

## Distribution and assessment of heavy metals in the coastal area of the Red Sea, Egypt.

M. E. A. El-Metwally<sup>1\*</sup>, A. I. Othman<sup>2</sup> and Kh. M. El-Moselhy<sup>1</sup>

1- Marine Pollution Dept., National Institute of Oceanography and Fisheries, Egypt

2-Zoology Dept., Faculty of Science, El-Mansoura University, Egypt

\* Corresponding author: metwally.niof@yahoo.com

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### ABSTRACT

In order to evaluate the contamination state of the Red Sea coastal area, concentrations of heavy metals (Cu, Zn, Cd, Pb, Fe and Mn) were determined in sea water and surface sediments along the western side from Suez to Shalateen. The studied locations were selected to cover potential natural and anthropogenic sources of metal input in the Egyptian Red Sea. Levels of Cu, Zn, Cd, Pb, Fe and Mn in water were 0.85 - 2.61, 2.13 - 14.42, 1.24 - 4.51, 0.11 - 0.31, 8.44 - 33.71 and 0.30 - 0.62 µg/l; while in sediments were 25.67 - 100.77, 52.60 - 143.00, 21.20 - 63.43, 1.23 - 6.63, 11632 - 28321 and 291.43 - 803.80 µg/g, respectively. There were obvious positive correlations between Cu, Zn, Pb and Fe in water; while sediments showed positive correlations between Cd, Zn and Pb as well as between Fe and Mn. The obtained data were further subjected to Principal Component Analysis (PCA). The results lend support to the argument that specific geographical distribution of heavy metals in Red Sea could be related to different types of metal input. In Suez area, highest metal load in water and sediments was due to combined effects of wastes discharge and maritime activities. High contamination of Cd, Zn and Pb in sediments was associated with the shipping process of phosphate ore, while elevated Fe and Mn levels were principally associated with natural input of terrigenous sediments. The sediments indices of enrichment factor and geo-accumulation index showed high enrichment of Pb and Cd due to contamination from phosphate shipping; and the inflow with terrigenous sediments led to moderated to highly contamination with Fe and Mn.

### INTRODUCTION

The subject of pollution is the focus of widespread public interest and is seen as a priority area for research in both developed and developing countries (Harrison, 2001). Heavy metals, particularly, receive major attention due to their toxicity, accumulation in the biota and subsequent impact on the environment and human health (Yang *et al.*, 2015). Since heavy metals are natural constituents of the earth's crust, they normally introduced to the aquatic system through weathering of rocks, soil and volcanic activity, but the predominant pathway of heavy metals to the aquatic environment comes from anthropogenic contamination including mining, maritime activities and industrial, municipal and agricultural discharges (Bradl, 2005; El-Moselhy *et al.*, 2006).

Sediments are the principal sink of metals in the aquatic system; they act as a reservoir, but also they can be mobile and become a source for bioavailable metals to aquatic organisms (Gargouri *et al.*, 2011). The behavior of heavy metals in the aquatic system is highly complex, and mediated by biogeochemical cycle; therefore the knowledge of metal concentrations in water and sediments can be very important in detecting the sources and degree of pollution in coastal areas.

Red Sea is a semi-enclosed tropical body of water located between the Mediterranean Sea and the Indian Ocean (Morcos, 1970). Water quality in the Red Sea is of growing interest from ecological and economic point of view. This unique marine body provides the habitat for one of the most diverse ecosystem on earth. In addition, it provides high economic value from fisheries production and tourism industry. The Red Sea region has been considered relatively free of pollution (Mansour *et al.*, 2011). However, due to rapid development of coastal area along the Egyptian Red Sea, the environment is currently under increasing threat from a wide range of human activities.

The published data on heavy metals levels in the Red Sea proper coastal area are relatively few (e.g., Hamed and El-Moselhy, 2000; Madkour and Dar, 2007; Mansour *et al.*, 2011; 2013; Dar *et al.*, 2016; El-Metwally *et al.*, 2017a, 2017b). Most of the studies focused on intensively stressed locations, like marinas and harbours. According to these investigations, Hurghada shipyard could be regarded as the most impacted location, due to enormous land based activities in the coastal area like solid wastes, antifouling paints and desalination plant (Madkour and Dar, 2007; Dar *et al.*, 2016). The main harbours on the Red Sea proper (Hurghada, Safaga, Qusier) showed high levels of metals due to shipping activities, boats wastes, paints and oil spill (Mansour *et al.*, 2011). The shipping operation of phosphate is another source of metal contamination as stated by Madkour *et al.* (2012) in El-Hamrween Harbour. Mansour *et al.* (2013) found that tourism associated activities like landfilling operations and mooring boats produced elevated levels of heavy metals in Hurghada coastal area.

There are few data on the status of metal contamination in the intertidal areas and lagoons of the Red Sea. These shallow ecosystems play major ecological role in the tropical habitats and provide the fisheries and nursery ground for many fish and invertebrates. It is also the habitat of mangrove swamps, seagrass meadows and a lot of invertebrate species. Because of the high toxicity of heavy metals to marine organisms, particularly the juveniles, it is extremely important to monitor the availability of metals in these ecosystems. Therefore, objectives of the present work are (1) to investigate the distribution of heavy metals in water and sediments of some coastal lagoons and intertidal areas, in order to determine the contribution of potential sources of metal pollution on Red Sea coastal habitats, (2) to assess the degree of heavy metal contamination using contamination indices and comparing to background values and previous studies.

