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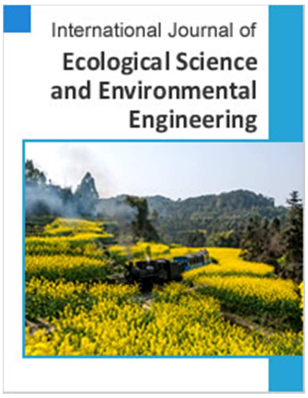

Hard Coral Tissue as Pollutant Indicator for Heavy Metals at Northern Hurghada, Red Sea, Egypt

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Abstract

The total organic matter (TOM) in corals is higher than in the sediment. The highest mean of TOM content of the corals *A. humilis* and *S. pistillata* was recorded in summer (7.04% and 5.27% respectively) while in the sediment it was low (3.15%) in the same season. The heavy metals (Fe, Cu, Ni, Cd and Pb) were measured in *A. humilis, S. pistillata* and the underlying sediments. However, *A. humilis* and *S. pistillata* have the great ability to concentrate Ni more than the sediment. The main reasons for the Ni increase are the anthropogenic impacts from boat mooring, desalination plants and anti-fouling paints. Cd has a great tendency to accumulate in the coral tissue and it reached to the maximum normal limit in *A. humilis* during autumn. Iron, copper and lead contents in both coral species show sub-equal values and in the range recorded by the other investigators in other localities. The increase of TOM in corals than sediment may cause in increase of Ni, Cu, and Pb in corals with a higher concentration than the underlying sediment.

1. Introduction

Hanna [1] studied the trace elements of North Atlantic deep-sea sediment and studied the toxic effect of the trace metals in the Red Sea as indicator of the environmental pollution. Bryan [2] reported that, trace metals are natural constituents of our environment and are naturally found in seawater, marine organisms and sediment. Therefore, knowing their natural levels or their permanent concentrations in a marine environment is essential for detecting and assessing trace metal pollution [3], [4], [5] Beltagy [6] determined some trace metals in sediment at Northern Red Sea and found that, the concentration of different metals differ with location, where the average contents of Cu, Mn, Cd and Pb were 16, 55, 48 and 75ppm respectively, while Fe percentage was 0.132%. El-Moselhy [7] reported that the average ranges of Pb, Cd and Cu in the surface sediment of the Suez Gulf were 40.82 μg/g; 4.52 μg/g and 41.70 μg/g, respectively. However, many biological and local environmental factors influenced the metal occurrences and uptakes in both coral forms such as, the exposed surface area for metal uptake, turbidity, overlying mucus thickness and the ability of metals to substitute inside the crystal lattice of the hard corals [8]. Moreover, The bioavailability, hydrodynamics of the environment, changes in tissue composition, and reproductive cycle influence the metal concentrations [9].

Beltagy and Moussa [10] demonstrated that, the distribution of organic matter in the Red Sea sediment is relatively small. The change in the total organic matter (TOM) content is easily observed by the change in the sediment odor, which is similar to H_2S odor. Moreover, their percentage increases as a result of organisms and plants grave [11]. The aim of this work is to measure the concentration of some heavy metals and organic matter in two dominant coral species (*Acropora humilis* and *Stylophora pistillata*) and their underlying sediment, then use these measurements as indicator for the pollution of the marine environment.

2. Materials and Methods

The area of study occurs in front of the Marine Biological Station (MBS) of the National Institute of Oceanography and Fisheries (NIOF), about 5 Km north to Hurghada (Figure 1). Hurghada lies at the northern part of the Red Sea proper between latitudes 27° 10`N - 27° 30`N and longitudes 33° 30`E – 33° 55`E. The reefs in the vicinity of Hurghada occur along roughly parallel ridges oriented from SSE to NNW [12].

