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SEDIMENTS, CORAL REEFS AND SEAWATER INTERACTIONS IN SOME COASTAL LAGOONS, RED SEA, EGYPT.

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ABSTRACT

The sediments, coral reefs and seawater interactions were studied in four coastal lagoons along the Red Sea. There are very commutative and correlative relations between these constituents, therefore, any alterations occur in the sediments and seawater will be directly reflected on the coral reef status and biodiversity. Consequently, the studied coral communities in the four lagoons are considered healthy and multifarious. The diversity index (H`) in the studied lagoons is varying between 2.07 and 3.35 while the evenness index (J) is fluctuated between 0.61 and 0.94. These values are high relative to some other localities in the northern Red Sea.

The heavy metals; Fe, Mn, Zn, Cu, Pb and Cd were studied in the sediments, seawater as well as the coral reefs. Safaga lagoon recorded the highest iron and manganese contents in the sediments, followed by Abu Ghsoun lagoon while Abu Shaar lagoon comes later. Despite the high landfilling effect surrounding Abu Shaar lagoon, Fe and Mn concentrations are low relative to the other lagoons. Seawater in Safaga lagoon recorded the highest average contents for Fe, Mn, Zn and Pb followed by Abu Shaar lagoon. These results support that the high trace metal contents in the seawater are mainly engaged with the high suspended particulate matter (SPM), the high turbidity rates as well as the subsurface interaction between the surface sediments and the water column. In the coral skeletons, Fe recorded its highest content in Abu Ghsoun lagoon followed by Safaga lagoon, indicating that the recovered coral species have more tolerance and adaptation than the original species.

INTRODUCTION

The coastal areas are a common place for the interaction of two ecosystems having their own characteristics. Coastal environment is a well developed natural system encompassing a very complex but one of the most productive ecosystems on earth. This zone is a transitional band and is very sensitive and susceptible because of the final destiny for most of the pollutants coming from the land and the sea. This situation imposes a permanent threat to this fragile environment with its all organisms living nearly at the edge of their tolerance. Coastal lagoon ecosystems embrace a great variety of habitats that include mangrove forest, salt marshes, intertidal pools, swamps, brackish and sea water systems; all possessing a high biological diversity and a rich and complex food chain. These ecosystems constitute important fishery and nursery grounds, and some of which include small human settlements (Green-Ruiz and Paez-Osuna 2001).

Shallow lagoons are a common feature of coastal environments. Tropical lagoons in particular play an important ecological role,

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because of their high primary and secondary productivity. However, at the same time, the waters and the bottom sediments of these lagoons suffer from natural contamination and man-induced pollution (De Pippo *et al.* 2004 and Smith 2001).

Along the Red Sea, the coastal lagoons are mostly characterized by their own faunal and floral community structures, whereas, the protective and sheltered nature allows many species of benthos are growing up in coincident to each other. The Red Sea coastal lagoons are being stressed due to overexploitation and have become very vulnerable to human related activities such as inappropriate effluent smoothers from the shipping and navigation activities, landfill and dredging, oil production and mining operations, sewage outflows, resource extraction, overfishing, recreation and urbanization along the coast (Daby 2003).

Heavy metals such as Zn, Fe, Cu, and Mn, are essential biological micronutrients required for the growth of many aquatic organisms. These micronutrients can become toxic at elevated concentrations, while other metals, for example Pb is not required for growth and is highly toxic in trace amounts. Therefore, the biogeochemical processes associated with the lagoons can alter the environmental characteristics of these contaminants, thus making them more toxic to aquatic organism (Cobelo-Garcia and Prego 2004 and Vazquez *et al.* 1999).

On the scope of the present work, the heavy metal dynamics in the sediments, waters and corals determine, evaluate and correlate between the different impacts of human uses on the coastal lagoons and their effects on the plant and animal species populations. Also these dynamics suggest the necessity of proposing eco-compatible interventions for the environmental restoration. These interventions should aim to safeguard the lagoon environments, restore the productive activity and to put a practice program for re-establishing the natural conditions together with the floral and faunal communities.

Geomorphology and the environmental setting of the study area

Abu Shaar lagoon is narrow and shallow embayment, lies 8km northern Hurghada (Fig 1B). This lagoon has two water inlets, from south and northeast. Its bottom floor is rocky covered by relatively thin sediments layer and its maximum depth is about 6m at the low tide time increases to about 10m at the northeast inlet. It has relatively high floral content but the coral status is exiguous due to the high turbidity rates, overfishing and anchoring.

Safaga lagoon is located 10km south of Safaga city (Fig. 1C). It occupies about 300,000 m^2, it has one inlet from the north and the maximum recorded depth is about 15m. Sea bottom surveying revealed the presence of several bottom facies including; sand bottom types (sand with seagrass, muddy sand and biogenic sand with coral patches) and coral reefs. The sludgy nature sediments are due to the continuous and high fine particles income from the different coastal activities especially phosphate shipping ports (Dar and Soliman 2003).

Shuni lagoon is located at 41 km northern Mersa Alam (Fig. 1D), it has ellipsoidal shape the lagoon elongation is 1.2km and more than 500m width. This lagoon is shallowness relative to the other lagoons and its maximum depth is about 4m in the high tide time. Shuni lagoon hasn't any definite inlets but it appears to be isolated through the low tide time, which considered discrete situation among the different lagoons. The lagoon base is invested with dense and thick seagrass and algal flora layer.

