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Distribution and Pollution Assessment of Heavy Metals in the Mangrove Sediments from Some Localities along the Egyptian Red Sea Coast.

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Abstract: *Five localities of mangrove environment along the Egyptian Red Sea Coast were selected for the present study. Three of these are located on the coast, whereas, the other two localities are islands. The samples were taken from the surface sediments. Granulometric analysis was carried out to recognize the textural characteristics of these sediments. Also, geochemical analysis was performed for some heavy metals such as Fe, Mn, Zn, Ni, Cu, Pb and Cd to define their concentrations and assess the potential natural and anthropogenic impacts on the considered sediments. It is noted that Wadi El-Gimal coastal area exhibited the highest mean contents of Fe (4851.6μg/g), Mn (805.4μg/g), Ni (91.0μg/g) and Pb (13.9μg/g) comparable to the other studied localities. The highest mean values of Cd were recorded in El-Queih coastal area and Abu-Minqar island (2.67μg/g and 1.99μg/g) respectively, while, the lowest mean content of cadmium was recorded in Wadi El-Gimal coastal area (0.2μg/g). The degree of pollution of the sediments by these metals was evaluated by calculating the following parameters: enrichment factors (EF), geo-accumulation and pollution load indices (I_{geo} and PLI). The results of these indices indicate that the studied sediments of all localities are virtually unpolluted by heavy metals. The high concentrations of Cd recorded in some samples of El-Queih and South Safaga coastal areas, and Abu-Minqar island might be attributed to oil spills (tar balls) or the garbage driven by seawater waves to these localities. In general, the levels of heavy metals in the study area do not constitute any serious environmental risk except for Cd which needs to be monitored at El-Queih and South Safaga coastal areas, and Abu-Minqar island. Therefore, the range of concentrations of the analyzed metals in the area under study can serve as baseline environmental data for the assessment the degree of pollution of these heavy metals in future.*

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I. Introduction

Mangrove environments represent nearly 75 % of the world's tropical and subtropical coastlines (Marchand et al. 2006a,b). Mangrove have indirect value in controlling coastal erosion and contributing to shorelines accretion (Chapman, 1977), being cultivated (Mann, 1982) or transplanted for the purpose. Mangrove systems are a valuable and ecologically significant habitat with many uses to man (Saenger *et.al*, 1983). The high productivity sustained through detritus food chains contributes to resident and migratory animals and birds and tropic balances in associated ecosystems.

Mangrove forests or swamps can be found on muddy, tropical coastal areas around the world. Mangroves are predominantly intertidal habitats that occur worldwide in the sub-tropics along sheltered and shallow-water coastlines. The roots and penumatophores of mangrove trees may extend into the intertidal and subtidal zones, where they become a rare feature: hard substrata in an otherwise soft sediment environment (Ellison and Farnsworth, 1992).

Mangroves form a habitat for a wide variety of species. The critical early life stages (i.e. the larvae and juveniles) of many fish and shellfish species utilize mangroves as nursery grounds, whereafter they emigrate to other systems such as coral reefs as adults (Ogden, 1997; Nagelkerken et al., 2002; Crona and Rönnback 2007). Mangrove mud crabs, shrimps, and giant freshwater prawn are other crustaceans of commercial value that utilize mangroves as habitat during some life stage (Walters *et al.,* 2008). Mangroves are also important to human for a variety of reasons, including aquaculture, agriculture, forestry, protection against shoreline erosion, and as a source of fuel and construction materials, to meet subsistence needs (Hogarth, 1999; Walters *et al.,* 2008).

Mangroves are estimated in Egypt to cover about 525 hectares (Kairo and Hegazy 2003). Four species of mangrove have been recorded from the Red Sea. Two of the four Red Sea mangrove species were found in the Egyptian Red Sea coastal zone; viz., *Avicennia marina* and *Rhizophora mucronata* (Zahran, 1965). *Avicennia marina* being most widespread in at least 14 mangrove stands distributed along the Red sea from Hurghada to Shalatien (GEF, 1997). *Rhizophora mucronata* coexists with *Avicennia marina* in few stands in the southern Sudanese border area. These forests are extremely important ecologically and environmentally for the continued existence and maintenance of coastal fisheries, for the shoreline protection, a refuge for wildlife including birds, for sediment stabilization; and to a minor extent mangrove provide forage of camels and other livestock as well as their using as firewood.

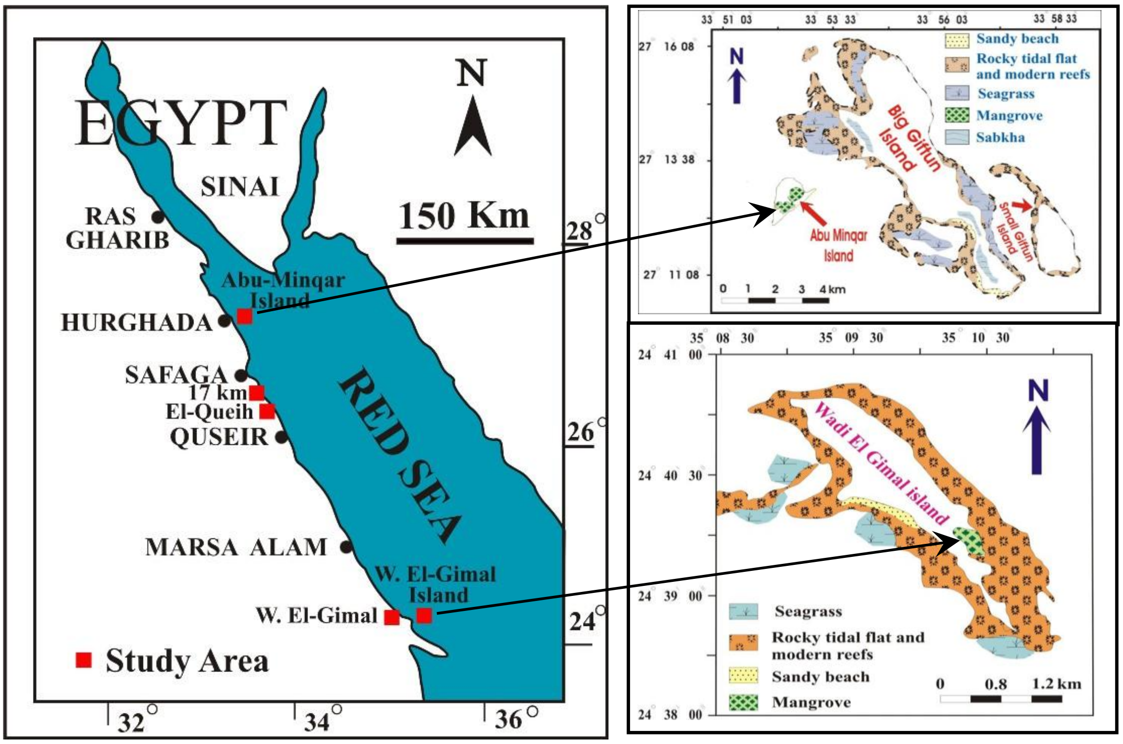
In the recent decade, mangrove ecosystem has been increasingly threatened owing to anthropogenic pressure of rapid urbanization and industrialization which imposes harmful chemicals via agricultural and aquaculture ponds run-off, oil spills, wastewater, and industrial effluents (MacFarlane et al. 2007; Vane et al. 2009; Polidoro et al. 2010, Chaudhuri et al. 2014).

Depending on physiochemical conditions mangrove sediments may act as a sink or source for trace metals in an aquatic ecosystem (Marchand et al. 2006 a, b; Keene et al. 2010; Nath et al. 2013; Wang et al. 2013). Therefore, trace metal cycling is a potentially serious problem in mangrove environments (Marchand et al. 2006a,b).

However, Five mangrove localities along the Egyptian Red Sea coast were selected for the present study. Three of them are located onshore on the beach within intertidal zone, namely from south to north, Wadi El-Gimal, El-Queih and site at 17 km south of Safaga town. Wadi El-Gimal area is located about 55 Km south Marsa Alam town with latitudes from 24° 39` 20.2″ N to 24° 40` 08.9″ N and longitudes from 35° 05` 30.8″ E to 35° 10` 19.4″ E. El-Queih area is located at 43 km south of Safaga town with latitudes from 26° 23` 46″ N to 26° 24` 09″ N and longitudes from 34° 06` 48″ E to 34° 07 26″ E. The third area is located at 17 Km south of Safaga town with latitudes from 26° 36` 28″ N to 26° 37` 10″ N and longitudes from 34° 00` 35″ to 34° 01` 06″E . The other two areas are offshore islands, the first one is Wadi El-Gimal island that is located about 5 km in the sea in front of Wadi El-Gimal in the nearshore zone with latitudes from 24° 39` 09.9″ N to 24° 39` 20.2″ N and longitudes from 35° 10` 25.4″ E to 35° 10` 19.4″ E.. The second is Abu-Minqar island which forms a small area about 1km$^2$ and located in the nearshore zone, nearly 2 km south east of Hurghada City with latitude 27$^o$ 15` N and longitude 33^o 52` E. All the above mentioned localities are shown in Figure no 1 and Plate no 1 (a-d).

The main objective of the present study is to identify the textural nature of the mangrove sediments and to evaluate the regime of heavy metals distribution in these sediments.

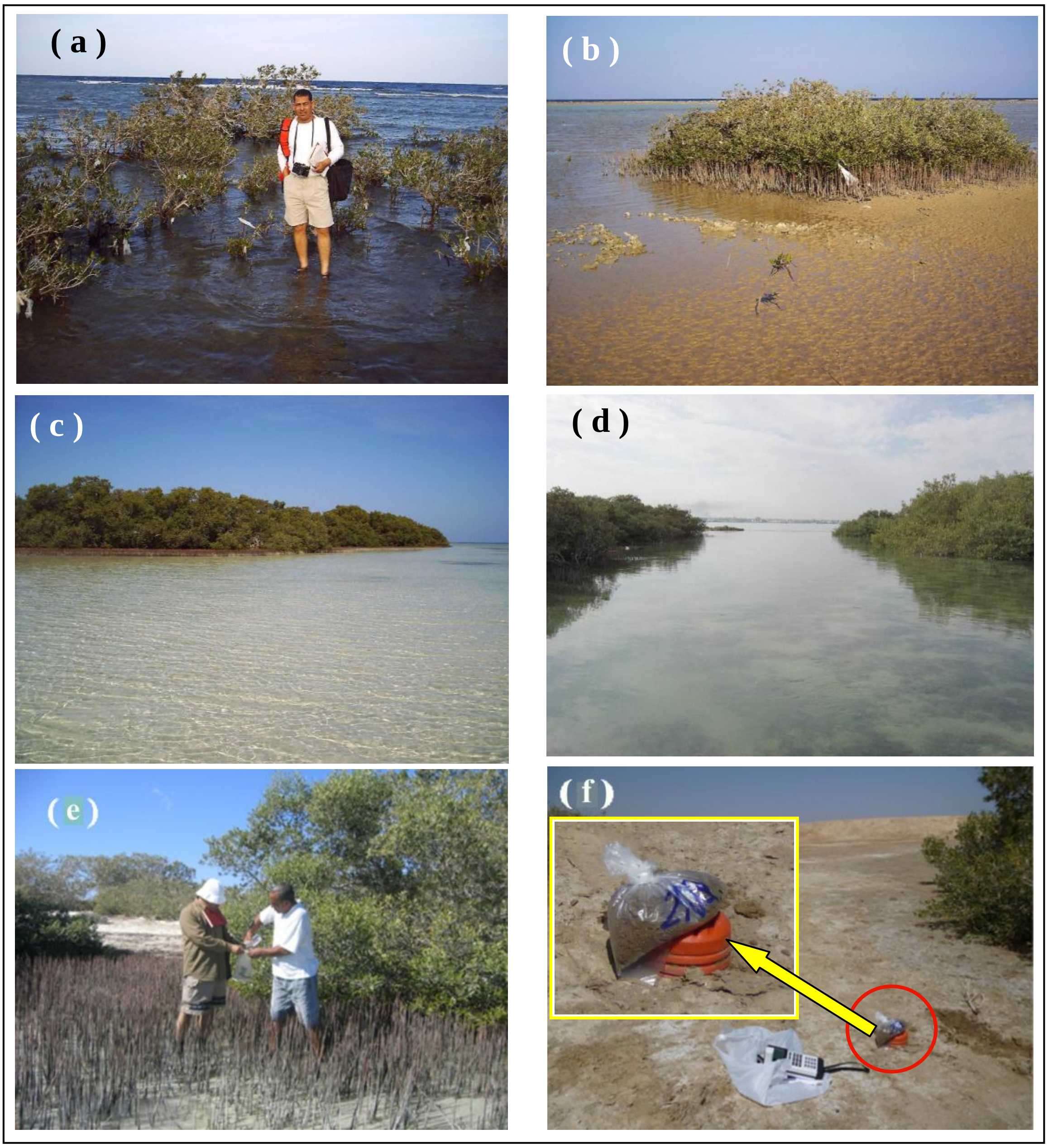
Figure no 1: Location Map of the studied mangrove areas.



