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# Metal pollution in marine sediments of selected harbours and industrial areas along the Red Sea coast of Egypt

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(With 8 figures and 5 tables)

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## Abstract

A study of the geochemistry and texture of marine surface-sediments in selected areas along the Red Sea coast was conducted in order to assess the possible influence of human activities on the composition of the sediments, to test for anomalous enrichments in heavy metals, and to evaluate and quantify metal release into the sea. Surface sediments reveal extremely high total concentrations of Zn (average 21.35 ppm) in Quseir Harbour, Cu (avg. 76.74 ppm) in El-Esh area, Pb (avg. 21.56 ppm and avg. 19.54 ppm) in Safaga and Hurghada Harbours, respectively, as well as Ni (avg. 38.37 ppm), Co (avg. 6.84 ppm) and Cd (avg. 1.33 ppm) in Safaga Harbour. Some samples show very high values of Cu (366 ppm) at El-Esh area. Our results indicate that the main sources of metals in the marine environments are of anthropogenic origin. In addition, trace metals are initially supplied to these areas from terrestrial sources via wadis or the atmosphere, and from biological activity in the sea. The obtained findings will be useful for the management and sustainable development of the areas in question.

**Keywords**: Metals, Marine pollution, Harbours, Industrial areas, Red Sea

## Zusammenfassung

Die marinen Oberflächensedimente von ausgewählten Lokalitäten im ägyptischen Teil des Roten Meers wurden geochemisch untersucht, um Hinweise auf den Einfluss menschlicher Aktivitäten auf die Sedimentzusammensetzung zu untersuchen, besondere Anreicherungen von Schwermetallen zu identifizieren und den Eintrag von Metallen in das Meer zu quantifizieren. Die untersuchten Sedimente zeigen extrem hohe Konzentrationen von Zn (durchschnittlich 21.35 ppm) im Hafen von Quseir, Cu (durchschn. 76.74 ppm) im Gebiet von El-Esh, Pb (durchschnittlich 21.56 und 19.54 ppm) in den Häfen von Safaga und Hurghada sowie Ni (durchschnittlich 38.37 ppm),

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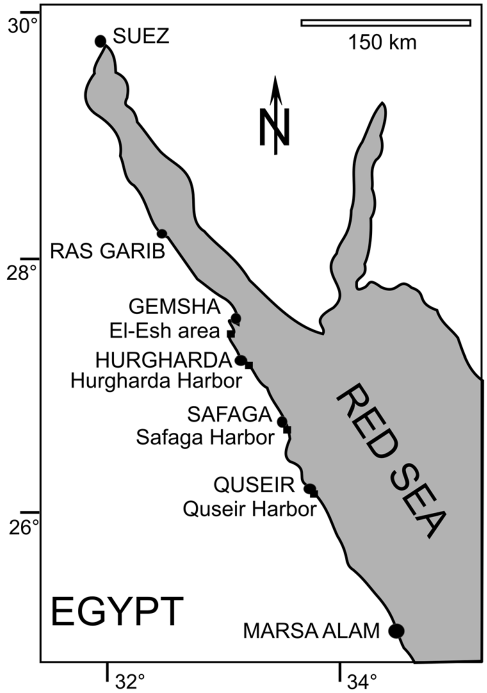


Fig. 1. Location map of the studied areas along the Red Sea coast, Egypt.

Co (durchschnittlich 6.84 ppm) und Cd (durchschnittlich 1.33 ppm) im Hafen von Safaga. Einige Proben im Gebiet von El-Esh zeigen auch sehr hohe Werte von Cu (366 ppm). Unsere Untersuchungen zeigen, dass die Hauptquelle von Metallen in den marinen Ablagerungsräumen menschlichen Ursprungs sind. Zusätzlich stammen Spurenmetalle aus terrestrischen Quellen und werden über Wadis, Atmosphäre und biologische Aktivität in das Meer eingetragen. Die präsentierten Ergebnisse können eine sinnvolle Basis liefern für die nachhaltige Entwicklung der untersuchten Gebiete.

**Stichworte**: Metalle, Marine Verschmutzung, Häfen, Industriegebiete, Rotes Meer

## Introduction

The marine environment of the Red Sea has been considered for a long time as being relatively unpolluted. In present times, however, some forms of pollutants, such as phosphate mining, oil fields, waste, sewage and other activities are associated with mobilization of metals into the marine environment. Heavy metals such as cadmium, mercury, lead, copper and zinc are regarded as being serious pollutants of aquatic ecosystems because of their environmental persistence, toxicity and ability to be incorporated into food chains (Förstner & Wittman 1983).

The study of trace metals in surface sediments of Quseir, Safaga, Hurghada Harbours and El-Esh area along the Red Sea coast of Egypt is a subject of much interest, especially at

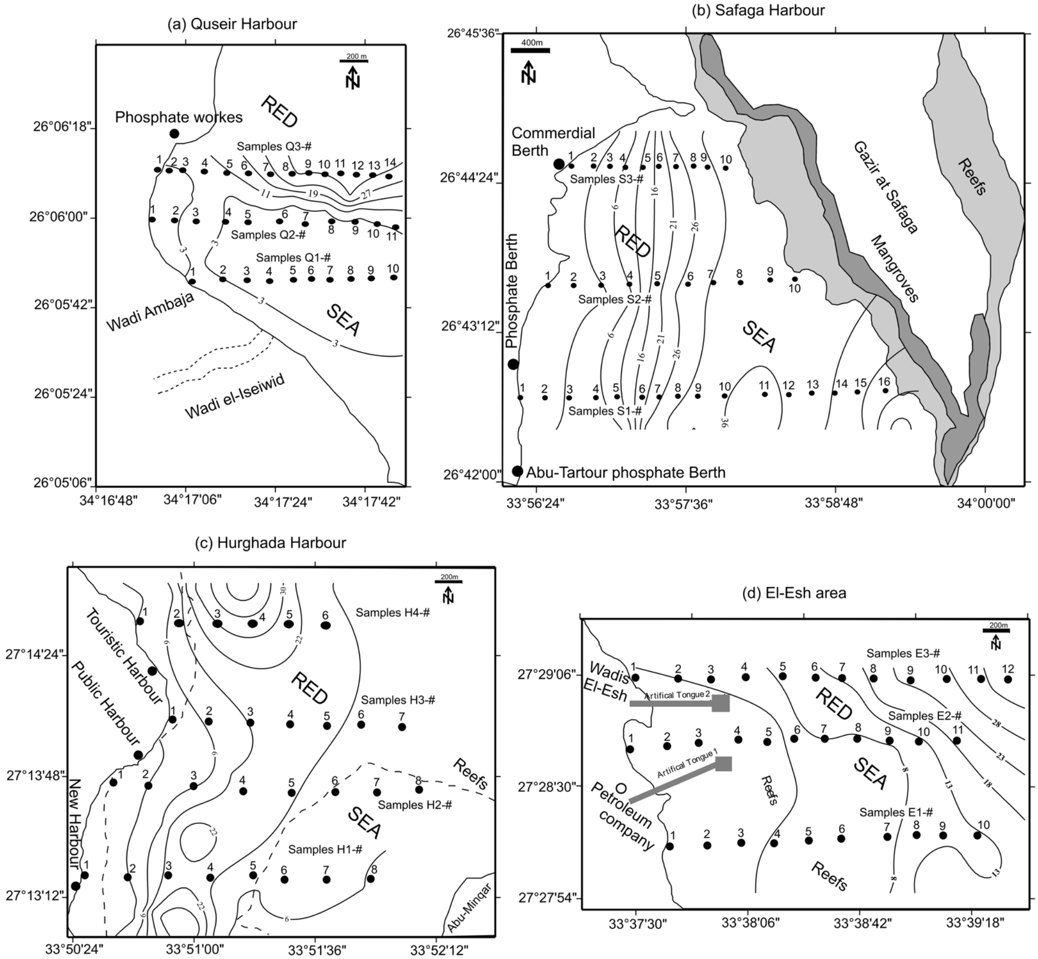


Fig. 2. Sample locations and bathymetric maps of (a) Harbours of Quseir, (b) Safaga, (c) Hurghada and (d) El-Esh area.

places where these areas receive a variety of stress from human activities. Considerable industrial and urban developments are currently taking place at many locations, both onshore and offshore. During the last years, several studies on marine surface-sediments of the Egyptian Red Sea coast have been carried out (e.g., PILLER & MANSOUR 1990; FRIHY et al. 1996; MANSOUR et al. 2000; DAR 2002 MADKOUR 2004; MANSOUR et al. 2005; MADKOUR et al. 2006; MADKOUR & DAR 2007; MADKOUR et al. 2008).