## MATERIALS AND METHODS

### Study area

The study locations were distributed along a wide area of the Egyptian Red Sea coast and corresponded to different environmental situations. Eight sites were selected on the Red Sea proper representing tourism, fishing and shipping activities; one oil production site on the Gulf of Suez; in addition to a site affected by urban and industrial activities at Suez City (Table 1, Fig. 1).

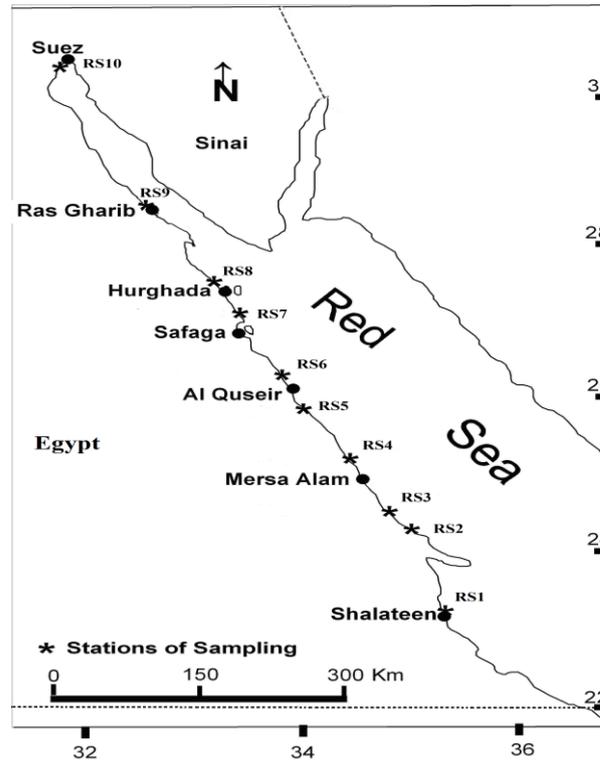


Fig. 1: Red Sea map showing the selected locations.

Table 1: Coordination and description of sampling locations.

Station	Location	Coordination	Description	Source of impact
RS1	Shalateen	23° 09' 05" N 35° 36' 51" E	Small fishing harbour.	Some anthropogenic effects from boats and fishermen
RS2	Qulaan	24° 21' 33" N 35° 17' 46" E	Adjacent to mangroves forests area	Occasional natural input from flood streams
RS3	Abu Ghosoun	24° 26' 00" N 35° 12' 00" E	North to an old phosphate shipping harbour	Little local people activities
RS4	Abu Dabab	25° 20' 28" N 34° 44' 17" E	Popular diving site.	Activities from the tourism village and the diving center
RS5	Sharm Al Bahari	25° 52' 06" N 34° 24' 48" E	Sheltered lagoon inhabits some mangrove swamps.	Little natural or anthropogenic impact
RS6	El-Hamraween	26° 15' 12" N 34° 12' 07" E	One of the oldest phosphate shipping harbours in Egypt.	Phosphate shipping, result in immense clouds of phosphate dust
RS7	Sharm El-Naqa	26° 54' 00" N 33° 57' 46" E	Popular diving site.	Activities from the tourism village and the diving center
RS8	Hurghada	27° 15' 00" N 33° 51' 00" E	Facing National Institute of Oceanography and Fisheries (NIOF), (Hurghada Branch)	Anthropogenic impact from the local residents.
RS9	Ras Gharib	28° 21' 01" N 33° 06' 64" E	In front of some petroleum companies	Petroleum production
RS10	Suez	29° 55' 29" N 32° 28' 31" E	In front of the NIOF (Suez Branch).	Impacted by industrial and sewage discharge into Suez Bay, in addition to maritime activities.

### Sampling

This study was manipulated during spring 2009 - winter 2010. In the field, each station was positioned using the Global Positioning System (GPS). Water temperature, pH and salinity were measured at each site using the Multiparameter

hydrolab (Hanna Instrument; Hi 9828). Subsurface water samples (20-50 cm depth) were collected seasonally in acid-washed polyethylene bottles, acidified and transported in ice box to the laboratory. Surface sediment samples (top 10 cm) were collected from the intertidal area using plastic spatula. Immediately after collection, samples were placed in polyethylene bags and transported to the laboratory. Then, sediments were dried to constant weight and sieved through a stainless steel sieve to pass < 63  $\mu\text{m}$  fraction. Metals were analyzed in this fraction due to strong association and high bioavailabilities of metals with fine grains (Salomons and Forstner, 1984). Sediment samples were collected twice "summer and winter" and the average was used as a representative for each site.

