*IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)*
*e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 10, Issue 2 Ser. I (Mar. – Apr. 2022), PP 32-45*
*www.iosrjournals.org*

# Study of sedimentological and geochemical characteristics of marine sediments at Safaga Harbour, Red Sea coast, Egypt

Bakheit B. Assran[1,]*, Abbas M. Mansour[2], Hashem A. Madkour[3], and Rafaat M. El Attar[2]
[1]*Egyptian Environmental Affairs Agency, Egypt*
[2]*Geology Department, Faculty of Science, South Valley University, Egypt*
[3]*National institute of Oceanography and Fisheries, Red Sea Branch, Egypt*
**e-mail: pakeetassran@gmail.com*

***Abstract**: A total of twenty eight surface sediment samples were taken from Safaga Harbour area. Over 77.91% of the sediment texture in the area is constituted of sand. The gravel ranges between 0.00% and 32.32%, averaging 8.30%. Mud fraction ranges between 0.11% and 35.23%, with a 13.78% average. The high mud fraction content is due to dredging and landfilling in the harbour region, as well as the green petroleum coke unloading and shipping activities of phosphate ore. The mean size ranging from coarse sand to coarse silt, with an average of medium sand, suggesting that from shoreline and high topographic locations towards the open water, the sediment change from gravely and coarse sand to muddy sand and mud as the mean size increases. The sediments are mostly poorly sorted, negatively skewed, and mesokurtic in nature. The surface sediments are low in Calcium (Aver. 17.27%), Magnesium (Aver. 0.78%), Strontium (Aver. 0.08%), carbonate content (Aver. 41.14%), organic matter (Aver. 2.08%), total phosphorous (Aver. 757.60 ppm), and total nitrogen (Aver. 478.25 ppm). To determine possible relations between various variables, correlation matrix, cluster analysis, cumulative curve and C-M pattern have been implied. An arcGIS technique was also used to create spatial distribution maps of various variables.*

**Keywords:** *Marine sediments, Geochemical, Safaga, Red Sea, Egypt.*

---

Date of Submission: 10-04-2022 Date of Acceptance: 28-04-2022

---

## I. Introduction

Particle size is an essential feature of sedimentary materials that may tell much about their history and origins. The dynamical conditions of deposition and transport of the constituent particles of rocks are commonly derived from their size. The size distribution is also an essential feature for assessing the probable behaviour of granular material under gravitational or applied fluid forces and estimating the economic utility of bulk materials ranging from foundry sands to china clay [1]. Study of the geochemical characteristics of marine sediments is very important in order to explain their distribution and inter-relations to detect the effects of human activities in the marine environment and to identify and characterise impacted areas.

## II. Materials and Methods

***Study area***

Safaga Harbour is considered one of the oldest ports in the Red Sea, where its real activity began in 1911 with the export of phosphate ore. The harbour has been serving for a long time as a passenger port, as well as international trade. The harbour is a natural bay, located 60 km south of Hurghada, and is protected from the north and east by Safaga Island (Gazirat Safaga). It lies at latitudes 26º 44' 56''N to 26º 44' 35''N and longitudes 33º 57' 5.6''E to 33º 56' 36.7''E. In Safaga Harbour, phosphate ore shipments and cement packing were conducted, which had stopped for more than two decades. The southern part of Safaga Harbour area is used as a fishermen's port. Safaga Harbour receives alumina and green petroleum coke. The alumina is unloaded through a telescope shot, where the alumina is sucked and transported by two conveyor belts to the alumina silos, whereas the green petroleum coke is unloaded through ship cranes to big fixed funnels at the Egyptalum Company berth, where it is transported to the warehouse by conveyor belt.

***Field work***

Safaga Harbour area divided into three transects SH1, SH2, and SH3 from north to south (Fig. 1), 28 sediment samples were collected from these transects with a depth ranging from zero to 34m below sea level, and distributed along a distance of 3096m from the shoreline (Fig. 2). The samples were collected in October 2018, using an outboard-engine fibreglass boat. The samples gathered from the area represent four different environments: supratidal, beach, intertidal, and subtidal areas.