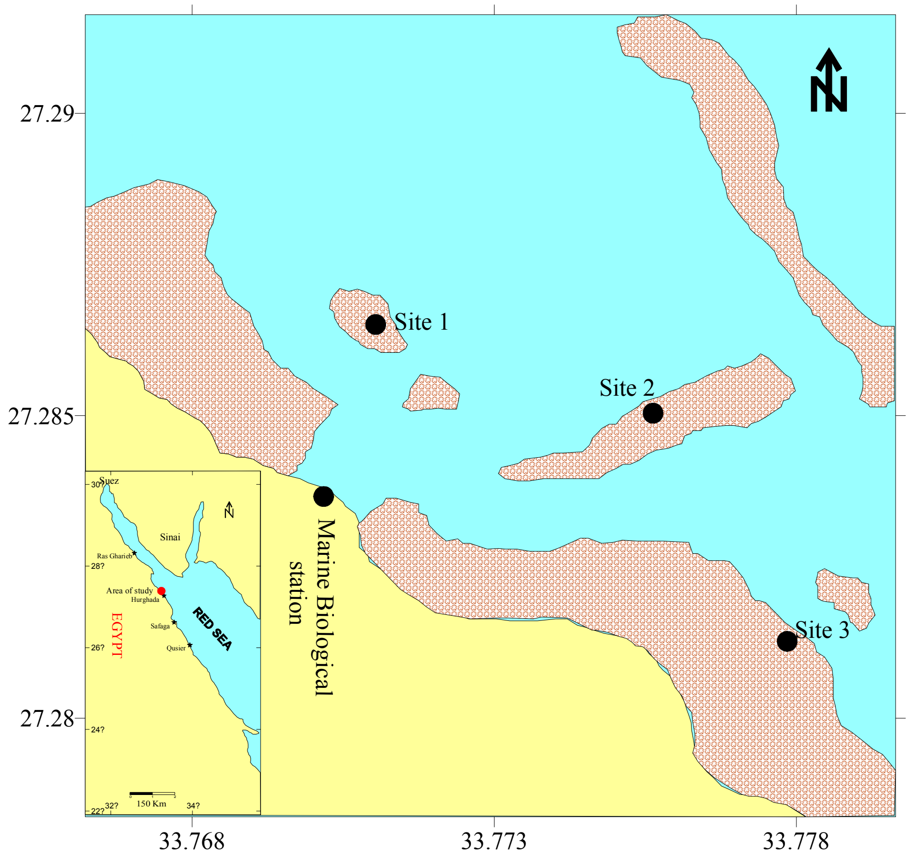

Figure 1. *Map showing the studied reef sites.*

The total organic matter (TOM) and some heavy metals (HM) were measured at each station: in coral tissue and skeleton and in bottom sediment. Samples of corals and sediment were collected at the beginning of each season during one year. At each season, three branches from each of *A. humilis* and *S. pistillata* were collected from 5m depth for measuring the TOM and HM in both skeleton and tissue (we choose the mentioned species due to the wide spread distribution and abundance at different sites). In addition, three sediment samples were collected from the same depth of the sampled corals.

The collected samples of coral branches and sediment were heated at 70 to 80°C to remove the moisture content of the samples in order to measure the TOM and HM. Samples either coral or sediment were ground using electrical agate morter for 10 minutes and kept in dry clean bags for the following procedures to be made. TOM in corals and sediment was determined by sequential weight loss method at 550°C [13] (Dean, 1974), where a certain weight of the sample (about 2 g of each sample) were burned in an oven at 550°C and the loss of weight is expressing the total organic matter as measured by Brenner and Binford [14].

For the determination of HM, Atomic Absorption Spectrophotometer (AAS) (model GPC A932 ver 1.1) was used for detecting the trace metals by (Chester [15] method with efficiency more than 95% and detection limit 0.001μg/g. Three replicates of each measurements with average difference less than 3%. A dried in the sunlight sample was powdered and then 0.5 g of each sample was digested in a 10ml of hot HNO_3. After the complete digestion, each sample was diluted to 25ml and the trace metals were determined using AAS technique. The measurements accuracy of Fe, Cu, Pb, Ni and Cd was checked by applying three replicates and the mean value was recorded in each sample. All concentrations are expressed in ppm. One-way ANOVA analysis was applied to obtain the significant differences in each data.

