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ORIGINAL ARTICLE

# Heavy metals contamination of the Quaternary coral reefs, Red Sea coast, Egypt

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**Abstract** In order to assess pollutants and impact of environmental changes along the Egyptian Red Sea coast, seven recent and Pleistocene coral species have been analyzed for Zn, Pb, Mn, Fe, Cr, Co, Ni, and Cu. Results show that the concentration of trace elements in recent coral skeletons is higher than those of Pleistocene counterpart except for Mn and Ni. In comparison with recent world-wide reefs, the present values are less than those of Central America coast (iron), Gulf of Aqaba, Jordan (lead, copper), Gulf of Mannar, India (chromium, zinc, manganese), Costa Rica, Panama (chromium, nickel), North-west coast of Venezuela and Saudi Arabia (copper). The present values are higher than those of Gulf of Aqaba, Jordan (iron, zinc, manganese), Gulf of Mannar, India (lead, cobalt, nickel), North-west coast of Venezuela (lead, zinc, chromium, manganese), Australia (copper, nickel, zinc, manganese). The highest values were recorded in *Stylophora pistillata* (iron, lead and copper), *Acropora cytherea* (cobalt), *Pocillopora verrucosa* (zinc) and the lowest concentrations were recorded in *Goniastrea pectinata* (iron, chromium, copper and nickel), *Favites pentagona* (lead, zinc and manganese), and *Porites lutea* (cobalt). The differences in metals content among the studied species are attributed to differences in microstructure and microarchitecture.

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## Introduction

Coral reefs are quite common in the tropical seas and oceans. They represent the marine equivalent of the tropical rain forest. Mostly corals grow in a pristine environment, but can be exposed to high metal concentrations as a result of near shore developmental activities such as coastal mining, harbor dredging, discharge of industrial and domestic effluents into the ocean, urbanization and over population (Bastidas and Garcia 1999; Esslemont 2000; Fallon et al. 2002; Gopinath et al. 2009). These metals might occur in coral skeletons as a result of structural incorporation of metals into aragonite (Goreau 1977), inclusion of particulate materials in skeletal cavities (Howard and Brown 1984), surface adsorption onto exposed skeleton (Brown et al. 1991; Kumar et al. 2010), and chelation with the organic matrix of the skeleton (Mitterer 1978). Therefore, the trace element levels in coral skeletons may function as good proxies for marine pollution.

Despite that many marine organisms secrete skeletons in coral reefs, scleractinian corals have been chosen for study due to the following reasons: corals accumulate the pollutant without being killed by the relatively high levels encountered in the marine environment, corals are sedentary, and therefore representative of the study sites, corals are abundant throughout the study area, corals are sufficiently long lived, corals are of a reasonable size, giving adequate skeleton for analysis and thin sections.

The concept of this paper depends on using Pleistocene corals which formed in pristine environment with respect to human activities as a reference to monitor pollution in

the recent counterparts. This study was designed to compare between scleractinian species along Red Sea coast and worldwide reefs.

## Materials and methods

Representative coral samples of seven species (Table 1), belong to three suborders were collected from four localities (Fig. 1), three of them are recent: Shalatein fishing harbor, Sharm El Bahari bay and El Hamarwien phosphate harbor and one of Pleistocene age in Wadi Quseir El-Kadium. The samples were collected from the tips of living scleractinians facing the open sea, from 1 to 4 m depth below the mean low tide level. The coral samples were initially identified and photographed.

The Pleistocene samples used in the present study were chosen from the youngest Pleistocene unit just on the coast to be sure that they consist of aragonite or are equivalent in mineralogy to modern corals, and the possibility of diagenetic alteration of pristine geochemical signatures in the fossil coral is minimal and can generally be neglected. As during diagenetic transformation, trace elements are exchanged and removed, thus changing the geochemistry of the coralline matrix that may affect coral proxy records (McGregor and Gagan 2003).