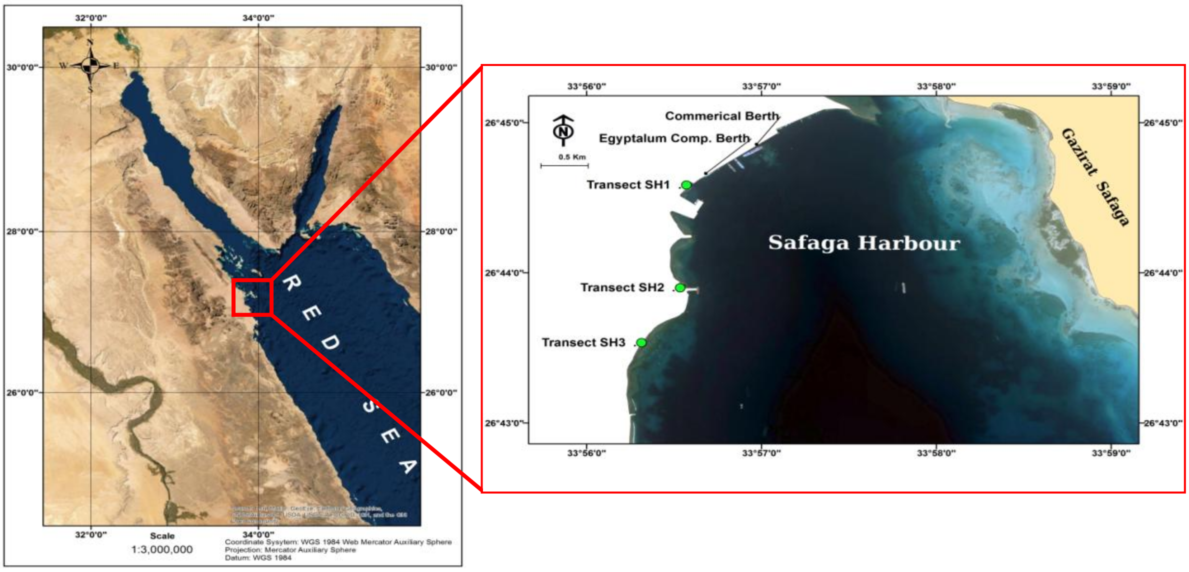


**Fig. 1:** Location map of the study area on the Red Sea coast, Egypt.

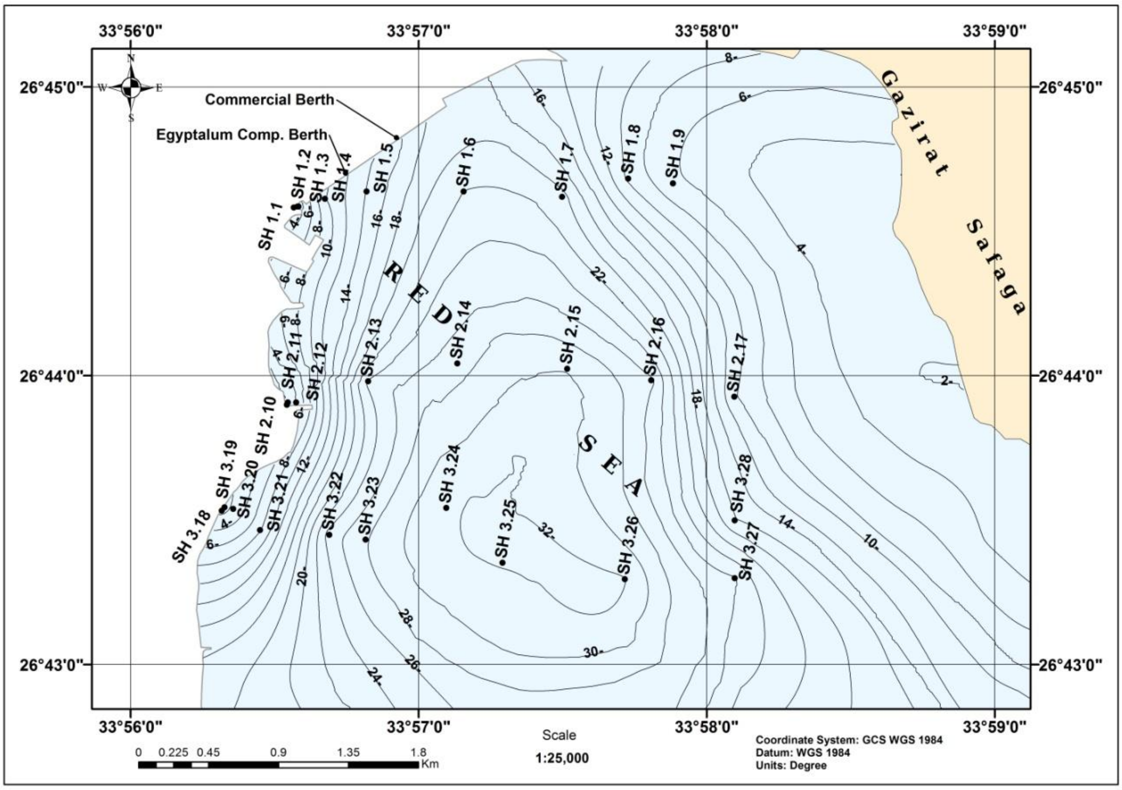


**Fig. 2:** Sample locations and bathymetric map of Safaga Harbour area.

***Laboratory methods and treatment of data***

The sediment samples had been gently washed with distilled water and spread out evenly on glass sheets to air-dry. Grain size analysis was performed on a series of sieves of different mesh sizes according to Folk and Ward [2]. Major metals in the sediments were determined according to Chester *et al.,* [3] to obtain the concentrations of Ca, Mg, and Sr by AAS (flame atomic absorption spectrophotometry) fitted with a BGC-SR lamp for background correction (GBC-932 Ver. 1.1). One gram of each prepared sample was treated by 1N

HCL acid, filtered, and washed several times with distilled water, dried and reweighed in order to calculate the percentage of carbonate content of the sediments. Total organic matter content was obtained by the loss on ignition at 550°C [4, 5, and 6]. The total phosphorus content was measured using persulfate digestion method [7], the total nitrogen in sediments was detected using persulfate digestion [8]. The concentrations of both total phosphorus and nitrogen were measured by a double beam spectrophotometer.

## III. Results and Discussion

***Environmental conditions***

In the present work, the physical properties of marine water were measured at the same sediment sampling sites. The pH recorded relatively varied values, from neutral to weakly alkali, noting that the tidal areas at the different transects recorded the lowest values. The pH values ranged from 6.99 to 9.20, with an average of 8.52. The temperature values ranged from 27.59 ºC to 28.32 ºC, averaging 27.82 ºC. The surface water salinity recorded similar values, ranged from 40.94 to 41.90‰, averaging 41.22‰. Moreover, the conductivity ranged from 61.22 to 62.22 ms/cm, averaging 61.45 ms/cm, and the total dissolved solids (TDS) ranged from 30.58 to 30.79 ppt, with an average of 30.69 ppt. The oxidation reduction potential varied from 175.10 to 234.70, averaging 193.79. The dissolved oxygen ranged from 8.17 to 9.05 mg/l, averaging 8.65 mg/l.

***Bottom facies of study area***

The sediments covering the topography of the area stranded between the shoreline (west) and Gazirat Safaga (east) are grey sand at the shoreline area and biogenic sand at Gazirat Safaga, and what is in between is muddy sand to mud, with seagrass bottom close to Gazirat Safaga (Fig. 3).