3. Results

3.1. Total Organic Matter (TOM)

The percentage of TOM showed differences from corals to sediment in the different seasons as shown in table 1. However, the TOM in *Acropora humilis* recorded the highest percentage of the total weight. Hence, its measurements reached the highest value in summer season (7.04%) and the lowest percentage at winter (4.49%). In the same affair *Stylophora pistillata* measured its highest value in summer (5.27%) but less than *A. humilis* and the least value in winter (4.34%). In sediment the TOM obeys the same trend i.e. its maximum value recorded in summer (3.15%) and the minimum was 2.77% in winter.

Generally, the ratio of TOM was the highest in *A. humilis* throughout the different seasons in the studied site. However, sediment showed the lowest ratio of organic matter and *S. pistillata* was in between. On the other hand, the maximum ratio of organic matter was measured during summer season, while the lower concentration was in winter for the investigated coral species and sediment (Table 1).

On the other hand, *A. humilis* exerts a significantly differences in the organic matter at the different seasons. One-way ANOVA analysis of variance (with season as factor) showed significant differences in the percentage of organic matter contents in *Acropora humilis* (Table 2, P = 0.0043). Mean% of total organic matters (TOM) at each season ranged between autumn 4.487, winter 5.003, spring 5.350 and summer 7.037%.

Table 1. *The seasonal distribution of TOM (in% of weight) in corals (A. humilis and S. pistillata) and sediment.*

Season	*A. humilis*	*S. pistillata*	Sediment
Autumn	5.01	4.39	3.08
Winter	4.49	4.34	2.77
Spring	5.35	4.82	2.84
Summer	7.04	5.27	3.15

Table 2. *One way analysis of variance (season as factor) for the total organic matter in A. humilis.*

Source	D.F.	Sum of squares	Mean squares	F- test
Between groups	3	10.961	3.654	Ratio = 10.084
Within group	8	2.899	0.362	P = 0.0043
Total	11	13.859		

3.2. Heavy Metals Concentrations (HM)

The present study was undertaken to determine the levels and natural variations of some important heavy metals in sediments and the studied coral species. The concentration of the investigated heavy metals (Fe, Cu, Ni, Cd and Pb) and their averages in sediments, as well as, the two coral species (*A. humilis* and *S. pistillata*) and sediment are shown in figure 2 and table 3.

Table 3. *The concentration of heavy metals in two coral species and sediment µg/g.*

Element	Fe			Ni			Cd		
Season	*A. humilis*	*S. pistillata*	Sediment	*A. humilis*	*S. pistillata*	Sediment	*A. humilis*	*S. pistillata*	Sediment
Autumn	289.18	290.53	1331.02	15.82	16.27	10.38	1.93	1.19	0
Winter	150.64	139.03	1852.41	15.42	16.18	12.07	1.55	0.92	1.28
Spring	151.21	112.03	1834.35	15.79	16.14	12.88	1.83	1.09	2.36
Summer	161.12	158.78	1305.79	13.68	14.29	12.35	0	0	0
Average	188.04	175.09	1580.89	15.18	15.72	11.92	1.77	1.07	1.82

Table 3. *Continued.*

Element	Cu			Pb		
Season	*A. humilis*	*S. pistillata*	Sediment	*A. humilis*	*S. pistillata*	Sediment
Autumn	5.67	6.21	3.12	15.47	16.72	11.82
Winter	4.11	4.16	4.10	15.17	16.25	11.97
Spring	4.89	4.85	3.89	15.4	16.04	12.19
Summer	5.63	3.33	2.8	13.51	11.6	11.84
Average	5.08	4.64	3.48	14.89	15.15	11.96