II. Materials and Methods

Field Sampling: Fourty nine surface sediment samples were collected from the five sites of mangrove areas along the Egyptian Red Sea coast. The samples were taken by pushing a plastic bottle about 10-15 cm deep into the sediment (Plate no 1e, 1f). Seven samples were collected from Wadi El-Gimal mangrove area and distributed along different distances from the shoreline towards the sea with water depth ranges from 0 cm to 55 cm. Fifteen samples were collected from El-Queih mangrove area and distributed from the shoreline toward the sea with water depth from 0 to 75 cm. Thirteen samples were collected from South Safaga mangrove area and distributed from shoreline with water depth from 0 to 35 cm. Furthermore, 9 samples were collected from the mangrove area of Wadi El-Gimal island and distributed from the shoreline toward the sea with water depth from 0 to 15 cm. Five samples were collected from mangrove area of Abu-Minqar island, where the center of the island downs to about 1m below sea level with a basin character, which constitutes the mangrove swamp (Plate no 1d). Of these, thirty nine samples were selected for grain size analysis and geochemical analysis.

Plate no 1: a: Photo shows the dwarfed mangrove at W. El-Gimal coastal area; b- Photo shows the mangrove at south Safaga coastal area; c- General View shows the healthy and dense mangrove trees at W. El-Gimal island; d-General View shows the mangrove swamp at Abu-Minqar island; e- Sampling from the mangrove sediments at W. El-Gimal island, f- Close up view of sample was taken from the mangrove sediments at El-Queih area.



Laboratory Techniques: Before proceeding with the different analyses, samples were washed several times by distilled water to remove the soluble salts and were dried at 70° C. Subsamples were obtained by quartering for carrying out granulometric and chemical analyses.

Grain size Analysis: The grain size analysis of 39 selected samples of the studied three coastal areas and two islands was performed by dry sieving for 20 minutes, using Ro-Tap shaker and ASTM sieves placed at one Phi interval from -1ϕ (2mm) to 4ϕ (63μm) folbwing the technique given by Folk and Ward (1957). The average percentages of gravel, sand and mud of the analyzed samples were calculated and plotted on triangular diagram, according to (Folk (1980) (Figure no 2). The grain-size parameters including standard deviations (sorting), skewness and kurtosis were obtained, following Folk and Ward (1957) using Grain-Size Statistics Program (GSSTAT) proposed by Poppe et al. (2004). The results are listed in Table no 1a.

Geochemical Analysis: Thirty nine samples were selected to determine the concentrations of seven heavy metals namely; Iron (Fe), Manganese (Mn), Zinc (Zn), Nickel (Ni), Lead (Pb), Cupper (Cu) and Cadmium (Cd). About 0.5 gram of the ground sample was completely digested in a Teflon cup by a mixture of hydrofluoric acid, nitric acid and perchloric acid on hot plate at temperature of approximately 200 °C (Anon, 1992; Paalman and Van Der Weijden, 1992). After complete digestion, the samples were diluted to 25 ml with double-distilled water and then filtered in 50 ml glass bottle to remove any insoluble residues. The analyses were carried out using the Flame Atomic Absorption Spectrophotometer (AAS GBC Model 932, Ver.1.1) with detection limits of 0.01μg/g at the National Institute of Oceanography and Fisheries, Hurghada, Red Sea Branch. To insure that the maximum accuracies of the analyses were obtained, three replicates of each measurement were performed. The results were expressed in μg/g. The zero level of the AAS was adjusted by blanks.

Estimation of Ecological Risk indices: Several indices have been applied to assess the ecological risk of heavy metals in the coastal and islands mangrove sediments including; enrichment factor (EF) (Salomons and Förstner, 1984), geo-accumulation index (I_{geo})(Müller, 1969), contamination factor (Cf) and contamination degree (Cd) (Hakanson, 1980) and metal pollution load index (PLI) (Tomlinson et al. 1980). The interpretation of these indices, in the present study is depending on the comparison with the background concentrations of Fe, Mn, Zn, Ni, Pb, Cu and Cd in the average shale obtained from Turekian and Wedepohl (1961).

III. Results and Discussion

Grain size Analysis: Generally, the sediments of the investigated mangrove coastal areas and islands were found that mainly consist of sand with small amounts of gravel and mud. The content values of sand vary from 71.47% to 99.36% and 77.84% to 99.98% with an averages value are 90.8% and 90.76% for coastal areas and islands respectively. The gravel amount of coastal areas ranges between 0.03% and 28.04% with mean value is 7.08% for the coastal analyzed samples, whereas in island samples, it varies from 0.01% to 20.29% with an average up to 8.31%. The average mud contents are 2.13% and 0.93 for the samples of coastal areas and islands respectively (Table no 1a,1b). The analyzed samples were plotted on Folk's (1980) diagram. It is noted that the samples of mangrove coastal areas and islands were scattered in the sand, slightly gravelly sand and gravely sand fields, except only one sample of W. El-Gimal area and one sample of El-Queih area were located in the muddy sand and gravelly muddy sand respectively (Figure no 2).

The mean size of analyzed samples of the coastal mangrove areas varies from coarse sand (0.04ϕ) to fine sand (2.94ϕ) with an average 1.45ϕ (medium sand). The mean size of the island mangrove sediments ranges between coarse sand (0.46ϕ) to medium sand (1.97ϕ) with mean value is 1.02ϕ (medium sand). The sorting values of the investigated sediments of coastal mangrove areas range from moderately well sorted (0.63ϕ) to poorly sorted (1.84ϕ) with mean value refers to poorly sorted sediments (1.32ϕ). The island mangrove sediments are also poorly sorted (mean value attains 1.19ϕ). The distribution of coastal mangrove sediments ranges between strongly coarse skewed (-0.53ϕ) to fine skewed (0.26ϕ). The distribution of island mangrove sediments oscillates between near symmetrical distribution (-0.04ϕ) to strongly fine skewed sediments (0.37ϕ) with mean value (0.07ϕ, near symmetrical distribution). The sediments of coastal mangrove areas exhibit K_G values ranging between very platykurtic (0.54ϕ) and very leptokurtic (2.67ϕ) with mean value refers to leptokurtic character (1.14ϕ). The island mangrove sediments show values of K_G vary from platykurtic (0.68ϕ) to very leptokurtic (1.51ϕ) with an average value 0.98ϕ (mesokurtic) (Table no 1a,1b).

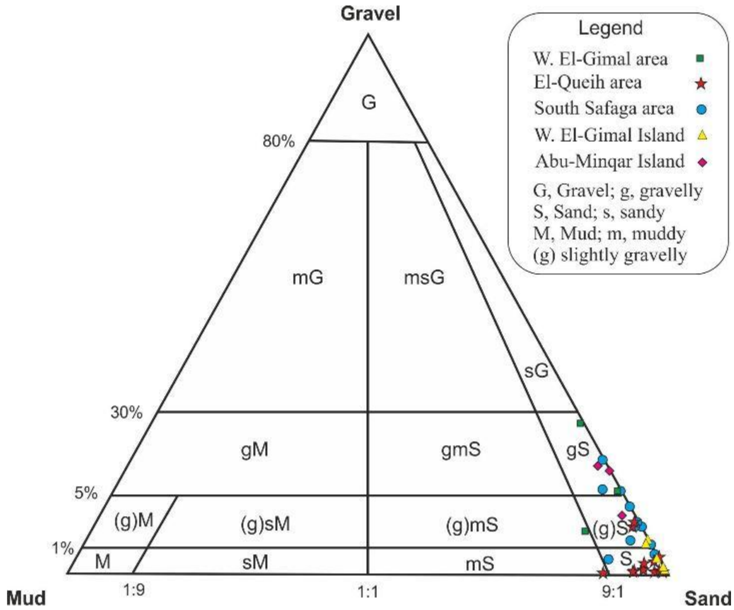
Table no 1a: Sediment types and grain size parameters for surface sediment samples of the coastal mangrove localities.

Locality	S. No.	sediment type			Grain size parameters (Folk&Ward,1957)			
		Gravel	Sand	Mud	Mz	σ_I	Sk_I	K_G
W.El-Gimal	WG1	1.41	98.48	0.11	2.69	0.63	-0.24	1.53
	WG2	28.04	71.47	0.49	0.95	1.79	0.08	0.54
	WG3	1.24	95.07	3.69	2.55	1.18	-0.49	1.03
	WG4	8.12	81.88	10.00	2.58	1.81	-0.37	2.40
	WG5	15.65	83.51	0.83	1.30	1.74	-0.29	0.85
	WG6	6.10	93.74	0.15	0.04	0.84	0.26	1.68
	WG7	9.63	89.82	0.55	1.22	1.50	-0.09	0.87
El-Queih	Q1	0.03	99.36	0.61	1.66	0.96	0.09	0.93
	Q2	2.20	96.42	1.38	1.26	1.56	-0.01	0.86
	Q3	3.26	96.64	0.09	0.75	1.18	0.10	0.88
	Q4	0.39	97.30	2.32	1.32	1.14	-0.27	0.87
	Q5	1.14	95.04	3.82	2.33	1.27	-0.35	0.94
	Q6	9.68	89.57	0.74	0.99	1.50	-0.07	0.72
	Q7	8.95	89.93	1.12	1.22	1.41	-0.19	0.96
	Q8	0.65	98.89	0.46	2.94	0.82	-0.53	2.23
	Q9	1.32	95.23	3.45	1.27	1.13	0.24	1.57
	Q10	0.20	88.81	10.99	2.10	1.61	0.19	1.19
	Q11	0.38	94.01	5.61	2.22	1.14	-0.03	0.88
South Safaga	S1	11.67	88.21	0.13	0.58	1.40	0.24	0.82
	S2	10.71	89.28	0.01	0.98	0.84	-0.36	1.84
	S3	8.05	91.76	0.20	0.66	1.20	-0.03	0.93
	S4	4.70	95.30	0.01	0.61	0.90	-0.13	1.05
	S5	3.32	96.60	0.09	2.09	1.10	-0.18	0.93
	S6	5.73	90.88	3.39	2.03	1.57	-0.45	0.93
	S7	8.22	90.43	1.36	1.50	1.53	-0.17	0.88
	S8	14.73	84.77	0.51	0.17	1.08	-0.02	2.67
	S9	15.20	81.87	2.94	1.52	1.82	-0.37	0.74
	S10	8.54	90.66	0.80	1.23	1.54	-0.07	0.78
	S11	7.80	92.04	0.16	0.41	1.11	0.10	0.99
	S12	20.53	78.66	0.81	1.21	1.84	-0.15	0.59
	S13	1.85	89.09	9.06	2.46	1.68	-0.31	1.39
Minimum		**0.03**	**71.47**	**0.01**	**0.04**	**0.63**	**-0.53**	**0.54**
Maximum		**28.04**	**99.36**	**10.99**	**2.94**	**1.84**	**0.26**	**2.67**
Average		**7.08**	**90.80**	**2.13**	**1.45**	**1.32**	**-0.12**	**1.14**

Table no 1b. Sediment types and grain size parameters for mangrove surface sediment Samples of W. El-Gimal and Abu-Minqar islands.