Abu Ghsoun lagoon lies directly northern Abu Ghsoun village about one km from phosphate and raw material harbor (Fig. 1E). The lagoon has about 1.5km long and about 300m width with maximum recorded depth is 6m in the high tide time. The lagoon is intersected by 4 dead coral ridges that provide the suitable substrates for the new coral recruits. The old generations of the coral reefs were completely dead while the new species are growing well with definite observing zonation. The bottom topography is flat consisting mainly of biogenic sand and coral fragments. Some sand mounds are observed and inhabited by suspension feeding burrowing fauna.

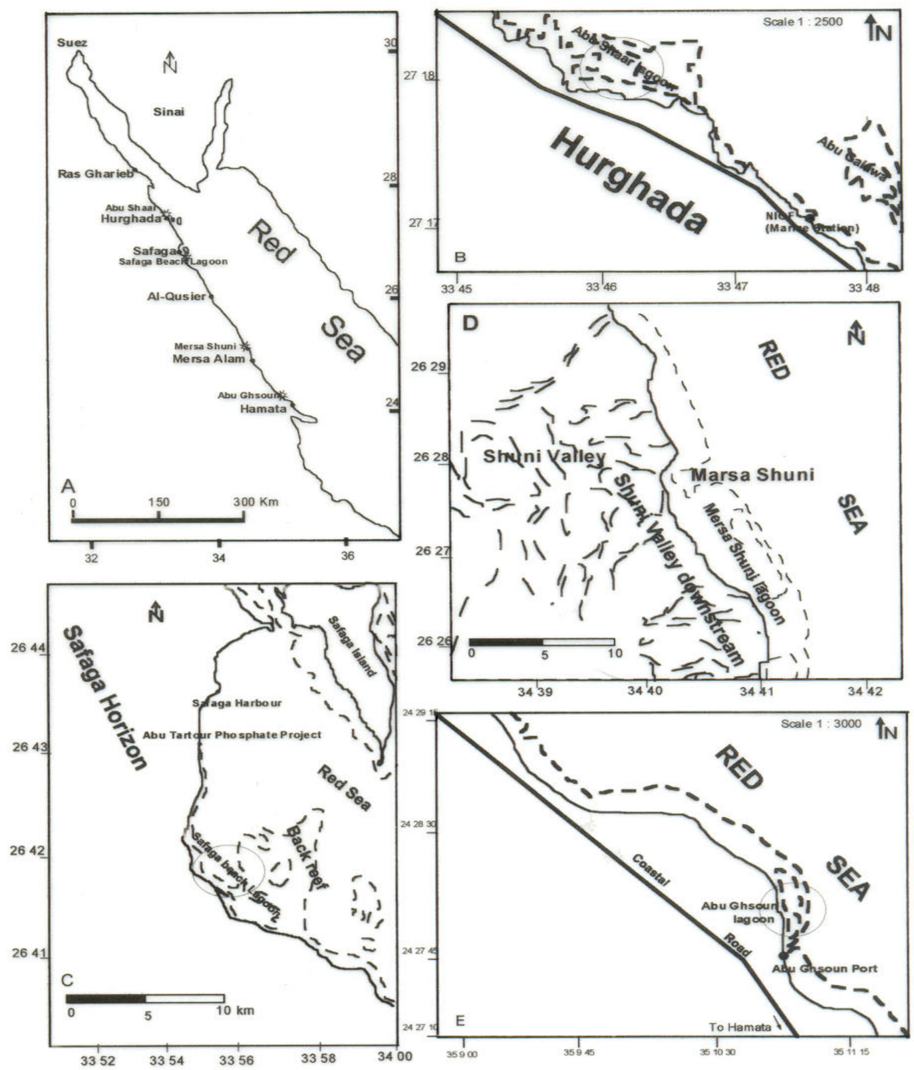

Fig. 1: The coastal lagoon locations along the Red Sea.

MATERIALS AND METHODS

A- Investigation of Sediments

Forty-eight sediment samples were collected from four coastal lagoons along the Red Sea (Fig. 1); 15 samples were collected from Abu Shaar lagoon (Hurghada), 14 samples from Safaga lagoon (Safaga), 9 samples from Shuni lagoon (Mersa Alam) and 10 samples from Abu Ghsoun lagoon (Hamata).

The samples were washed and dried in the direct sunlight then powdered in agate mortar to less than 80 mesh size, 0.5gm of each sample was digested in Teflon cup using a mixture of HF, HNO_3 and $HClO_4$ acids (Chester *et al.* 1994) to the complete dissociation then diluted with de-ionized distilled water to about 25ml. Fe, Mn, Zn, Cu, Pb and Cd have been determined in µg/g by the AAS (Atomic Absorption Spectrophotometer, GBC 932, Ver 1.1). The measurement accuracies were obtained by applying three replicates in each measurement with reading variation less than 5%.

B- Investigation of Seawater

Seawater were sampled using water sampler (PVC tube ≈ 3L), 15 samples were collected from Abu Shaar, 14 samples from Safaga, 9 samples from Shuni and 10 samples from Abu Ghsoun lagoons.