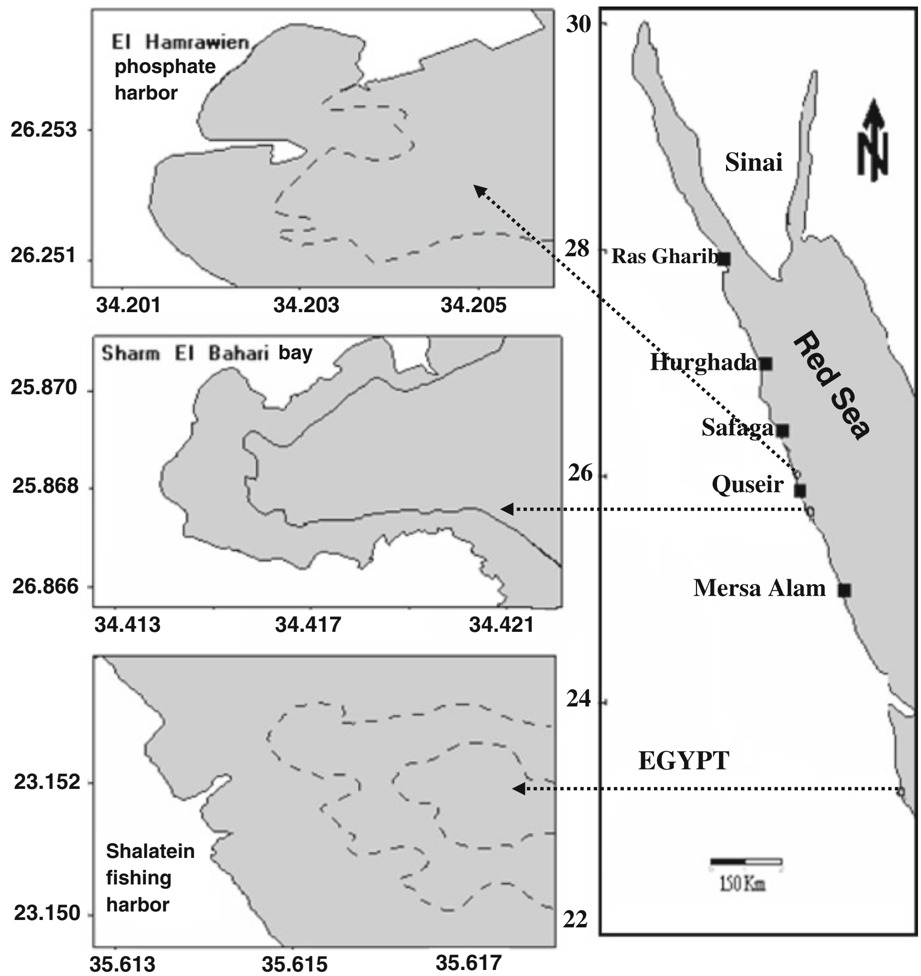
For Zn, Pb, Mn, Fe, Cr, Co, Ni and Cu analysis, 28 coral samples are washed with sodium hypochloride for 24 h, and then with distilled water. They were oven-dried at 60°C and powdered in an agate mortar. 0.2 g of powdered coral sample was digested in 5 mL of HCl and 15 mL $HNO_3$–$HClO_4$ (5:1). The digested sample was centrifuged at 200 rpm and