Island	S. No.	sediment type			Grain size parameters (Folk&Ward,1957)			
		Gravel	Sand	Mud	Mz	σ_I	Sk_I	K_G
W.El-Gimal	Gi1	0.63	98.93	0.44	1.84	0.73	-0.04	1.16
	Gi2	6.42	93.43	0.15	0.49	1.17	0.37	1.51
	Gi3	5.60	93.11	1.30	0.64	1.32	0.18	0.84
	Gi4	2.74	96.41	0.85	0.89	1.27	0.00	0.84
	Gi5	0.01	99.98	0.01	1.97	0.50	0.01	1.18
Abu-Minqar	AM1	20.29	79.64	0.07	0.73	1.53	-0.06	0.68
	AM2	10.93	86.73	2.33	1.14	1.56	-0.08	0.86
	AM3	19.86	77.84	2.29	0.46	1.45	0.17	0.74
Minimum		**0.01**	**77.84**	**0.01**	**0.46**	**0.50**	**-0.04**	**0.68**
Maximum		**20.29**	**99.98**	**2.33**	**1.97**	**1.56**	**0.37**	**1.51**
Average		**8.31**	**90.76**	**0.93**	**1.02**	**1.19**	**0.07**	**0.98**

Figure no 2: Nomenclature of the analyzed samples of mangrove sediments at different localities and islands after Folk (1980).



Geochemical analyses:

Heavy metals distribution: The concentrations of heavy metals in surface coastal and island mangrove sediments are listed in Tables no 2a,2b. Generally, the levels of average metal concentration are noted in the following descending order: Fe> Mn > Zn> Ni> Pb> Cu> Cd.

Iron distribution: The mangrove sediments of W. El-Gimal coastal area exhibited the highest mean concentration of Fe (4851.6 μg/g). On the other hand, the minimum value of Fe mean content was recorded in W. El-Gimal island sediments (1130.8 μg/g) (Table no 2a,b and Figure no 3a). The overall average content of all the analyzed sediments reached 2913.2μg/g (Table no 3). The Fe mean value of the present investigated sediments is extremely higher than the mean content of Fe in surface sediments at coastal area, northern Hurghada obtained by Nour et al. (2018) (355.44μg/g) and is relatively higher than the highest value of Fe obtained by Khalafallah et al. (2019) in mangrove sediments at Abu Hamra (30km South Safaga city)(2360.06±83.10μg/g). Meanwhile, The Fe mean value of the present study is relatively lower than the background value of the Red Sea sediments (3000 μg/g) recorded by Hanna (1992). Furthermore, the range of Fe values of the present study is much lower than that recorded by El-Metwally et al. (2017) from the coastal area of the Red Sea in Ras-Gharib, Hurghada, Safaga, and Qusier cities (3324-19296 μg/g). Also, it is lower than that obtained by El-Metwally et al. (2019) in different sites of coastal areas on the Egyptian Red Sea (11632-28321μg/g). Hanna (1992) reported that between 63% and 80% of the total Fe is held in the lattice structure of minerals (lithogenous origin). He also pointed out that generally, the sediments were collected in 1984 had higher mean value of total Fe (5500 μg/g) than those collected in 1934 (3000 μg/g) and he attributed this increase to man-made sources. Mansour et al. (2000) attributed the high concentrations of Fe in the shallow marine sediments along the Red Sea coast to the terrigenous contamination. Madkour (2005) attributed the relatively high levels of Fe, Mn and Pb in sediments and coral reef of Wadi El-Gimal, Red Sea, to natural input of terrigenous sediments through streams. Dar et al. (2016a) stated that Fe in the marine environment is mostly having terrestrial origin from both natural and anthropogenic inputs that may introduce the marine environment in the forms of oxides, oxyhydroxides, and silicate chains. Correlation coefficient results illustrate that Fe has a strong positive correlation with Mn (r=0.86), Zn (r=0.77), Ni (r=0.76), Cu (r=0.72) and mud (r=0.52) (Table no 4). On the other hand, Fe shows weak negative correlation with gravel (r=-0.08), sand (r=-0.13), Pb (r=-0.22) and Cd (r=-0.31). From the forementioned discussion, it is believed that the highest mean concentration of Fe in W. El-Gimal coastal area probably due to the terrestrial origin of sediments from natural inputs of W. El-Gimal stream from the basement rocks of the hinterland area in the Eastern Desert.

Manganese distribution: Manganese (Mn) is a naturally occurring element and comprises about 0.1% of the Earth's crust (NAS, 1973). The analyzed samples of W. El-Gimal coastal mangrove sediments showed the

Table no 2a: Heavy metal concentrations of surface mangrove sediments in coastal areas.

Locality	S. No.	Fe*	Mn*	Zn*	Ni*	Pb*	Cu*	Cd*
W.El-Gimal	WG1	6418.9	632.9	76.2	84.8	12.8	26.3	0.00
	WG2	4918.2	647.0	59.6	78.9	0.0	20.1	0.00
	WG3	6746.8	1448.7	121.1	173.6	0.0	45.4	0.78
	WG4	6507.2	1578.1	99.4	104.1	56.5	26.0	0.00
	WG5	3808.5	722.9	39.5	44.3	0.0	13.3	0.00
	WG6	2351.9	242.6	23.2	76.8	28.3	9.1	0.00
	WG7	3209.4	365.8	29.5	74.8	0.0	11.7	0.64
	Min.	**2351.9**	**242.6**	**23.2**	**44.3**	**0.0**	**9.1**	**0.00**
	Max.	**6746.8**	**1578.1**	**121.1**	**173.6**	**56.5**	**45.4**	**0.78**
	Avg.	**4851.6**	**805.4**	**64.1**	**91.0**	**13.9**	**21.7**	**0.20**
El-Queih	Q1	579.9	61.3	7.2	21.3	44.2	8.1	2.39
	Q2	308.1	62.7	9.8	17.1	16.0	7.7	4.51
	Q3	2919.4	260.7	18.0	21.3	39.1	23.9	3.91
	Q4	4067.0	440.2	55.0	34.5	0.0	22.6	2.82
	Q5	4899.3	386.5	8.4	97.9	0.0	18.2	4.61
	Q6	448.8	99.0	21.1	40.7	0.0	6.6	2.31
	Q7	6110.0	1189.9	170.3	67.9	0.6	18.4	0.68
	Q8	5447.9	661.0	110.0	48.8	0.0	14.4	1.17
	Q9	4426.4	545.7	106.5	33.7	0.0	10.0	3.06
	Q10	6803.6	1241.2	248.3	120.4	41.3	32.1	2.49
	Q11	7030.6	1192.7	250.2	105.4	9.8	27.1	1.47
	Min.	**308.1**	**61.3**	**7.2**	**17.1**	**0.0**	**6.6**	**0.68**
	Max.	**7030.6**	**1241.2**	**250.2**	**120.4**	**44.2**	**32.1**	**4.61**
	Avg.	**3912.8**	**558.3**	**91.3**	**55.4**	**13.7**	**17.2**	**2.67**
South Safaga	S1	2348.9	211.0	41.0	40.0	21.2	5.5	1.15
	S2	809.1	47.1	19.4	27.3	0.0	5.3	2.96
	S3	2017.7	123.4	26.7	43.2	0.0	8.8	4.82
	S4	418.7	44.7	29.7	17.1	28.0	7.6	4.91
	S5	5195.7	798.9	58.8	54.6	0.0	12.4	3.65
	S6	3776.9	330.6	43.4	37.6	0.0	11.2	2.78
	S7	3064.4	217.7	35.4	69.6	0.0	10.7	0.00
	S8	2017.7	130.5	19.9	48.3	0.0	9.7	0.00
	S9	6349.6	434.0	91.3	54.2	0.0	21.1	0.00
	S10	3831.1	145.5	30.3	60.9	17.9	9.6	0.00
	S11	3020.3	206.0	41.7	61.0	6.8	10.8	0.00
	S12	4476.9	284.7	36.7	43.4	0.0	11.6	0.00
	S13	3966.1	283.6	58.8	43.7	27.0	11.4	0.00
	Min.	**418.7**	**44.7**	**19.4**	**17.1**	**0.0**	**5.3**	**0.00**
	Max.	**6349.6**	**798.9**	**91.3**	**69.6**	**28.0**	**21.1**	**4.91**
	Avg.	**3176.4**	**250.6**	**41.0**	**46.2**	**7.8**	**10.4**	**1.56**

Table no 2b: Heavy metal concentrations of surface mangrove sediments in the islands.

Island	S.No.	Fe*	Mn*	Zn*	Ni*	Pb*	Cu*	Cd*
W.El-Gimal	Gi1	1986.2	68.4	23.5	0.0	11.7	13.1	2.52
	Gi2	1311.5	72.3	15.1	0.0	7.9	10.9	2.91
	Gi3	776.2	36.4	9.9	0.0	9.1	8.6	0.01
	Gi4	281.4	16.4	10.4	0.0	2.0	10.2	1.36
	Gi5	1298.9	73.2	21.1	3.7	0.0	16.4	1.19
	Min.	**281.4**	**16.4**	**9.9**	**0.0**	**0.0**	**8.6**	**0.01**
	Max.	**1986.2**	**73.2**	**23.5**	**3.7**	**11.7**	**16.4**	**2.91**
	Avg.	**1130.8**	**53.3**	**16.0**	**0.7**	**6.1**	**11.8**	**1.60**
Abu-Minqar	AM1	1418.7	50.6	3.2	1.3	0.0	18.2	2.94
	AM2	1317.8	58.5	4.1	4.9	8.5	14.5	0.96
	AM3	1746.6	33.6	21.8	69.5	24.4	11.3	2.06
	Min.	**1317.8**	**33.6**	**3.2**	**1.3**	**0.0**	**11.3**	**0.96**
	Max.	**1746.6**	**58.5**	**21.8**	**69.5**	**24.4**	**18.2**	**2.94**
	Avg.	**1494.4**	**47.6**	**9.7**	**25.2**	**11.0**	**14.7**	**1.99**

* = values in μg/g , Min. = minimum Max. = maximum Avg. = average

Table no 3: Mean concentration values of heavy metals of surface mangrove sediments in coastal areas and islands.

