autumn), while in sediments, it ranged from  $10.10 \pm 1.68 \mu\text{g g}^{-1}$  (st. VI during autumn) to

$19.23 \pm 2.47 \mu\text{g g}^{-1}$  (st. III during winter). The annual means of Co concentrations in water and sediments of the different sites recorded the highest values at st. I ( $0.28 \pm 0.09 \mu\text{g l}^{-1}$  and  $18.31 \pm 0.78 \mu\text{g g}^{-1}$ ) followed by st. III ( $0.25 \pm 0.03 \mu\text{g l}^{-1}$  and  $17.00 \pm 2.82 \mu\text{g g}^{-1}$ ) and st. V ( $0.22 \mu\text{g l}^{-1}$  and  $15.09 \mu\text{g g}^{-1}$ ), while st. VI recorded the lowest values ( $0.15 \pm 0.04 \mu\text{g l}^{-1}$  and  $11.33 \pm 1.25 \mu\text{g g}^{-1}$ ).

Table 6. Seasonal variations of cobalt concentrations in water ( $\mu\text{g l}^{-1}$ ) and sediments ( $\mu\text{g g}^{-1}$ ) collected from the different sites

Sites		Cobalt				
		Winter	Spring	Summer	Autumn	Annual mean
St. I	Water ( $\mu\text{g l}^{-1}$ )	$0.22 \pm 0.00$	$0.27 \pm 0.04$	$0.22 \pm 0.08$	$0.42 \pm 0.01$	<b><math>0.28 \pm 0.09</math></b>
St. II		$0.14 \pm 0.03$	$0.19 \pm 0.02$	$0.16 \pm 0.01$	$0.19 \pm 0.02$	<b><math>0.17 \pm 0.03</math></b>
St. III		$0.22 \pm 0.01$	$0.27 \pm 0.06$	$0.28 \pm 0.09$	$0.22 \pm 0.07$	<b><math>0.25 \pm 0.03</math></b>
St. IV		$0.13 \pm 0.02$	$0.14 \pm 0.03$	$0.16 \pm 0.09$	$0.25 \pm 0.03$	<b><math>0.17 \pm 0.05</math></b>
St. V		$0.16 \pm 0.04$	$0.23 \pm 0.03$	$0.16 \pm 0.02$	$0.32 \pm 0.00$	<b><math>0.22 \pm 0.08</math></b>
St. VI		$0.15 \pm 0.01$	$0.14 \pm 0.2$	$0.10 \pm 0.02$	$0.19 \pm 0.05$	<b><math>0.15 \pm 0.04</math></b>
St. VII		$0.15 \pm 0.02$	$0.18 \pm 0.01$	$0.18 \pm 0.02$	$0.28 \pm 0.01$	<b><math>0.20 \pm 0.05</math></b>
St. I	Sediments ( $\mu\text{g g}^{-1}$ )	$19.23 \pm 3.26$	$18.33 \pm 2.83$	$17.33 \pm 5.14$	$18.33 \pm 2.49$	<b><math>18.31 \pm 0.78</math></b>
St. II		$15.13 \pm 0.96$	$13.73 \pm 0.74$	$15.80 \pm 1.31$	$14.90 \pm 0.14$	<b><math>14.89 \pm 0.86</math></b>
St. III		$19.23 \pm 2.47$	$18.83 \pm 2.37$	$16.86 \pm 1.17$	$13.07 \pm 1.83$	<b><math>17.00 \pm 2.82</math></b>
St. IV		$14.63 \pm 1.64$	$15.80 \pm 1.49$	$15.47 \pm 0.87$	$12.60 \pm 2.08$	<b><math>14.63 \pm 1.44</math></b>
St. V		$16.67 \pm 1.84$	$14.00 \pm 3.65$	$16.33 \pm 1.13$	$13.37 \pm 2.67$	<b><math>15.09 \pm 1.65</math></b>
St. VI		$11.00 \pm 3.29$	$13.07 \pm 1.64$	$11.13 \pm 1.35$	$10.10 \pm 1.68$	<b><math>11.33 \pm 1.25</math></b>
St. VII		$12.5 \pm 2.92$	$13.70 \pm 2.83$	$12.80 \pm 3.02$	$10.93 \pm 0.83$	<b><math>12.37 \pm 1.17</math></b>