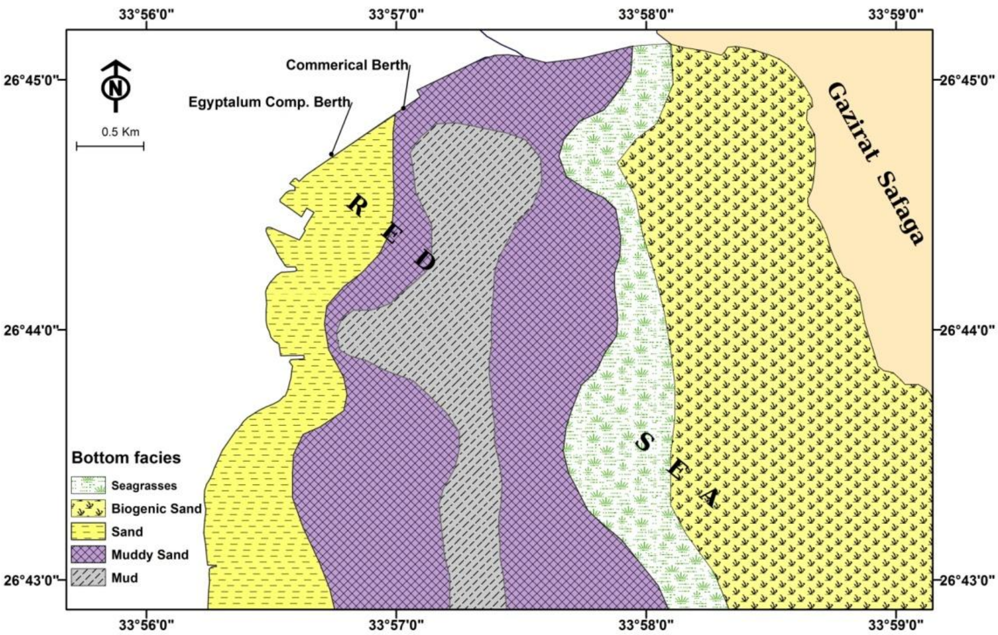


**Fig. 3:** A map showing the distribution of bottom facies at Safaga Harbour.

***Sediments texture of the area***

The investigated transects of Safaga Harbour are composed of over 77.91% sand fraction (Table 1). Gravel fraction varies from 0.00 to 32.32%, with an average of 8.30% (Table 1). Gravel fraction is dominant in the supratidal, beach and intertidal areas (except the intertidal area of transect SH3) and at the ends of transects. This is due to increase of terrigenous materials (pebbles) at the shoreline, in addition their locations close to Gazirat Safaga, which is rich in coral fragments, where gravel increases with decreasing water depth. Mud fraction varies from 0.11 to 35.23%, with an average of 13.78% (Table 1). The area recorded a high average value of mud fraction. The highest values of mud were recorded at the deepest parts of the area, where the mud fraction increases with increasing water depth (Fig. 4). The high content of mud fraction is related to landfilling and dredging in the harbour area, unloading of green petroleum coke and phosphate ore shipment.

**Table 1:** Sediment types, grain size parameters, water depth and distance from shoreline for all samples at Safaga Harbour.

| Sa. No. | Sediment type | | | Grain size parameters (Folks & Ward,1957) | | | | Depth (m) | D. Sh. (m) |
|---|---|---|---|---|---|---|---|---|---|
| | Gravel | Sand | Mud | Mz | $6_I$ | $Sk_I$ | $K_G$ | | |
| SH 1.1 | 12.573 | 85.634 | 1.793 | 0.72 | 0.99 | -0.46 | 1.23 | 0.0 | 0 |
| SH 1.2 | 13.416 | 86.475 | 0.109 | 0.43 | 0.98 | -0.34 | 1.04 | 0.0 | 0 |
| SH 1.3 | 20.291 | 76.507 | 3.202 | 0.43 | 1.44 | -0.08 | 1.10 | 0.5 | 20 |
| SH 1.4 | 0.312 | 79.688 | 20.000 | 3.00 | 1.69 | -0.25 | 0.96 | 14.0 | 39 |
| SH 1.5 | 0.000 | 97.561 | 2.439 | 1.49 | 0.66 | 0.51 | 1.89 | 14.0 | 244 |
| SH 1.6 | 0.000 | 67.223 | 32.777 | 3.69 | 1.87 | -0.02 | 1.96 | 23.0 | 803 |
| SH 1.7 | 0.136 | 69.820 | 30.044 | 3.31 | 1.85 | -0.15 | 0.99 | 23.0 | 1415 |

Cont. table 1:

| Sa. No. | Sediment type | | | Grain size parameters (Folks & Ward,1957) | | | | Depth (m) | D. Sh. (m) |
|---|---|---|---|---|---|---|---|---|---|
| | Gravel | Sand | Mud | Mz | $6_I$ | $Sk_I$ | $K_G$ | | |
| SH 1.8 | 5.404 | 81.504 | 13.092 | 2.65 | 1.87 | -0.42 | 1.06 | 7.0 | 1652 |
| SH 1.9 | 5.000 | 80.931 | 14.069 | 2.64 | 1.90 | -0.44 | 1.09 | 5.0 | 1943 |
| SH 2.10 | 15.157 | 83.057 | 1.786 | 0.61 | 1.34 | -0.26 | 1.28 | 0.0 | 0 |
| SH 2.11 | 32.322 | 67.504 | 0.174 | 0.12 | 1.10 | 0.09 | 0.53 | 0.0 | 0 |
| SH 2.12 | 19.788 | 72.949 | 7.263 | 1.23 | 2.10 | 0.13 | 1.06 | 0.7 | 47 |
| SH 2.13 | 0.158 | 68.656 | 31.186 | 3.30 | 2.21 | -0.15 | 0.97 | 30.0 | 550 |
| SH 2.14 | 0.098 | 69.299 | 30.603 | 3.23 | 2.25 | -0.20 | 0.97 | 26.0 | 1081 |
| SH 2.15 | 0.650 | 77.276 | 22.074 | 3.20 | 1.86 | -0.26 | 1.22 | 31.0 | 1714 |
| SH 2.16 | 1.113 | 81.061 | 17.826 | 3.00 | 1.71 | -0.35 | 1.12 | 30.0 | 2167 |
| SH 2.17 | 31.055 | 68.462 | 0.483 | 0.13 | 1.13 | 0.15 | 0.56 | 7.0 | 2570 |
| SH 3.18 | 15.677 | 79.493 | 4.830 | 0.67 | 1.47 | -0.23 | 1.24 | 0.0 | 0 |
| SH 3.19 | 22.703 | 77.168 | 0.129 | 0.36 | 1.12 | -0.34 | 0.59 | 0.0 | 0 |
| SH 3.20 | 0.000 | 64.771 | 35.229 | 4.19 | 1.38 | 0.28 | 2.09 | 1.5 | 49 |
| SH 3.21 | 10.749 | 87.826 | 1.425 | 0.81 | 1.38 | -0.15 | 1.42 | 6.0 | 267 |
| SH 3.22 | 0.373 | 72.583 | 27.045 | 3.12 | 2.25 | -0.17 | 0.98 | 30.0 | 685 |
| SH 3.23 | 0.000 | 81.848 | 18.152 | 2.59 | 1.87 | -0.31 | 0.96 | 28.0 | 907 |
| SH 3.24 | 0.000 | 81.745 | 18.254 | 2.97 | 1.74 | -0.30 | 0.94 | 32.0 | 1277 |
| SH 3.25 | 0.000 | 72.764 | 27.236 | 3.16 | 2.14 | -0.19 | 0.94 | 32.0 | 1760 |
| SH 3.26 | 0.157 | 83.843 | 16.000 | 2.78 | 1.67 | -0.38 | 0.95 | 34.0 | 2464 |
| SH 3.27 | 10.630 | 81.900 | 7.470 | 1.57 | 1.93 | 0.20 | 1.00 | 27.0 | 3096 |
| SH 3.28 | 14.741 | 83.991 | 1.267 | 0.41 | 1.36 | 0.00 | 1.04 | 13.0 | 2976 |
| Stdev | 10.024 | 7.679 | 12.067 | 1.31 | 0.43 | 0.24 | 0.36 | 13.2 | 1020 |
| Min | 0.00 | 64.77 | 0.11 | 0.12 | 0.66 | -0.46 | 0.53 | 0.0 | 0 |
| Max | 32.32 | 97.56 | 35.23 | 4.19 | 2.25 | 0.51 | 2.09 | 34.0 | 3096 |
| Avg. | 8.30 | 77.91 | 13.78 | 1.99 | 1.62 | -0.15 | 1.11 | 14.8 | 990 |