The present study focuses on the geochemistry of marine surface-sediments in some areas (Quseir, Safaga, Hurghada Harbours and El-Esh area) along the Red Sea coast (Fig. 1). It aims to assess the potential influence of human activities on the composition of the sediments, focusing on any anomalous enrichment in heavy metals and to evaluate and quantify metal release into the sea.

## Study areas

Quseir Harbour (N 26°05'02'' to N 26°06'12'', E 34°16'58'' to E 34°17'08'') is the oldest harbour at the Egyptian Red Sea coast. It is situated in a small bay at the mouth of Wadi Ambaji (Fig. 2a). The sea bottom character includes dense seagrass meadows (Fig. 3a).

Safaga Harbour (N 26°43'42'' to N 26°44'22'', E 33°56'20'' to E 33°56'05'') is the largest harbour of the Egyptian Red Sea coast (Fig. 2b). The coastal zone along the Red Sea of Safaga is a site for industrial development and for future establishment of dense recreational resorts. It includes Safaga Harbour, which is most important for the international trade.

Hurghada Harbour is situated at N 27°13'09'' to N 27°14'72', E 33°50'73'' to E 33°50'85'' (Fig. 2c). The southern portion of the Harbour was subject to dredging activities and disposal of garbage from the boats.

El-Esh area lies about 30km to the north of Hurghada (N 27°27'93'' to N 27°28'80'', E 33°38'00'' to E 33°38'20'') (Fig. 2d). Recently, the area was subject to impacts by drilling for oil production, when more than 500m long artificial sediment tongues were constructed. There are two potential sources for terrestrial materials to marine environment: anthropogenic activities and sediment input from Wadis El-Esh.

## Materials and methods

In the year 2001, 133 samples were collected from the study areas (Fig. 2). Surface sediment samples were collected by hand, grab sampler and Scuba diving. They include three different environmental zones: beach, intertidal zone and offshore zone down to 50m of water depth. Scuba diving was used in areas rich with corals where grab sampler failed to collect samples.

LOWRANCE X25 Instrument was used to record the depth and GPS (Magellan) was used to determine the coordinates. Submarine photographs were taken with a Sea & Sea Marine II camera. Temperature, salinity, dissolved oxygen (DO), pH, total dissolved salts (TDS), oxidation reduction potential (Eh) and specific conductivity (SPC) were measured at different depths using Hydrolab Instrument (Surveyor (4) 1997) during the sample collection (Tab. 1).

Granulometric analysis was carried out by mechanical wet sieving. Geochemical analysis was carried out on all sediment samples. It includes determination of total carbonate content, determination of organic matter by sequential weight loss at 550C° (Dean 1974; Flannery et al. 1982; Brenner & Binford 1988), determination of total phosphorus (American Public Health Association "APHA" 1995). The total digestion method was used to determine heavy metals according to Oregioni & Aston (1984). Concentrations of heavy metals (Fe, Mn, Zn, Cu, Pb, Ni, Co and Cd) were determined by AAS (Atomic

Tab. 1. Measured hydrographic parameters of water masses (Hydrolab Instrument Surveyor (4) 1997).

| Studied areas | | Depth (m) | Temp. oC | DO mg\L | Sal. o/oo | pH | ORP (Eh) | SPC ms\cm | TDS g\L |
|---|---|---|---|---|---|---|---|---|---|
| Quseir Harbour | Min. | 5 | 23.9 | 7.0 | 40.8 | 7.7 | 346.0 | 60.9 | 39.1 |
| | Max. | 40 | 24.9 | 7.5 | 41.3 | 8.8 | 378.5 | 61.5 | 39.5 |
| | Avg. | 23 | 24.4 | 7.2 | 41.1 | 8.2 | 366.7 | 61.3 | 39.3 |
| Safaga Harbour | Min. | 5 | 25.1 | 6.3 | 41.1 | 8.2 | 388.0 | 61.2 | 39.2 |
| | Max. | 40 | 26.3 | 6.5 | 41.4 | 8.4 | 409.7 | 61.6 | 39.5 |
| | Avg. | 23 | 25.8 | 6.4 | 41.3 | 8.3 | 395.5 | 61.4 | 39.3 |
| Hurghada Harbour | Min. | 5 | 26.2 | 5.6 | 41.7 | 8.0 | 384.0 | 62.0 | 39.7 |
| | Max. | 50 | 28.9 | 6.9 | 42.3 | 8.8 | 399.0 | 62.9 | 40.1 |
| | Avg. | 26 | 28.2 | 6.3 | 42.0 | 8.3 | 391.7 | 62.4 | 39.9 |
| El-Esh area | Min. | 26 | 28.2 | 6.3 | 42.0 | 8.3 | 391.7 | 62.4 | 39.9 |
| | Max. | 50 | 28.9 | 6.9 | 42.3 | 8.8 | 399.0 | 62.9 | 40.1 |
| | Avg. | 38 | 28.5 | 6.6 | 42.2 | 8.6 | 395.3 | 62.6 | 40.0 |

Absorption Spectrophotometery) (GBC–932 ver. 1.1) with detection limits of 0.01 ppm at the National Institute of Oceanography and Fisheries, Red Sea Branch. Results are given in ppm.

## Results and discussion

### Nature of sediments and grain size

The beach sediments in Quseir Harbour are coarse sands, mainly of terrigenous origin. The tidal flat is very narrow and extends smoothly and slopes gently seaward. The sediments covering the bottom topography of this area are fine sand to sandy mud (Fig. 3a). Most sediment samples have brown color, which is due to phosphate shipment operations.

Shoreward, Safaga Harbour is skirted by high basement mountains. The beach sediments are generally coarse sands mixed with common rock-forming detritus from the surrounding strata. The sediments covering the intertidal zone are fine to very fine sands and rich in terrigenous constituents. On the other hand, bottom deposits of Safaga Harbour are mud to sandy mud (Fig. 3b). This area is influenced by phosphate shipment; packing of cement and other activities enter this harbour.