### **Metal analyses**

Metal contents in seawater were analyzed according to Brewer *et al.* (1969). Briefly, the metals were pre-concentrated from one liter of seawater using ammonium pyrolydine dithiocarbamate (APDC) as chelating agent at pH 3-4, after that the extraction was taken in methyl isobutyl ketone (MIBK) as solvent. The organic extract was evaporated and further heated with concentrated nitric acid, then cooled, filtered and made-up to 10 ml with deionized distilled water. For sediments, complete digestion method was used according to Oregioni and Aston (1984). Dried sediment samples were left overnight in a mixture of concentrated nitric, perchloric and hydrofluoric acids (3:2:1) in Teflon vessels. The sample were then digested at 100 °C for about two hours, cooled, filtered and diluted to 25 ml with deionized water. Metals concentrations were determined using Atomic Absorption Spectrophotometer (AAS model GBC A932 Ver. 1.1).

**Quality control** De-ionized distilled water was used to prepare all aqueous solutions. All chemicals were of high analytical grade; acids were from Merck, Germany. Whatman filter papers were used. All plastics and glassware were soaked in 10% nitric acid overnight then rinsed with distilled water prior to use. Samples were measured against acid blank. Accuracy and precision of the method were verified by analysis of certified sediments reference materials (SD-M-2/IM) provided by the International Atomic Energy Agency (IAEA), Vienna. Analytical results of the quality control samples indicated a satisfactory performance of heavy metals determination within the range of certified values with 90.4-97.5% recovery for metals studied.

### **Statistical Analysis**

Heavy metal data in water were subjected to two-way analysis of variance to test differences between sites over time. Significant regional differences in sediments were assessed using one-way analysis of variance (significant values,  $p \leq 0.05$  for all analysis). Prior to ANOVA, assumption of homogeneity (Batlett's test) and normality (Shapiro-Wilk test) of data were assessed. Duncan's multiple range test was used to further determine the position of the variance in significant results. For multivariate analysis, Pearson's correlation and principal component analysis (PCA) were conducted to assess possible metal association and the sources of heavy metals in water and sediments. Statistical analysis was carried out using software packages SPSS 18.0 for windows, and Origin Pro 9.

### **Ecological risk assessment**

Several quantitative geochemical methods have been adopted to evaluate the contamination and ecological risk of heavy metals in marine sediments (El Zrelli *et al.*, 2015). Among most widely used techniques are the enrichment factor (EF) and geo-accumulation index ( $I_{\text{geo}}$ ).

Enrichment factor was calculated by dividing the enrichment of metal by enrichment in the background value according to the equation:

$$EF = (Metal/Fe)_{sample} / (Metal/Fe)_{background}$$

Geo-accumulation index was described by Muller (1979) as the following equation:

$$I_{geo} = \text{Log}_2 [C_n / (1.5 \times B_n)]$$

where  $C_n$  is the measured metal concentration, and  $B_n$  is the background level. The pollution extent was evaluated over seven categories according to the scale proposed by Muller (1981).

## RESULTS AND DISCUSSION

### Physical parameters

The levels of physical measurements were determined in sea water to indicate any significant influence on the concentrations of metals in water or sediments. In general, the values of pH ranged from 7.5 to 8.44. The surface water temperature varied from 19.1 in winter to 34.28 °C in shallow water during summer. The salinity correlated significantly with temperature (Table 7) and ranged from 39.7 to 43.0‰. As listed in Tables (7 and 8), the correlation between physical measurements and heavy metal concentrations in water and sediments were insignificant, except for the levels of Mn in water which significantly increased with higher salinity. These results indicated that, the heavy metals values were mainly attributed to direct input from various sources.

### Heavy metals distribution

Annual concentrations of heavy metals in water are listed in Table 2, and seasonal distribution is illustrated in Figure 2. Generally, metal levels were in the following order: Fe > Zn > Pb > Cu > Mn > Cd. The distribution of all metals varied significantly among studied sites ( $p < 0.05$ ).

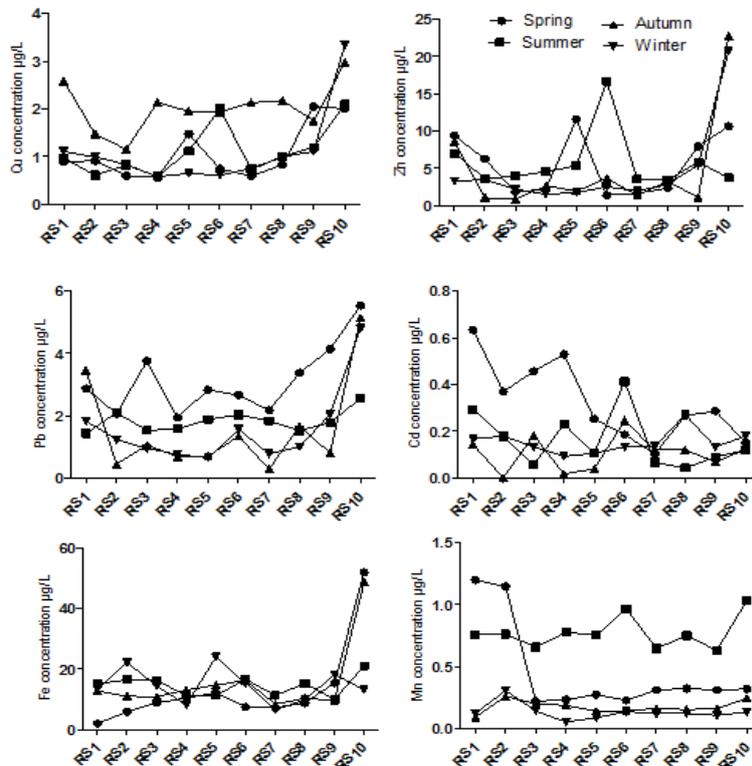


Fig. 2: Seasonal variations of heavy metals ( $\mu\text{g/L}$ ) in water samples collected from the Red Sea coast.