In the seawater samples, the various trace metals were determined in (µg/L) using the AAS technique according to Martin (1972). One liter of each sample was filtered through 0.45µ membrane and adjusts the pH in the range 4-5 with HCl. The trace metal contents of each sample were catch within ammonium pyrrolidine dithiocarbamate (APDC) and methyl isobutyl ketone (MIBK) complex and then extracted using 6N HNO_3 acid. The extracted solution is digested on hot plate to volatilize the acid and then solved in about 10 ml of de-ionized water for the trace metal determinations.

C- Investigation of Corals

The coastal lagoons were surveyed using the Line Intercept Transect (LIT) method (English *et al.* 1997) to estimate the percentage cover of the coral reefs relative to the other benthos. The percentage was calculated from the following formula:

$$\text{Percentage cover} = \frac{\text{Intercept length}}{\text{Transect length}} \text{ X } 100$$

Diversity (H`) and evenness index (J) were calculated in each lagoon according to Shannon-Wiener (1948) and Pielou (1966) and:

i) Shannon-Wiener species diversity (H).

$$Hs = -\sum_{i=1}^{s} Pi \ln Pi$$

(s) = Total species, (i) = Each species

$$Pi = \frac{\text{Number of colonies species (i)}}{\text{Number of total colonies}}$$

ii) Pielou`s evenness index (J).

$$J = \frac{H}{\ln s} \quad \text{where, s = number of species.}$$

The different coral species were identified according to Sheppard & Sheppard (1991) and Veron (2000). Samples were collected by the SCUBA diving. For trace metal determinations, 54 living coral samples representing eighteen species (the most frequent species) were collected from the four coastal lagoons. 14 samples from Abu Shaar, 10 samples from Safaga, 12 samples from Shuni lagoons and the rest eighteen samples were collected from Abu Ghsoun lagoon.

The collected specimens were cleaned in running water to remove the adhering fauna, flora and the strange materials, dried in the sunlight and powdered, then 0.5gm of each sample was digested in a 10ml of hot HNO_3 (Chester *et al.* 1994). After the complete digestion, each sample was diluted to 25ml and the trace metals were determined as (µg/g) using AAS technique. The measurements accuracy was checked by applying three replicates in each sample.

RESULTS AND DISCUSSION

I- Impacts of Environmental Conditions

As a common factor, turbidity serves as a carrier of pollutants in most lagoons, whereas, it is generally accompanied with the high landfill and dredging, raw material shipping and mining. In addition to the high natural and anthropogenic sedimentation rates that increase the organic matter content in the water column, block solar irradiance and change the underlying sediment facies by increasing the fine particle accumulations and consequently, increase the anoxic conditions inside the coastal lagoons that can increase the benthos suffocation and mortality.

Turbidity is related to landfill, constructions and beach enhancing processes from the coastal development at Abu Shaar lagoon. The particulate and fine sediments are resulted from the wave winnowing for the coastal areas and the redeposition inside the lagoon basin, while in Safaga lagoon the situation appears to be more complicated due to presence more than one source point of the fine and particulate sediment accumulations and pollutants in the lagoon. The heavy metals enrichment in Safaga lagoon is mainly due to the huge fine particles income to the coastal area mainly from the smoothers of phosphate raw material shipping, cement packing industry, landfilling, shipyards, navigation activities and construction residuals.

At Shuni lagoon, the heavy metals have uncertain sources but the trace metal contents are accompanied with the local activities of the anoxic conditions below the seagrass bed and the natural flood inputs. There is limited source point of heavy metals present in the Abu Ghsoun lagoon. Longtime ago Abu Ghsoun Port, which is located directly southern this lagoon was used for shipping the different raw materials as phosphates, feldspars and ilmenites. Due to the presence particulate materials enriching in the lagoon, most of the benthos inside the lagoon especially the coral communities were degraded. Since three years ago, these activities were constricted and the Port is in development stages, consequently most of the faunal and floral assemblages in this lagoon are recovering again with healthy situation.

II- Coral reef biodiversities

The Northern Red Sea is characterized by generic diversity (Sheppard *et al.* 1992). The acute environmental variations; sedimentation, temperature, salinity and the man-made disturbances are responsible for the community structure differences (Schuhmacher and Mergner 1985), which play the vital role in the genera composition as; the growth rate, biodiversity and tolerance limit (Mergner *et al.* 1992).

As shown in table (1), the number of genera in the studied lagoons is relatively high compared to those recorded by Ali (1994), Kotb (1996) and Mohammad (2003), while the recoded species are lower than Mohammad (2003) and higher than the other investigators. Three of the studied lagoons; Safaga, Shuni and Abu Ghsoun lagoons recorded the same diversity (H`) and evenness index (J) with other comparative studies, while Abu Shaar lagoon is relatively lower than them.

At Abu Shaar lagoon, the recorded coral cover is about 40.04% (30.74% hard corals and 9.3% soft corals) from the total benthos, while the algal flora covers 19.5% and the rest represents the other benthos. Twenty nine species of hard and soft corals were recorded in the lagoon mostly from the branching forms followed by the massive species with percentage of about 44.8% and 40.08% from the coral cover respectively. *Acropora clathrata*, *Stylophora pistillata* and *Sinularia polydactyla* are the most frequent and dominant species in this lagoon.