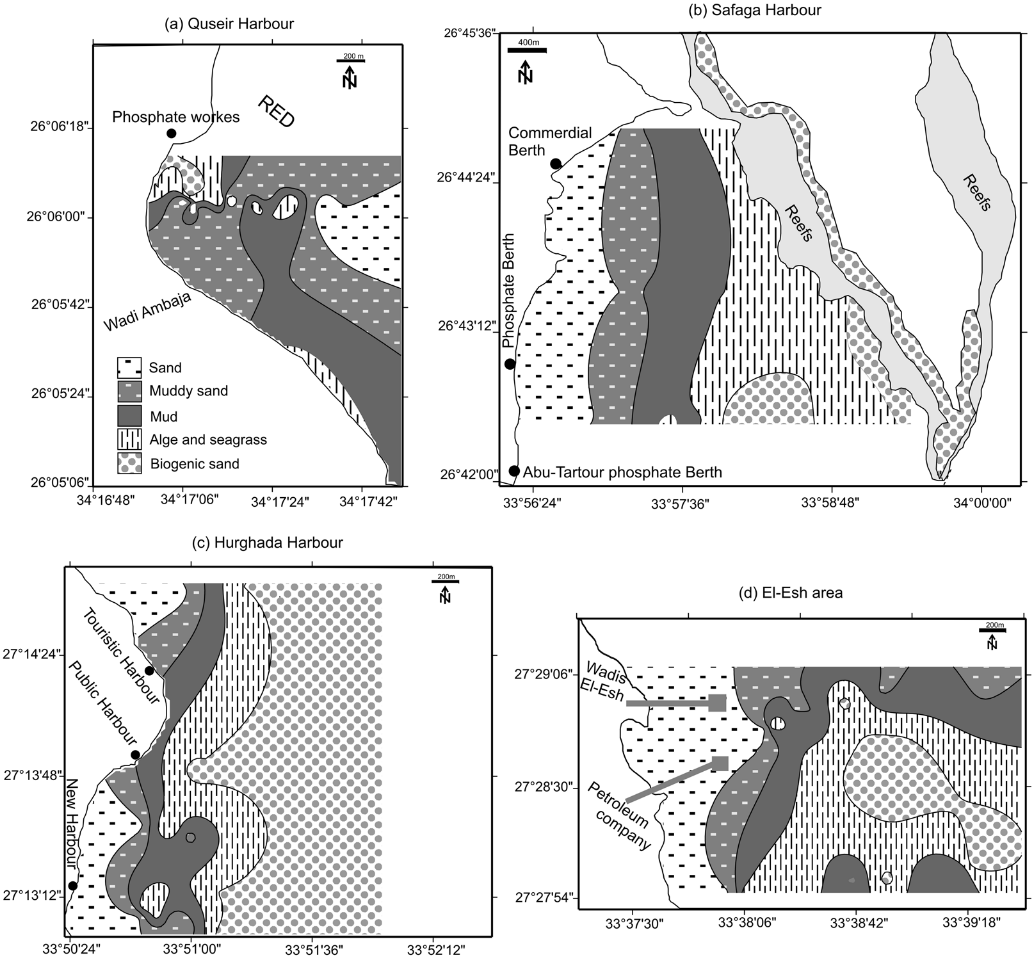


Fig. 3. Bottom facies maps of the Harbours of (a) Quseir, (b) Safaga, (c) Hurghada and (d) El-Esh area.

The beach sediments of Hurghada Harbour are generally coarse sand, mixed with significant amounts of biogenic fragments. The intertidal zone is a rocky tidal flat covered by a thin layer of soft deposits, especially in the Public Harbour (Fig. 3c). This zone merges seawards to a lagoon-like structure at the fore-reef zone. Patch reefs and fringing reefs characterize the area in front of Hurghada Harbour. Along the intertidal zone are some patches of seagrass. Dense fleshy and coralline algae are abundant within the reefs. Gastropods, bivalves and crustaceans are observed in the area.

In the El-Esh area, in front of the shoreline, small sand dunes covered by some vegetation occur. These dunes separate between the shore zone and sabkha evaporates. The very gentle slope of this area creates a wide sabkha basin and a wider tidal flat of about

Tab. 2. Physical and geochemical properties and trace metal concentrations from the studied localities (* values = ppm; TOM = total organic matter).

| Variables | Quseir Harbour | | Safaga Harbour | | Hurghada Harbour | | El-Esh area | |
|---|---|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | Range | Mean | Range | Mean |
| Gravel % | 0.002 – 14.1 | 2.8 | 0.27 – 20.55 | 6.2 | 0.32 – 10.63 | 4.5 | 0.05 – 10.49 | 4.1 |
| Sand % | 59.7 – 98.8 | 85.0 | 35.16 – 90.75 | 68.8 | 59.54 – 94.30 | 84.9 | 44.07 – 95.94 | 79.2 |
| Mud % | 1.2 – 35.3 | 12.2 | 1.14 – 61.22 | 25.1 | 0.39 – 37.66 | 10.6 | 0.28 – 50.74 | 16.7 |
| Mz phi | 1.6 – 3.8 | 2.7 | 0.18 – 3.74 | 2.4 | 0.84 – 3.46 | 1.9 | 0.61 – 3.89 | 2.3 |
| CaCO3 % | 3.9 – 63.3 | 33.1 | 7.92 – 96.41 | 53.7 | 4.36 – 96.82 | 78.6 | 24.58 – 95.95 | 73.4 |
| TOM % | 0.9 – 5.9 | 2.1 | 0.79 – 5.4 | 3.4 | 0.97 – 4.3 | 3.0 | 1.05 – 6.6 | 3.2 |
| P* | 632 – 10974 | 6303 | 1200 – 9630 | 5125 | 830 – 3708 | 2472 | 232 – 4408 | 3170 |
| Fe % | 1.3 – 1.5 | 1.39 | 0.15 – 2.81 | 1.21 | 0.21 – 1.67 | 1.02 | 0.07 – 1.68 | 0.67 |
| Mn* | 41 – 1458 | 902 | 66.5 – 1747 | 1145 | 22.5 – 421.8 | 112 | 32.76 – 1557 | 153 |
| Zn* | 7.9 – 44 | 21.4 | 3.5 – 47.3 | 15.4 | 0.6 – 93.4 | 9.1 | 4.8 –114.7 | 14.5 |
| Cu* | 1.2 – 10 | 4.1 | 1.8 – 142.8 | 9.1 | 0.5 – 43.2 | 4.1 | 1.4 – 366 | 76.7 |
| Pb* | 0.2 – 27.5 | 10.5 | 0.5 – 118.7 | 21.6 | 3.1–128.9 | 19.5 | 0.03 – 187 | 11.3 |
| Ni* | 14.3 – 38.3 | 26.5 | 13.8 – 82.1 | 38.4 | 3.9 –16.9 | 8.9 | 1.2 – 33.4 | 9.8 |
| Co* | 1.5 – 10.9 | 5.7 | 0.5 – 13.6 | 6.8 | 0.9 – 11.1 | 4.0 | 0.6 – 26.7 | 3.6 |
| Cd* | 0.04 – 3.4 | 1.0 | 0.2 – 4.1 | 1.3 | 0.1 – 0.5 | 0.3 | 0.03 – 2.4 | 0.5 |

300 – 500 m. A prominent feature, which characterizes the seaward part of the tidal flat, is the presence of many seagrass patches and some coral reef patches (Fig. 3d).

The purpose of the grain size analysis of the sediments is not only to obtain a classification system for the sediments but also to understand the physical characteristics of these sediments and to reveal the relation and the influence of grain size, source material and depositional environment on the geochemistry of these sediments and concentrations of heavy metals. The areas under study receive sediments from two different sources: (1) siliciclastic-terrigenous sediment from the hinterland mountains and (2) biogenic carbonates from the sea. Generally, the particle size of the sediments change from coarse sand near the beach to fine sand with increasing distance from the beach towards the deeper water. Mean grain size (Mz) reveal a range from coarse sand to very fine sand. Sediments of Quseir Harbour vary from medium to very fine sand, while those of Safaga Harbour, Hurghada Harbour and El-Esh area change from coarse to very fine sand (Fig. 4). These results indicate that from the shore towards the open sea, mean grain size generally decreases and the sediments change from gravelly and coarse sand to muddy sands (Tab. 2).

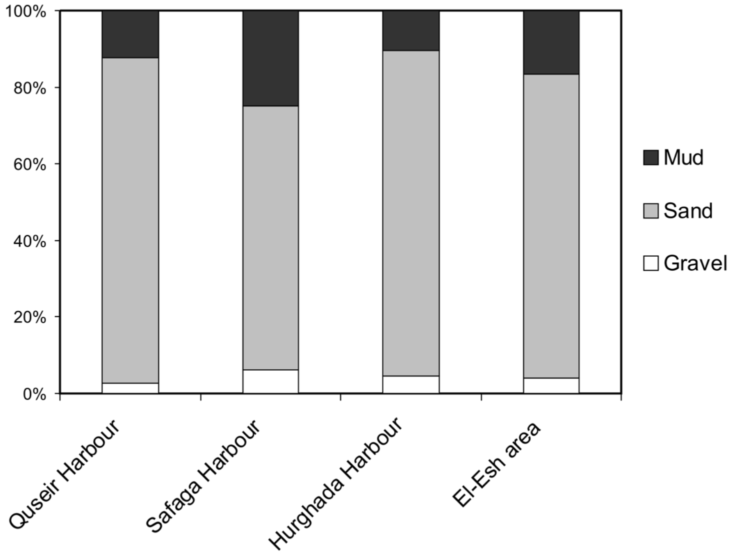


Fig. 4. Distribution of gravel, sand and mud fractions of coastal marine sediments of the studied localities.