### 3.3.7. Manganese

Different seasons showed variations in Mn concentration in water only (Table 7). The range of Mn concentrations in water samples collected from the different studied sites was ranged from  $0.06 \pm 0.04 \mu\text{g l}^{-1}$  at st. V during autumn to  $0.39 \pm 0.07 \mu\text{g l}^{-1}$  at st. III during summer. While in sediments were ranged from  $106.0 \pm 10.20 \mu\text{g g}^{-1}$  at st. VI during summer to  $323.33 \pm 46.35 \mu\text{g g}^{-1}$  at st. III during winter. St. III recorded the highest annual mean of Mn concentrations in water and sediments ( $0.30 \pm 0.06 \mu\text{g l}^{-1}$  and  $306.92 \pm 14.24 \mu\text{g g}^{-1}$ ), while st. II showed the lowest annual mean in water ( $0.16 \pm 0.04 \mu\text{g l}^{-1}$ ). St. VII recorded the lowest one in sediments ( $121.25 \pm 07.48 \mu\text{g g}^{-1}$ ).

### 3.3.8. Iron

Iron concentrations in seawater collected from different sites of the study area ranged from  $8.68 \pm 0.80 \mu\text{g l}^{-1}$  (st. V during winter) to  $36.53 \pm 2.76 \mu\text{g l}^{-1}$  (st. III during autumn), while in sediments, it was ranged from  $4172.00 \pm 430.37 \mu\text{g g}^{-1}$  (st. VI during summer) to  $14222.33 \pm 691.02 \mu\text{g g}^{-1}$  (st. I during autumn). Table 8 shows, slightly seasonal variations for iron concentrations in water and sediments of the study area. The highest annual mean values of iron concentration in seawater ( $25.31 \pm 7.94 \mu\text{g l}^{-1}$ ) was detected at st. III, while the lowest value ( $12.70 \pm 2.02 \mu\text{g l}^{-1}$ ) was observed at st. II (Phosphate harbour). While in sediments, st. I showed the highest



annual mean of iron ( $13830.75 \pm 282.50 \mu\text{g g}^{-1}$ ) and the lowest value ( $6119.42 \pm 1528.64 \mu\text{g g}^{-1}$ ) recorded at st. VI.

**Table 7. Seasonal variations of manganese concentrations in water ( $\mu\text{g l}^{-1}$ ) and sediments ( $\mu\text{g g}^{-1}$ ) collected from the different sites**

Sites		Manganese				
		Winter	Spring	Summer	Autumn	Annual mean
St. I	Water ( $\mu\text{g l}^{-1}$ )	$0.22 \pm 0.11$	$0.18 \pm 0.04$	$0.27 \pm 0.08$	$0.12 \pm 0.05$	<b><math>0.20 \pm 0.06</math></b>
St. II		$0.15 \pm 0.09$	$0.14 \pm 0.03$	$0.21 \pm 0.06$	$0.13 \pm 0.06$	<b><math>0.16 \pm 0.04</math></b>
St. III		$0.28 \pm 0.07$	$0.30 \pm 0.02$	$0.39 \pm 0.07$	$0.24 \pm 0.05$	<b><math>0.30 \pm 0.06</math></b>
St. IV		$0.22 \pm 0.03$	$0.19 \pm 0.01$	$0.25 \pm 0.04$	$0.15 \pm 0.04$	<b><math>0.20 \pm 0.04</math></b>
St. V		$0.20 \pm 0.07$	$0.16 \pm 0.03$	$0.30 \pm 0.01$	$0.06 \pm 0.01$	<b><math>0.18 \pm 0.10</math></b>
St. VI		$0.10 \pm 0.06$	$0.21 \pm 0.00$	$0.33 \pm 0.00$	$0.06 \pm 0.04$	<b><math>0.18 \pm 0.12</math></b>
St. VII		$0.12 \pm 0.05$	$0.23 \pm 0.09$	$0.37 \pm 0.01$	$0.12 \pm 0.09$	<b><math>0.21 \pm 0.12</math></b>
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St. I	Sediments ( $\mu\text{g g}^{-1}$ )	$234.67 \pm 17.15$	$252.67 \pm 47.23$	$256.33 \pm 63.91$	$284.33 \pm 16.42$	<b><math>257.00 \pm 20.54</math></b>
St. II		$191.67 \pm 13.47$	$206.33 \pm 11.79$	$215.67 \pm 13.72$	$172.33 \pm 03.86$	<b><math>196.50 \pm 18.90</math></b>
St. III		$323.33 \pm 46.35$	$301.33 \pm 17.97$	$312.67 \pm 11.12$	$290.33 \pm 18.37$	<b><math>306.92 \pm 14.24</math></b>
St. IV		$191.67 \pm 09.88$	$182.00 \pm 14.00$	$170.33 \pm 2.05$	$186.67 \pm 33.21$	<b><math>182.67 \pm 09.12</math></b>
St. V		$185.33 \pm 18.62$	$175.67 \pm 16.42$	$173.67 \pm 35.12$	$148.33 \pm 11.95$	<b><math>170.75 \pm 15.79</math></b>
St. VI		$130.33 \pm 20.17$	$139.33 \pm 26.71$	$106.00 \pm 10.20$	$161.00 \pm 34.65$	<b><math>134.17 \pm 22.77</math></b>
St. VII		$129.33 \pm 08.38$	$124.67 \pm 09.29$	$119.00 \pm 09.20$	$112.00 \pm 07.26$	<b><math>121.25 \pm 07.48</math></b>