Mz = mean size $6_I$ = sorting $SK_I$ = skewness $K_G$ = kurtosis D.Sh = distance from the shoreline Stdev = standard deviation Min. = minimum Max. = maximum Avg. = average

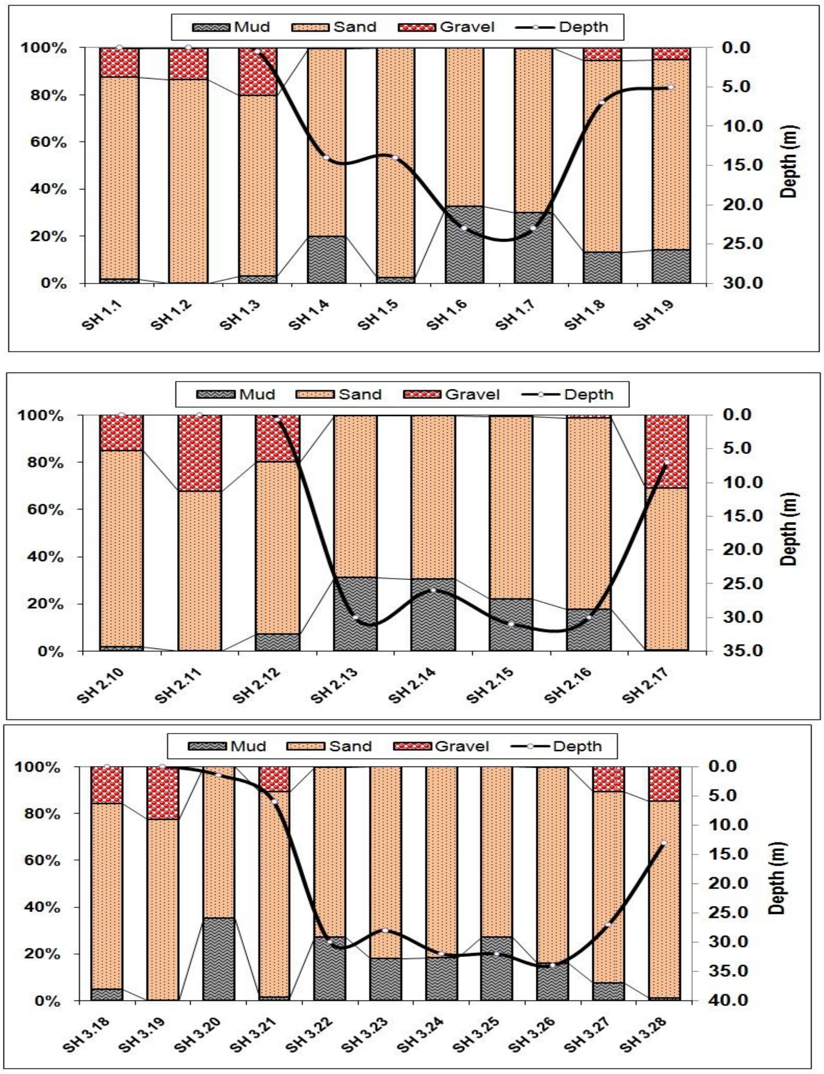


**Fig. 4:** Distribution of gravel, sand and mud fractions of the samples in different transects at Safaga Harbour.

***Distribution of grain size parameters***

The mean size (Mz) of Safaga Harbour sediments is ranging from 0.12 to 4.19Φ, with an average of 1.99Φ, indicating medium sand fraction (Table 1). 50% of the sediment samples of Safaga Harbour are within the fine-to-very fine category of the sand class, whereas 35% are within the coarse sand class. Sorting of the sediments is expressed by the inclusive graphic standard deviation (6/). It depends on four major factors [9]: a) the type of material supplied to the environment of deposition; b) the agent of deposition; c) the current characteristics; and d) the rate of supply. The marine sediments representing this area have a sorting (6/) ranging between 0.66 and 2.25Φ, with an average of 1.62Φ (Table 1), which means poorly sorted sediments. As illustrated in table 1, about 71% of sediment samples are poorly sorted, whereas 18% are very poorly sorted. Skewness measures the ratio of sorting in the extremes of distribution compared with the sorting at the center, and it is a quantitative measure used to describe the deviation of straight line from normality. The inclusive graphic skewness ($Sk_I$) of the sediments varies from -0.46 to 0.51Φ, averaging -0.15Φ, which means coarse skewed mode (Table 1). About 67.85% of the sediments from Safaga Harbour are within coarse skewed classes (coarse skewed and strongly coarse skewed), while 17.86% of sediment samples are within fine skewed classes (fine skewed and strongly fine skewed). The graphic kurtosis ($K_G$) of sediments sampled from Safaga Harbour ranges from 0.53 to 2.09Φ, averaging 1.11Φ (Table 1), indicating mesokurtic sediments. About 57.14% of the samples are mesokurtic and 32.15% are leptokurtic and very leptokurtic, while 10.71% of the sediments are very platykurtic.

The results of the mean size (Mz) of Safaga Harbour sediments range from coarse sand to coarse silt. These results, indicate that from the shore and high topographic areas towards the open sea, the mean size values generally increase and the sediments change from gravely and coarse sand to muddy sand and mud. The sorting vary from moderately and poorly sorted at the supratidal and beach areas to poorly and very poorly sorted towards the open sea with poorly sorted close to Gazirat Safaga. The skewness values of the investigated sediments indicate that from the shore towards the open sea, the skewness generally changed from strongly coarse to coarse skewness with a mixture of strongly coarse and fine skewness close to Gazirat Safaga. The majority of skewness results are negative, represented by strongly coarse and coarse skews. Also, the kurtosis ranged from very platykurtic to very leptokurtic. This variation in the character of sediments is related to the diversity of skeletal grains, current and wave actions, and clastic materials inputs.

The distribution of particle size in sediments is a function of the availability of different sizes of particles in the parent material and the processes operating where the particles were deposited [10]. The subtidal area of Safaga Harbour, which is located between the coastline and Gazirat Safaga, received amount of sediments resulting from the landfilling and dredging processes to construct the harbour, unloading of green petroleum coke, phosphate shipment and cement packing. In general, the sediments of this area show a gradual change in the particle size from coarse sand with moderately to poorly sorted, negative skewness and leptokurtic character at the supratidal and beach areas to a mixture of fine and very fine sand with poorly to very poorly sorted, negative skewness and mesokurtic to leptokurtic characters seaward with increasing depth and distance from the shoreline. At the end of transects, close to Gazirat Safaga, the particle size shows a mixture of fine, medium to coarse sand with poorly sorted, positive skewness and mesokurtic to platykurtic characters. The gradual change in the particle size is due to the weak wave action and currents that quarry out the fine sediments from the harbour area and deposit them in the subtidal zone. This is in addition to the abundance of biogenic constituents close to Gazirat Safaga that shelter the harbour area from strong wave and current actions, creating ideal conditions for the sedimentation process.