## Geochemistry

### *Carbonate*

The total carbonate content in investigated sediments varies between 33.1 % at Quseir Harbour and 78.6 % at Hurghada Harbour (Tab. 2). The carbonate content in Quseir and Safaga Harbours is low due to the input of terrigenous material (Fig. 5). Hurghada Harbour and El-Esh area are rich in coral reefs and therefore reveal the highest carbonate content (Fig. 5).

### *Organic matter*

The average distribution of total organic matter varies from 2.1 % at Quseir Harbour to 3.4 % at Safaga Harbour (Fig. 5). The organic matter is mainly derived from the autolysis of dead cells or actively excreted by diverse organisms such as benthic algae, copepods, sea urchins and plankton (Kenneth 1988). Organic matter serves as a source of food for several animal. The variation in organic matter content of the sediments in the studied localities, especially beach samples, is mostly due to local contamination by hydrocarbons, (e.g. tar balls spilled onto the beach by waves). This is the main reason for their high content in El-Esh area and Hurghada Harbour (Fig. 5). Other factors for the high rate of organic matter are input from wadis, landfilling and dredging, and probably direct discharge of domestic waste and sewage from cities. Additionally, a high primary productivity and the abundance of seagrass and algae bottom facies are the main reasons for high organic matter content in El-Esh area and Quseir Harbour.

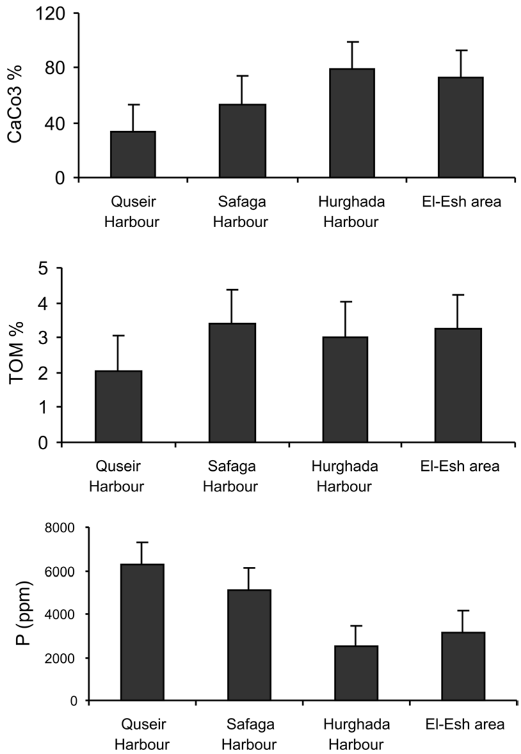


Fig. 5. Distribution of carbonate content, total organic matter, and phosphorus of coastal marine sediments of the studied localities.

*Total phosphorus*

The average total phosphorus of the sediments sampled in the study areas varies from 2472 ppm at Hurghada Harbour to 6303 ppm at Quseir Harbour (Tab. 2; Fig. 5). The highest phosphorus content was found in samples from Quseir and Safaga Harbours (Fig. 5). Abnormally high phosphorus values of these harbours were found near the phosphate-loading berth, which decrease with increasing distance from the berth. The results indicate that phosphate pollution is mainly localized in the vicinity of the loading berth, although its influence may be also detected in other areas along the coast. Moreover, phosphate loading operations at the Quseir and Safaga Harbours create immense clouds of dust, which settle in the adjacent areas. In addition, phosphate dust accelerates nutrient level, creating algal blooms in the tidal flat. Phosphate dust can cause water turbidity, which leads to a reduced light penetration and direct smoothing, and interference with feeding and respiratory processes.

*Heavy metals*

Iron is an essential element in the marine ecosystem and consequently one of the most abundant elements in marine sediments of the Red Sea. Quseir and Safaga Harbours reveal the maximum values of iron content (1.39 % and 1.21 %, resp.) (Fig. 5). The high concentration in these localities is due to human activities. The anthropogenic sources

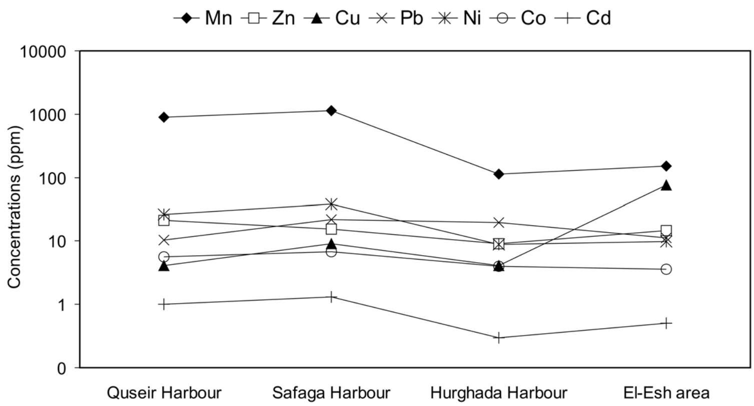


Fig. 6. Distribution of heavy metals in the coastal marine sediments of the studied localities.

of iron to the marine environment in these areas are: shipment of mineral products from phosphate mines in the Eastern Desert, paints of marine ships, corrosion of the marine constructions, landfilling and construction residuals, in addition to the terrestrial contribution of some wadis nearby these harbours. Also, cement and bauxite packing in Safaga Harbour contribute to the Fe content.

Manganese is an essential metal in the terrestrial sediments. The average contents of Mn range between 112 ppm at Hurghada Harbour and 1145 ppm at Safaga Harbour (Tab. 2). The sources of Mn in the marine environment of the Red Sea are the same as for Fe. Mn shows a negative correlation with the distance from the shoreline, except for Quseir Harbour, which reflects its detrital origin (Tab. 3).

Zinc plays an important role as an essential trace element in all living systems from bacteria to humans (Merian 1991). The average distribution of zinc concentrations in the studied localities ranges from 9 ppm at Hurghada Harbour to 21 ppm at Quseir Harbour (Fig. 6). Sediments from Quseir and Safaga Harbours show high zinc concentrations (Fig. 6). Beach and tidal flat sediments in Hurghada and El-Esh area also record high values (Fig. 6). The increased content of Zn in the beach and tidal flat sediments is attributed to phosphate shipment operations in Quseir and Safaga Harbours. Rock phosphate contains large amounts of Zinc and cadmium as impurities (McMurtry et al. 1995). Zinc is also abundant in volcanic and metamorphic rocks. Additionally, the main anthropogenic source of zinc includes zinc sulphate used in house construction, air-conditioning ducts, garbage cans, galvanized pipes, batteries and wear of automobile tires. High correlation coefficients occur between Zn and Pb for the sediments of Safaga Harbour (0.8), Hurghada Harbour (0.7) and El-Esh area (0.98), respectively. Also, the high correlation between Zn and Cu are 0.6, 0.6 and 0.97 for sediments of Harbours of Quseir, Safaga and Hurghada, respectively. However, there is no such relationship in the El-Esh area (Tab. 3).