Locality	Fe	Mn	Zn	Ni	Pb	Cu	Cd
W. Gimal	4851.6	805.4	64.1	91.0	13.9	21.7	0.20
El-Queih	3912.8	558.3	91.3	55.4	13.7	17.2	2.67
S. Safaga	3176.4	250.6	41.0	46.2	7.8	10.4	1.56
W. Gimal isl.	1130.8	53.3	16.0	0.7	6.1	11.8	1.60
A.Minqar isl.	1494.4	47.6	9.7	25.2	11.0	14.7	1.99
Minimum	**1130.8**	**47.6**	**9.7**	**0.7**	**6.1**	**10.4**	**0.2**
Maximum	**4851.6**	**805.4**	**91.3**	**91.0**	**13.9**	**21.7**	**2.7**
Overall av.	**2913.2**	**343.0**	**44.4**	**43.7**	**10.5**	**15.2**	**1.6**

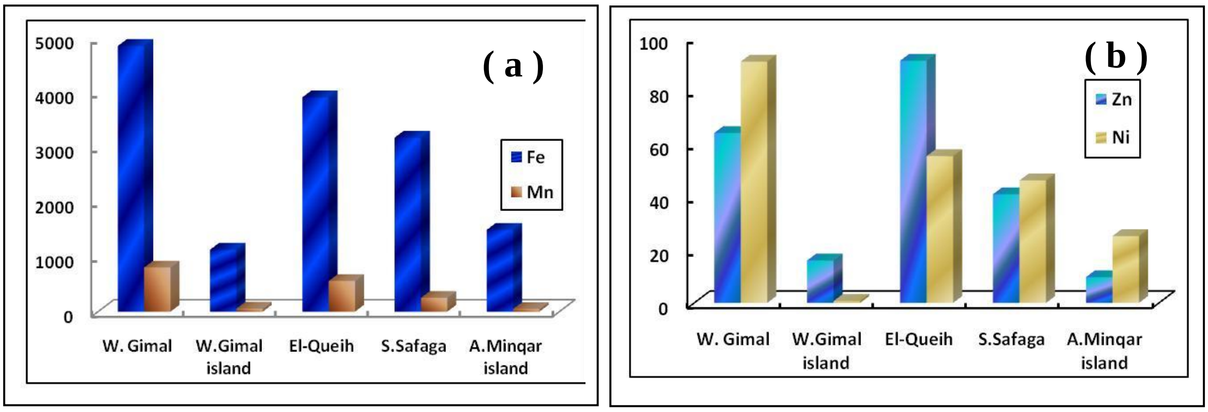
Table no 4: Correlation coefficient among sediment type contents and heavy metal concentrations.

	Gravel	Sand	Mud	Fe	Mn	Zn	Ni	Pb	Cu	Cd
Gravel	1.00									
Sand	-0.92	1.00								
Mud	-0.25	-0.15	1.00							
Fe	-0.08	-0.13	0.52	1.00						
Mn	-0.15	-0.08	0.59	0.86	1.00					
Zn	-0.24	0.00	0.60	0.77	0.82	1.00				
Ni	-0.03	-0.16	0.49	0.76	0.77	0.62	1.00			
Pb	-0.08	0.11	-0.08	-0.22	-0.12	-0.06	-0.13	1.00		
Cu	-0.19	-0.01	0.48	0.72	0.76	0.62	0.67	-0.13	1.00	
Cd	-0.33	0.37	-0.10	-0.31	-0.22	-0.15	-0.27	0.33	-0.13	1.00

highest mean concentration of Mn (805µg/g). Meanwhile, the lowest mean content (47.6 µg/g) was recorded in Abu-Minqar mangrove island sediments (Table no 2a,b and Figure no 3a). Also, the samples of W. El-Gimal island showed a very low mean concentration of Mn (53.3µg/g) comparable to its mean concentration in W. El-Gimal coastal area (805.4µg/g). The overall mean content of Mn in the mangrove surface sediments under investigation (343.0µg/g) (Table no 3), is much higher than the mean content of Mn of surface sediments at coastal area of northern Hurghada obtained by Nour et al. (2018) (51.95µg/g), and that recorded in Abu Hamra mangrove sediments (91.04±8.20µg/g) by Khalafallah et al. (2019). On the other hand, it is much lower than that obtained by El-Metwally et al. (2019) for the surface sediments from different sites on the Egyptian Red Sea coast (291.43 - 803.80µg/g). On the opposite side, the average concentration of Mn in all the studied sediments reached 343.0µg/g. The Mn average concentration of the present study is nearly three times higher than the Mn background value of the Red Sea sediments (116 µg/g)) recorded by Hanna (1992). Generally, It is noted that there is a relationship between the amount of Mn in most of the analyzed samples and the content of Fe. When the content of Fe is high, the content of Mn is also high and vice versa. This means that Mn is associated with Fe in ferromagnesian and accessory iron minerals (Madkour, 2005). Dar et al. (2016a) stated that Mn is mainly associated with Fe in its terrestrial source, nature, ways of accumulation, and also cooperated with Fe in the oxide and oxyhydroxide forms. However, the mean concentrations of Mn in W. El-Gimal, El-Queih and south Safage coastal areas are higher than the background value of the Red Sea sediments (116µg/g) recorded by Hanna (1992). On the other hand, the mean values of Mn concentration in W. El-Gimal and Abu-Minqar islands are much lower than Mn background value of Hanna (1992). Table no 4 illustrated the Mn values strongly positive correlate with the values of Fe (r=0.86), Zn (r=0.82), Ni (r=0.77), Cu (r=0.76) and mud (r=0.59). Simultaneously, Mn values weakly negative correlated with gravel (r=-0.15), sand (r=-0.08), Pb (r=-012) and Cd (r=-0.22).

Zinc distribution: The mean content of zinc (Zn) was ranged between 9.7 µg/g in the analyzed mangrove sediments of Abu-Minqar island and 91.3 µg/g that recorded in the coastal mangrove sediments of El-Queih area (Table no 2a,b and Figure no 3b). Furthermore, it is noted that the mean concentration of Zn in W. El-Gimal island sediments only reached 16.0 µg/g and forms one fourth of its mean content in the nearby W. El-Gimal mangrove coastal sediments that attained 64.1 µg/g. However, the mean concentration values of Zn for the under study sediments (9.7-91.3 µg/g) with an overall average 44.4µg/g (Table no 3), are lower than the mean values of Zn obtained by El-Metwally et al (2019) for the surface sediments from different sites on the Egyptian Red Sea coast (52.60-143.0µg/g). Nonetheless, The overall average concentration of Zn for all analyzed sediments in the present study is nearly twice times higher than that mentioned by Hanna (1992) (24 µg/g) and that obtained by Khalafallah et al. (2019) (26.38µg/g). Also, it is much higher than the average concentration of Zn recorded by Nour et al. (2018) from coastal sediments, northern Hurghada (7.47µg/g). Correlation coefficient illustrated that Zn is strongly positively correlated with Fe (r=0.77), Mn (r=0.82), Ni (r=0.62), Cu (r=0.62) and mud (r=0.6). It is weakly negative correlated with gravel (r=-0.24), Cd (r=-0.15) and Pb (r=-0.06) (Table no 4).

Nickel distribution: The highest value of Ni average concentration was recorded in mangrove sediments of W. El-Gimal coastal area (91.0µg/g), while the lowest mean value, exhibited by the nearby mangrove sediments of W. El-Gimal island (0.7µg/g) (Tables no 2a,b and Figure no 3b). The overall average concentration of the present analyzed samples is 43.7µg/g (Table no 3). Such average value is lower than that recorded by Uosif et al. (2016) for Quseir Harbour (55.7µg/g) and much higher than that obtained by Uosif et al. (2016) for South and North of Quseir (13.1 and 12.8µg/g respectively). Also, the overall average content of Ni for the present considered sediments is extremely higher than that obtained by Nour et al. (2018) for coastal sediments, northern Hurghada (1.73µg/g). The correlation coefficient illustrated that Ni is positively correlated with Fe (r=0.76), Mn (r=0.77), Cu (r=0.67), Zn (r=0.62) and mud (r=0.49) (Table no 4). On the opposite side, it is weakly negative correlated with gravel (r=-0.03), sand (r=-0.16), Pb (r=-0.13) and Cd (r=-0.27).



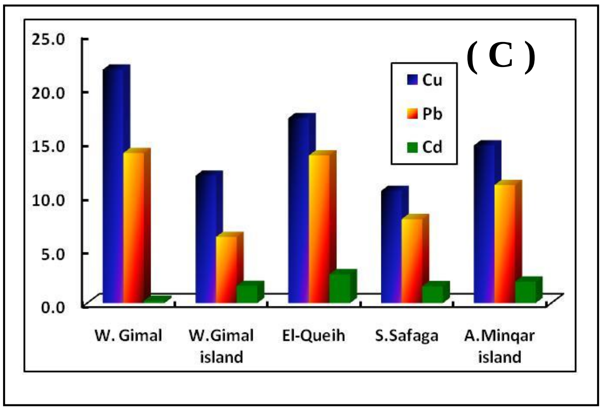
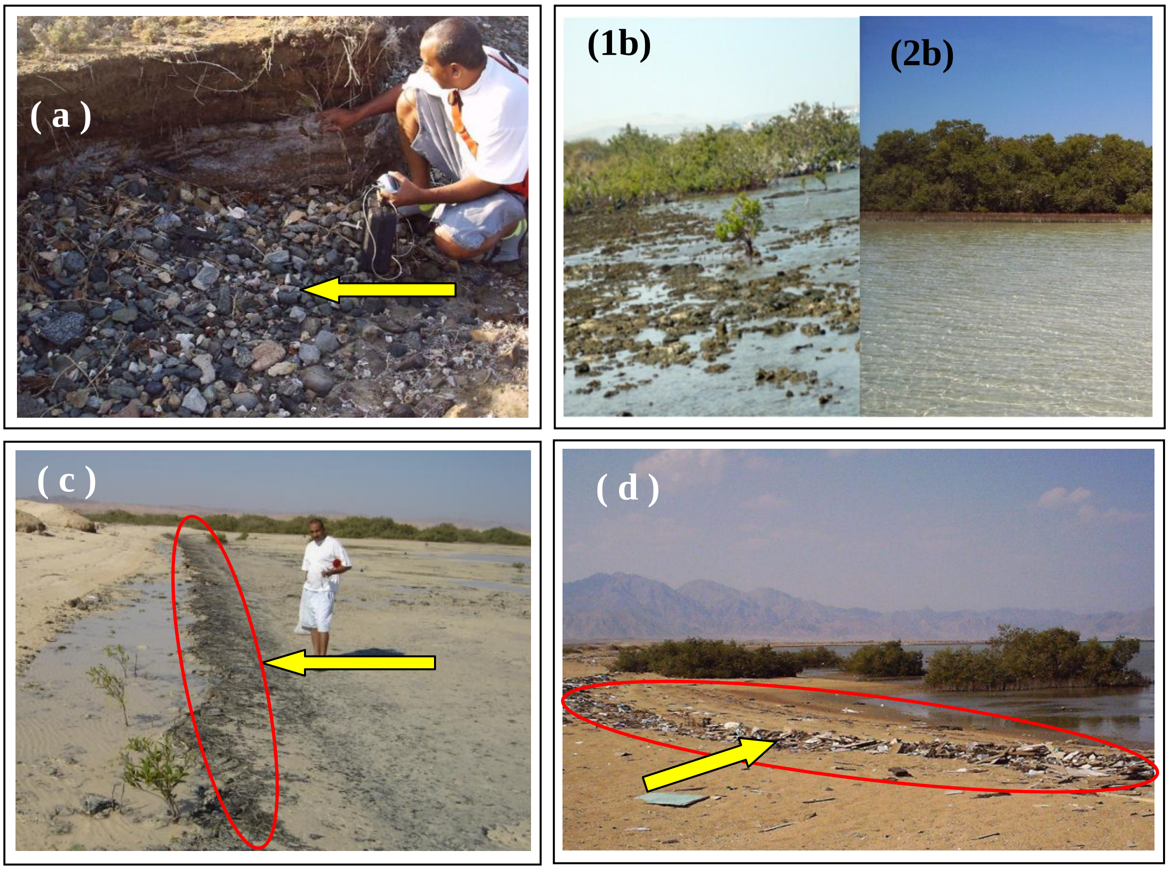


Figure no. 3: Shows the distribution of heavy metals in all the studied localities.
(a): distribution of Iron (Fe) and Manganese (Mn).
(b): distribution of Zinc (Zn) and Nickel (Ni).
(c): distribution of Copper (Cu), lead (Pb) and Cadmium (Cd).