Twenty six coral species were recorded in the Safaga lagoon, 16 of them are stony corals representing 56% and two soft coral species 12.33%, algal cover 5.8% and the other benthos 16.97%. The hard coral species are commonly as *Montipora stillosa, Stylophora pistillata, Favia* sp. and *Millepora dichotoma,* while the soft species represented by *Xenia* sp. *a*nd *Sarcophyton* sp.

The reef edge of the Shuni lagoon has good visibility to more than 25m depth, where 34 coral species recorded in the reef slope. The coral situation is very healthy relative to the other lagoons, whereas the coral cover is about 59.97% representing hard and the soft coral species. The dominant hard corals are *Millepora dichotoma*, *Stylophora pistillata* and *Acropora hyacinthus*.

There are 27 hard corals species observed in the Abu Ghsoun lagoon. They represent about 54.23%, 12.47% dead corals, 10% soft corals, while the rest percentage represents the algal flora. The hard coral species are mostly of branching forms (62.60% from the corals) followed by the massive and solitary forms. *Stylophora pistillata* and *Platygyra daedalea* are the most dominant species in this lagoon (Fig. 2).

III- Heavy Metal Distributions

A- Sediments

In shallow lagoons, sediments play an important role in biogeochemical cycles. The sediments have several roles: they act as sinks of organic detritus material through sedimentation; they consume oxygen due to bacterial mineralization, nitrification and benthic fauna respiration. Furthermore, they supply nutrients through re-mineralization of organic matter depending on the oxygen concentration, nitrification and de-nitrification takes place in sediments (Zaldivar *et al.* 2003). Semi-enclosed coastal areas are more sensitive to anthropogenic impacts because of their lower ability to flush the contaminants than coastal areas with open boundaries to the sea and the difficulty to disperse the contaminants out to the open sea, which implies drastic consequences on metal distribution and contamination (Owen and Sandhu 2000). Processes such as metal mobilization and removal can control total metal concentrations in the lagoons. The shallow depth of the lagoons promotes re-suspension of the sediments by constant wind driven waves and tidal mixing (Abd El-Wahab 2002). This activity encourages the release of the metals from sediments into the water column. The continuous decomposition of organic matter (breakdown and dissolving) can also release incorporated metals into the lagoon system (Dal Monte and Di Silvio 2004; Abd El-Wahab and El-Sorogy 2003 and Vazquez *et al.* 1999).

Table 1: Comparison of species diversity (H́); evenness index (J); number of species and genera in the studied lagoons relative to some previous studies in the Red Sea.

	Kotb (1996) Sharm El-Sheikh	Ali (1994) Hurghada	Mohammad (2003) Hurghada	The Present Study				
				Abu Shaar	Safaga	Shuni	Abu Ghsoun	Total
No. of genera	24	-----	23	17	20	18	13	30
No. of species	35	40	55	29	26	34	27	48
Diversity (H`)	2.82	2.47	2.7 - 3.39	2.07	2.88	3.35	2.85	2.07 - 3.35
Eveness index (J)	0.79	0.85	0.88 - 0.94	0.61	0.88	0.94	0.86	0.61 - 0.94

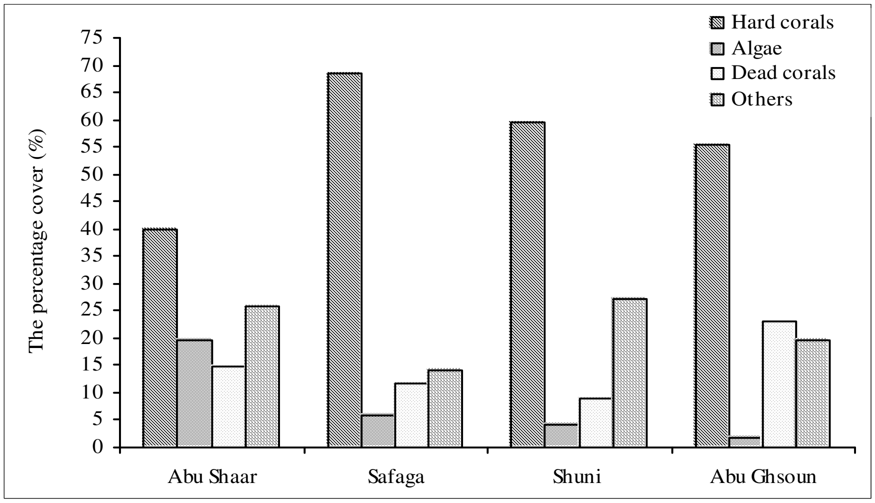

Fig. 2: The percentage covers of the bethic structures in the studied lagoons.

Generally, the upper layers of marine sediments are often enriched in oxidized manganese and iron precipitates as a result of biogeochemical processes (Kristiansen *et al.* 2002). These processes include burial, reduction and thus dissolution of solid Mn and Fe. Colloids may play an essential role in regulating concentration and speciation as well as transport and bioavailability of metals in all types of the marine environment (Ingri *et al.* 2004). The increased light levels at the sediment-water interface provide an important environmental stimulus that can contribute to increase the reduction rates in the sediments (Cotner *et al.* 2004). Mn (IV) and Fe (III) are readily reduced under these anoxic conditions and they may serve as electron acceptors in microbial oxidation of organic carbon.