**Table 8. Seasonal variations of iron concentrations in water ( $\mu\text{g l}^{-1}$ ) and sediments ( $\mu\text{g g}^{-1}$ ) collected from the different sites**

Sites		Iron				
		Winter	Spring	Summer	Autumn	Annual mean
St. I	Water ( $\mu\text{g l}^{-1}$ )	$17.20 \pm 2.69$	$13.33 \pm 1.38$	$16.83 \pm 2.11$	$14.57 \pm 1.45$	<b><math>15.48 \pm 1.85</math></b>
St. II		$10.44 \pm 2.06$	$11.56 \pm 2.71$	$14.63 \pm 0.38$	$14.17 \pm 2.23$	<b><math>12.70 \pm 2.02</math></b>
St. III		$19.10 \pm 0.96$	$20.37 \pm 3.82$	$25.23 \pm 6.99$	$36.53 \pm 2.76$	<b><math>25.31 \pm 7.94</math></b>
St. IV		$10.30 \pm 0.67$	$14.14 \pm 3.50$	$16.29 \pm 3.95$	$17.16 \pm 2.68$	<b><math>14.47 \pm 3.06</math></b>
St. V		$8.68 \pm 0.80$	$11.90 \pm 3.66$	$17.31 \pm 3.27$	$16.28 \pm 4.96$	<b><math>13.54 \pm 4.00</math></b>
St. VI		$11.77 \pm 1.37$	$14.09 \pm 5.77$	$18.10 \pm 5.24$	$12.60 \pm 2.87$	<b><math>14.14 \pm 2.81</math></b>
St. VII		$11.29 \pm 1.44$	$10.92 \pm 1.69$	$20.23 \pm 6.12$	$15.27 \pm 3.34$	<b><math>14.43 \pm 4.34</math></b>
<hr/>						
St. I	Sediments ( $\mu\text{g g}^{-1}$ )	$13813.67 \pm 780.99$	$13555.00 \pm 1565.57$	$13732.00 \pm 1470.48$	$14222.33 \pm 691.02$	<b><math>13830.75 \pm 282.50</math></b>
St. II		$11663.00 \pm 653.07$	$11966.00 \pm 1980.71$	$10698.00 \pm 689.83$	$10196.00 \pm 584.13$	<b><math>11130.75 \pm 825.02</math></b>
St. III		$13159.67 \pm 1347.54$	$12522.33 \pm 1034.17$	$11172.33 \pm 843.04$	$11859.33 \pm 1631.36$	<b><math>12178.42 \pm 855.40</math></b>
St. IV		$5859.00 \pm 501.21$	$5558.67 \pm 765.97$	$4898.67 \pm 265.50$	$5278.67 \pm 1251.44$	<b><math>5398.75 \pm 409.03</math></b>
St. V		$10802.67 \pm 1422.20$	$10665.67 \pm 663.75$	$10514.33 \pm 811.08$	$9780.00 \pm 1044.04$	<b><math>10440.67 \pm 455.92</math></b>
St. VI		$6721.33 \pm 868.01$	$5804.67 \pm 776.59$	$4172.00 \pm 430.37$	$7779.67 \pm 1649.13$	<b><math>6119.42 \pm 1528.64</math></b>
St. VII		$7028.67 \pm 972.39$	$6595.67 \pm 762.06$	$7020.33 \pm 836.59$	$6853.00 \pm 449.08$	<b><math>6874.42 \pm 202.69</math></b>