Lead distribution: The highest mean value of Pb (13.9µg/g) was illustrated by W. El-Gimal coastal mangrove sediments, whereas the lowest mean value (6.1µg/g) was detected in W. El-Gimal island sediments (Table no 2a,b and Figure no 3c) with an overall average for all samples under investigation is 10.5µg/g (Table no 3). This value is higher than that recorded by Khalafallah et al. (2019) for Abu Hamra mangrove sediments (5.77µg/g). Also, It is more than three times, higher than the Red Sea background (3.0µg/g) mentioned by Hanna (1992). On the other hand, it is much lower than that obtained by Dar et al. (2016) (41.66µg/g), Nour et al. (2018) (41.89) and El-Metwally et al. (2019) (21.63µg/g). It is noted from Table no 4, that the lead is negatively correlated with most of the other elements except two elements where it is weakly positive correlated with sand and cadmium (r=0.11 and r=0.33 respectively).

Copper distribution: W. El-Gimal coastal mangrove sediments showed the maximum average concentration of Cu (21.7µg/g), whilst the sediments of south Safaga coastal mangrove exhibited the minimum average concentration of Copper (10.4µg/g) (Table no 2a,b and Figure no 3c). The overall average Cu concentration of all the analyzed samples attained 15.2µg/g (Table no 3). Generally, such overall mean content of Cu (15.2µg/g) is slightly lower than that mentioned by Hanna (1992) (17.6µg/g) for the Red Sea background of Cu. Meanwhile, it is similar to that obtained by Dar et al. (2017) (15.6µg/g) and equivalents to twice times to that recorded by Khalafallah et al. (2019) for Abu Hamra mangrove sediments (7.43µg/g). However, it is noted that W. El-Gimal coastal mangrove sediments show high mean value of Cu (21.7µg/g) comparable to that recorded in the neighbouring mangrove sediments of W. El-Gimal island (11.8µg/g). The same feature is also noted for Fe, Mn, Zn, Ni and Pb mean values for the two localities. The high concentrations of such elements in the coastal mangrove sediments besides the mutual positive correlation between them (Table no 4), infer that all these elements are incorporated in the ferromagnesian minerals of the terrigenous particles drained to the beach by Wadi El-Gimal stream from the basement rocks in the hinterlands of the eastern desert (Figure no 4a). Therefore, it is believed that the frequent inputs of such ferromagnesian clastic particles lead to the enrichment of the coastal mangrove sediments by these elements and don't give a chance for the accumulation of the enough nutrients required to the growth of the mangrove plants. Consequently, the mangrove plants in such area seem to be dwarfed comparable to the dense and healthy mangrove trees in the nearby W. El-Gimal island (Figure no 4b). From the correlation coefficient, it is observed that Cu is strongly positive correlated with Fe **(**r=0.72), Mn (r=0.76), Ni (r=67), Zn (r=0.62) and mud (r=0.48). On the other hand, it is weakly negative correlate with gravel (r=-0.19), Cd (-0.13), and sand (r=-0.01).

Figure no 4: a- Photo shows the terrigenous particles of basement rocks at W. El-Gimal coastal area (arrow); b- photos show the dwarfed mangrove trees at W. El-Gimal coastal area (1b) and dense, healthy mangrove trees at W. El-Gimal island (2b); c- Photo shows the oil spills on the coastal mangrove at El Queih area; d- Photo shows the garbage driven by sea water waves to S. Safaga mangrove coastal area.



Cadmium distribution: The highest mean content of Cd was displayed by El-Queih coastal mangrove sediments with value attained 2.67µg/g, whereas the lowest mean content was observed in W. El-Gimal coastal mangrove sediments with value reached 0.2µg/g (Tables no 2a and Figure no 3c). Generally, the analyzed samples of El-Queih coastal mangrove sediments and some samples from south Safaga as well as Ab-Minqar samples showed higher values of Cd than the analyzed samples from other localities in the present study (Table no 2a,b). This probably due to oil spills (tar balls) or the garbage driven by seawater waves from offshore to these localities (Figures 4c,d). However, the overall average concentration of Cd in all the analyzed samples up to 1.99µg/g. This value is much higher than that mentioned by Hanna (1992) (0.4µg/g**)** and lower than that obtained by Dar et al. (2017) (2.62µg/g) for the different mangrove swamp sediments along the Red Sea Coast**.** The correlation coefficient matrix illustrated that Cd positively correlated with sand and Pb (r=0.37**,** 0.33) respectively, whereas, it is negatively correlated with gravel, mud and all the other elements.

Assessment of sediments pollution:

To interpret and assess the status of metal pollution in the mangrove surface sediments, metal levels were compared to the background levels of heavy metals recorded by Turekian and Wedepohl (1961) for average shale. Pollution conditions were assessed by metal pollution indices, such as Enrichment factor (EF), geo-accumulation index (I_{geo}), contamination factor (CF) and pollution load index (PLI),. These indices were widely used to describe the contamination condition of surface sediments in aquatic environment (Chen et al., 2007).

Enrichment factor (EF):

Enrichment Factor (EF) is a good tool to differentiate the metal source between anthropogenic and naturally occurring (Chen et al, 2007). Its formula according to Salomons and Förstner (1984) and classification according to Birch (2003) are cited in Table no 5.

Manganese (Mn)

The enrichment factor for Mn in Wadi El-Gimal coastal area ranges from 0.55 to 1.35 with an average of 0.87. In El-Queih coastal area, EF values vary from 0.44 to 1.22, averaging 0.81. The EF values in south Safaga coastal area range between 0.21 to 0.85, with an average of 0.43. In Wadi El-Gimal island, the EF values in range between 0.19 to 0.32 with mean value is 0.28. In Abu-Minqar island, the EF values range between 0.11 to 0.25, with an average of 0.18. Generally, the enrichment factor values for all samples are less than 1, except only one sample in Wadi El-Gimal area (WG4) which attained 1.35 (Table no 6 and Figure no 5). According to the classification of Birch (2003), all samples fall in class "no enrichment" except one sample in Wadi El-Gimal coastal mangrove area (WG4), which falls in the minor enrichment class.

Zinc (Zn):

The enrichment factor for Zn in Wadi El-Gimal ranges from 0.46 to 0.89 with an average of 0.61. In El-Queih area, EF values vary from 0.08 to 2.34, with mean value 1.16. The EF values in south Safaga range between 0.39 to 3.53, averaging 0.88. In Wadi El-Gimal island, the EF values in range between 0.57 to 1.84, averaging 0.88. The EF values in Abu-Minqar island, oscillate between 0.11 to 0.62, with mean value of 0.30 (Table no 6 and Figure no 5). According to the classification of Birch (2003), the considered samples fall in classes of no enrichment to minor enrichment of zinc.

Nickel (Ni):

In Wadi El-Gimal coastal area, the enrichment factor for Ni ranges from 2.74 to 7.70 with mean value of 4.67. In El-Queih area, EF values vary from 1.73 to 21.39, averaging 5.99. The EF values in south Safaga range between 2.01 to 9.62, with mean value of 4.45. In Wadi El-Gimal island, the EF values in range between 0.00 to 0.66 , averaging 0.13. The EF values in Abu-Minqar island range between 0.21 to 9.39 , with an average of 3.49 (Table no 6 and Figure no 5). According to the classification of Birch (2003), the investigated samples of El Queih coastal area fall in moderately severe enrichment, while Wadi El-Gimal and south Safaga coastal areas, and Abu-Minqar island fall in moderate enrichment class. On the other hand, the EF mean values in Abu-Minqar island fall in class of no enrichment.

Copper (Cu):

The average value of enrichment factor for Cu in Wadi El-Gimal coastal area was 0.45. In El-Queih area, mean EF values is 0.84. The EF average value in south Safaga was 0.48. In Wadi El-Gimal island, the EF mean value was 1.57. The average EF in Abu-Minqar island was 1.06 (Table no 6 and Figure no 5). According to Birch (2003) classification, the samples of Wadi El-Gimal and Abu-Minqar islands fall in class of minor enrichment and all the coastal areas fall in class of no enrichment.

Lead (Pb):

The mean value of enrichment factor for Pb in Wadi El-Gimal coastal area recorded 0.77. In El-Queih area, EF values for some samples oscillate from 0.00 to 3.16, except two samples (Q1, Q3) showed high EF values(17.98 and 12.24) respectively, with an average value attained 3.20. The EF values in south Safaga range between 0.00 to 2.13, except one sample (S4) exhibited high EF value reached 15.78, with mean value of 1.63. In Wadi El-Gimal island, the EF values in range between 0.00 to 2.77, averaging 1.45. The EF values in Abu-Minqar island range between 0.00 and 3.30, with an average of 1.61(Table no 6 and Figure no 5). According to mean values of the studied localities and classification of Birch (2003), the samples of W. El-Gimal coastal area fall in class of no enrichment. The samples of South Safaga area (excluding sample S4 fall in severe enrichment), Wadi El-Gimal and Abu-Minqar islands fall in minor enrichment, whereas the samples of El-Queih area fall in moderate enrichment, except Q1 and Q3 fall in severe enrichment.

Table no 5: Equations of pollution indicators used in the present study and their classification.

Enrichment factor (EF):

EF = (M/Fe) sample / (M/Fe) background

Where (M/Fe) sample is the ratio of metal and Fe concentrations in the sample, and (M/Fe) background is the ratio of metal and Fe concentrations in the Earth's crust. Birch (2003) determined seven classes of EF in sediments:

EF < 1	No enrichment;	EF < 3	Minor enrichment;
EF = 3–5	Moderate enrichment;	EF = 5–10	Moderately severe enrichment;
EF = 10–25	Severe enrichment	EF = 25–50	Very severe enrichment;
EF > 50	Extremely severe enrichment.		