Copper is an essential nutrient. Its concentration in the areas under study varies from 4 ppm at Hurghada Harbour to 76 ppm at the El-Esh area (Fig. 6). In the El-Esh area, sediments have the highest copper concentrations of the studied localities due to terrigenous influx (Fig. 6). Generally, Cu concentrations reveal a decreasing trend offshore. The incomparable copper contents of the source sediments at El-Esh area refers to the presence of some basic dykes. The beach and intertidal sediment samples record high values of copper contents in Quseir, Safaga and Hurghada Harbours (Fig. 6). The distribution of copper contents in these areas is attributed to the influence of terrigenous sediments. In addition, antifoulants used to paint hulls of boats can contain copper, which may be relevant considering the extensive boat traffic of tourist boats, especially in Safaga and Hurghada Harbours. The correlation coefficients between Cu and Pb are 0.35, 0.62 and 0.65 for the sediments of Harbours of Quseir, Safaga and Hurghada, respectively (Tab. 3). This indicates that these two anthropogenetic metals tend to accumulate under the same conditions.

The average distribution of Pb contents in the studied localities varies from 10 ppm at Quseir Harbour to 21 ppm at Safaga Harbour (Tab. 2). Harbours of Safaga and Hurghada have the highest values of Pb contents (Fig. 6). Anthropogenic activities in Safaga and Hurghada Harbours may represent the main sources for the high Pb contents. These include oil spills, motor boats, coal shipment in Safaga Harbour and untreated wastes. Despite the fact that oil production activities stopped some 20 years ago, there are still some indications of coastal oil pollution around Hurghada Harbour. In addition, the contribution of Pb from leaded petrol in outboard-boat engines may be significant, especially in Hurghada Harbour. The high levels of Pb in sediments from the harbours reflect the presence of polluting activities. These observations readily explain the large anomalies of Pb in the carbonate sediments. On the other hand, some samples of El-Esh area record high values of Pb (187 ppm) (Tab. 2). The El-Esh area represents an oil production area, suggesting that this is the main source of Pb in this area. Sediment samples from Quseir Harbour have the lowest values of Pb content. They vary from 0.1 ppm to 8 ppm, averaging 10 ppm (Fig. 6).

The average concentration of nickel in the investigated sediment ranges from 9 ppm at Hurghada Harbour to 38 ppm at Safaga Harbour (Tab. 2). Sediments from Harbours of Safaga and Quseir record the highest nickel content (Fig. 6). This may be attributed to shipment of phosphate-mine products, cement packing and other anthropogenic activities in Safaga and Quseir Harbours, in addition to a terrigenous influx from Wadi Ambaji in front of Quseir Harbour. Hurghada Harbour and El-Esh area reveal the lowest values of Ni concentrations relative to Quseir and Safaga Harbours (Fig. 6).

The average distribution of cobalt levels in marine sediments of the studied localities varies from 4 ppm at El-Esh area to 7 ppm at Safaga Harbour (Tab. 2). Cobalt levels have the highest values in the sediment samples of Quseir and Safaga Harbours compared with

**Quseir Harbour**

| | Gravel | Sand | Mud | Carb.% | TOM % | P* | Mn* | Zn* | Cu* | Pb* | Ni* | Co* | Cd* | Depth | D. Sh |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gravel | 1 | | | | | | | | | | | | | | |
| Sand | -0.7 | 1 | | | | | | | | | | | | | |
| Mud | 0.5 | -1.0 | 1 | | | | | | | | | | | | |
| Carb.% | 0.7 | -0.5 | 0.4 | 1 | | | | | | | | | | | |
| TOM % | 0.7 | -0.5 | 0.3 | 0.5 | 1 | | | | | | | | | | |
| P* | 0.6 | -0.6 | 0.4 | 0.8 | 0.5 | 1 | | | | | | | | | |
| Mn* | -0.3 | 0.0 | 0.2 | -0.7 | -0.3 | -0.7 | 1 | | | | | | | | |
| Zn* | 0.6 | -0.9 | 0.8 | 0.5 | 0.3 | 0.6 | 0.0 | 1 | | | | | | | |
| Cu* | 0.3 | -0.4 | 0.4 | 0.3 | 0.0 | 0.4 | -0.2 | 0.6 | 1 | | | | | | |
| Pb* | 0.3 | -0.1 | 0.0 | 0.5 | 0.2 | 0.6 | -0.7 | 0.3 | 0.3 | 1 | | | | | |
| Ni* | -0.3 | 0.2 | -0.1 | -0.8 | -0.3 | -0.7 | 0.7 | -0.1 | 0.0 | -0.5 | 1 | | | | |
| Co* | -0.4 | 0.3 | -0.2 | -0.5 | -0.2 | -0.5 | 0.5 | -0.2 | 0.0 | -0.3 | 0.5 | 1 | | | |
| Cd* | 0.7 | -0.7 | 0.6 | 0.8 | 0.4 | 0.7 | -0.3 | 0.8 | 0.5 | 0.3 | -0.5 | -0.2 | 1 | | |
| Depth | 0.2 | -0.6 | 0.7 | 0.3 | 0.1 | 0.4 | 0.1 | 0.6 | 0.2 | -0.1 | -0.2 | 0.0 | 0.5 | 1 | |
| D. Sh | -0.3 | 0.1 | 0.0 | -0.2 | -0.2 | -0.2 | 0.4 | -0.2 | -0.4 | -0.6 | 0.0 | 0.2 | -0.1 | 0.4 | 1 |

**Safaga Harbour**

| | Gravel | Sand | Mud | Carb.% | TOM % | P* | Mn* | Zn* | Cu* | Pb* | Ni* | Co* | Cd* | Depth | D. Sh |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gravel | 1 | | | | | | | | | | | | | | |
| Sand | -0.1 | 1 | | | | | | | | | | | | | |
| Mud | -0.3 | -0.9 | 1 | | | | | | | | | | | | |
| Carb.% | 0.1 | -0.2 | 0.1 | 1 | | | | | | | | | | | |
| TOM % | 0.2 | -0.6 | 0.5 | 0.7 | 1 | | | | | | | | | | |
| P* | -0.1 | 0.1 | -0.1 | 0.1 | 0.0 | 1 | | | | | | | | | |
| Mn* | 0.0 | -0.2 | 0.2 | -0.8 | -0.2 | 0.1 | 1 | | | | | | | | |
| Zn* | 0.2 | 0.1 | -0.1 | -0.5 | -0.2 | 0.2 | 0.6 | 1 | | | | | | | |
| Cu* | 0.4 | 0.1 | -0.2 | -0.3 | -0.2 | -0.2 | 0.2 | 0.6 | 1 | | | | | | |
| Pb* | 0.2 | 0.4 | -0.4 | -0.5 | -0.5 | 0.1 | 0.4 | 0.8 | 0.6 | 1 | | | | | |
| Ni* | 0.3 | -0.1 | 0.0 | -0.5 | 0.0 | 0.1 | 0.8 | 0.8 | 0.5 | 0.5 | 1 | | | | |
| Co* | 0.0 | -0.2 | 0.2 | -0.7 | -0.2 | 0.0 | 0.8 | 0.5 | 0.5 | 0.4 | 0.6 | 1 | | | |
| Cd* | 0.2 | 0.4 | -0.4 | -0.7 | -0.8 | 0.0 | 0.3 | 0.3 | 0.4 | 0.4 | 0.2 | 0.4 | 1 | | |
| Depth | 0.0 | -0.6 | 0.6 | 0.6 | 0.8 | -0.1 | -0.1 | -0.4 | -0.3 | -0.6 | -0.1 | -0.2 | -0.7 | 1 | |
| D. Sh | -0.2 | 0.1 | 0.0 | 0.6 | 0.4 | -0.2 | -0.6 | -0.5 | -0.2 | -0.4 | -0.5 | -0.5 | -0.5 | 0.3 | 1 |