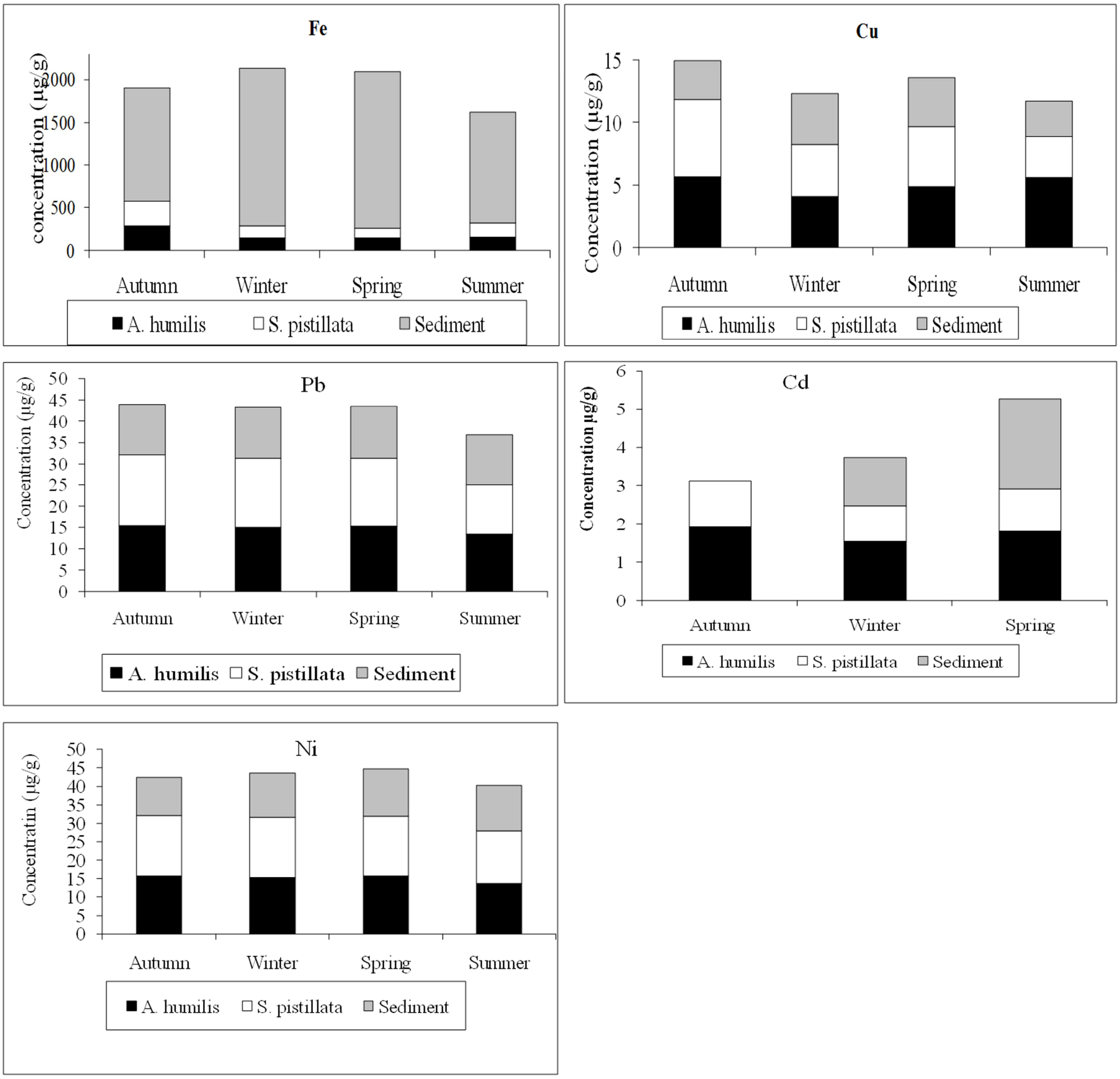

Figure 2. *The concentration of the heavy metals (HM), Fe, Cu, Ni, Cd and Pb in the corals and sediment.*

Iron (Fe) concentration showed a high difference in concentration in both of *A. humilis* and *S. pistillata* tissues and hard skeleton, as well as, in sediments at the different stations. The concentration of Fe in *A. humilis* and *S. pistillata* reached their maximum concentrations in autumn (289.18 µg/g and 290.53 µg/g respectively) as shown in figure 2 and table 3. While, the concentration of Fe in sediment (which recorded a very higher value than corals) measured the highest concentration in winter season (1852.41 µg/g). Nickel concentrations (Ni) in the different stations of the studied areas pointed out that, the highest concentrations in *A. humilis* and *S. pistillata* were obtained in autumn (15.82 µg/g and 16.27 µg/g), while the lowest values in summer.