**Table 1** Mean heavy metals concentrations (ppm, $n = 5$) in recent corals along the Red Sea coast

| Locality species | Heavy metals | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Zn | Pb | Mn | Fe | Cr | Co | Ni | Cu |
| El Hamarwein | | | | | | | | |
| 1 | 11.2 | 16.1 | 25.3 | 173 | 2.2 | 12.6 | 36.81 | 2.1 |
| 2 | 17.9 | 17.4 | 3.8 | 63.8 | 2.5 | 11.9 | 16 | 1.9 |
| 3 | 34.7 | 15.8 | 16.9 | 69.9 | 2.1 | 12.1 | 15.8 | 2 |
| 4 | 21.1 | 20.7 | 3.3 | 62.1 | 2.3 | 11.6 | 15.5 | 1.6 |
| 5 | 12.1 | 21.8 | 63 | 69.7 | 1.9 | 12.9 | 15.1 | 1.7 |
| 6 | 9.6 | 17.7 | 3.9 | 70.5 | 1.5 | 13 | 17.9 | 1.5 |
| 7 | 7.6 | 18.5 | 3.2 | 146.6 | 1.7 | 12.7 | 26.9 | 1.6 |
| Sharm Al Bahari | | | | | | | | |
| 1 | 30.8 | 19.6 | 5.6 | 65.7 | 2.5 | 16.8 | 26.8 | 2.5 |
| 2 | 104 | 18.8 | 5.4 | 49.1 | 2.7 | 13.4 | 29.5 | 2.4 |
| 3 | 35.1 | 18.9 | 5.6 | 53.6 | 2.5 | 13.5 | 27.8 | 2.3 |
| 4 | 26.3 | 17.8 | 4.9 | 63.3 | 1.8 | 8.8 | 15.1 | 2.6 |
| 5 | 22.2 | 16.4 | 5.1 | 60.9 | 2.6 | 12.8 | 18.9 | 2.7 |
| 6 | 29.7 | 18.4 | 7.8 | 61.3 | 2 | 10 | 15.8 | 2.4 |
| 7 | 36.8 | 14.6 | 13.9 | 73.3 | 2.1 | 9.9 | 15.3 | 2 |
| Shalateen | | | | | | | | |
| 1 | 33.3 | 44.8 | 5.6 | 88.4 | 2.5 | 16.7 | 31.1 | 3.2 |
| 2 | 13.1 | 36.8 | 6.2 | 36.5 | 2.3 | 12.8 | 14.7 | 2.8 |
| 3 | 12.4 | 22.7 | 7.3 | 66.5 | 2 | 19 | 18.4 | 2.5 |
| 4 | 30.3 | 42.8 | 5.6 | 74.8 | 2.8 | 14.8 | 32.5 | 2.9 |
| 5 | 17.8 | 43.6 | 5.9 | 44.7 | 2.1 | 15.8 | 27.6 | 3.1 |
| 6 | 14.4 | 40.8 | 5.7 | 36.1 | 2.3 | 13 | 13.9 | 2.3 |
| 7 | 14 | 33.7 | 6.9 | 63.8 | 2.5 | 14.7 | 16.5 | 2.1 |
| Minimum | 7.6 | 14.6 | 3.2 | 36.1 | 1.5 | 8.8 | 13.9 | 1.5 |
| Maximum | 104 | 44.8 | 63 | 173 | 2.8 | 19 | 32.5 | 3.2 |
| Mean | 30.2 | 24.7 | 10 | 71.1 | 2.2 | 13.3 | 20.3 | 2.3 |
| SD | 20.4 | 10.6 | 13.2 | 32.2 | 0.34 | 2.4 | 7.3 | 0.49 |

1, *Stylophora pistillata*; 2, *Pocillopora verrucosa*; 3, *Acropora cytherea*; 4, *Porites lutea*; 5, *Fungia fungites*; 6, *Goniastrea pectinata*; 7, *Favites pentagona*

**Fig. 1** Location map




the centrifuged liquid was used for the determination of trace elements in coral samples using an Inductively Coupled Plasma Atomic Emission Spectrophotometer (laboratory of Egyptian Nuclear Material Authority).

## Geologic setting

### Pleistocene reefs

Pleistocene reefs occur along the Red Sea coast in three units with elevations ranges from 10 to 35 m above the present sea level and with maximum width of about 550 m and interrupted in front of wadi mouths. The vertical pattern shows a transgressive sequence in the lower (youngest) and upper (oldest) units and a regressive one in the middle unit (El-Sorogy 2008). The contact between the different reef units is not always obvious. They either onlap onto ancient steep cliffs or form leveled stepped elevations on coastal plain. The most abundant fossils are scleractinians (faviids, poritiids, and acroporids), as well as preserved pelecypods, gastropods and echinoids.

The Pleistocene samples were collected from the lower unit, which is easily traced along the Red Sea coast. It has three prominent morphological steps at elevations of 1.5, 3.5 and 9 m, respectively above the present sea level. The lower unit has been dated at 110,000 ± 8,000 years B.P. at the southern tip of Sinai Peninsula (Gvirtzman and Friedman 1977). It is considered to have been built during the last interglacial times (Oxygen isotope stage 5 of deep sea cores).

### Recent reefs

Recent coral samples were collected from Shalatein fishing harbor, Sharm El Bahari bay and El Hamarwien phosphate harbor (Fig. 1), where field observations proved that they are polluted by different human activities.

#### *El Hamrawien phosphate harbor*

It lies at the mouth of Wadi El Hamarwien directly on the main Safaga–Quseir road (Fig. 1), at 20 km north of Quseir city (lat. 28°21′54″N and long. 33°05′20″E). It represents the old phosphate harbor at the Egyptian Red Sea coast.

This location consists of two bays (the small closed northern bay and open big southern bay). The main phenomenon in this area is immense clouds of phosphate dusts derived from phosphate export (Fig. 2), which depends on the wind direction, then settle down on the coastal area or directly fall into the sea water.

The coastal area is narrow due to closing it with the main Safaga–Quseir road and represents sabkha environment, while the beach is very narrow with medium to coarse beach sands and rock boulders scattered especially near the asphaltic road.