**Hurghada Harbour**

| | Gravel | Sand | Mud | Carb.% | TOM % | P* | Mn* | Zn* | Cu* | Pb* | Ni* | Co* | Cd* | Depth | D. Sh |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gravel | 1 | | | | | | | | | | | | | | |
| Sand | 0.4 | 1 | | | | | | | | | | | | | |
| Mud | -0.6 | -1.0 | 1 | | | | | | | | | | | | |
| Carb.% | 0.2 | -0.1 | 0.1 | 1 | | | | | | | | | | | |
| TOM % | -0.1 | -0.5 | 0.5 | 0.8 | 1 | | | | | | | | | | |
| P* | -0.2 | -0.2 | 0.2 | 0.3 | 0.3 | 1 | | | | | | | | | |
| Mn* | -0.4 | -0.1 | 0.2 | -0.9 | -0.5 | -0.1 | 1 | | | | | | | | |
| Zn* | -0.2 | 0.0 | 0.1 | -0.4 | -0.1 | -0.4 | 0.4 | 1 | | | | | | | |
| Cu* | -0.2 | 0.0 | 0.0 | -0.4 | -0.2 | -0.5 | 0.4 | 1.0 | 1 | | | | | | |
| Pb* | -0.3 | 0.0 | 0.0 | -0.3 | -0.1 | -0.5 | 0.3 | 0.7 | 0.6 | 1 | | | | | |
| Ni* | 0.1 | 0.3 | -0.3 | -0.2 | -0.3 | 0.0 | 0.1 | -0.2 | -0.1 | -0.2 | 1 | | | | |
| Co* | 0.0 | -0.2 | 0.2 | 0.1 | 0.2 | 0.2 | 0.0 | -0.2 | -0.1 | -0.2 | 0.2 | 1 | | | |
| Cd* | 0.1 | -0.2 | 0.1 | 0.1 | 0.1 | -0.1 | -0.2 | -0.1 | -0.1 | -0.1 | 0.2 | -0.2 | 1 | | |
| Depth | -0.2 | -0.6 | 0.6 | 0.2 | 0.3 | 0.3 | 0.0 | -0.2 | -0.2 | -0.3 | 0.1 | 0.3 | 0.3 | 1 | |
| D. Sh | 0.2 | 0.0 | -0.1 | 0.5 | 0.3 | -0.1 | -0.6 | -0.3 | -0.2 | -0.3 | 0.4 | 0.3 | 0.3 | 0.0 | 1 |

**Elsh area**

| | Gravel | Sand | Mud | Carb.% | TOM % | P* | Mn* | Zn* | Cu* | Pb* | Ni* | Co* | Cd* | Depth | D. Sh |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gravel | 1 | | | | | | | | | | | | | | |
| Sand | -0.3 | 1 | | | | | | | | | | | | | |
| Mud | 0.1 | -1.0 | 1 | | | | | | | | | | | | |
| Carb.% | 0.2 | -0.1 | 0.1 | 1 | | | | | | | | | | | |
| TOM % | 0.4 | -0.3 | 0.3 | 0.6 | 1 | | | | | | | | | | |
| P* | -0.4 | 0.0 | 0.1 | 0.1 | -0.4 | 1 | | | | | | | | | |
| Mn* | 0.2 | 0.0 | 0.0 | -0.6 | 0.2 | -0.6 | 1 | | | | | | | | |
| Zn* | 0.3 | -0.1 | 0.0 | -0.4 | 0.4 | -0.6 | 0.9 | 1 | | | | | | | |
| Cu* | 0.1 | 0.2 | -0.3 | -0.2 | -0.3 | 0.2 | 0.0 | 0.0 | 1 | | | | | | |
| Pb* | 0.3 | -0.1 | 0.0 | -0.3 | 0.4 | -0.7 | 1.0 | 1.0 | -0.1 | 1 | | | | | |
| Ni* | -0.2 | 0.1 | -0.1 | -0.4 | -0.2 | 0.1 | 0.3 | 0.3 | 0.3 | 0.2 | 1 | | | | |
| Co* | -0.1 | 0.2 | -0.2 | -0.4 | -0.5 | 0.1 | 0.1 | 0.0 | 0.0 | -0.1 | 0.6 | 1 | | | |
| Cd* | -0.1 | 0.2 | -0.2 | -0.8 | -0.7 | 0.2 | 0.2 | 0.1 | 0.3 | 0.0 | 0.4 | 0.6 | 1 | | |
| Depth | 0.2 | -0.3 | 0.3 | 0.5 | 0.3 | 0.1 | -0.3 | -0.1 | -0.4 | -0.1 | -0.3 | -0.2 | -0.4 | 1 | |
| D. Sh | 0.1 | -0.1 | 0.1 | 0.7 | 0.4 | 0.1 | -0.4 | -0.2 | -0.3 | -0.2 | -0.2 | -0.2 | -0.6 | 0.8 | 1 |

◄ Tab. 3. Correlation coefficient between geochemical analysis, heavy metals, depth and distance from the shore line (Carb.% = Carbonate content, TOM = total organic matter, P = Phosphorous, D.Sh = distance from shore line, * values = ppm).

Hurghada Harbour and El-Esh area (Fig. 6). DE CARLO & SPENCER (1995) illustrated that Co concentrations between 50 and 80 ppm may be representative of the amount of natural Co associated primarily with the readily solubilized mineral assemblage of the sediments. MANSOUR (1999) stated that Co and Ni are principally derived from ultramafic rocks.

The average concentrations of cadmium in the studied sediments range between 0.3 ppm at Hurghada Harbour and 1.3 ppm at Safaga Harbour (Tab. 2). Safaga and Quseir Harbours recorded relatively high cadmium concentrations (Fig. 6), while Hurghada Harbour and El-Esh area recorded the lowest values of Cd compared with the other studied localities (Fig. 8). Cadmium is closely associated with zinc, where rock phosphates contain large amounts of Cd and Zn as impurities (MCMURTRY et al. 1995). Our results may suggest an anthropogenic input of Cd directly into these harbours. The most likely sources are industrial wastewaters, phosphate shipment and sewage. The cadmium concentration in the sediments of Safaga Harbour also reflect increased automotive traffic entering the harbour. Moreover, amounts of cadmium accumulate in the deposits by contaminated materials, i.e. by coal packing, in Safaga Harbour.

When comparing the current study with data published in previous papers, it is evident that heavy metal concentrations differ from place to place (Tab. 4). Metal content ratios depend on the source type. For example, Cu concentrations are very high in the El-Esh area, while Cd concentrations are highest in Quseir and Safaga Harbour. This is contrary to most previous studies, where the origin of Cadmium is chiefly non-lithogenic (e.g., EL-RAYIS et al. 1986). Approximately one-half to two-thirds of the Zn is of anthropogenic origin, whereas for Cd the value may exceed 90 % (DE CARLO & SPENCER 1995). Generally, the behaviour of heavy metals in the studied marine sediments is complex due to anthropogenic inputs and geographic variations in the terrigenous fluxes by wadis.

*Trace metals clusters*

Trace metals clusters include the contaminant metals Cd, Co, Ni, Zn, Pb and Cu. Samples are classified into five main clusters (Fig. 7; Tab. 5).

Cluster 1 contains 47 samples (35.34 % of the total samples) and is characterized by concentrations of Ni (X= 10.88 ppm, S= 5.29 ppm) Pb (X= 9.28 ppm, S= 7.75 ppm) and Zn (X= 7.83 ppm, S= 5.78 ppm). This cluster represents the lowest concentration of contaminants. Samples derive from Harbours of Hurghada, Quseir, Safaga and the El-Esh area (Figs 8a and 8d). About 55 % of these samples are from to Hurghada Harbour (Fig. 8c).