Table 2: Annual mean concentrations ( $\pm$ SD) of heavy metals ( $\mu\text{g/l}$ ) in surface water collected from different sites along the Red Sea coast.

Site	Cu	Zn	Pb	Cd	Fe	Mn
RS1	1.39 $\pm$ 0.80	7.06 $\pm$ 2.70	2.40 $\pm$ 0.93	0.31 $\pm$ 0.23	10.87 $\pm$ 5.98	0.54 $\pm$ 0.54
RS2	1.00 $\pm$ 0.36	3.58 $\pm$ 2.12	1.46 $\pm$ 0.79	0.18 $\pm$ 0.15	13.90 $\pm$ 6.98	0.62 $\pm$ 0.42
RS3	0.85 $\pm$ 0.23	2.21 $\pm$ 1.30	1.82 $\pm$ 1.32	0.21 $\pm$ 0.17	12.58 $\pm$ 3.29	0.30 $\pm$ 0.24
RS4	0.97 $\pm$ 0.78	2.73 $\pm$ 1.30	1.24 $\pm$ 0.62	0.22 $\pm$ 0.23	10.78 $\pm$ 2.04	0.31 $\pm$ 0.32
RS5	1.30 $\pm$ 0.55	5.14 $\pm$ 4.59	1.52 $\pm$ 1.05	0.13 $\pm$ 0.09	15.55 $\pm$ 5.83	0.31 $\pm$ 0.30
RS6	1.32 $\pm$ 0.75	6.06 $\pm$ 7.14	1.90 $\pm$ 0.58	0.25 $\pm$ 0.12	13.95 $\pm$ 4.35	0.37 $\pm$ 0.40
RS7	1.05 $\pm$ 0.72	2.13 $\pm$ 0.97	1.27 $\pm$ 0.89	0.11 $\pm$ 0.03	8.44 $\pm$ 2.07	0.31 $\pm$ 0.24
RS8	1.25 $\pm$ 0.62	2.94 $\pm$ 0.46	1.89 $\pm$ 1.03	0.18 $\pm$ 0.11	11.06 $\pm$ 2.89	0.34 $\pm$ 0.29
RS9	1.53 $\pm$ 0.45	5.09 $\pm$ 2.87	2.19 $\pm$ 1.40	0.15 $\pm$ 0.10	13.35 $\pm$ 4.21	0.30 $\pm$ 0.24
RS10	2.61 $\pm$ 0.66	14.42 $\pm$ 8.87	4.51 $\pm$ 1.34	0.14 $\pm$ 0.03	33.71 $\pm$ 19.49	0.43 $\pm$ 0.41

Mean concentrations of Cu, Zn, Pb, Cd, Fe and Mn in seawater ranged from 0.85 to 2.61, 2.13 - 14.42, 1.24 - 4.51, 0.11 - 0.31, 8.44 - 33.71 and 0.30 - 0.62  $\mu\text{g/l}$ , respectively. According to local variation of metals, site RS10 (Suez) showed significant high concentrations of Cu, Zn, Pb and Fe comparing to other sites, while Cd was elevated in sites RS1 and RS6; as well as, concentration of Mn recorded relative high concentrations in site RS2. Temporal fluctuations of metals in water revealed that the different seasons showed little influence on metals variation. Slight, but significant, high levels of Pb and Cd were recorded in spring, Cu in autumn, and Mn in summer.

Table 3 shows average concentration of metals in surface sediments from the Egyptian Red Sea coast. Concentrations of Cu, Zn, Pb, Cd, Fe and Mn ranged from 25.67 to 100.77, 52.60 - 143.00, 21.20 - 63.43, 1.23 - 6.63, 11632 - 28321 and 291.43 - 803.80  $\mu\text{g/g}$ , respectively. Distribution of all metals varied significantly between studied sites ( $p < 0.05$ ). Significant high concentrations of Cd, Pb and Zn were found in sediments from station RS6. While, samples from site RS10 recorded high levels of Cu, Zn and partially Pb. The distribution of Fe and Mn in Red Sea sediments was quite similar and showed their highest concentrations in site RS2.

Table 3: Mean concentrations ( $\pm$ SD) of heavy metals ( $\mu\text{g/g}$ ) in sediments collected from different sites along the Red Sea coast.