The tidal flat is very narrow and extends smoothly with gentle slope seaward. Most of marine sediments have brown color due to the phosphate dusts. The offshore zone includes the spread of seagrass and algae on the muddy bottom floor especially in the northern bay, while the corals and other fauna such as mollusks and sponges have been recorded in the southern bay. The coral cover increases seaward with high diversity.

*Sharm El Bahari bay*

It represents relatively small protected bay surrounded by fringes of mangrove and located at 33 km south of Quseir, at latitude 25°52′07″N and longitude 34°24′49″E (Fig. 1). The mangrove swamp is healthy and the density increases at the entrance of the sharm and also at the northern side; the mangrove trees reach more than 4 m height. The sharm is surrounded with raised beach from both north and south.

The coastal area is wide and represented with sabkha environment with higher plants (Fig. 3), while the beach is narrow, its northern part formed by the gritstone while the rest of beach is medium sand.

The tidal flat is very wide, nearly horizontal and extends smoothly with very gentle slope seaward. Its bottom floor is rocky, mainly from the dead coralline limestone covered with thin layer of fine sand and mud inhabited with mangrove trees. The offshore zone includes seagrass and algae on the muddy bottom floor especially in the southern side, while the coral reefs were found as patches scattered in the middle area of the bay.

**Fig. 3** Coastal zone with mangrove and Pleistocene reefs during low tide at Sharm El Bahari bay

*Shalatein fishing harbor*

It is located at 700 km south of Hurghada, at latitude 23° 09′ 05″ N and longitude 35°36′51″E (Fig. 1). This area is shallow, crowded with the ships and boats (Fig. 4), also the suction pumps room of main Shalatein desalination plant was constructed on the metal jetty situated in the middle of the harbor, in addition the rejected pipeline is fixed at the southern side (Fig. 5).

**Fig. 2** Phosphate dust during loading operation at El Hamrawien phosphate harbor

**Fig. 4** Drainage of reject water resulting from desalination plant at Shalatein fishing harbor

**Fig. 5** Crowded ships and boats with other solid pollutants at Shalatein fishing harbor

Shalatein harbor is very wide and shallow, where the coastal area is wide and includes some trees, while the beach is sandy. The tidal flat is very wide, extends smoothly with very gentle slope seaward. Its bottom floor is sandy with some spots of algae and seagrass. Also, barrier of coral reefs was situated parallel to the shoreline. The offshore zone includes seagrass and algae on the soft bottom floor, while the coral reefs were found as barrier at about 2 km from the shoreline with healthy community and diversity.

## Results and discussion

Coral reef ecosystems are recognized as being particularly threatened by pollutants (Howard and Brown 1984). There are still few data about the major and trace elements composition of skeletal corals. Chemical analysis of coral skeletons has emerged as a powerful tool for detecting historical trends in environmental conditions (Poulsen et al. 2006). Previous studies have also detected coral growth responses to oil spills (Guzman et al. 1991, 1994; Eakin et al. 1993). Guzman and Jarvis (1996) measured vanadium in coral cores as a long-term tracer of oil pollution in the Caribbean. A study published by Readman et al. (1996) suggested that hydrocarbon biomarkers could be detected in the skeleton of a massive coral (*Porites lutea*) collected in the Arabian Gulf, with higher concentrations in the 1991 year-band compared to other year-bands. However, comprehensive data on heavy metal concentrations in the skeletal corals are scarce in the Red Sea region. So this work will focus on eight heavy metals measured in the seven scleractinian species (both Recent and Pleistocene) along the Red Sea coast (Tables 1, 2) and comparison values with other studies (Table 3).

The average concentration of trace elements in recent corals along the Red Sea coast shows high concentrations of Zn, Pb, Fe, Cr, Co and Cu in comparison with their Pleistocene counterparts.

The concentration of Fe ranges from 36.1 to 173 ppm with an average value of 71.1 ± 32.2 ppm. The highest value is recorded in *Stylophora pistillata* of El Hamrawien phosphate harbor and the lowest value is recorded in *Goniastrea pectinata* of Shalatein fishing harbor. In general, the recorded values correlated with the values of Fe in Panamian coast (70.8 ppm) by Guzman and Jimenez (1992). The present Fe values increase than the values of the Red Sea coast in Saudi Arabia (22 ppm) as reported by Hanna and Muir (1990) and Jordanian Gulf of Aqaba (25.76 ppm) as reported by Al-Rousan et al. (2007). They decrease than the values of Central America coast (113.2 ppm) as reported by Guzman and Jimenez (1992) and Red Sea coast (126.92 ppm) as reported by Khaled et al. (2003). In Pleistocene samples, the concentration of Fe ranges from 11.1 to 259 ppm. Except *Goniastrea pectinata* and *Favites pentagona* at all of the three localities, Fe concentrations of recent corals are statistically higher than those of Pleistocene corals.