Cluster 2 includes 53 samples (39.85 % of the total samples) with high contents of Ni (X= 34.5 ppm, S= 9.8 ppm); Zn (X= 18.98 ppm, S= 8.52 ppm); Cd (X= 1.15 ppm, S= 1.09 ppm) and Pb (X= 10.53 ppm, S= 7.84 ppm). Most samples of this cluster derive from Quseir and Safaga Harbours (Figs 8a and 8b). These high concentrations of Ni, Zn,

Tab. 4. Comparison of metal concentrations (in ppm) in marine sediments between the current work and other studies from the Egyptian Red Sea coast (Nd: not detected).

| Trace metals | | Other studies of the Egyptian Red Sea coast | | | | | | | The present work | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mansour (1999) Sharm Abu Makhadeg | Mansour et al. (2000b) Red Sea coast | Dar (2002) Hurghada area | Madkour (2005) Wadi El-Gemal | Mohammed et al. (2005) coastal lagoons | Madkou et al. (2006) Hamrawein Harbour | Madkour & Dar (2007) Hurgada Shipyard | Quseir Harbour | Safaga Harbour | Hurghada Harbour | El-Esh area |
| Zn | range | 29.6–104 | 13.6–73.5 | 8.8 – 245 | 18.2–283.0 | 2.56 – 10.13 | 23–174 | 77.2 – 349.6 | 7.9 – 44 | 3.5 47.3 | 0.6 – 93.4 | 4.8–114.7 |
| | avg. | 63.0 | 17.6 | ~~~~ | 79.10 | 5.50 | 73.0 | 179.9 | 21.4 | 15.4 | 9.1 | 14.5 |
| Cu | range | 18.7 – 65 | 11.7–57.8 | 2.5 – 95.3 | 5.2–453.6 | 0.16 – 1.63 | 10.2 – 32 | 34.2 – 1862.8 | 1.15 – 10 | 1.8–142.8 | 0.5 – 43.2 | 1.4–366 |
| | avg. | 40.0 | 14.0 | ~~~~ | 36.20 | 0.57 | 18.0 | 413.8 | 4.1 | 9.1 | 4.1 | 76.7 |
| Pb | range | 0.5 – 64 | 14.4 – 71 | 9.9–114.4 | 12.8–96.3 | 1.19 – 8.61 | 28 – 66 | 27.5 – 206.9 | 0.2–27.5 | 0.5–118.7 | 3.1–128.9 | 0.03–187 |
| | avg. | 39.6 | 19.8 | | 41.70 | 4.29 | 39.0 | 110.0 | 10.5 | 21.6 | 19.5 | 11.3 |
| Ni | range | 26 – 44.2 | 4.6 – 57.8 | 9.9–613.1 | 11.2–156.3 | ~~~~ | 25 – 53 | Nd – 37.5 | 14.3–38.3 | 13.8–82.1 | 3.9–16.9 | 1.2 – 33.4 |
| | avg. | 34.0 | 23.5 | ~~~~ | 51.40 | ~~~~ | 42.0 | 6.4 | 26.5 | 38.4 | 8.9 | 9.8 |
| Co | range | 1.9 – 10.8 | 4.7 – 18.9 | 0.99–12.8 | 0.2–3.9 | ~~~~ | ~~~~ | ~~~~ | 1.5–10.9 | 0.5 – 13.6 | 0.9 – 11.1 | 0.6 – 26.7 |
| | avg. | 7.0 | 9.6 | ~~~~ | 1.80 | ~~~~ | ~~~~ | ~~~~ | 5.7 | 6.8 | 4.0 | 3.6 |
| Cd | range | 0.3 – 1.3 | 0.1 – 1.71 | 1 – 5.25 | 0.02–0.16 | 0.295 – 3.685 | 1.7 – 3.7 | 1.4 – 3.7 | 0.04–3.4 | 0.2 – 4.1 | 0.1 – 0.5 | 0.03–2.4 |
| | avg. | 0.9 | 1.0 | ~~~~ | 0.08 | 0.70 | 2.3 | 2.1 | 1.0 | 1.3 | 0.3 | 0.5 |

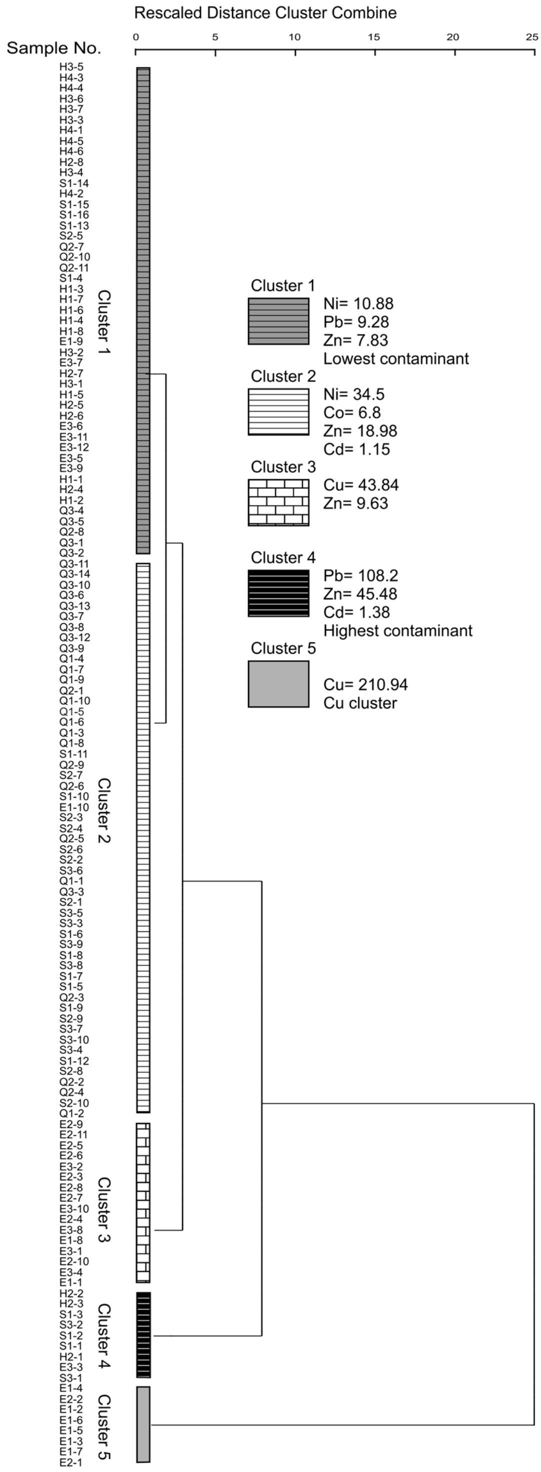


Fig. 7. Dendrogram from cluster analysis (Ward's method) of trace metals of sediment samples throughaout the studied localities (compare Fig. 2).

Cd and Pb in Quseir and Safaga Harbours are probably related to phosphate shipment. Rock phosphate contains large amounts of Cd, Zn, Ni, Pb and Co and should be considered in metal transport assessments, ecosystem studies and environmental assessments (Kpomblekuo & Tabatabi 1994). Industrial wastewaters and sewage, in addition to automotive traffics in Harbour of Safaga, are other reasons for increasing rates of contamination. Moreover, the increase of these metals in the beach and tidal flat sediments reflect the influx of terrigenous fragments rich in these metals, which are principally derived from volcanic and metamorphic rocks.

The 16 samples of cluster 3 are separated by moderate to high concentrations of Cu (X= 43.84 ppm, S= 11.42 ppm) and Zn (X= 9.63 ppm, S= 4.13 ppm). Samples of this cluster are restricted to El-Esh area (Fig. 8d). This reflects the terrigenous source from the hinterland areas.

Cluster 4 consists of 9 samples (6.77 % of the total samples) and is characterized by the highest values of Pb (X= 108 ppm, S= 36.99 ppm), Zn (X= 45.48 ppm, S= 35.18 ppm), Cd (X= 1.38 ppm, S= 1.49 ppm) and Ni (X= 34.85 ppm, S= 28.24 ppm). Most samples of this cluster are from Safaga and Hurghada Harbours (Figs 8a and 8b). The high concentration of Pb is due to several anthropogenic inputs which include motor boats, coal and cement packing in Safaga Harbour, untreated waste, oil pollution around Hurghada Harbour, antifoulants used to paint hulls of boats. The high concentration of nickel may be attributed to the presence of shipment of phosphate mines in Safaga Harbour. Generally, the Cd concentration in the marine sediments of this cluster reflects clearly anthropogenic inputs of Cd contained materials of Safaga and Hurghada Harbours.