## 4. Discussion

Heavy metal contamination in the marine environments is now a major worldwide environmental problem. Heavy metals abundances clearly record the dramatic changes in the environmental conditions and provide a basis for identifying anthropogenic influences on the marine environments [25,26,27]. All metals reported in the present study are mainly the normal constituents of oil, sewage, wastewaters from different sources, effluents of desalination plants, antifouling and anticorrosive paints that protect the marine vessels and metal-rich dusts transported from mountains to the sea by the prevailing winds [25,28,29,30].

In the present study, st. III (Hurghada harbour) recorded the highest heavy metals concentrations in water and sediments during the study period except of cobalt, while st. VII (Ras Elbehar area) recorded the second highest values of Zn, Ni and Mn in water samples, this may

attributed to: increase sewage, wastewater discharges associated with fishing harbours disposals and antifouling paints found in the area; desalination plant input; zinc, copper and cupric oxide released from the antifouling and anticorrosive paints that protect the hulls of marine vessels; gasoline fuel emissions from atmosphere, recreational yachts and fishing boats may increase the Pb concentration. In addition to the limited water currents and slow rate of water exchange in these sites tend to enhance the conditions suitable for accumulation of organic matter. St. VI (Gemsha Bay) recorded the lowest concentrations of Cd, Ni, Pb and Co in water and sediments, st. II (Phosphate harbour) recorded the lowest values of Zn, Mn and Fe, which may due to the little exposure to anthropogenic activities and absence of severe heavy metals sources, also sandy texture of sediments observed at the two sites which lowering preservation, adsorption and accumulation of metals on its surface. The general trend observed in our investigation for the concentrations of heavy metals in seawater was ranked in the following

order: Fe > Zn > Pb > Cu > Ni > Cd > Mn > Co, while in the sediments was Fe > Mn > Zn > Pb > Cu > Ni > Co > Cd.

Cadmium is highly toxic and originates from anthropogenic activities. It was found that more than 90% of cadmium in marine environments is of anthropogenic origin [31,32]. Cadmium is a relatively rare element with concentrations ranging from  $2 \times 10^{-4}$  to  $2.9 \mu\text{g l}^{-1}$  in the open oceans [33]. However, in polluted estuaries or harbours and ports, values up to  $50 \mu\text{g l}^{-1}$  have been recorded [34]. The annual means of cadmium concentrations in seawater of the investigated area ( $0.22 \pm 0.06 - 0.39 \pm 0.03 \mu\text{g l}^{-1}$ ) were within the normal range of open oceans and less than the critical threshold level ( $0.7 \mu\text{g l}^{-1}$ ) of the Australian Water Quality Guidelines for 99% protection marine organisms. In the sediments, the annual means of cadmium concentrations exceeded the TEL ( $0.6 - 0.7 \mu\text{g g}^{-1}$ ) and about to reach the PEL of marine sediments quality guidelines.

While copper is an essential trace element required by most aquatic organisms but its high concentration is toxic [35]. Copper concentrations in seawater ranged from  $8 \times 10^{-4} \mu\text{g l}^{-1}$  in pristine open oceans up to  $29.2 \mu\text{g l}^{-1}$  at highly polluted sites [33]. The annual means of copper concentrations in seawater of the investigated sites ( $0.68 \pm 0.26 - 3.85 \pm 0.70 \mu\text{g l}^{-1}$ ) were exceeded the lower concentration in pristine open oceans and Australian Water quality Guidelines. Copper concentration in seawater at st. III and st. V were higher the normal levels and about to reach the limited concentration ( $3 \mu\text{g l}^{-1}$ ) for 90% protection for marine species recoded at the Australian Water quality Guidelines, while the annual means of copper concentration in the sediments of the investigated area ( $9.78 \pm 0.95 - 90.67 \pm 15.04$ ) showed that, most sites were lower than the TEL of Cu, except st. III which about to reach the PEL, and st. V which slightly increased TEL of the marine sediments quality guidelines.