Whereas the value of Ni in sediment was relatively low ranged from 10.38 µg/g (in autumn) to 12.88 µg/g (in spring). Cadmium (Cd) concentration in *A. humilis* recorded higher values than *S. pistillata* and sediment. The maximum concentrations were measured in autumn for *A. humilis* and *S. pistillata* (1.93 µg/g and 1.19 µg/g respectively), but reached its maximum in spring for sediment (2.36 µg/g).

One-way ANOVA analysis of variance with season as factor showed that, there were significant differences in Cd concentration among seasons in *Acropora* (Table 4, P = 0.0009). The results obtained at the different seasons are relatively close to each other with exception of summer. Mean Cd concentrations at each season varied at different season as follow: autumn 1.93, winter 1.55, spring 1.83 and summer 0.0 µg/g.

Another one-way ANOVA analysis of variance with season as factor showed that, there were significant differences in Cd concentration among seasons in *Stylophora* (Table 5, P = 0.0009). The same results obtained in *Stylophora* with minimum readings in summer (or no data obtained in summer). Mean Cd concentrations at each season are autumn 1.187, winter 0.917, spring 1.093 and summer 0.0 µg/g (see figure 2).

On the other hand, one-way ANOVA analysis illustrated that, there was a significant differences in Cd concentration among seasons in sediment (Table 6, P = 0.0041), in which the spring reached the maximum value. In which the mean Cd concentrations at each season ranged from autumn 0.0, winter 1.283, spring 2.363 and summer 0.0 µg/g.

Copper (Cu) concentration reached its maximum concentration for *A. humilis* in autumn (5.67 µg/g) but the lowest value was 4.11ppm in winter. In *S. pistillata* there was the same trend as shown in table 3, where the highest concentration (6.21 µg/g) was recorded in autumn but the lowest value was in summer (3.33 µg/g). However, in sediment the maximum concentration reached 4.10 µg/g in winter, while the minimum value was measured in summer (2.80 µg/g). The average concentration of copper showed that, the highest values were recorded in corals than sediment in different seasons. The concentration of lead showed the same pattern in both coral species but another pattern in the sediment. However, it ranged between 13.51 µg/g to 15.47 µg/g in the coral reef *A. humilis.* The maximum concentration of lead in *S. pistillata* reached 16.72 µg/g in autumn and the lowest value was determined in summer (11.60 µg/g). On the other hand the maximum value of lead in sediment was 12.19 µg/g in spring and the lowest was 11.82 µg/g in autumn.

One-way ANOVA analysis of variance with season as factor showed that, there were also significant differences in Pb concentration among seasons in *Stylophora* like in case of Cd (Table 7, P = 0.0112). In summer the lowest concentration obtained. Mean Pb concentrations at each season are autumn 16.72, winter 16.25 spring 16.04 and summer 11.60 µg/g.

Table 4. *One way analysis of variance (season as factor) for cadmium in A. humilis.*

Source	D.F.	Sum of squares	Mean squares	F- test
Between groups	3	7.27	2.42	Ratio = 16.25
Within group	8	1.19	0.15	P = 0.0009 *
Total	11	8.46		

* = significant different

Table 5. *One way analysis of variance (season as factor) for cadmium in S. pistillata.*

Source	D.F.	Sum of squares	Mean squares	F- test
Between groups	3	2.67	0.89	Ratio = 16.38
Within group	8	0.43	0.05	P = 0.0009 *
Total	11	3.10		

Table 6. *One way analysis of variance (season as factor) for the Cd concentration in sediment.*

Source	D.F.	Sum of squares	Mean squares	F- test
Between groups	3	11.541	3.847	Ratio = 10.223
Within group	8	3.01	0.376	P = 0.0041*
Total	11	14.551		

Table 7. *One way analysis of variance (season as factor) for the Pb in S. pistillata.*

Source	D.F.	Sum of squares	Mean squares	F- test
Between groups	3	51.19	17.06	Ratio = 7.29
Within group	8	18.73	2.34	P = 0.0112 *
Total	11	69.92		

4. Discussion

According to Abd El-Wahab [5] and Dar [11] the increase of heavy metals may be attributed generally o the presence of power plants, desalination plant, fishing and diving boats as well as domestic sewage, which take place in the area. Moreover, the high population densities, great urbanization and intensive coastal activities may cause the interchange between the sediments and coral reefs through the water motion in the area. So, these factors lead to contaminate the coastal waters, sediments and corals by the heavy metals. Table 8 pointed out that some of the comparable concentrations of organic matter from different areas.