Geo-accumulation index (Igeo):

$$I_{geo} = \log_2(C_n/1.5B_n)$$

Where C_n is the concentration of element in the enriched samples, and the B_n is the background (the concentration of element n in the average shale of Turekian and Wedepohl (1961). The factor 1.5 is introduced to minimize the effect of possible variations in the background values (correction factor) which may be attributed to lithogenic variations in the sediments. The following classification of (I_{geo}) is according to Müller (1981):

I_{geo} value	I_{geo} class	Pollution intensity
< 0	0	unpolluted
0-1	1	unpolluted to moderately polluted
1-2	2	moderately polluted
2-3	3	moderately to strongly polluted
3-4	4	strongly polluted
4-5	5	strongly to very strongly polluted
> 5	6	very strongly polluted

Contamination Factor (CF):

$$CF = C_{metal}/C_{background}$$

where C_{metal} denotes the content of the specific heavy metal investigated in the sediment and $C_{background}$ is the local uncontaminated background level for the same metal. In the present study, the results of Mohamed (2000) for sediments collected from shallow water sediments of the Red Sea were used as background values for heavy metals. Hakanson (1980) classified the CF into four categories as follows:

CF<1:	low contamination;	1≤CF<3:	moderate contamination;
3≤CF<6:	considerable contamination;	CF≥6:	very high contamination.

Contamination Degree (Cd):

$$Cd = \Sigma (CF_1 + CF_2 + CF_3 + \ldots\ldots +CF_n).$$

Where Cd is the sum of the CF for the pollutant metals according to Hakanson (1980). The sum of the contamination factors of all elements examined represents the contamination degree of the environment. Four classes were recognized according to Hakanson (1980) as follows:

Cd<6:	low contamination degree;	6≤ Cd <12:	moderate contamination degree;
12≤Cd<24:	considerable contamination degree;	Cd ≥ 24:	very high contamination degree.

Pollution Load Index (PLI):

$$PLI = (CF1 \times CF2 \times \ldots\ldots\ldots \times CF n)^{1/n}$$

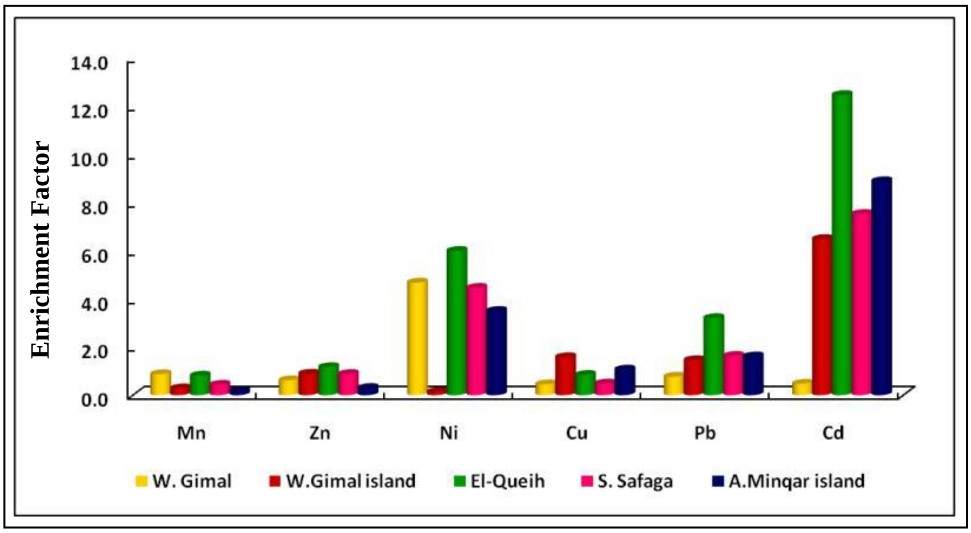
where *n* is the number of metals and CF the contamination factor of the studied metals. According to Tomlinson et al. (1980)

PLI = zero: indicates no pollution, PLI = 1: indicates baseline levels of pollutants,
PLI > 1: indicates deterioration in the sediment quality.

Cadmium (Cd):

The enrichment factor for Cd in Wadi El-Gimal area ranged from 0.00 to 1.81 with an average of 0.47. In El-Queih area, EF values vary from 1.74 to 22.50, averaging 12.46. The EF values in south Safaga range between 0.00 to 23.97 (sample S4), averaging 7.52. In Wadi El-Gimal island, the EF values in range between 0.20 to 14.21, with mean value of 6.48. The EF values in Abu-Minqar island range between 2.23 to 14.35, with an average of 8.88. According to Birch (2003) classification, the samples of Wadi El-Gimal fall in no enrichment class, while South Safaga area, Wadi El-Gimal and Abu-Minqar islands fall in class of moderately severe enrichment. The coastal area of El-Queih falls in severe enrichment class.

Figure no 5: Enrichment Factor of the studied sediments in mangrove coastal areas and islands.



Geo-accumulation index (I_{geo}):

The values of geo-accumulation index (*I*geo) for the metals studied were calculated using the Müller's (1969) formula. The background used in the present study is the content of metal in the average shale of Turekian and Wedepohl (1961). The pollution extent could be classified according to the scale proposed by Müller (1981) who distinguished seven classes of contamination (Table no 5).

Iron (Fe)

The average values of geo-accumulation index for Fe varying from -0.64 in Wadi El-Gimal coastal area to -2.91 in the nearby Wadi El-Gimal island sediments (Table no 6 and Figure no 6). According to the classification of Müller (1981), The I_{geo} average values of Fe for the investigated sediments in all the localities are less than zero and classified as unpolluted sediments (class 0).

Manganese (Mn)

The average values of geo-accumulation index for Mn vary from -0.93 in Wadi El-Gimal coastal area to -4.78 in both Wadi El-Gimal and Abu-Minqar islands. According to the classification of Müller (1981), the I_{geo} values for Mn of the analyzed sediment samples in all the localities are less than zero and classified as unpolluted sediments (class 0).

Zinc (Zn)

The calculated mean values of geo-accumulation index for Zn oscillate between -1.38 in the sediments of Wadi El-Gimal coastal area and -4.44 in Abu-Minqar island sediments (Table no 6 and Figure no 6). According to the classification of Müller (1981) The *Igeo* values for Zn of the samples in the area are less than zero and classified as unpolluted sediments (class 0)

Nickel (Ni)

The lowest recorded mean value of geo-accumulation index for Ni was found in Wadi El-Gimal island (-10.8), whereas the highest mean value was exhibited by the sediments of Wadi El-Gimal coastal area (0.32) (Table no 6 and Figure no 6). According to the classification of Müller (1981) The I_{geo} values for Ni of the samples in the area are less than zero and classified as unpolluted (class 0).

Table no 6: Enrichment Factor (EF) and Geoaccumulation Index (I_{geo}) values of surface mangrove sediments.
Q = El-Queih area, WG = Wadi El-Gimal area, S = South Safaga area, Gi = Wadi El-Gimal island, AM = Abu-Minqar island.
Min. = Minimum, Max. = Maximum Avg. = Average.