**Table 2** Heavy metals concentrations (ppm) in Pleistocene corals from Wadi Quseir El-Kadium, Red Sea coast

| Species | Zn | Pb | Mn | Fe | Cr | Co | Ni | Cu |
|---|---|---|---|---|---|---|---|---|
| *Stylophora pistillata* | 5.4 | 17.7 | 3.1 | 21.9 | 1.8 | 12.5 | 23.5 | 1.5 |
| *Pocillopora verrucosa* | 5.1 | 9.2 | 1.2 | 11.1 | 1.5 | 12.2 | 20.2 | 1.3 |
| *Acropora cytherea* | 6.8 | 11.8 | 2.7 | 21.8 | 1.1 | 12.1 | 24.7 | 1.1 |
| *Porites lutea* | 20.9 | 5.9 | 2.01 | 13.7 | 1.6 | 12.8 | 19.9 | 1.6 |
| *Fungia fungites* | 5.9 | 6.7 | 1.9 | 17.8 | 1.6 | 12.8 | 21.7 | 1.3 |
| *Goniastrea pectinata* | 72 | 26.6 | 85.3 | 131 | 1.7 | 14.3 | 32.7 | 1.5 |
| *Favites pentagona* | 73 | 24.9 | 40.4 | 259 | 1.8 | 12.8 | 18.3 | 1.5 |
| Minimum | 5.1 | 5.9 | 1.2 | 11.1 | 1.1 | 12.1 | 18.3 | 1.1 |
| Maximum | 73 | 26.6 | 85.3 | 259 | 1.8 | 14.3 | 32.7 | 1.6 |
| Mean | 27.0 | 14.7 | | 68.0 | 1.6 | 12.8 | 23.0 | 1.4 |

**Table 3** Comparison between heavy metals (mean concentrations in ppm) in the present study and other worldwide localities

| Reference | Cu | Ni | Co | Cr | Fe | Mn | Pb | Zn | Site |
|---|---|---|---|---|---|---|---|---|---|
| This study | 2.3 | 20.3 | 13.3 | 2.2 | 71.1 | 10 | 24.7 | 30.2 | 1 |
| Kumar et al. (2010) | 2.4 | 0.86 | 2.55 | 13.27 | 0.38 | 118 | 1.75 | 93.21 | 2 |
| | 2 | 91.6 | NA | 7.3 | 113.2 | 7.3 | 31 | 10.2 | 3 |
| Guzman and Jimenez (1992) | 3.8 | 93.7 | NA | 9.9 | 70.8 | 6.9 | 32.3 | 8.9 | 4 |
| | 3.3 | 93.1 | NA | 9.3 | 81.9 | 7 | 32 | 9.2 | 5 |
| Bastidas and Garcia (1999) | 16.33 | NA | NA | 0.797 | 62.05 | NA | 0.208 | 10.67 | 6 |
| Al-Rousan et al. (2007) | 5.36 | NA | NA | NA | 25.76 | 8.22 | 47.91 | 5.52 | 7 |
| Esslemont (1996) | 0.23 | 1.62 | NA | <0.3 | NA | NA | 0.04 | 1.87 | 8 |
| Khaled et al. (2003) | 7.58 | NA | NA | NA | 126.92 | NA | 5.56 | 6.47 | 9 |
| Abd El-Wahab & El-Sorogy (2003) | 1.92 | 0.76 | 0.49 | NA | NA | 2.07 | 1.54 | 4.31 | 10 |
| Hanna and Muir (1990) | 0.97 | 0.08 | NA | NA | 4 | 4.56 | 39 | 2 | 11 |
| | 0.18 | 2.58 | NA | NA | 22 | 6.62 | 31 | 6 | |

1, Present study; 2, Gulf of Mannar, India; 3, Costa Rical; 4, Panama; 5, Central America; 6, north-west coast of Venezuela; 7, Jordanian Gulf of Aqaba; 8, Australia; 9, Red Sea and Gulf of Aqaba; 10, Red Sea; 11, Saudi Arabia Red Sea; NA, not available

Pb in corals is well known indicators of anthropogenic activity (Shen and Boyle 1987). Pb is a toxic element to corals (Beyersmann 1994). The main sources of Pb in the marine environment are from storm water runoff from hinterland and sewage input (Peters et al. 1997). The concentration of Pb in recent samples ranges from 14.6 to 44.8 ppm with an average value of 24.7 ± 10.6 ppm. The highest value is recorded in *Stylophora pistillata* of Shalatein fishing harbor and the lowest value is recorded in Favites pentagona of Sharm El Bahari bay. Lubricating oil from diesel and gasoline powered motors of boats and ships is an important source of Pb in marine environment. This reason may be causes Shalatein fishing harbor seems to be enrichment in Pb concentration than the other two studied sites.