Site	Cu	Zn	Pb	Cd	Fe	Mn
RS1	46.10 $\pm$ 16.36	52.60 $\pm$ 8.63	24.33 $\pm$ 3.91	1.23 $\pm$ 0.42	15676.3 $\pm$ 6334.1	377.40 $\pm$ 174.85
RS2	29.83 $\pm$ 11.97	70.43 $\pm$ 10.11	21.20 $\pm$ 3.74	2.43 $\pm$ 0.31	28321.3 $\pm$ 2723.0	803.80 $\pm$ 145.55
RS3	100.77 $\pm$ 38.86	67.80 $\pm$ 23.72	26.20 $\pm$ 13.93	3.77 $\pm$ 0.85	16629.0 $\pm$ 3808.6	314.13 $\pm$ 147.10
RS4	51.67 $\pm$ 1.78	56.67 $\pm$ 9.51	29.77 $\pm$ 1.52	3.33 $\pm$ 0.51	11681.0 $\pm$ 975.9	316.33 $\pm$ 63.37
RS5	25.67 $\pm$ 5.27	54.17 $\pm$ 10.77	24.00 $\pm$ 1.41	1.80 $\pm$ 0.10	20524.3 $\pm$ 4451.3	476.10 $\pm$ 116.62
RS6	51.30 $\pm$ 20.45	114.53 $\pm$ 12.63	63.43 $\pm$ 25.39	6.63 $\pm$ 3.91	21739.0 $\pm$ 3869.1	575.87 $\pm$ 84.80
RS7	49.00 $\pm$ 29.36	68.40 $\pm$ 9.13	25.33 $\pm$ 5.57	1.97 $\pm$ 0.49	14989.7 $\pm$ 3676.3	322.93 $\pm$ 79.89
RS8	64.17 $\pm$ 23.53	76.87 $\pm$ 12.64	39.03 $\pm$ 12.72	2.27 $\pm$ 0.51	14250.0 $\pm$ 250.0	375.00 $\pm$ 47.70
RS9	51.33 $\pm$ 13.18	62.73 $\pm$ 8.54	27.07 $\pm$ 10.56	1.83 $\pm$ 0.25	11632.3 $\pm$ 4022.4	291.43 $\pm$ 42.73
RS10	97.53 $\pm$ 13.84	143.00 $\pm$ 14.81	45.63 $\pm$ 4.31	3.13 $\pm$ 0.06	20027.0 $\pm$ 1658.6	354.77 $\pm$ 8.64

Comparing present data with the previous studies (Table 4) showed accordance with analogous sites in Suez Bay (Mohamedein, 2002; El-Moselhy and Gabal, 2004) and Red Sea coastal area (Abouhend and El-Moselhy, 2015). But these data were much lower than metal levels recorded in water and sediments of Hurgada Harbour and Safaga shipyard (Madkour and Dar 2007; Dar *et al.* 2016). Harbours normally have high levels of metals due to direct effect of land-based wastes, antifouling paints and gasoline fuel from large number of mooring boats, in addition to weak water exchange in these semi-enclosed embayments with seawater. Also, the present results

were lower than the data recorded in Suez Gulf (Hamed and Emara, 2006), Korean coast (Na and Park, 2012), Aegean Sea (Fytianos and Vasilikiotis, 1983) and Shantou Bay, China (Qiao *et al.*, 2013). Based on the background levels of heavy metals in sediments, the present study revealed high levels of metals comparing to the background value of the Red Sea (Hanna, 1992), and high Pb, Cd, Fe, Cu (in most studied sites) and Zn (in sites RS2 and RS10) relating to the world average shale values (Forstner and Wittmann, 1979).

Table 4: Concentrations of heavy metals in water ( $\mu\text{g/l}$ ) and sediments ( $\mu\text{g/g}$ ) in the present study and other locations

Region	Cu	Zn	Pb	Cd	Fe	Mn	reference
<b>a) Water</b>							
Red Sea	0.8-2.6	2.1-14.4	1.2-4.5	0.1-0.3	8.4-33.7	0.3-0.6	present study
Suez Bay	0.3-8.9	4.2-25.5	0.07-9.3	0.01-1.3			Mohammedein, 2002
Suez Gulf	1.2-5.3	8.1-23.3	1.8-2.6	0.15-0.18			El-Moselhy and Gabal, 2004
Red Sea	0.6-3.8	1.7-11.4	1.9-4.3	0.2-4	12.7-25.3	0.16-0.3	Abuhend and El-Moselhy, 2015
Hurghada harbour	0.0-14.7	3-11.4	0.0-11.4	0.5-0.9	0.0-194.5		Madkour and Dar, 2007
Suez Gulf	1.1 - 4.8	6.8-25.19	0.6-3.2	0.04-0.3		1.3-4.6	Hamed and Emara, 2006
Aegean Sea	0.7-2.1	13.4-23	3.5-20.5	0.2-0.5			Fytianos and Vasilikiotis, 1983
<b>b) Sediments</b>							
Red Sea	25-101	52-143	21- 63	1.2 - 6.6	11,632-28,321	291-804	present study
Suez Bay	3.4-124	4.2-150	4.1-114	1.3-4.8			Mohammedein, 2002
Red Sea	8.5-111	19.2-190	16-80	1.7-4.4	4,172-14,222	106-323	Abuhend and El-Moselhy, 2015
Hurghada harbour	34-1862	77-350	27.5-207	1.5-3.7			Madkour and Dar, 2007
Korean coast	8.3 - 164.4	45.5-225.9	25-360	0.07-0.43			Na and Park, 2012
Shantou Bay, China	24.4-79.3	84.9-246.5	35.6-64.8	0.3-1.74	29300-39300	428-809	Qiao <i>et al.</i> , 2013
Red Sea, background	17.6	24	3	0.4	3000	116	Hanna, 1992
Average shale	45	95	20	0.3		850	Forstner and Wittmann, 1979

For the ecological assessment of sediments contamination, EF and  $I_{\text{geo}}$  values are given in Tables 5 and 6. The EF values indicated no enrichment of metals ( $<1$ ) except Pb and Cd which showed low enrichment in most sites (0.7 – 2.9 for Pb and 0.6- 2.3 for Cd).