A comparison of the organic matter contents in the coral species and the underlying sediments with other studies, indicated that, the TOM contents lies in the range of the data recorded by Brenner and Binford [14] in Florida Lake but higher than that found by Mansour [16] in the Red Sea and Mahmoud and El-Deek [17] in the Mediterranean Sea. On the other side, the tissue constituent of corals may be the main reason for the increase of TOM in corals than in sediment. The high organic matter concentration in the sediments plays an important role in the concentration of some trace metals in the bottom sediment [18, 19], because the presence of organic matter helps to concentrate the trace metals as insoluble sulphides.

Iron content in the sediments of the different coral reef sites is relatively higher than that measured by Beltagy [6] in Hurghada and much lower than the iron content in the Gulf of Aqaba measured by Abu Hilal [20]. It is also much lower than the iron content recorded by Al-Abdali [21] in the Arabian Gulf. In the coral reefs, iron content in *Acropora* changed from 150.64 µg/g to 289.18 µg/g while in *Stylophora* it varied between 112.03 µg/g and 290.53 µg/g. There is a significant variation between the different seasons, this is may be attributed to the variation of the redox potentiality of the areas [5] and [11]. Moreover the iron concentration in coral reef lies in the range measured by Hanna and Muir [22] from 81 to 778ppm (Table 9). Nickel content in the sediments is lower than its contents in the measured coral species. Nickel has high bioaccumulation tendency in the tissues of invertebrates and then become much higher than in the sediments [23, 24, and 25]. The recorded nickel values in corals are slightly higher than the measured values (0.05-15.0ppm) by Hanna [1] probably due to increase in the human activities along the Red Sea coast of Hurghada (Table 9). Cadmium concentration in the sediments is higher than in the two coral species and its concentration in *A. humilis* (1.55 µg/g – 1.93 µg/g) is slightly higher than *S. pistillata* (0.92 µg/g – 1.19 µg/g). The average content of cadmium in corals is much lower than the average range obtained by Hanna and Muir [22]. Cadmium also has bioaccumulation tendency in the benthic fauna tissues. Cd content in sediments is lower than the recorded values by Abu Hilal [20] and Mohamad [26] but it is slightly higher than range of contents recorded by Al-Abdali [21] and Belal [4]. The anthropogenic sources of nickel and cadmium may be due to anti-fouling paints, building materials and shipyards. Many studies illustrate that the marine sediments are contaminated with Cu in several parts of the world as; Arabian Gulf [21], Suez Bay [4] and some lagoons on the Egyptian Red Sea [5]. The measured values of copper in the corals are in the same range measured by Hanna [1] in the Eastern Red Sea. Where the average contents of Cu in sediments is much lower than that recorded by Abu Hilal [20], Al Abdali [21], Mohamad [26] and Belal [4]. According to Ramadan and Shata [27], the highest concentration of copper in invertebrates (as shells) is attributed to its uptake through biological activities [8, 9]. Cu of anti-fouling paints is used in shipyards, and in the boat engines along the coastal area off the studied sites. Lead concentration may be associated with carbonate phase and organic matter contents [26], [28]. In the studied site, lead averages in *A. humilis* and *S. pistillata* are much lower relative to the values recorded by Hanna [1] and Hanna and Muir [22]. In the same respect, the measured lead in sediments is also much lower than the averages of Abu Hilal [20], Al Abdali [21] and Belal [4].