***Cluster analysis***

Cluster analysis (hierarchical cluster) was performed with the programme SPSS using Ward's method on all grain size data obtained by the sieving method (Table 2; Fig. 5) in order to obtain more objective results. Cluster analysis includes gravel, sand and mud separates all samples of the studied area into four main clusters according to the abundance of size fractions (Table 2; Fig. 5). The first cluster represents 28.57% of the total samples and is characterized by high sand (Avg. = 80.99%, STD = 1.90%), high mud (Avg. = 17.43%, STD = 2.97%) and low gravel (Avg. = 1.58%, STD = 2.27%) contents. The samples from this cluster fall in deep parts of Safaga Harbour area. In addition, some samples from SH1 transect close to the harbour berth. Cluster 2 represents 25.00% of the total samples and is characterized by the highest fraction of mud (Avg. = 30.59%, STD = 2.91%) and lowest amount of sand (Avg. = 69.30%, STD = 2.84%) and gravel (Avg. = 0.11%, STD = 0.13%) contents. Most samples from this cluster fall in the deepest areas. The high content of mud is due to the unloading of green petroleum coke and phosphate ore shipments. The third cluster represents 17.86% of the total samples and is characterized by the highest fraction of gravel (Avg. = 25.23%, STD = 6.01%), low sand content (Avg. = 72.52%, STD = 4.45%) and lowest mud content (Avg. = 2.25%, STD = 3.08%). The samples of this cluster are distributed at the beach, intertidal area and close to Gazirat Safaga. Cluster 4 represents 28.57% of the total samples and is characterized by the highest content of sand (Avg. = 85.74%, STD = 5.46%), high content of gravel (Avg. = 11.62%, STD = 5.07%) and low content of mud (Avg. = 2.64%, STD = 2.37%).

**Table 2:** Some statistical parameters of the main grain size categories of cluster computed by (Ward's method) cluster analysis.

| Fraction | Parameter | Cluster 1 | Cluster 2 | Cluster 3 | Cluster4 |
|---|---|---|---|---|---|
| Gravel | STD | 2.27 | 0.13 | 6.01 | 5.07 |
| | Min | 0.00 | 0.00 | 19.79 | 0.00 |
| | Max | 5.40 | 0.37 | 32.32 | 15.68 |
| | Avg. | 1.58 | 0.11 | 25.23 | 11.62 |
| Sand | STD | 1.90 | 2.84 | 4.45 | 5.46 |
| | Min | 77.28 | 64.77 | 67.50 | 79.49 |
| | Max | 83.84 | 72.76 | 77.17 | 97.56 |
| | Avg. | 80.99 | 69.30 | 72.52 | 85.74 |
| Mud | STD | 2.97 | 2.91 | 3.08 | 2.37 |
| | Min | 13.09 | 27.05 | 0.13 | 0.11 |
| | Max | 22.07 | 35.23 | 7.26 | 7.47 |
| | Avg. | 17.43 | 30.59 | 2.25 | 2.64 |

STD = standard deviation  Min. = minimum  Max. = maximum  Avg. = average

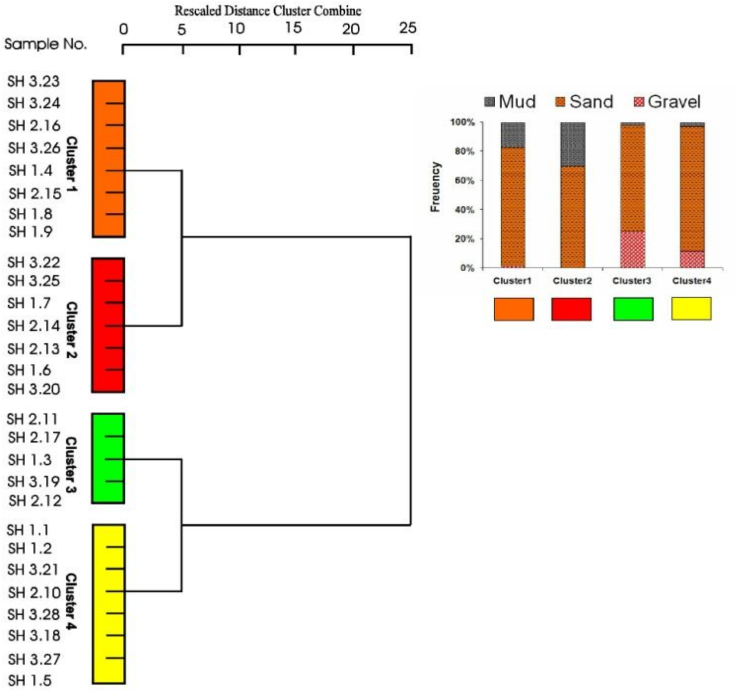


**Fig. 5:** Dendrogram of cluster analysis using Ward's method and histogram showing cluster of grain size texture.

***Relationships between size parameters and depositional environments***

In the sediments of Safaga Harbour, the correlation coefficient shows that gravel is highly negatively correlated with mean size (-0.88), mud (-0.77), depth (-0.70) and also negatively correlated with sorting (-0.51), while mud fraction has a very strong positive correlation with mean size (0.95), strong positive with sorting (0.71) and moderate positive with depth (0.64). Additionally, the mud has a moderate negative correlation with sand (-0.56). Also, as illustrated in table 3, the mean size is positively correlated with sorting (0.68) and depth (0.68). Sorting is positively correlated with depth (0.63).