Pb values in the study area increase than those of the Gulf of Mannar, India (1.75 ppm) as reported by Kumar et al. (2010) and north-west coast of Venezuela (0.208 ppm) as reported by Bastidas and Garcia (1999). The average value of Pb in the recent samples of the study area is less than Jordanian Gulf of Aqaba (47.91 ppm) as reported by Al-Rousan et al. (2007), and from the Red Sea coast of Saudi Arabia (31 ppm) as reported by Hanna and Muir (1990). In Pleistocene samples, the concentration of Pb ranges from 5.9 to 26.6 ppm.

The concentration of Co in recent samples ranges from 8.8 to 19 ppm with an average value of 13.3 ± 2.4 ppm. The highest value is recorded in *Acropora cytherea* of Shalatein fishing harbor and the lowest value is recorded in *Porites lutea* of Sharm El Bahari bay. In spite of the rarity of Co analysis in worldwide reefs, our Co concentrations are more than those of Gulf of Mannar, India (2.55 ppm) as reported by Kumar et al. (2010), and Red Sea coast (0.49 ppm) as reported by Abd El-Wahab and El-Sorogy (2003). In Pleistocene samples, the concentration of Co ranges from 12.1 to 14.3 ppm.

The concentration of Cr ranges from 1.5 to 2.8 ppm with an average value of 2.2 ± 0.34 ppm. The highest value is recorded in *Porites lutea* of Shalatein fishing harbor and the lowest value is recorded in *Goniastrea pectinata* of El Hamrawien phosphate harbor. In spite of the rarity of Cr analysis in worldwide reefs, our Cr concentration is lower than those of Gulf of Mannar, India (13.27 ppm) as reported by Kumar et al. (2010), Costa Rica (7.3 ppm), Panama (9.9 ppm), and Central America (9.3 ppm) as reported by Guzman and Jimenez (1992). In general, our Cr values are more than the values of north-west coast of Venezuela (0.797 ppm) as reported by Bastidas and Garcia (1999). In Pleistocene samples, the concentration of Cr ranges from 1.1 to 1.8 ppm.

Zn and Cu are essential elements for living organisms and play an important role in growth, cell metabolism and survival of most animals including corals. The concentration of Cu in recent samples ranges from 1.5 to 3.2 ppm with an average value of 2.3 ± 0.49 ppm. The highest value is recorded in *Stylophora pistillata* of Shalatein fishing harbor and the lowest value is recorded in *Goniastrea pectinata* of El Hamrawien phosphate harbor. Our Cu values are comparable with those of Gulf of Mannar, India (2.4 ppm) as reported by Kumar et al. (2010), Costa Rica (2.0 ppm), Panama (3.8 ppm) and Central America (3.3 ppm) as reported by Guzman and Jimenez (1992). Our values are less than the values of north-west coast of Venezuela (16.33 ppm) as reported by Bastidas and Garcia (1999) and Gulf of Aqaba (7.58 ppm) as reported by Khaled et al. (2003). Cu values of the study area are higher than those of Australia (0.23 ppm) as reported by Esslemont (1996) and Saudi Arabia (1.23 ppm) as reported by Hanna

and Muir (1990). In Pleistocene samples, the concentration of Cu ranges from 1.1 to 1.6 ppm.

Zn is an essential micro nutrient of coral reefs and also commonly used for protein synthesis and cell repair (Brown and Howard 1985). The concentration of Zn in recent samples ranges from 7.6 to 1.4 ppm with an average value of 30.2 ± 20.4 ppm; while in Pleistocene samples it ranges from 5.1 to 73 ppm. The highest value is recorded in *Pocillopora verrucosa* of Sharm El Bahari bay and the lowest value is recorded in *Favites pentagona* of El Hamrawien phosphate harbor. The Zn values in recent samples are mostly higher than all the worldwide reef areas except Gulf of Mannar, India (93.21) as reported by Kumar et al. (2010). The concentration of Zn was 1.87 ppm in Australia (Esslemont 1996), 10.67 ppm in north-west coast of Venezuela (Bastidas and Garcia 1999), 5.52 ppm in Jordanian Gulf of Aqaba (Al-Rousan et al. 2007) and 4.31 ppm from the Red Sea (Abd El-Wahab and El-Sorogy 2003).