Table 8. *Comparison of total organic matter (TOM) in corals and sediment in different localities.*

Location	Organic matter%	Author
Red Sea (water)	----------	[29]
Florida lakes (sediment)	0.8-84.2	[14]
Alexandria (Abu-Qir Bay) (water)	----------	[30]
Alexandria (Sediment)	1.97	[17]
Red Sea (sediment)	0.09-1.9	[16]
Red Sea (Hurghada) Sediment	2.77-3.15	The present investigation
Acropora	4.49-7.04	
Stylophora	4.34-5.27	

Table 9. *Comparison of some trace metals (µg/g) in corals and sediment between the study sites and other sites.*

Location	Fe	Ni	Cd	Pb	Cu	Author
Red Sea (sediment)	1322 Average	-------------	-------------	-------------	-------------	[6]
Australia (Coral reefs)	81-778	0.78-3.87	2.99-12.56	11-30	2.99-12.56	[22]
Eastern Red Sea (Some coral reefs)	-------------	0.05-15.0	-------------	3.48-55.0	0.59-4.2	[1]
Northern Gulf of Aqaba Jordanian (sediment)	3451-14603	29.9-62	3.8-13.7	96.3-183	6.9-25.6	[20]
Arabian Gulf (unpolluted sediments)	10000-20000	70-80	1.2-2.0	15-30	15-30	[21]
Red Sea	-------------	0.1-111.5	0.0-3.1	0.5-127	6-249.	[26]
Suez Bay (sediments)	1728-2953	14.98-50.79	1.89-2.48	26.33-88.08	5.04-51.17	[4]
Red Sea (sediment)	1305.79-1852.41	10.38-12.88	1.28-2.36	11.82-12.19	2.80-4.10	The
(*Acropora*)	150.64-289.18	13.68-15.82	1.55-1.93	13.51-15.47	4.11-5.67	present
(*Stylophora*)	112.03-290.53	14.29-16.27	0.92-1.19	11.60-16.72	3.33-6.21	work

Positive correlation's (Pearson correlations) were found between Cu, Ni, Pb and the TOM content of corals (however, the concentration of these elements is associated by the increase of the TOM in the coral species are higher than in sediment). The finding of Al-Abdali [21] and Belal [4] supports this result. Dar [11] concluded that, trace metals are associated with different sediment phases (exchangeable carbonate, Fe-oxides and organic matter contents), where these phases are associated with Fe, Cu, Ni, Cd and Pb. Corals absorb HM e.g Pb, Cd, Cu, Ni, and Fe, wherever the high concentrations can kill corals [22] and other invertebrates [27].

The two coral species at the studied areas appeared to tolerate these levels of heavy metals and flourish in the Red Sea, where *A. humilis* and *S. pistillata* are the most abundant species in the region. By comparing the concentrations of heavy metals in the present study and Hanna and Muir [22] results, the concentrations of Fe, Cd, Pb and Cu in the coral reefs are in the safe limit (Table 9). Ni concentration exceeds their safe limit (0.05-15.0 µg/g) according to Hanna [1] that means that the coral reef start suffering from pollution that may affect the growth, reproduction and surviving. On the other hand, Cd showed a slightly increase in *A. humilis*. The present data indicates that, the two studied coral species preserve the environmental pollution and may tolerate the environmental chemical pollution [1]. Generally, coral reefs may have the ability to concentrate some heavy metals with higher concentrations than the underlying sediment.

5. Conclusion

It was concluded that, the high organic matter concentration in the sediments plays an important role in the concentration of some trace metals in the bottom sediment in the form of insoluble sulphides. Moreover, heavy metals may be attributed generally to the presence of power plants, desalination plant, fishing and diving boats as well as domestic sewage. Moreover, the high population densities, great urbanization and intensive coastal activities may cause the interchange between the sediments and coral reefs through the water motion in the area.

The variation in the different seasons may be contributing the variation of the redox potentiality of the areas. On the other hand, the coral species appeared to tolerate some levels of heavy metals and flourish in the Red Sea, where *A. humilis* and *S. pistillata* are the most abundant species in the region. The coral reef start suffering from pollution that may affect the growth, reproduction and surviving. Generally, coral reefs may have the ability to concentrate some heavy metals with higher concentrations than the underlying sediment

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