Table (3). Correlation coefficient between sediment types, grain size parameters, water depth and distance from shoreline of Safaga Harbour sediments.

| | Gravel | Sand | Mud | Mz | Sorting | $Sk_I$ | $K_G$ | Depth | D. Sh. |
|---|---|---|---|---|---|---|---|---|---|
| Gravel | 1.00 | | | | | | | | |
| Sand | -0.09 | 1.00 | | | | | | | |
| Mud | **-0.77** | **-0.56** | 1.00 | | | | | | |
| Mz | **-0.88** | -0.35 | **0.95** | 1.00 | | | | | |
| Sorting | **-0.51** | -0.45 | **0.71** | **0.68** | 1.00 | | | | |
| SkI | 0.19 | -0.15 | -0.06 | -0.12 | -0.24 | 1.00 | | | |
| KG | -0.44 | 0.15 | 0.27 | 0.33 | -0.14 | 0.36 | 1.00 | | |
| Depth | **-0.70** | -0.09 | **0.64** | **0.68** | **0.63** | -0.11 | -0.07 | 1.00 | |
| D. Sh. | -0.17 | 0.03 | 0.12 | 0.20 | 0.31 | -0.03 | -0.25 | **0.54** | 1.00 |

***C-M pattern application***

According to Visher [11], there are three modes of transportation: suspension, saltation and surface creeping or rolling. The forces controlling the transportation and the grain size deposition in these populations are tidal currents, swash and backwash, wave action, fallout from suspension turbidity currents, longshore currents and transport by suspension. Application of the C-M pattern to the sediments of Safaga Harbour shows that the vast majority of samples (96.43%) fall in the classes I, II and IV, indicating uniform rolling transportation mode, and one sample represents 3.57% fall in the class VI, indicating the grade between rolling and suspension (Fig. 6).

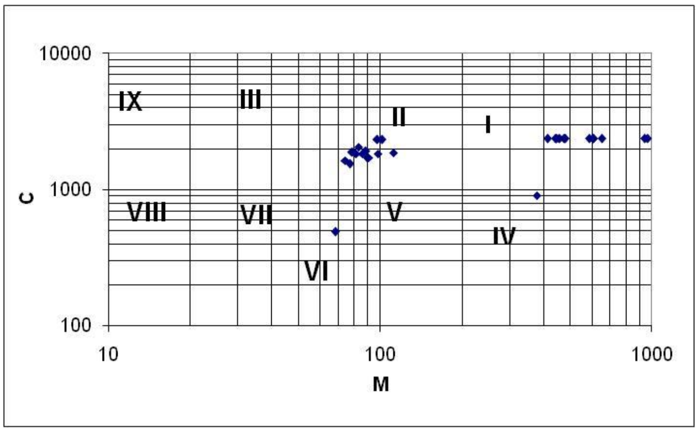


**Fig. 6:** C-M pattern of sediments of different transects at Safaga Harbour.

***Distribution of cumulative curve***

The cumulative curve gives a clear view of the variation of grain size of sediments and enables to study their environmental conditions. The curve illustrates three modes of transport; suspension, saltation and surface creep [11], which are represented by segments, each of which represents a mode of transportation. The mean cumulative curve of all sediment samples at Safaga Harbour indicates that the majority of samples (55.18%) show the saltation population of transportation. The rolling population is small (9.48%) compared to the suspension population (35.34%) (Fig. 7).

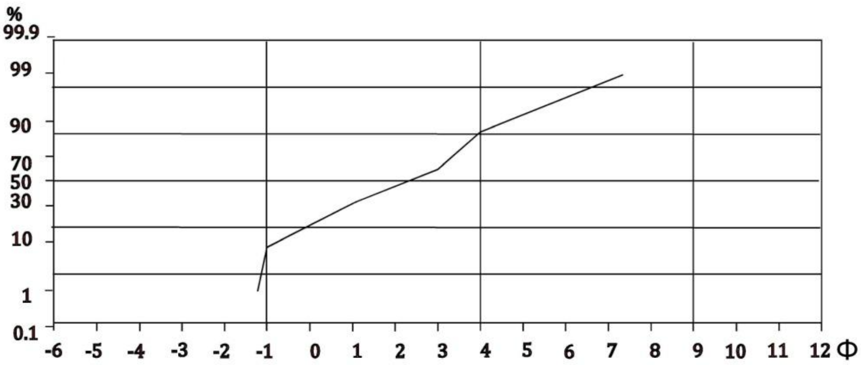


**Fig. 7:** Mean probability cumulative curve of sediments of Safaga Harbour.

***Geochemical characteristics of marine sediments***

***Calcium (Ca)***

In carbonate minerals, calcium and magnesium are the former categories. Madian [12] reported that calcium content is high in Hurghada Marina and Master Line area due to the biogenic origin, and it is low at Desert Rose and Magawish Petroleum Company due to the terrigenous sediments of the landfilling materials. In the present study, calcium content varied from 2.72% to 39.35%, averaging 17.27% (Table 4). The lowest values of calcium concentrations were recorded at transect SH1 due to the human impacts resulting from the activities of green petroleum coke unloading, phosphate shipment, and cement packing, in addition to landfilling and dredging operations in Safaga Harbour area. In contrast, the samples close to Gazirat Safaga recorded the highest values of calcium due to the abundance of biogenic fragments of coral reefs. The results of the correlation matrix (Table 5) showed that calcium is positively correlated with carbonate (0.96), strontium (0.78), magnesium (0.70), and distance from the shoreline (0.64).

***Magnesium (Mg)***

Both magnesium and calcium are in a delicate equilibrium, according to Irving [13], where small changes in alkalinity and carbon dioxide tension may cause precipitation. Biologically, they are two of the most significant elements, both in terms of quantity and specific effect. The magnesium content of the sediments of the studied area ranges from 0.18% to 2.12%, with an average of 0.78% (Table 4). The results of the correlation coefficient (Table 5) show that magnesium has a positive correlation with TOM (0.80), Ca (0.70), carbonate (0.67), distance from the shoreline (0.52), and Sr (0.51).

***Strontium (Sr)***

Strontium is derived from modern corals, which are carbonate-secreting organisms, and it entered the structure lattice of carbonate minerals [14]. The strontium content of the sediments in the area under study varies between 0.01% and 0.22%, averaging 0.08% (Table 4). The correlation coefficient shows that Sr is significantly positively correlated with Ca (0.78) and carbonate (0.74) (Table 5). This suggests a synchronised increase of Sr with carbonate and Ca, indicating that Sr is essentially cooperative with carbonate minerals. In addition, it has a positive relationship with distance from the shoreline (0.59) and Mg (0.51).

***Carbonates***

Several environmental parameters control carbonate deposition: temperature, light, sedimentation, salinity, pressure and water depth. Of these, the two most important parameters are temperature and water depth [15]. Maxwell [16], classified sediments based on carbonate content to high carbonate (>80%), impure carbonate (80 – 60%), transitional (60 – 40%), terrigenous (40 – 20%) and high terrigenous (<20%). According to this classification, terrigenous and high terrigenous carbonate sediments represent the largest proportion of sediments sampled at Safaga Harbour (Avg. 41.14%) (Table 4).