Iron shows the highest average contents in Safaga lagoon; 1054.63µg/g followed by Abu Ghsoun 782.53µg/g and Shuni lagoons 557.47µg/g, while Abu Shaar lagoon comes later (Table 2 and Fig. 3). Also, Mn recorded its highest average value 234.42 µg/g in Safaga lagoon. The high concentrations of both metals in Safaga lagoon is attributed to the high and continuous incoming suspended and particulate sediments from the northward human activities in addition to the weak reworking effects in the lagoon (Dar 2004b). The moderate metal concentrations at Abu Ghsoun and Shuni lagoons are mainly due to the long-term metals retention in the sediments, the misfit water mixing with the open sea and the metal reduction by the seagrass beds. Despite the high landfilling effect surrounding Abu Shaar lagoon, Fe and Mn concentrations are very low relative to the other lagoons. This is may attributed to the fine particle dispersant by the long shore currents and tidal currents through the two inlets present. The two metals are doing as scavengers, electron acceptors and holders for the other trace metals inside their mineral frameworks of their oxihydroxides, sulfides and carbonates (Shen *et al.* 1991; Alison 1996 and David 2003).

The other metals; Zn and Pb are generally recorded low concentrations in the four lagoons, except Shuni lagoon is recorded the highest average Zn content 9.22 µg/g, also Abu Ghsoun lagoon recorded the highest average Pb content 6.63 µg/g followed by

Safaga lagoon 5.63 µg/g. The highest Zn average content in Shuni lagoon is accompanied with the longterm accumulations while the highest Pb contents in Abu Ghsoun and Safaga lagoons are attributed to the local reducing conditions and the metal retention in these sediments whereas Hatje *et al.* (2003) reported that the common increase in pH with increasing salinity, will favour the sorption of trace metals onto suspended particulate matter (SPM) that suggests the association of trace metals with particles and the metals retention (Fig. 3).

Cu as well as Cd values in the studied lagoons are disregardful with exception of some samples in Shuni and Abu Ghsoun lagoons were recorded abnormal Cd values; 8.25µg/g and 5.96µg/g respectively (Table 2). These values can not be generalized to the current situation of the lagoons and can not be consider as pollution sign in these lagoons. Generally, except Safaga lagoon, the other lagoons show no signs of trace metal contamination.

B- Seawater

The heavy metal contents in seawater are highly dependant upon the pH, salinity, suspended particulate matter (SPM) and organic matter content, also, both the rate and extent of heavy metals adsorption are reduced due to competition of major seawater ions (particularly Ca and Mg) with metals on the particles (Hatje *et al.* 2003). Saad and Fahmy (1996) attributed the high metal contents in the bottom water of the Red Sea near Jeddah to the interaction with coral reef fragments and the metals release from the sediments to the overlying waters occurs due to the high turbidity. Marek and Edward (2003) pointed out that actual concentrations of heavy metals in seawater are substantially lower than the calculated concentrations of these metals in solution in equilibrium with their hydroxides, basic carbonates and other sparingly soluble salts that may potentially form in seawater. Therefore, biological processes and adsorption have been explained the spontaneous removal of heavy metal cations from seawater. They also added that the heavy metal cations present in the seawater tend to adsorb on colloids suspended in water and on the sediments on the ocean floor, while Fe (III) and Mn (IV) hydroxides are among the strongest scavengers of heavy metals. The adsorption of heavy metal cations on iron hydroxides leads to partial dehydration of metal cations. The oxidation of Mn and the formation of Mn oxide coatings control the relatively slow increase of Mn uptake compared to the other elements in the seawater.

In the studied lagoons, seawater is considered the real sensor for the heavy metals. Safaga lagoon is recorded the highest average values for Fe 42.40µg/L, Mn 1.32µg/L, Zn 3.23µg/L and Pb 1.19µg/L, followed by Abu Shaar lagoon (Table 3 and Fig. 4). Cu and Cd recorded very low concentrations in the four lagoons. The average contents of Mn, Zn, Cu and Cd that recorded in the seawater of the different lagoons are much lower than the average of surface water, average of bottom water and the mean values that recorded by (Saad and Fahmy 1996) near Jeddah. These results support that the high trace metal contents in the studied coastal lagoons are mainly engaged with the high SPM contents, the high turbidity rates and local conditions as the subsurface interaction between the surface fine sediments and the overlying water, as well as the mobilization of metals between the interstitial water and the surrounding sediments which may invoke metal oxidation and releasing to the surrounding media. The recorded data prove that the main metal sources are coincided with the anthropogenic inputs.

C- Coral Reef Skeletons

Net reef growth is a product of accretional, sedimentological and erosional processes. Accretion may be biological, through the growth of framework building corals and other calcareous organisms, or physical or microbial through mineralization of existing framework, or geological through sediment accumulation and in-filling (Hibino and Van Woesik 2000). Some of the fine sediment reaches coastal waters can increase turbidity and degrade coral reefs through a number of biological processes. High concentration of SPM on nearshore coral reefs is generally assumed to be the main stress factors and the common anthropogenic influences on the coral reefs (Anthony 1999). He also suggested that SPM occurring over lagoonal or inshore reefs may be an important food source for corals relative to other food sources.