The concentration of Mn in recent samples ranges from 3.2 to 63 ppm with an average value of 10 ± 13.2 ppm, while in Pleistocene samples they ranges from 1.2 to 85.3 ppm. The highest value is recorded in *Fungia fungites* of El Hamrawien phosphate harbor bay and the lowest value is recorded in *Favites pentagona* of El Hamrawien phosphate harbor. Mn concentration in corals is an indicator of detrital inputs (Matson 1989; Linn et al. 1990). As in Zn the concentration of Mn in recent samples is mostly larger than all the worldwide reef areas except Gulf of Mannar, India (118 ppm) as reported by Kumar et al. (2010). The concentration of Mn was 7.3 ppm in Costa Rica (Guzman and Jimenez 1992), 6.62 ppm in Saudi Arabia coast (Hanna and Muir 1990), 8.22 ppm in Jordanian Gulf of Aqaba (Al-Rousan et al. 2007) and 2.07 ppm from the Red Sea (Abd El-Wahab and El-Sorogy 2003).

The concentration of Ni in recent samples ranges from 13.9 to 32.5 ppm with an average value of 20.3 ± 7.3 ppm, while in Pleistocene samples they ranges from 18.3 to 32.7 ppm. The highest value is recorded in *Porites lutea* of Shalatein fishing harbor and the lowest value is recorded in *Goniastrea pectinata* of Shalatein fishing harbor. The concentration in recent samples increases than those of the values of Gulf of Mannar, India (0.86 ppm) as reported by Kumar et al. (2010), Australia (1.62 ppm) as reported by Esslemont (1996) and from the Red Sea coast of Saudi Arabia (0.18 ppm) as reported by Hanna and Muir (1990). The average value of Ni in the recent samples of the study area is less than Costa Rica (91.6 ppm), Panama (93.7 ppm) and Central America (93.1 ppm) as reported by Guzman and Jimenez (1992).

To assess the amount of the environmental impact on skeletons of scleractinian corals, comparison was done with recent studies and standard levels (Pleistocene background). Figure 6 shows that mean concentrations in most recent samples are higher than those of Pleistocene ones except nickel and manganese. *Stylophora pistillata* (2–6 times), *Pocillopora verrucosa* (to 20 times), *Acropora cytherea* (2–5 times), *Porites lutea* (1.5–8 times), *Fungia fungites* (1.5–4 times), *Goniastrea pectinata* and *Favites pentagona* have lower content in most recent values.

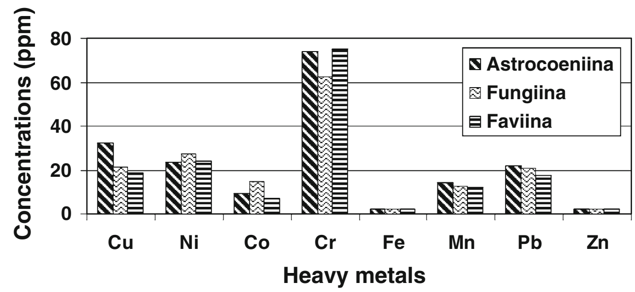



**Fig. 6** Comparison between mean concentrations (ppm) of heavy metals in the recent species with others Pleistocene background

The content of the recent values is normalized to the equivalent of Pleistocene ones (Fig. 7). Suborder Astrocoeniina showed strong difference in chromium, copper and cobalt content (3.5, 3, 4 times, respectively) higher than the average of Pleistocene levels. Suborder Fungiina shows enrichment in chromium, nickel and cobalt (4.5, 4, 3.6 times, respectively) higher than the average of Pleistocene levels, while faviina shows negative relation with most studied elements comparison to Pleistocene.

## Conclusions

The average metal accumulation levels in coral samples of the study area is in the following order Fe > Zn > Pb > Ni > Co > Mn > Cu > Cr. The differences in distribution patterns of trace elements among scleractinian species (Recent and Pleistocene) may attribute, in general, to the microstructure and microarchitecture of these skeletons.