Sediment samples of Safaga Harbour have low carbonate content, varying from 8.14% to 88.87%, averaging 41.14% (Table 4). Furthermore, the supratidal, beach and intertidal samples are very terrigenous, terrigenous and transitional carbonates, which appear clearly at transect SH1 close to the harbour berth (Fig. 8), which has mostly very terrigenous and terrigenous carbonates. Fine sediments, mainly fine and very fine sand (mostly non-carbonates) are transported from the harbour area into the deeper parts close to the harbour, indicating terrigenous contamination resulting from the dredging and landfilling operations that occurred to construct the harbour, in addition to the fine particulates spread during green petroleum coke unloading operations on Egyptalum Company's berth at Safaga Harbour. On the other hand, from the spatial distribution of carbonates (Fig. 8), it is clear that the carbonate content increases in the samples close to Gazirat Safaga, where coral fragments are abundant, confirming the existence of two different sources of carbonates, one terrestrial and the other biogenic.

The correlation coefficient results (Table 5) show that the carbonate has a very strong positive correlation with Ca (0.96), a strong positive with Sr (0.74) and a moderate positive correlation with Mg (0.67) and distance from the shoreline (0.68).

Table 6 shows a comparison of the current findings with earlier studies conducted on the Egyptian Red Sea coast. The results demonstrate that the carbonate content recorded by Mansour *et al.*, [17] in Safaga Harbour, averaging 78.02%, is higher than those in the current work and also those recorded by Madkour [18] in Hurghada Harbour and El-Esh area (Avg. 78.6 and 73.4%, respectively). Mansour *et al.*, [19] recorded higher carbonate content in Hurghada area (Avg. 66.3) compared to those found in the current study. Comparable carbonate content was recorded in Qusier and Safaga harbours (Avg. 33.1 and 53.7%, respectively) studied by Madkour [18]. Also, a comparable value of carbonate content was recorded in Hamrawein Harbour with an average of 49% [20] compared to the current study area. Madkour [18] reported that the low carbonate content in Qusier and Safaga harbours indicates a terrigenous materials oversupply.

***Organic matter and Organic Carbon***

The quantity and nature of organic matter deposited are inexorably connected to the environmental conditions in which it is deposited. The total organic matter distribution along the studied area of Safaga Harbour ranges between 0.44% and 6.27%, with an average of 2.08%, and organic carbon content varies from 0.24% to 3.48%, averaging 1.16% (Table 4). The values of total organic matter and organic carbon in the present study are probably due to direct discharge of domestic waste and the organic productivity in some areas due to seagrass bottom facies. From the spatial distribution map of total organic matter (Fig. 9), it is noticed that the low contents of total organic matter are distributed close to the harbour berth and the shoreline. This is due to the contamination resulting from the crumbs falling under the berth of Egyptalum Company in Safaga Harbour during the unloading of green petroleum coke. Furthermore, the impact of phosphate shipment activities in the area.

The correlation coefficient results illustrate that the total organic matter has a significant positive correlation with Mg (0.80) and a weak positive correlation with carbonate (0.49), depth (0.45), Ca (0.43), and distance from the shoreline (0.37) (Table 5).

In comparison, the distribution of the organic matter content in the current study is lower than that recorded in Safaga Harbour (Avg. 4.89%) by Mansour *et al.*, [17], and it is also lower than that recorded in

Hurghada area (Avg. 5.25%) by Mansour *et al.*, [19]. Comparable values of organic matter content were recorded by Madkour [18] in Qusier Harbour, Safaga Harbour, Hurghada Harbour, and El-Esh area (2.0, 3.4, 3.0, and 3.2%, respectively), Madkour *et al.*, [20] in Hamrawein Harbour (Avg. 3.8%), and Youssef *et al.*, [21] in Makadi Bay (Avg. 3.04%) (Table 6).

***Total phosphorus***

Phosphorus (P) eutrophication has had a negative impact on several aquatic ecosystems worldwide [22]. Phosphorus eutrophication is described as the over enrichment of phosphorus to aquatic ecosystems, resulting in increased growth of algae blooms or water plants, anoxic episodes, and changes in biomass and species composition [23 and 24]. Madkour [18] stated that the high phosphorus values of Quseir and Safaga harbours were found near the phosphate-loading berths, which decrease with increasing distance from the berth. In the area under study, the total phosphorous concentrations vary between ND and 5379.52 ppm, averaging 757.60 ppm (Table 4), where the supratidal, beach and intertidal areas south of Safaga Harbour (Transects SH2 and SH3) recorded the highest values of total phosphorous concentrations in the studied area (Fig. 10). This is due to the impact of human activities that have been operating in Safaga Harbour region for more than two decades, such as phosphate shipment activities. The average value of total phosphorous (757.60 ppm) in Safaga Harbour is slightly higher than the threshold effect level (600 ppm) regulated by sediment quality guidelines [25].

In comparison (Table 6), the sediments of Safaga Harbour in the current study display a higher average concentration of total phosphorous than that recorded by Mansour *et al.*, [17] for the same area, where they declared that the average concentration of phosphate in Safaga Harbour is 129.00 ppm. On the other hand, Madkour [18] recorded values of total phosphorous in Qusier, Safaga, Hurghada harbours, and El-Esh area (6303.2, 5125.8, 2472.3, and 3170.3 ppm, respectively) higher than that in the current study. Moreover, Madkour *et al.*, [20] recorded an average concentration of total phosphorous in Hamrawein Harbour (5011 ppm) higher than that found in the current work. Total phosphorous shows a weak negative correlation with distance from the shoreline (-0.46) and depth (-0.44) (Table 5).

***Total Nitrogen***

An important parameter for the environmental status estimation of terrestrial and aquatic ecosystems is the total organic carbon (TOC) and total nitrogen (TN) content, in soils and sediments. There is a lack of data about total nitrogen in the sediments of the Red Sea coast, as it was not previously investigated by researchers in the region. Liang *et al.*, [26] stated that the total nitrogen content of the entire Duliujianhe River was 124.00 - 1948.44 mg/kg. They attributed that to the presence of organic pollution and inorganic nitrogen pollution along the river. Sediments from the southwestern Gulf of Mexico studied by Escobar-Briones and García-Villalobos [27] recorded an average total nitrogen concentration of 0.12 ± 0.03%. They stated that the higher values are associated with oil seepage in the abyssal plain. The total nitrogen in marine sediments of Safaga Harbour in the current work varies between ND and 1606.85 ppm, with an average of 478.25 ppm (Table 4). These values may be due to waste water discharge, either domestically or from boats. Total nitrogen has a weak positive correlation with mean size (0.34) and a weak negative correlation with gravel (-0.31) (Table 5).