An increase of turbidity in reef waters can affect the ecology and composition of reef communities by: (a) reducing light availability, which is the primary energy source for clear water corals; (b) increasing energy demand for self-cleaning activities and therefore hampering other vital functions like feeding, growth or reproduction; and (c) smothering tissues if high accumulation occurs, which is often lethal. In turn, a reduced coral cover and diversity is likely to adversely affect fish communities (Thomas *et al.* 2003). The degree of degradation is very much dependent on the fine sediment quantity and quality, the sedimentation rate, and the residence time of the particulate fine sediments (Yimnang *et al.* 2003). Indeed, recent studies have shown that anthropogenic impacts to coral reefs may induce phase shifts in benthic species composition (Done *et al.* 1996) that could alter the bio-constructional processes and the net function of the reef.

Many marine organisms are able to regulate the metal concentration in their tissues where, they excrete essential metals as copper, zinc and iron that are present in excess. The ability of invertebrates to adsorb metals is largely dependent on the physical and chemical characteristics of the metal as well as the seawater in which they live. Several heavy metals as Fe, Zn, Cu and Mn can be measured in trace amounts in the coral structure (Shen *et al.* 1991).

These elements may have directly replaced calcium within the aragonite skeletal framework or as suspended particulate matter introduced into the skeletal pore spaces (Dar 2004a) or as metals incorporation inside the carbonate skeleton during the biosynthesis (Fairbanks *et al.* 1997). Putten *et al.* (2000) documented that the metals are not necessarily incorporated into the calcite structure but can also be adsorbed onto the skeletal organic matrix or entrapped as separate mineral phases. Reichelt-Brushett and McOrist (2003) suggested that not all metals taken up by the living corals are transferred to the skeleton whereas, the coral reef zooxanthellae and coral tissues accumulate most metals (Fe, Mn, Ni, Cu, Zn, Pb and Cd) in greater concentrations than the coral skeletons which means that corals discriminate between metals in their biogenic precipitation of the aragonite skeleton.

The high concentration of Fe in the coral skeleton is confirmed with the high sedimentation rates and the metal content of the suspended sediments (Bastidas and Garcia 1999). Mn substitutes on an ionic level for Ca^{2+} in the skeletons of corals and/or it may adsorbed or occluded within biogenic aragonite or trapping of discrete detrital particles in the more turbid reef setting as well as manganese carbonate commonly occurs as mineral phase share the same crystal structure of calcite (Dar 2004a and Shen *et al.* 1991). Manganese in the coral reefs displays a sensitivity that makes it an effective indicator of seawater conditions i.e., salinity changes and manganese ion concentration, while Zn is enriched in the coral skeleton relative to seawater where, it is more preferentially taken up by the growing aragonite crystal, compared with manganese (Ramos *et al.* 2004). They added that the Cd uptake increases in coral with the salinity increasing that attributed to the biologic factors (differences in coral growth rates and zooxanthallae activity) and influence of the underlying sediments (in scavenging for cadmium in seawater).

Putten *et al.* (2000) suggested that skeletal Pb presumably originates from both dissolved and particulate Pb. The total dissolved and particulate Pb concentrations are not necessarily representative the bioavailable concentrations. The effect of copper on scleractinian corals is of environmental concern because there are numerous sources of copper as; sewage discharge and antifouling paints acting on the coral reefs (Reichelt-Brushett and Harrison 2000). Cu content in the aragonite lattice of the corals reflects the Cu concentration in the seawater and the extra-lattice Cu is also influenced by the ambient seawater (Kawahata 2004).

Table 4 and Fig. 5, show that Fe recorded the highest average concentration 53.67µg/g at Abu Ghsoun lagoon followed by Safaga lagoon 41.74µg/g, Abu Shaar lagoon 31.45µg/g and Shuni lagoon 30.88µg/g. Mn in the Safaga, Abu Shaar and Abu Ghsoun lagoons has the concentration manner whereas the average concentrations are relatively the same; 2.66µg/g, 2.45µg/g and 2.18µg/g respectively, while Shuni lagoon recorded much lower average percentage 0.67µg/g than the other lagoons. Pb has strong representation in Abu Ghsoun lagoon more than the other lagoons. The average recoded Pb content in this lagoon is 5.69µg/g followed by Safaga lagoon 3.52µg/g, Shuni lagoon 2.94µg/g and Abu Shaar 2.57µg/g. Zn average content at Abu Shaar lagoon is higher than other lagoons, which may be attributed to anthropogenic inputs of the construction residuals and the long-term bio-accumulation of the metal. Cu and Cd were recorded very low concentration and have nay pollution signs.

The recoded Fe results indicate that the recovering coral species have more adaptation to consume high metal concentrations than the old species, also, indicated that Fe in the hard corals is present as independent carbonate mineral (Siderite, $FeCO_3$) more than the occurrence in the adsorption or particulate forms.

Generally, the fact that the heavy metals tend to bio-accumulate inside the aragonite framework of the coral skeletons as carbonate minerals occupies the in-between pores of these skeletons depending on the presence of Fe as holder for the other metal traces. This investigation is agreeable with Dar (2004a), he concluded that the bioaccumulation mechanism of heavy metals in the hard skeletons of the reef-building corals is mainly dependent on the bio-mineralization process during the coral skeleton formation.