S. No.	Fe		Mn		Zn		Ni		Cu		Pb		Cd	
	EF	I_{geo}	EF	I_{geo}	EF	I_{geo}	EF	I_{geo}	EF	I_{geo}	EF	I_{geo}	EF	I_{geo}
WG1	-	-0.14	0.55	-1.01	0.59	-0.90	3.12	0.33	0.43	-1.36	0.47	-1.2	0.00	-12.1
WG2	-	-0.53	0.73	-0.98	0.60	-1.26	3.79	0.22	0.43	-1.75	0.00	-15.4	0.00	-9.81
WG3	-	-0.07	1.19	0.18	0.89	-0.24	6.07	1.36	0.71	-0.57	0.00	-18.2	1.81	0.79
WG4	-	-0.12	1.35	0.31	0.76	-0.52	3.77	0.62	0.42	-1.38	2.05	0.9	0.00	-10.1
WG5	-	-0.89	1.05	-0.82	0.51	-1.85	2.74	-0.61	0.37	-2.34	0.00	-18.2	0.00	-10.5
WG6	-	-1.59	0.57	-2.39	0.49	-2.62	7.70	0.19	0.41	-2.89	2.84	-0.08	0.00	-9.33
WG7	-	-1.14	0.63	-1.80	0.46	-2.27	5.50	0.15	0.38	-2.53	0.00	-18.2	1.49	0.51
Min.		**-1.59**	**0.55**	**-2.39**	**0.46**	**-2.62**	**2.74**	**-0.61**	**0.37**	**-2.89**	**0.00**	**-18.2**	**0.00**	**-12.1**
Max.		**-0.07**	**1.35**	**0.31**	**0.89**	**-0.24**	**7.70**	**1.36**	**0.71**	**-0.57**	**2.84**	**0.91**	**1.81**	**0.79**
Avg.		**-0.64**	**0.87**	**-0.93**	**0.61**	**-1.38**	**4.67**	**0.32**	**0.45**	**-1.83**	**0.77**	**-10.0**	**0.47**	**-7.24**
Q1	-	-3.61	0.59	-4.38	0.61	-4.31	8.66	-1.67	1.47	-3.06	17.98	0.56	11.67	2.41
Q2	-	-4.52	1.13	-4.35	1.58	-3.86	13.10	-1.98	2.63	-3.13	3.16	-0.91	22.02	3.33
Q3	-	-1.28	0.50	-2.29	0.31	-2.98	1.73	-1.66	0.86	-1.50	12.24	0.38	20.98	3.12
Q4	-	-0.80	0.60	-1.53	0.67	-1.37	2.00	-0.97	0.58	-1.58	0.00	-18.2	13.77	2.65
Q5	-	-0.53	0.44	-1.72	0.08	-4.09	4.72	0.54	0.39	-1.89	0.00	-17.4	22.50	3.36
Q6	-	-3.98	1.22	-3.69	2.34	-2.76	21.39	-0.73	1.54	-3.35	0.00	-17.3	11.28	2.36
Q7	-	-0.21	1.08	-0.10	1.38	0.26	2.62	0.01	0.32	-1.88	0.02	-5.74	1.74	0.60
Q8	-	-0.38	0.67	-0.95	1.00	-0.37	2.12	-0.47	0.28	-2.23	0.00	-18.2	2.72	1.38
Q9	-	-0.68	0.68	-1.22	1.20	-0.42	1.80	-1.00	0.24	-2.76	0.00	-18.2	14.94	2.77
Q10	-	-0.06	1.01	-0.04	1.81	0.80	4.18	0.84	0.50	-1.07	1.43	0.46	12.16	2.47
Q11	-	-0.01	0.94	-0.10	1.77	0.81	3.54	0.64	0.40	-1.32	0.33	-1.61	3.28	1.71
Min.		**-4.52**	**0.44**	**-4.38**	**0.08**	**-4.31**	**1.73**	**-1.98**	**0.24**	**-3.35**	**0.00**	**-18.2**	**1.74**	**0.60**
Max.		**-0.01**	**1.22**	**-0.04**	**2.34**	**0.81**	**21.39**	**0.84**	**2.63**	**-1.07**	**17.98**	**0.56**	**22.50**	**3.36**
Avg.		**-1.46**	**0.81**	**-1.85**	**1.16**	**-1.66**	**5.99**	**-0.59**	**0.84**	**-2.16**	**3.20**	**-8.74**	**12.46**	**2.38**
S1	-	-1.59	0.50	-2.60	0.87	-1.80	4.02	-0.75	0.25	-3.62	2.13	-0.50	2.67	1.35
S2	-	-3.13	0.32	-4.76	1.19	-2.88	7.96	-1.31	0.69	-3.67	0.00	-15.6	14.45	2.72
S3	-	-1.81	0.34	-3.37	0.66	-2.42	5.05	-0.65	0.45	-2.95	0.00	-16.6	23.53	3.42
S4	-	-4.08	0.59	-4.83	3.53	-2.26	9.62	-1.98	1.90	-3.15	15.78	-0.10	23.97	3.45
S5	-	-0.45	0.85	-0.67	0.56	-1.28	2.48	-0.30	0.25	-2.44	0.00	-15.8	19.59	3.02
S6	-	-0.91	0.49	-1.95	0.57	-1.72	2.35	-0.84	0.31	-2.59	0.00	-17.3	13.57	2.63
S7	-	-1.21	0.39	-2.55	0.57	-2.01	5.36	0.04	0.37	-2.66	0.00	-16.2	0.00	-10.1
S8	-	-1.81	0.36	-3.29	0.49	-2.84	5.64	-0.48	0.50	-2.80	0.00	-16.6	0.00	-9.81
S9	-	-0.16	0.38	-1.55	0.71	-0.64	2.01	-0.32	0.35	-1.68	0.00	-17.2	0.00	-9.55
S10	-	-0.89	0.21	-3.13	0.39	-2.24	3.75	-0.15	0.26	-2.81	1.11	-0.74	0.00	-12.1
S11	-	-1.23	0.38	-2.63	0.69	-1.77	4.77	-0.15	0.38	-2.64	0.53	-2.14	0.00	-12.5
S12	-	-0.66	0.35	-2.16	0.41	-1.96	2.29	-0.64	0.27	-2.55	0.00	-17.2	0.00	-10.6
S13	-	-0.84	0.40	-2.17	0.74	-1.28	2.60	-0.63	0.30	-2.57	1.61	-0.15	0.00	-9.55
Min.	-	**-4.08**	**0.21**	**-4.83**	**0.39**	**-2.88**	**2.01**	**-1.98**	**0.25**	**-3.67**	**0.00**	**-17.3**	**0.00**	**-12.5**
Max.	-	**-0.16**	**0.85**	**-0.67**	**3.53**	**-0.64**	**9.62**	**0.04**	**1.90**	**-1.68**	**15.78**	**-0.10**	**23.97**	**3.45**
Avg.	-	**-1.44**	**0.43**	**-2.74**	**0.88**	**-1.93**	**4.45**	**-0.63**	**0.48**	**-2.78**	**1.63**	**-10.5**	**7.52**	**-4.43**
Gi1	-	-1.83	0.19	-4.22	0.59	-2.60	0.00	-10.9	0.69	-2.37	1.39	-1.36	12.30	2.49
Gi2	-	-2.43	0.31	-4.14	0.57	-3.24	0.00	-10.9	0.87	-2.64	1.42	-1.92	14.21	2.69
Gi3	-	-3.19	0.26	-5.13	0.63	-3.85	0.00	-10.9	1.17	-2.97	2.77	-1.72	0.20	-5.49
Gi4	-	-4.65	0.32	-6.28	1.84	-3.77	0.00	-10.9	3.82	-2.72	1.68	-3.91	3.03	1.60
Gi5	-	-2.45	0.31	-4.12	0.81	-2.76	0.66	-10.5	1.33	-2.04	0.00	-11.7	2.65	1.40
Min.	-	**-4.65**	**0.19**	**-6.28**	**0.57**	**-3.85**	**0.00**	-10.9	**0.69**	**-2.97**	**0.00**	**-11.7**	**0.20**	**-5.49**
Max.	-	**-1.83**	**0.32**	**-4.12**	**1.84**	**-2.60**	**0.66**	-10.5	**3.82**	**-2.04**	**2.77**	**-1.36**	**14.21**	**2.69**
Avg.	-	**-2.91**	**0.28**	**-4.78**	**0.89**	**-3.24**	**0.13**	**-10.8**	**1.57**	**-2.55**	**1.45**	**-4.12**	**6.48**	**0.54**
AM1	-	-2.32	0.20	-4.65	0.11	-5.49	0.21	-10.7	1.35	-1.89	0.00	-10.9	14.35	2.71
AM2	-	-2.43	0.25	-4.45	0.15	-5.12	0.87	-10.2	1.15	-2.22	1.52	-1.82	2.23	1.09
AM3	-	-2.02	0.11	-5.25	0.62	-2.71	5.36	0.04	0.68	-2.58	3.30	-0.30	10.06	2.19
Min.	-	**-2.43**	**0.11**	**-5.25**	**0.11**	**-5.49**	**0.21**	**-10.7**	**0.68**	**-2.58**	**0.00**	**-10.9**	**2.23**	**1.09**
Max.	-	**-2.02**	**0.25**	**-4.45**	**0.62**	**-2.71**	**5.36**	**0.04**	**1.35**	**-1.89**	**3.30**	**-0.30**	**14.35**	**2.71**
Avg.	-	**-2.25**	**0.18**	**-4.78**	**0.30**	**-4.44**	**2.15**	**-6.9**	**1.06**	**-2.23**	**1.61**	**-4.36**	**8.88**	**2.00**
Overall Min		**-4.65**	**0.11**	**-6.28**	**0.08**	**-5.49**	**0.00**	**-10.9**	**0.24**	**-3.67**	**0.00**	**-18.2**	**0.00**	**-12.5**
Overall Max		**-0.01**	**1.35**	**0.31**	**3.53**	**0.81**	**21.39**	**1.36**	**3.82**	**-0.57**	**17.98**	**0.91**	**23.97**	**3.45**
Overall Avg.		**-1.55**	**0.58**	**-2.58**	**0.87**	**-2.12**	**4.30**	**-2.57**	**0.76**	**-2.36**	**1.89**	**-8.62**	**7.62**	**-1.88**

Cupper (Cu)

The highest average value of *Igeo* for Cu was observed in Wadi El-Gimal coastal sediments (-1.83), whereas the lowest mean value was exhibited by South Safaga coastal sediments (-2.78). Following Müller's classification (1981), The *Igeo* values for Cu of the considered sediments in all localities are less than zero and classified as unpolluted (class 0)

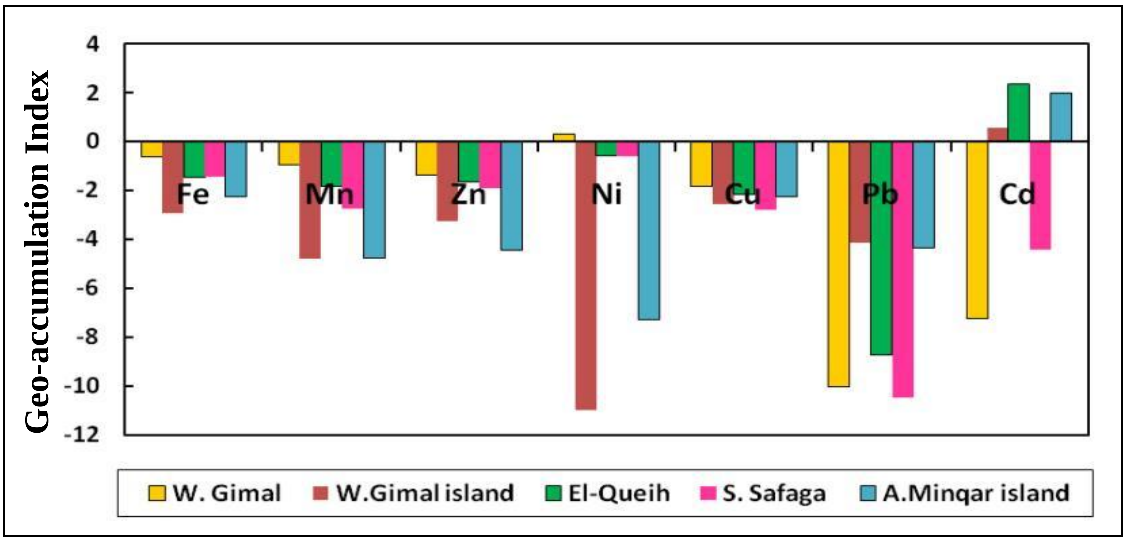
Lead (Pb)

The average values of geo-accumulation index for Pb range from -10.5 in in South Safaga coastal sediments to -4.12 in Wadi El-Gimal island sediments. According to Müller's (1981) classification, the I_{geo} values for Pb of all the analyzed samples in the area under investigation are less than zero and classified as unpolluted sediments (class 0).

Cadmium (Cd):

The high mean values of geo-accumulation index for Cd were detected in El-Queih area coastal area sediments and Abu-Minqar island sediments (2.38, 2.0) respectively. The sediments of Wadi El-Gimal island exhibited I_{geo} mean value attained 0.54. on the other hand, the low mean values were recorded in Wadi El-Gimal and South Safaga coastal areas (-7.24, -4.43) respectively. Following Müller's (1981) classification, the I_{geo} mean values for Cd of the samples in the area of Wadi El-Gimal and South Safaga coastal areas are less than zero and classified as unpolluted (class 0). The sediments of Wadi El-Gimal island are classified as unpolluted to moderately polluted (class1) and Abu-Minqar island sediments are classified as unpolluted to moderately polluted (class2). The sediments of El-Queih coastal area are classified as moderately to strongly polluted with cadmium (class3).

Figure no 6: Geo-accumulation index of the studied sediments in mangrove coastal areas and islands.



Contamination Factor (CF):

Contamination factor is usually used to express the contamination level of sediments (Hakanson, 1980). The formula and classification of the contamination factor (CF) are cited in Table no 5. Generally, the contamination factors for iron (Fe), copper (Cu) and lead (Pb) in all the studied localities exhibited mean values less than 1. According to the classification of Hakanson (1980), the studied sediments in such localities were subjected to low contamination of these elements. On the other hand, the average values of manganese (Mn), zinc (Zn), nickel (Ni) and cadmium (Cd), ranged between (0.08, 0.15, 0.02, 0.23) and (1.32, 1.44, 2.27, 2.97) respectively (Table no 7 and Figure no 7). That means, the investigated sediments were subjected to moderate contamination of the Mn, Zn, Ni and Cd elements.