Table 5: Enrichment factor (EF) of heavy metals from different sites on the Red Sea

Site	Cu	Zn	Pb	Cd	Mn
RS1	0.501	0.419	1.552	0.589	0.623
RS2	0.180	0.311	0.749	0.644	0.734
RS3	1.033	0.510	1.576	1.700	0.489
RS4	0.754	0.606	2.549	2.138	0.700
RS5	0.213	0.330	1.169	0.658	0.600
RS6	0.402	0.659	2.918	2.287	0.685
RS7	0.557	0.570	1.690	0.986	0.557
RS8	0.768	0.674	2.739	1.196	0.681
RS9	0.752	0.674	2.327	1.180	0.648
RS10	0.830	0.893	2.278	1.172	0.458

Table 6: Geo-accumulation index of heavy metals from different sites on the Red Sea

	Cu	Zn	Pb	Cd	Fe	Mn
RS1	0.804	0.547	2.435	1.036	1.801	1.117
RS2	0.176	0.968	2.236	2.018	2.654	2.208
RS3	1.932	0.913	2.542	2.652	1.886	0.852
RS4	0.969	0.655	2.726	2.472	1.376	0.862
RS5	-0.040	0.589	2.415	1.585	2.189	1.452
RS6	0.958	1.670	3.817	3.466	2.272	1.727
RS7	0.892	0.926	2.493	1.715	1.736	0.892
RS8	1.281	1.094	3.117	1.920	1.663	1.108
RS9	0.959	0.801	2.589	1.609	1.370	0.744
RS10	1.885	1.990	3.342	2.383	2.154	1.028

The sediments of RS6 showed highest enrichment with Pb and Cd. Results of  $I_{geo}$  showed that most sites were classified according to Muller's (1981) scale to be uncontaminated with Cu and Zn (<1), moderately contaminated with Fe and Mn (1–2), and moderately to highly contaminated with Pb and Cd (2-3). The site RS2 was moderately to highly contaminated with Fe (2.6) and Mn (2.2), while the site RS6 was strongly contaminated with Pb (3.8) and Cd (3.5).

To understand the sources of metal contamination in sea water, PCA was applied to data, which showed two principal components (eigenvalues >1) with accumulative account of 87.66% of all data variation (Fig. 3). The 1<sup>st</sup> PC was related to Cu, Zn, Pb and Fe; meanwhile, correlations between these four metals were significant (Table 7). This pattern can be defined as anthropogenic component as it is coincided with high levels of these metals in water from Suez (site RS10). The 2<sup>nd</sup> PC was related to Cd and Mn; it was probable linked to human activities (sites RS1, RS6) and natural input via occasional floods (Site RS2). In sediments, PCA analysis (Fig. 4) resulted in three principal components with accumulated account for 93.13%. One PC included Cd, Zn and Pb which was associated with anthropogenic activities in site RS6 (El-Hamraween) and site RS10 (Suez). This pattern also was indicated statistically by significant correlation between Zn, Pb and Cd (Table 8). Another PC, describing anthropogenic source, included positive loading of Cu and associated with site RS10.

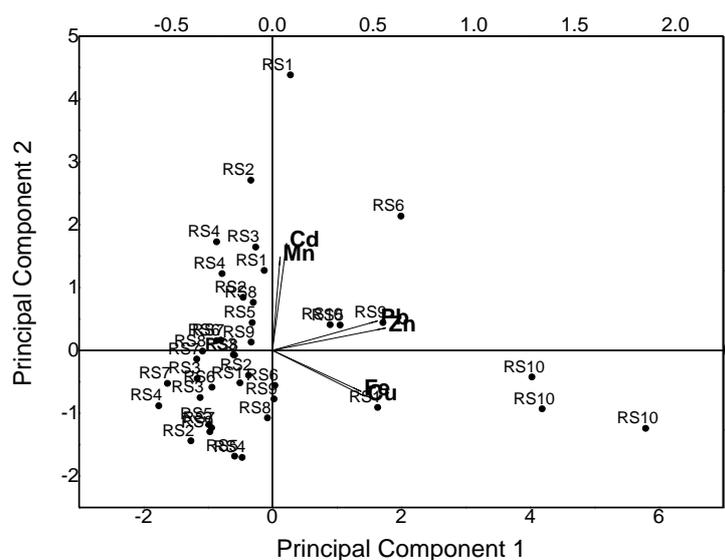


Fig. 3: Principal component analyses (PCA) diagram grouping the studied sites according to metal levels in seawater.