Nickel is one of the largest trace metal constituents of crude oil [29,36], hence its presence in high concentration in marine environments may indicate direct input from oil pollutants. Nickel can enter the environment naturally through weathering of minerals and rocks and through anthropogenic sources [37]. The investigated range of annual means of Ni concentrations in seawater of the study area ( $0.40 \pm 0.27 - 1.60 \pm 0.45 \mu\text{g l}^{-1}$ ) was within the normal range and less than the critical threshold level ( $7 \mu\text{g l}^{-1}$ ) of the Australian Water Quality Guidelines for 99% protection marine organisms. While Ni concentrations in sediments of the study area were around or slightly higher than the TEL of Ni, but didn't reach PEL of marine sediments guidelines.

Zinc is an essential trace element required by most organisms for their growth and development. Zinc concentrations recorded throughout the world's open oceans average of  $5 \mu\text{g l}^{-1}$  [38]. It can enter the environment from both natural and anthropogenic processes [39]. The annual means of Zn concentrations in seawater and sediments at the different studied Site were within the normal range of the different water and sediments quality guidelines except, st. III, which Zn concentration exceeded the world's open oceans average ( $5 \mu\text{g l}^{-1}$ ), Australian Water Quality Guidelines for 99% protection of marine species ( $7 \mu\text{g l}^{-1}$ ) and the PEL of marine sediment quality guidelines ( $120 - 124 \mu\text{g g}^{-1}$ ).

Lead is among the most pervasive of pollutants has introduced to the marine environment due to human activities. In local coastal regions, lead pollution may also be present in sewage contamination [40]. Anthropogenic outputs of lead to the environment outweigh all natural sources. Lead reaches the aquatic environment through precipitation, fall-out of lead dust and municipal wastewater discharges [41,42]. The annual means of Pb concentrations in seawater and sediments of the different Site were around the range of the Australian Water Quality Guidelines for 99% protection ( $2.2 \mu\text{g l}^{-1}$ ) and lower than the TEL of marine sediments quality guidelines except, st. III, which recorded Pb concentrations up to the level of 95% protection in water and the PEL in sediments.

Cobalt is an essential metal for living organisms in low concentrations but may be toxic in high concentrations [43]. It is adsorbed to suspended particles and sediments but its solubility may be increased by complexing with organic matter, such as from sewage works [39]. De Carlo and Spencer illustrated that, Co concentrations between 50 and  $80 \text{mg g}^{-1}$  may be representative of the amount of natural Co associated primarily with the readily solubilized mineral assemblage of the sediments [32]. While, practical quantitation limit (PQL) for cobalt is  $2 \mu\text{g l}^{-1}$  in marine water [44,45] The annual means of cobalt concentrations in seawater of the study area were higher than the Australian Water Quality Guidelines value for 99% and lower than 95% for protection limit and the practical quantitation limit ( $2 \mu\text{g l}^{-1}$ ). While in sediments, Co concentrations were lower than the limit suggested by DeCarlo and Spencer who illustrated that, Co concentrations between 50 and  $80 \text{mg g}^{-1}$  may be representative of the amount of natural Co in the marine sediments [32].

Manganese is widely distributed in the earth's crust. It is present in natural waters in suspended form, although soluble forms may persist at low pH or low DO. Its toxicity is low compared to other trace metals [46]. The practical quantitation limit (PQL) for manganese is  $2 \mu\text{g l}^{-1}$  in marine water [44,45]. Annual means of Mn concentrations in seawater of different sites were lower than the practical quantitation limit ( $2 \mu\text{g l}^{-1}$ ). While in sediments, there were observed variations between different sites but all Mn values were lower than the TEL of marine sediments quality guidelines ( $460 \mu\text{g g}^{-1}$ ).

Iron is the fourth most abundant element in the earth's crust and may be present in natural waters in varying quantities depending up on the geology of the area and other chemical components of the waterway [47]. The current analytical practical quantitation limit (PQL) for iron in marine water is  $2 \mu\text{g l}^{-1}$  [44,45]. The anthropogenic sources of iron to the marine environment in these areas are shipment of mineral products from phosphate mines in the Eastern Desert, paints of marine ships, corrosion of the marine constructions, land filling and construction residuals. Annual means of iron concentrations in seawater of the studied sites were exceeded the practical quantitation limit ( $2 \mu\text{g l}^{-1}$ ) and within the range of the Canadian guideline. While Fe concentrations in sediments were lower than the TEL of marine sediments guidelines.