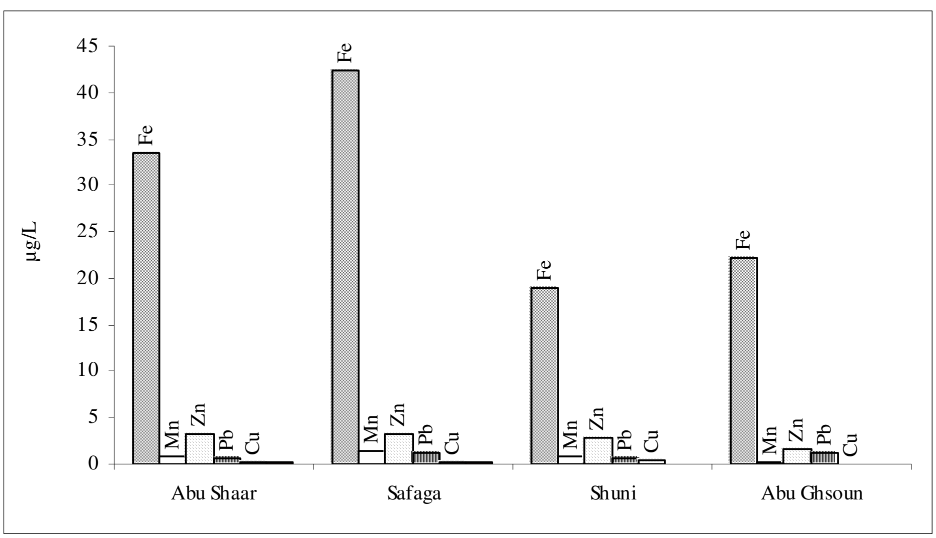

Fig. 3: The average trace metal contents in the lagoonal sediments.

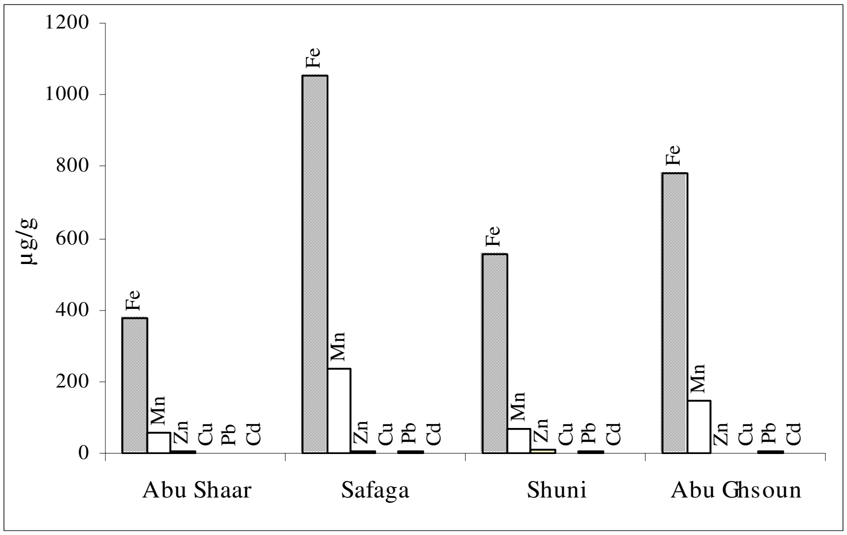

Fig.4: The average trace metal distributions in the seawater of the lagoons.

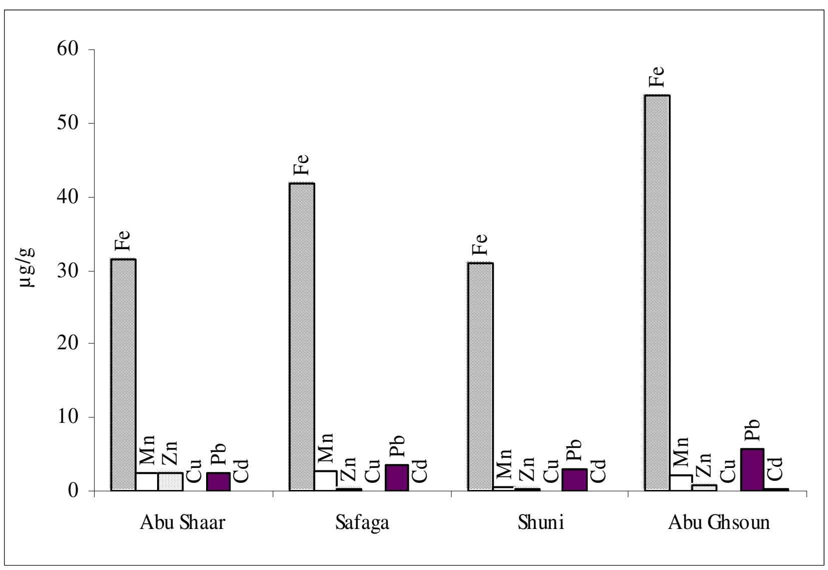

Fig. 5: The average trace metals in the coral reefs of the lagoons.

Table 2: Minimum, maximum and average metal contents in sediments of the studied lagoons.