Table 7: Correlation coefficient between heavy metals in water and physical measurements

	Cu	Zn	Pb	Cd	Fe	Mn	Temp	pH	Salinity
Cu	1.00								
Zn	<b>0.958</b>	1.00							
Pb	<b>0.945</b>	<b>0.939</b>	1.00						
Cd	-0.210	-0.014	-0.045	1.00					
Fe	<b>0.898</b>	<b>0.907</b>	<b>0.896</b>	-0.276	1.00				
Mn	0.132	0.293	0.208	0.378	0.172	1.00			
Temp	-0.303	-0.195	-0.312	0.025	-0.170	0.524	1.00		
pH	0.428	0.457	0.412	-0.203	0.593	0.381	0.417	1.00	
Salinity	-0.154	0.063	-0.058	0.462	-0.015	<b>0.756</b>	<b>0.769</b>	0.495	1.00

Bold marks significance at the 0.05 level

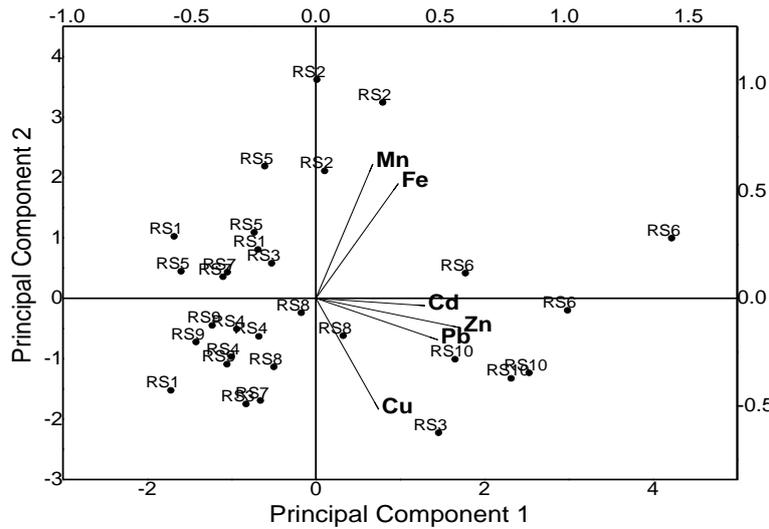


Fig. 4: Principal component analyses (PCA) diagram grouping the studied sites according to metal levels in sediments.

The last PC had positive loading on Fe and Mn which was associated with natural contamination from site RS2 (Qulaan). This pattern illustrated common input source of Fe and Mn and was further indicted by highly significant correlation between them (Table 8).

Table 8: Correlation coefficient between heavy metals in sediments and physical measurements

	Cu	Zn	Pb	Cd	Fe	Mn	Temp	pH	Salinity
Cu	1.00								
Zn	0.529	1.00							
Pb	0.301	<b>0.791</b>	1.00						
Cd	0.283	0.567	<b>0.809</b>	1.00					
Fe	-0.231	0.340	0.132	0.257	1.00				
Mn	-0.505	0.108	0.081	0.231	<b>0.906</b>	1.00			
Temp	-0.526	-0.518	-0.661	-0.558	0.422	0.464	1.00		
pH	0.139	0.407	0.058	-0.109	0.378	0.231	0.417	1.00	
Salinity	-0.257	-0.115	-0.201	-0.114	0.584	0.565	<b>0.769</b>	0.495	1.00

Bold marks significance at the 0.05 level

The present study evaluated metal hazard due to anthropogenic and natural sources of contamination in the coastal area of the Egyptian Red Sea. The major stresses were found associated with urban, industrial and maritime activities in Suez City (site RS10). In this site, high levels of Cu, Zn, Pb and Fe were recorded in water due to discharge of domestic and industrial wastes, in addition to antifouling paints

and fuel from many boats in the Suez Bay. Naturally, these metals precipitate to bottom sediments through adsorption onto particulate matter (Salomons and Forstner 1984) and accumulated to high levels as recorded for Cu, Zn and Pb in the present sediment samples. The Results of site RS6 at El-Hamraween reflected the problem of ore shipping in the Red Sea; where sediments of this site were rich in Zn, Cd and Pb due to shipping operation of phosphate in the port. The loading operation involved immense clouds of dust which eventually sink in the sediments; this phosphate dust normally contains large amounts Cd, Zn and Pb as impurities (McMurtry *et al.*, 1995). Similar results were recorded by Madkour *et al.* (2012) in El-Hamraween and by Abu-Hilal (1987) in Aqaba harbour. Mansour *et al.* (2011) attributed high levels of Zn, Ni, Co and Cd in the harbours of Safaga and Qusier to the shipment of phosphate and bauxite. Regarding other anthropogenic stresses, effects of recreational activities (sites RS4, RS5 and RS7) and off shore oil production platforms (RS9) showed comparatively low levels of heavy metals in our study. In fact, recreational sites in the present investigation were under moderate tourism pressure, and controlled conditions in number of boats and coastal reclamation. However, earlier study (Mansour *et al.*, 2013) showed high contamination condition (Fe, Mn, Zn Pb and Cu) in the sediments due to uncontrolled activities associated with tourism like landfilling and dredging operations in addition to high capacity of mooring boats and yacht.