Cluster 5 includes 8 samples (6.02 % of the total samples) and is characterized by very high concentrations of Cu (X= 210.94 ppm, S= 88.9 ppm). All samples fall in El-Esh area where sediment samples are very rich in copper content compared to the other studied localities (Fig. 8d). This is attributed to the strong effect of terrigenous sediments rich in copper from El-Esh area. However, the copper concentrations follow a decreasing offshore-trend.

## Conclusions and recommendations

Sediments sampled in Quseir and Safaga Harbours have the highest values of iron and manganese content compared with Hurghada Harbour and El-Esh area. This is attributed to the high input of terrigenous fragments including mafic minerals and the packing of cement in Safaga Harbour.

Harbours of Quseir and Safga also record the highest values of Zn, Ni, Co and Cd when compared with Hurghada Harbour and El-Esh area. The high concentrations of these metals may be caused by anthropogenic activities. The main factor is phosphate and bauxite shipment in Safaga and Quseir Harbours. The second factor is sediment input of terrestrial materials from wadis.

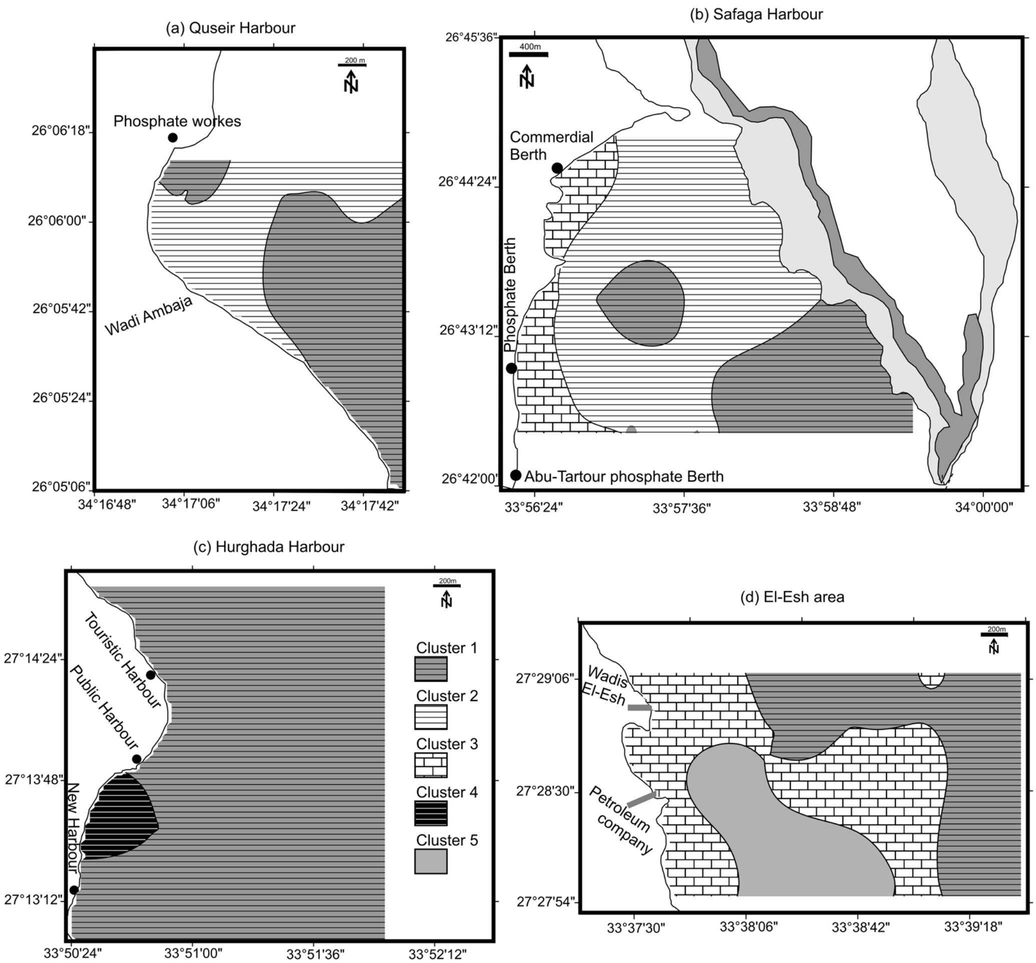


Fig. 8. Distribution of clusters according to trace metals of Harbours of (a) Quseir, (b) Safaga, (c) Hurghada and (d) El-Esh area.

Highest levels of lead occur in sediments of Safaga and Hurghada Harbours. A number of anthropogenic activities, including oil spills, motor boats, coal shipment in Safaga Harbour and untreated wastes, are the main reasonable sources for the high concentrations. These observations readily explain the large Pb anomalies in the carbonate sediments.

In El-Esh area, sediments reveal the highest copper concentrations of the studied localities. The copper derives from terrigenous sediment input from the hinterland.

Marine sediments are widely known as a significant and important archive of geochemical information. The analysis of marine sediments of the studied localities provides investigators with data to characterize the degree of anthropogenic influence and may allow for the identification of particular pollution sources.

Tab. 5. The trace metals of the clusters computed by cluster analysis (Ward's method) based on 6 variables of trace metals (* values = ppm, S = standard deviation, Min. = minimum, Max. = maximum, X = average).

| | Cd* | Co* | Ni* | Zn* | Pb* | Cu* |
|---|---|---|---|---|---|---|
| Cluster 1 (47 samples) | | | | | | |
| S | 0.5 | 2.1 | 5.3 | 5.8 | 7.8 | 4.6 |
| Min | 0.1 | 0.5 | 2.3 | 0.6 | 1.4 | 0.5 |
| Max | 3.5 | 11.1 | 24.7 | 26.1 | 35.5 | 21.3 |
| X | 0.5 | 3.8 | 10.9 | 7.8 | 9.3 | 4.2 |
| Cluster 2 (53 samples) | | | | | | |
| S | 1.1 | 2.3 | 9.8 | 8.5 | 7.8 | 1.9 |
| Min | 0.0 | 1.5 | 18.5 | 8.0 | 0.2 | 1.2 |
| Max | 3.6 | 11.0 | 57.8 | 44.1 | 37.1 | 12.1 |
| X | 1.2 | 6.8 | 34.5 | 19.0 | 10.5 | 4.8 |
| Cluster 3 (16 samples) | | | | | | |
| S | 0.8 | 6.3 | 7.4 | 4.1 | 6.0 | 11.4 |
| Min | 0.0 | 0.6 | 1.2 | 4.8 | 0.0 | 28.4 |
| Max | 2.4 | 26.7 | 33.0 | 22.0 | 20.0 | 66.1 |
| X | 0.6 | 4.1 | 6.9 | 9.6 | 5.6 | 43.8 |
| Cluster 4 (9 samples) | | | | | | |
| S | 1.5 | 4.0 | 28.2 | 35.2 | 37.0 | 45.6 |
| Min | 0.3 | 0.6 | 6.0 | 12.3 | 61.5 | 4.0 |
| Max | 4.1 | 13.6 | 82.1 | 114.7 | 187.3 | 142.8 |
| X | 1.4 | 5.5 | 34.8 | 45.5 | 108.2 | 30.9 |
| Cluster 5 (8 samples) | | | | | | |
| S | 0.7 | 2.7 | 9.9 | 3.5 | 2.3 | 88.9 |
| Min | 0.1 | 0.6 | 6.0 | 6.8 | 0.0 | 114.1 |
| Max | 2.3 | 8.6 | 33.4 | 18.0 | 6.6 | 366.1 |
| X | 0.7 | 3.4 | 15.7 | 13.0 | 3.1 | 210.9 |

The gathered information can be useful for management and suitable development of the areas under study. In addition, it represents a database for future research. Further research and assessment of coral-reef related ecosystems in the Egyptian Red Sea are needed to ensure a sound basis for environmental and resource management. Therefore, studies in different fields are urgently needed to help managers identifying anthropogenic impacts, and better assessing the needs for remediation by detecting any changes, from the existing level expected with operation of future activity.

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