Contamination degree (Cd):

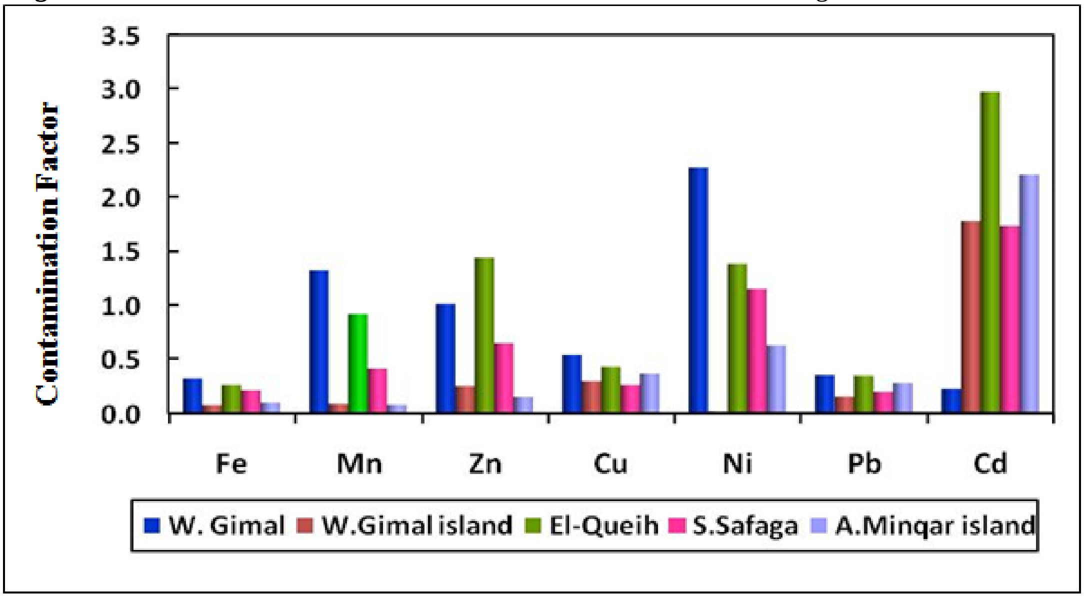
The sediments of W. El-Gimal mangrove coastal area exhibited average value of contamination degree of 6.04. El-Quieh coastal area sediments showed mean value of 7.74. South Safaga, mangrove coastal sediments recorded mean value for Cd of 4.61. The sediments of W. El-Gimal and Abu-Minqar mangrove islands illustrated mean values of 2.66, 3.81 respectively (Table no 7). From the forementioned Contamination degree (Cd) mean values, the sediments of South Safaga coastal area, W. El-Gimal and Abu-Minqar islands fall in the

Table no 7: Contamination factors (CF) of heavy metals and pollution load index (PLI) for surface sediments at the study areas.
Min. = Minimum Max. = Maximum Avg. = Average

Locality	S. No.	Contamination Factor (CF)							Cont. deg. (Cd)	PLI
		Fe	Mn	Zn	Cu	Ni	Pb	Cd		
W.El-Gimal coastal area	WG1	0.43	1.04	1.20	0.65	2.11	0.32	0.00	5.76	0.00
	WG2	0.33	1.06	0.94	0.50	1.97	0.00	0.00	4.80	0.00
	WG3	0.45	2.38	1.91	1.13	4.33	0.00	0.87	11.06	0.00
	WG4	0.43	2.59	1.57	0.65	2.60	1.43	0.00	9.26	0.00
	WG5	0.25	1.19	0.62	0.33	1.10	0.00	0.00	3.50	0.00
	WG6	0.16	0.40	0.37	0.23	1.91	0.71	0.00	3.78	0.00
	WG7	0.21	0.60	0.46	0.29	1.86	0.00	0.71	4.15	0.00
	Min.	**0.16**	**0.40**	**0.37**	**0.23**	**1.10**	**0.00**	**0.00**	**3.50**	**0.00**
	Max.	**0.45**	**2.59**	**1.91**	**1.13**	**4.33**	**1.43**	**0.87**	**11.06**	**0.00**
	Avg.	**0.32**	**1.32**	**1.01**	**0.54**	**2.27**	**0.35**	**0.23**	**6.04**	**0.00**
El-Queih coastal area	Q1	0.04	0.10	0.11	0.20	0.53	1.12	2.66	4.76	0.00
	Q2	0.02	0.10	0.15	0.19	0.43	0.40	5.01	6.31	0.00
	Q3	0.19	0.43	0.28	0.60	0.53	0.99	4.34	7.37	0.01
	Q4	0.27	0.72	0.87	0.56	0.86	0.00	3.13	6.42	0.00
	Q5	0.33	0.63	0.13	0.45	2.44	0.00	5.12	9.11	0.00
	Q6	0.03	0.16	0.33	0.16	1.01	0.00	2.57	4.27	0.00
	Q7	0.41	1.95	2.68	0.46	1.69	0.01	0.76	7.96	0.00
	Q8	0.36	1.08	1.73	0.36	1.22	0.00	1.30	6.06	0.00
	Q9	0.30	0.90	1.68	0.25	0.84	0.00	3.40	7.36	0.00
	Q10	0.45	2.04	3.91	0.80	3.00	1.04	2.77	14.01	1.39
	Q11	0.47	1.96	3.94	0.68	2.63	0.25	1.63	11.55	0.16
	Min.	**0.02**	**0.10**	**0.11**	**0.16**	**0.43**	**0.00**	**0.76**	**4.27**	**0.00**
	Max.	**0.47**	**2.04**	**3.94**	**0.80**	**3.00**	**1.12**	**5.12**	**14.01**	**1.39**
	Avg.	**0.26**	**0.92**	**1.44**	**0.43**	**1.38**	**0.35**	**2.97**	**7.74**	**0.14**
South Safaga coastal area	S1	0.16	0.35	0.65	0.14	1.00	0.54	1.28	4.10	0.00
	S2	0.05	0.08	0.31	0.13	0.68	0.00	3.29	4.54	0.00
	S3	0.13	0.20	0.42	0.22	1.08	0.00	5.36	7.41	0.00
	S4	0.03	0.07	0.47	0.19	0.43	0.71	5.46	7.35	0.00
	S5	0.35	1.31	0.93	0.31	1.36	0.00	4.06	8.31	0.00
	S6	0.25	0.54	0.68	0.28	0.94	0.00	3.09	5.78	0.00
	S7	0.20	0.36	0.56	0.27	1.73	0.00	0.00	3.12	0.00
	S8	0.13	0.21	0.31	0.24	1.20	0.00	0.00	2.11	0.00
	S9	0.42	0.71	1.44	0.53	1.35	0.00	0.00	4.45	0.00
	S10	0.26	0.24	0.48	0.24	1.52	0.45	0.00	3.18	0.00
	S11	0.20	0.34	0.66	0.27	1.52	0.17	0.00	3.16	0.00
	S12	0.30	0.47	0.58	0.29	1.08	0.00	0.00	2.71	0.00
	S13	0.26	0.47	0.93	0.28	1.09	0.68	0.00	3.71	0.00
	Min.	**0.03**	**0.07**	**0.31**	**0.13**	**0.43**	**0.00**	**0.00**	**2.11**	**0.00**
	Max.	**0.42**	**1.31**	**1.44**	**0.53**	**1.73**	**0.71**	**5.46**	**8.31**	**0.00**
	Avg.	**0.21**	**0.41**	**0.65**	**0.26**	**1.15**	**0.20**	**1.73**	**4.61**	**0.00**
W.El-Gimal island	Gi1	0.13	0.11	0.37	0.33	0.00	0.30	2.80	4.04	0.00
	Gi2	0.09	0.12	0.24	0.27	0.00	0.20	3.23	4.15	0.00
	Gi3	0.05	0.06	0.16	0.22	0.00	0.23	0.01	0.72	0.00
	Gi4	0.02	0.03	0.16	0.26	0.00	0.05	1.51	2.03	0.00
	Gi5	0.09	0.12	0.33	0.41	0.09	0.00	1.32	2.36	0.00
	Min.	**0.02**	**0.03**	**0.16**	**0.22**	**0.00**	**0.00**	**0.01**	**0.72**	**0.00**
	Max.	**0.13**	**0.12**	**0.37**	**0.41**	**0.09**	**0.30**	**3.23**	**4.15**	**0.00**
	Avg.	**0.08**	**0.09**	**0.25**	**0.30**	**0.02**	**0.16**	**1.78**	**2.66**	**0.00**
Abu-Minqar island	AM1	0.09	0.08	0.05	0.45	0.03	0.00	3.27	3.98	0.00
	AM2	0.09	0.10	0.06	0.36	0.12	0.21	1.07	2.01	0.00
	AM3	0.12	0.06	0.34	0.28	1.73	0.62	2.29	5.43	0.00
	Min.	**0.09**	**0.06**	**0.05**	**0.28**	**0.03**	**0.00**	**1.07**	**2.01**	**0.00**
	Max.	**0.12**	**0.10**	**0.34**	**0.45**	**1.73**	**0.62**	**3.27**	**5.43**	**0.00**
	Avg.	**0.10**	**0.08**	**0.15**	**0.37**	**0.63**	**0.28**	**2.21**	**3.81**	**0.00**

low contamination degree, according to Hakanson's (1980) classification. On the other side, W. El-Gimal and El-Quieh coastal areas are related to moderate contamination degree.

Figure no 7: Contamination Factor of the studied sediments in coastal mangrove areas and islands.



Pollution load index (PLI):

Pollution load index (PLI) was computed according to Tomlinson et al., (1980). The equation cited in Table no 5. It was found that the pollution load index of almost all the analyzed sediments of zero values, except two samples in El-Queih coastal area illustrated values of 0.16 and 1.39, with mean value is 0.14. According to the classification proposed by Tomlinson et al., (1980), all the studied sediments indicate no pollution, except only one sample indicates deterioration in the sediment quality.

IV. Conclusions

Generally, the sediments of the investigated mangrove coastal areas and islands are mainly consist of sand with small amounts of gravel and mud. The mean size of analyzed samples of the coastal mangrove areas varies from coarse sand to fine sand, whereas the mean size of the island mangrove sediments ranges between coarse sand to medium sand. The sorting values of the investigated sediments range from moderately well sorted to poorly sorted. Their distribution ranges between strongly coarse skewed to strongly fine skewed sediments. The K_G values are ranging between very platykurtic to very leptokurtic.

In general, the levels of average heavy metal concentration in the investigated sediments are noted in the following descending order: Fe> Mn > Zn> Ni> Pb> Cu> Cd. The mangrove sediments of W. El-Gimal coastal area exhibited the highest mean concentration of Fe, Mn, Ni, Cu and Pb comparable to the sediments of the nearby W. El-Gimal island, which illustrated lower mean values of such elements. The enrichment of W. El-Gimal coastal area sediments with these elements may infer that all these elements are drained to the beach by Wadi El-Gimal stream from the basement rocks in the hinterlands of the eastern desert. The analyzed samples of El-Queih coastal mangrove sediments and some samples from south Safaga as well as Abu-Minqar samples showed higher values of Cd than the analyzed samples from other localities in the present study. This probably due to oil spills (tar balls) or the garbage driven by seawater waves from offshore to these localities.

The calculated mean values of enrichment factor (EF) showed that the considered samples fall in class of "no enrichment" for Mn and "minor enrichment" for Zn and Cu. For Ni EF, they fall in different classes, varying from "no enrichment" to "moderately severe enrichment". The mean values of EF for Pb and Cd, illustrated that the investigated sediments fall in different classes of enrichment ranging between "no enrichment" and "severe enrichment" classes.

The geo-accumulation index (I_{geo}) average values of Fe, Mn, Zn, Ni, Cu and Pb for the investigated sediments in all the localities are less than zero and classified as "unpolluted sediments". According to the obtained mean values of I_{geo} for Cd, the sediments are classified as "unpolluted, moderately polluted and moderately to strongly polluted" with cadmium.

The computed mean values of contamination factors for iron, copper and lead indicated that the sediments in all the studied localities were subjected to "low contamination" of these elements. On the other hand, the average values of manganese, zinc, nickel and cadmium, explained that the investigated sediments were subjected to" moderate contamination" of such elements.

The obtained average values of contamination degree (Cd), suggested that the sediments under consideration were subjected to low contamination degree until moderate contamination degree.

The pollution load index (PLI) of almost all the analyzed sediments of zero value indicating no pollution in the sediments. Finally from the foregoing data, it is obvious that the mangrove sediments in the area under consideration were subjected to weak pollution with Cd in small parts, but almost all the other localities are considered unpolluted . Therefore, the range of concentrations of the analyzed metals in the area under study can serve as baseline environmental data for assessment the degree of pollution of these heavy metals in future.

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