On the other hand, the obtained results showed significant effect of natural input of heavy metals. Where, sediments of site RS2 showed highest content of Fe and Mn, which was attributed to natural input from Wadi Qulaan. Beltagy (1984) reported that the coastal area of the Red Sea received minor amounts of metals with terrigenous materials from weathering of rocks; these metals contributed to the background level in bottom sediments. Nevertheless, much higher amounts of metals associated with terrigenous sediments enter the sea via small wadis with occasional floods. In accordance with our finding, a previous study by Madkour (2005) attributed relatively high levels of Fe, Mn and Pb in sediments and coral reef of Wadi El-Gemal, Red Sea, to natural input of terrigenous sediments through streams.

## CONCLUSION

Monitoring of the coastal area and identifying different sources of contamination are crucial for protection and maintaining of the fragile ecosystem in the Red Sea. In the present study, concentrations of heavy metals were determined in water and sediments along the western coastline of the Red Sea, whereas contribution of natural and different human activities in metal pollution was evaluated. The obtained results indicated that the anthropogenic source reflected metal specific area and/or metal specific source of contamination. Whereas, high Cu, Zn, Pb and Fe levels were found in location affected by different industrial wastewater, and high Cd, Pb and Zn values were associated with shipping of raw materials. Besides, the data of Fe and Mn revealed natural contribution due to input of terrigenous sediments. EF and  $I_{geo}$  values of heavy metals in sediments of different sites reflected high levels of Pb and Cd in phosphate shipping site indicated strongly contamination condition; while Fe and Mn were moderately to highly contaminated in site receiving occasional flood.

Results of this study can be used to help decision makers in planning integrated strategy for protection and management of the coastal resources. Such strategy will depend on reduction of current pollution input, keeping recreational activities under control and establishing short and long term monitoring program for coastal area.

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## ARABIC SUMMARY

## توزيع و تقييم تواجد العناصر الثقيلة على الساحل المصرى للبحر الأحمر

محمد المتولى على المتولى<sup>١</sup>، عزة إسماعيل عثمان<sup>٢</sup>، خالد محمد المصلحي<sup>١</sup>

١- شعبة البيئة البحرية، المعهد القومي لعلوم البحار و المصايد، مصر

٢- قسم علم الحيوان، كلية العلوم، جامعة المنصورة، مصر

تم رصد مستويات العناصر الثقيلة ( النحاس، الزنك، الرصاص، الكاديوم، الحديد و المنجنيز) فى عشر محطات على طول الساحل المصرى للبحر الأحمر من السويس شمالا و حتى الشلاتين جنوبا. وتم قياس هذه العناصر فى المياه و الرواسب.

سجلت تركيزات العناصر الثقيلة فى المياه تباينا واسعا بين المواقع المختلفة و بين المواسم. و لكن ظهر واضحا تلوث المياه فى موقع السويس بالنحاس، الزنك، الرصاص و الحديد، حيث سجلت أعلى تركيزات فى هذا الموقع. و تعزى هذه التركيزات المرتفعة لصراف المخلفات الصناعية و الصرف الصحى فى جونة السويس بالإضافة الى انطلاق كميات من العناصر الثقيلة من النشاطات البحرية الكثيفة فى المنطقة الغربية للجونة، و خصوصا الرصاص من المحروقات و النحاس و الزنك من دهانات المراكب. ولم تختلف هذه النتائج كثيرا عن الدراسات السابقة بالبحر الأحمر، بينما كانت النتائج عموما فى نطاق النتائج العالمية للمياه الغير ملوثة.

أما بالنسبة للرواسب، فقد أظهرت الدراسة وجود تركيزات أعلى للعناصر و خاصة الحديد فى المكون الأصغر حجما من الرواسب (أقل من ٠.٠٦٣ ملليمتر) و الذى تمت دراسته فى هذا البحث. وقد أظهرت النتائج وجود تراكيزات عالية من العناصر الثقيلة فى ثلاث مواقع و هى السويس و الحمراوين و القلعان. حيث سجل النحاس و الزنك و الرصاص تركيزات عالية فى السويس نتيجة لترسب هذه العناصر من مصادر التلوث المختلفة مع المواد العالقة إلى الرواسب. بينما سجلت الحمراوين تركيزات عالية من الزنك و الرصاص و الكاديوم، و تعزى هذه النتيجة لعمليات الشحن البدائية لخام الفوسفات من ميناء الحمراوين و الذى ينتج عنها غبار كثيف من الفوسفات يترسب فى الميناء. فى حين أن موقع القلعان لا يتعرض لأى نوع من النشاطات البشرية، و لكنه يقع على مصب وادى القلعان و يتعرض على فترات متباعدة لبعض السيول و التى تكون محملة بالرواسب الغنية ببعض المعادن من الوادى. و قد سجلت راسب القلعان أعلى تركيزات من الحديد و المنجنيز نتيجة لتعرض الموقع لهذه السيول. ويمكن أن تعزى التغييرات فى مجتمع الديدان عديدة الأشواك إلى العمليات الهندسية التى أجريت لتوسيع كورنيش الإسكندرية خلال العقدين الماضيين و التى أدت إلى تغيير كبير فى تضاريس خط الساحل وكذلك تعديل نظام الصرف الصحى لمدينة الإسكندرية.