The seasonal variations of heavy metals in seawater are potentially influenced by the physical and chemical properties of seawater, such as temperature, salinity, pH, turbidity and dissolved oxygen levels [48]. Besides, the

metal solubility is principally controlled by the water pH, nature and concentration of organic ligands, oxidation state of metal and the redox conditions within the environment [49].

The averages of heavy metals concentrations at all the study area during different seasons showed that, the highest metals concentrations in water samples were recorded during winter (Cu, Zn and Pb) and summer (Cd, Mn and Fe), while the lowest concentrations were observed during autumn (Cu, Ni, Zn and Mn). The higher metal concentrations in summer could be attributed to an increase in the rate of metal accumulation due to the higher temperature, also high evaporation rate may be affected. In addition, summer could increase the amount of toxicant flushed into the water, in particular sewage, desalinations plants and high fishing activities. But the lower salinity in autumn could reduce the rate of metal accumulation due to sedimentation [50].

Sediments represent the most important sink of metals in estuarine and coastal waters due to their strong metal-adsorbing capacity [51]. The majority of suspended particles in seawater have a strong affinity for binding to metals, and metals in the formation of complexes with suspended particles are subsequently precipitated into bottom sediments, causing metal accumulation in sediments [52]. In the present investigation, the highest heavy metals concentrations were observed in sediments during winter (Ni, Pb, Co, Mn and Fe) and autumn (Cd, Cu and Zn), while the lowest values were recorded during summer (Cu, Zn, Pb, Mn and Fe).

Although most sedimentary metals are not available for aquatic organisms, variations in the physical and chemical properties of seawater may induce the release of metals into the water column in a more available form [53]. It is well-known that the water pH, salinity, electrical conductivity, and redox potential have a significant effect on both adsorption and accumulation of metals in sediments [54]. As an example, at higher pH, higher concentration of Cd in sediments is found due to precipitation of dissolved Cd [49]. In our study, another important point is that the Pb concentrations in the sediment samples are quite high, this can be ascribed to the unsolved Pb in seawater adsorbed by sediments [55].

Generally, the levels of heavy metals in water samples investigated in the present study were in agreement with level recorded by Hamed and Emara [56] and Zhao *et al.* [57], while lower than that stated by ObuidAllah *et al.* [58] and Ali *et al.* [59] and higher than that recorded by Shriadah *et al.* [60]. While in sediments, our results were in agreement with Dar [61], El-Moselhy and Abd El-Aziz [62], Madkour *et al.* [63], Madkour and Dar [14], Ali *et al.* [59], Mansour *et al.* [64] and Dar [65] but it were higher than that recorded by Mansour *et al.* [66]; Madkour [67] and Madkour [68] and lower than that recorded by El-Sayed and Youssef [69].

## 5. Conclusion

Monitoring and data collected from water and sediments of the Northern Red Sea coastal area during the year 2012 can offer time-integrated information of heavy metal concentrations in seawater and sediments of the study area. Moreover, these results can be used to evaluate

possible risks associated with increasing the anthropogenic effects. Heavy metals in water and sediment at the different sites along the Northern Red Sea coast is not subjected serious contamination sources. This investigation was successful in establishing baseline data for future use in pollution control strategies and management, also are urgently needed to help managers identifying anthropogenic impacts, and better assessing the needs for remediation by detecting any changes, from the existing level expected with operation of future activity.

## 6. Recommendations

Red Sea coastal area requires integrated protection planning and management to achieve ecological sustainable use of coastal resources and conservation of different environments through the following points:

1. The concentrations of heavy metals in marine water, sediments and different marine organisms should be investigated and use to monitor natural and anthropogenic impacts, and to assess any changes or bias from the existing level due to different activities.
2. The contamination sources control for protection of marine environments.
3. Sewage, oil production activities, fishing activities, shipyards, desalination plants and the mooring zones in the coastal area require pronounced solutions to minimize or prevent the tidal habitat degradation.

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