Location		Fe	Mn	Zn	Pb	Cu	Cd
Abu Shaar Lagoon	*Range*	94 .26 – 919 .39	9.75 – 177 .61	1 .70 – 9 .51	*Nd* – 5 .78	0 .12 – 3 .29	*Nd* – 0 .13
	Average	378 .35	57 .46	3 .46	1 .28	0 .75	0 .04
Safaga Lagoon	*Range*	863 .37 – 1144 .93	64.29 – 431 .71	2.70 – 12 .68	3 .01 – 7 .20	0 .16 – 1 .37	0 .26 – 0 .40
	Average	1054 .63	234 .42	7.11	5 .63	0 .67	0 .32
Shuni Lagoon	*Range*	130 .75 – 1620 .42	14.13 – 119 .34	4.96 – 16 .94	*Nd* – 6 .62	0 .34 – 0 .92	*Nd* – 8 .25
	Average	557 .47	69.95	9.22	3 .63	0 .60	1 .08
Abu Ghsoun Lagoon	*Range*	528 .58 – 924 .80	54.04 – 243 .37	0 .87 – 3 .32	0 .55 – 14 .84	0 .03 – 0 .93	0 .33 – 5 .96
	Average	782 .53	147 .05	2 .22	6 .63	0 .25	1 .34

* **Nd:** not detected, the values in mg/g.

Table 3: Minimum, maximum and average metal contents in seawater of the different lagoons.

Location		Fe	Mn	Zn	Pb	Cu	Cd
Abu Shaar Lagoon	*Range*	8.50 – 58.70	0.34 – 1.58	0.28 – 10.31	*Nd* – 2.24	0.02 – 0.80	*Nd* – 0.73
	Average	33.43	0.89	3.13	0.58	0.27	0.13
Safaga Lagoon	*Range*	24.83 – 66.96	0.97 – 1.75	1.55 – 10.67	0.54 – 2.42	0.11 – 1.26	0.07 – 0.25
	Average	42.40	1.32	3.23	1.19	0.26	0.14
Shuni Lagoon	*Range*	5.14 – 44.94	*Nd* – 1.50	2.28 – 3.97	0.20 – 1.46	0.30 – 0.98	Not detected
	Average	18.91	0.72	2.85	0.65	0.43	
Abu Ghsoun Lagoon	*Range*	11.60 – 32.01	*Nd* – 0.66	0.77 – 5.37	*Nd* – 2.18	0.04 – 0.21	0.03 – 0.13
	Average	22.12	0.19	1.68	1.12	0.08	0.08

* **Nd:** not detected, the values in mg/L.

Table 4: Minimum, maximum and average metal contents in coral skeletons of the different lagoons.

Location		Fe	Mn	Zn	Pb	Cu	Cd
Abu Shaar Lagoon	*Range*	3.45 – 65.12	*Nd* – 12.13	0.21 – 24.58	*Nd* – 5.52	*Nd* – 0.09	*Nd* – 0.30
	Average	31.45	2.45	2.34	2.57	0.02	0.12
Safaga Lagoon	*Range*	10.89 – 88.47	*Nd* – 7.13	0.12 – 0.66	1.58 – 6.00	Not detected	*Nd* – 0.60
	Average	41.74	2.66	0.26	3.52		0.11
Shuni Lagoon	*Range*	10.93 – 87.30	*Nd* – 5.24	0.20 – 1.33	1.50 – 4.65	*Nd* – 0.04	*Nd* – 0.25
	Average	30.88	0.67	0.39	2.94	0.01	0.10
Abu Ghsoun Lagoon	*Range*	21.14 – 133.21	*Nd* – 4.47	0.40 – 3.96	*Nd* – 15.09	0.07 – 0.16	0.06 – 0.44
	Average	53.67	2.18	0.89	5.69	0.10	0.29

* **Nd:** not detected, the values in mg/g.

CONCLUSION

The coastal lagoons are the most productive habitats along the Red Sea. Despite the human inputs in the investigated lagoons, the benthos cover especially the coral reefs are healthy, diversely and productive.

There is strong interaction between the main components of the coastal lagoons: sediments, coral reefs and seawater. Consequently any alteration occurs in sediments and/or seawater will directly affect the coral reef situation inside these lagoons.

The sediments, coral reefs and seawater contaminated with the trace metals are considered disregardful relative to many coastal lagoons near urbanization zones in the world, whereas, no importunate alteration recorded.

The continuous particulate suspended matter (SPM) and the sediment accumulations in these lagoons will be the worst outcomes possible in future. The overloading of particulate and suspended sediments is responsible for the coral reefs death and the phase shifts from coral to algal dominance.

It would be expected that most of the studied trace metals (Fe, Mn, Zn and Pb) have to be trapped in the lagoons environment (sediments, water and coral reefs) once the metals are mostly associated with the particulate phase in seawater and the net transport of sediments in the coastal zone is directed landward. In addition to the initial effect of causing outright mortality and drastic changes in community composition, sediment can prevent recruitment of coral larvae as well as recovery of adult colonies that are stressed and / or killed as a result of re-suspension events.

Generally, the heavy metals tend to bio-accumulate inside the aragonite framework of the coral skeletons as carbonate minerals occupies the in-between pores of these skeletons depending on the presence of Fe as holder for the other metal traces.

Thus, the sediments, seawater and coral reefs bioassay constitute an important step in the assessment of the marine environment quality, providing an integrated measure of contamination, and they are becoming widely used tools in monitoring programs, permissions for dumping dredging material, and other regulatory activities.

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