The highest values of the analyzed trace elements (Fig. 8) were recorded in *Stylophora pistillata* (Fe, Pb, and

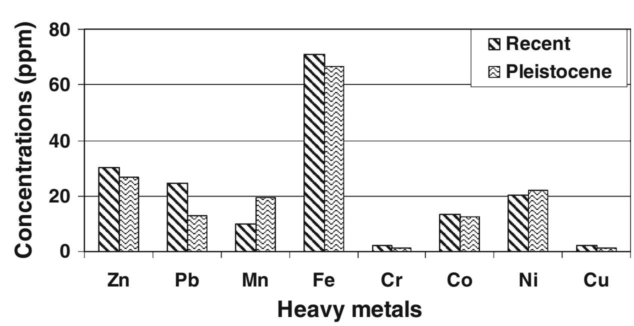



**Fig. 7** Mean values of recent skeletons normalized to Pleistocene ones

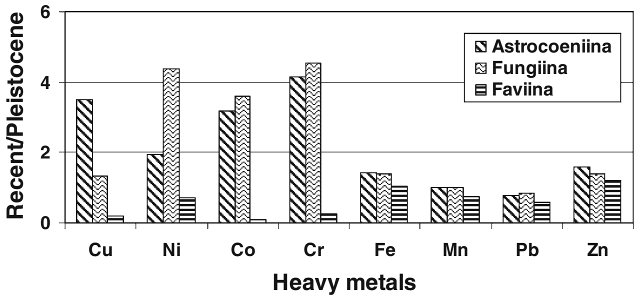



**Fig. 8** Comparative mean concentrations of heavy metals in recent skeletons

Cu), *Acropora cytherea* (Co), *Pocillopora verrucosa* (Zn) which belong to the suborder Astrocoeniina of branched growth, small sized crystallites comprising the polycrystalline fibers, and large reaction surface area. *Porites lutea* (Cr, Ni), and *Fungia fungites* (Mn) belong to suborder Fungiina with septa composed of small, loosely arranged sticks with isolated trabecular centers, loose crystal packing, high total surface area and high amounts of intergranular porosity (Constantz 1986).

The lowest concentrations were recorded in recent skeletons of *Goniastrea pectinata* (Fe, Cr, Cu, and Ni), *Favites pentagona* (Pb, Zn, Mn), *Porites lutea* (Co). Except of *Porites lutea*, the other two species belong to suborder Faviinae of massive growth form. Septa are essentially laminar, consisting of massive and linear arrangement of trabecular centers. They exhibit tight crystal packing of wide aragonite fibers, which restricts the reactive surface area and intercrystalline porosity to a minimum, in contrast to Fungiina and Astrocoeniina. However, skeletons of *Goniastrea pectinata* and *Favites pentagona* of Pleistocene age have enrichment of Zn, Mn, and Fe. This may be attributed to digenesis processes which led to increase inter-and-intraporosity of skeletons, and consequently saturation by elements from hinterland area.

Due to the existence of many sources that continue to discharge metal into the sea, it is difficult to determine the metal input into the coastal water from each source. Therefore, we tried to review and survey all the potential sources and activities along the coastline that may contribute to the metal budget reaching the ecosystem.

The natural and anthropogenic sources of heavy metals may include: terrigenous inputs from wadis during flash floods that transport terrestrial material into the sea (metals from mineral forming basement and sedimentary rocks all over the coastline), huge desalination plants, agriculture activities, land traffic increase, sedimentation caused by filling and coastal construction and dredging, oil spills and discharges, industrial discharges (fertilizers, plastic stabilizers), ship-based sewage and solid waste, soft waste dumping (alloys, dyes, automobile tires, anti-fouling paints and galvanizing materials), shipment of mineral products (mainly phosphate) that is considered as possible hazardous increase of suspended matter. Furthermore, the development of the tourism sector especially along the northern and the central parts of the Egyptian Red Sea coast, which is considered as a pollution source through boat anchors, boat grounding, and cans and other metal littering. Also mining of the hot brine pools in the Red Sea (Nawab 1983) could yield thousands of tones of Zn, Cu, Ag, and Au with some contamination of the surrounding waters.

In conclusion, recent coral reefs along the Red Sea coast suffer high concentration of pollutants in comparison with those of Pleistocene ones. In spite of all the studied heavy metals in scleractinian coral along the Red Sea coast situated in safety limits, where they are mostly under the maximum permissible levels (MPL), according to WHO (1982), the study area is getting contaminated by trace elements and if the levels of trace elements continue to increase, the toxic effect on marine ecosystem will also increase. Therefore, the trace element accumulation in coral skeleton is a direct indicator of industrial effluents discharge. The pretreatment of industrial and domestic effluents, before discharged into coastal area of the Red Sea coast, is wanted to protect the marine ecosystem.

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