**Table 4:** Major, minor and total organic matter constituents of marine sediments of Safaga Harbour.

| Sa. No. | Ca % | Mg % | Sr % | Carb. % | TOM % | O.C. % | TP* | TN* | Depth (m) | D. sh (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| SH 1.1 | 2.72 | 0.25 | 0.01 | 8.43 | 0.61 | 0.34 | 20.59 | 206.65 | 0 | 0 |
| SH 1.2 | 5.41 | 0.24 | 0.02 | 19.03 | 0.59 | 0.33 | ND | 557.58 | 0 | 0 |
| SH 1.3 | 3.26 | 0.46 | 0.03 | 9.65 | 1.13 | 0.63 | 25.63 | 104.61 | 0.5 | 20 |
| SH 1.4 | 6.85 | 0.36 | 0.02 | 17.76 | 2.15 | 1.19 | 35.89 | 375.07 | 14 | 39 |
| SH 1.5 | 5.60 | 0.40 | 0.03 | 8.14 | 0.98 | 0.55 | ND | ND | 14 | 244 |
| SH 1.6 | 7.20 | 0.35 | 0.02 | 27.62 | 0.87 | 0.48 | 62.93 | 258.85 | 23 | 803 |
| SH 1.7 | 8.80 | 0.60 | 0.03 | 24.45 | 1.75 | 0.97 | 6.76 | 176.99 | 23 | 1415 |
| SH 1.8 | 15.85 | 0.47 | 0.05 | 38.13 | 1.18 | 0.65 | 10.66 | 720.22 | 7 | 1652 |
| SH 1.9 | 24.17 | 0.94 | 0.08 | 61.50 | 2.08 | 1.15 | ND | 1606.85 | 5 | 1943 |
| SH 2.10 | 8.77 | 0.40 | 0.07 | 22.11 | 1.74 | 0.97 | 4433.30 | ND | 0 | 0 |
| SH 2.11 | 9.51 | 0.62 | 0.07 | 16.99 | 1.53 | 0.85 | 2314.24 | 224.77 | 0 | 0 |
| SH 2.12 | 12.05 | 0.66 | 0.04 | 18.90 | 1.64 | 0.91 | 1858.28 | 768.92 | 0.7 | 47 |

Cont. table 4:

| Sa. No. | Ca % | Mg % | Sr % | Carb. % | TOM % | O.C. % | TP* | TN* | Depth (m) | D. sh (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| SH 2.13 | 18.59 | 0.72 | 0.06 | 48.87 | 2.03 | 1.13 | 634.23 | 746.49 | 30 | 550 |
| SH 2.14 | 16.70 | 0.88 | 0.07 | 51.37 | 5.43 | 3.01 | 231.76 | 792.14 | 26 | 1081 |
| SH 2.15 | 17.19 | 1.22 | 0.10 | 43.43 | 3.04 | 1.69 | 78.13 | 351.00 | 31 | 1714 |
| SH 2.16 | 19.12 | 0.88 | 0.10 | 45.53 | 2.18 | 1.21 | 326.33 | 749.16 | 30 | 2167 |
| SH 2.17 | 39.35 | 1.72 | 0.19 | 73.21 | 2.53 | 1.40 | ND | ND | 7 | 2570 |
| SH 3.18 | 6.35 | 0.88 | 0.13 | 18.89 | 2.20 | 1.22 | 2217.97 | 409.56 | 0 | 0 |
| SH 3.19 | 8.38 | 0.18 | 0.10 | 12.17 | 0.44 | 0.24 | 1835.32 | 610.48 | 0 | 0 |
| SH 3.20 | 22.40 | 1.12 | 0.08 | 48.43 | 2.79 | 1.55 | 5379.52 | 185.25 | 1.5 | 49 |
| SH 3.21 | 36.96 | 1.31 | 0.16 | 88.87 | 2.77 | 1.54 | 61.75 | 39.02 | 6 | 267 |
| SH 3.22 | 28.84 | 0.84 | 0.09 | 56.23 | 2.08 | 1.15 | 833.61 | 627.15 | 30 | 685 |
| SH 3.23 | 22.99 | 0.83 | 0.07 | 58.82 | 2.07 | 1.15 | 430.21 | 1436.41 | 28 | 907 |
| SH 3.24 | 26.64 | 0.76 | 0.09 | 64.82 | 1.88 | 1.05 | 188.26 | 530.94 | 32 | 1277 |
| SH 3.25 | 24.11 | 1.02 | 0.08 | 59.11 | 2.52 | 1.40 | 117.75 | 591.32 | 32 | 1760 |
| SH 3.26 | 23.51 | 2.12 | 0.08 | 57.75 | 6.27 | 3.48 | 104.06 | 533.26 | 34 | 2463.5 |
| SH 3.27 | 25.23 | 0.51 | 0.18 | 66.16 | 1.26 | 0.70 | 5.69 | 472.41 | 27 | 3096 |
| SH 3.28 | 37.14 | 1.01 | 0.22 | 85.64 | 2.51 | 1.39 | ND | 315.92 | 13 | 2976 |
| Stdev | 10.68 | 0.45 | 0.05 | 24.11 | 1.28 | 0.71 | 1376.23 | 388.86 | 13 | 1020 |
| Gm | 13.75 | 0.66 | 0.06 | 33.15 | 1.76 | 0.98 | 193.45 | 413.75 | 12 | 650 |
| Min | 2.72 | 0.18 | 0.01 | 8.14 | 0.44 | 0.24 | ND | ND | 0 | 0 |
| Max | 39.35 | 2.12 | 0.22 | 88.87 | 6.27 | 3.48 | 5379.52 | 1606.85 | 34 | 3096 |
| Avg. | 17.27 | 0.78 | 0.08 | 41.14 | 2.08 | 1.16 | 757.60 | 478.25 | 15 | 990 |

Carb.% = carbonate content TOM = total organic matter O.C. = organic carbon TP = total phosphorus TN= total nitrogen *= values ppm D.sh.= distance from the shoreline Stdev = standard deviation Gm= Geomean Min= minimum Max= maximum Avg.= average ND = not detected

**Table 5:** The correlation coefficient among sediment texture, mean size, geochemical components, depth and distance from the shoreline of marine sediments at Safaga Harbour.

| | Gravel | Sand | Mud | Mz | Carb. % | Ca % | Mg % | Sr % | TP* | TN* | TOM % | Depth | D.sh |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gravel | 1 | | | | | | | | | | | | |
| Sand | -0.09 | 1 | | | | | | | | | | | |
| Mud | **-0.77** | **-0.56** | 1 | | | | | | | | | | |
| Mz | **-0.88** | -0.35 | **0.95** | 1 | | | | | | | | | |
| Carb. % | -0.21 | -0.02 | 0.19 | 0.22 | 1 | | | | | | | | |
| Ca % | -0.06 | -0.06 | 0.09 | 0.11 | **0.96** | 1 | | | | | | | |
| Mg % | -0.08 | -0.13 | 0.15 | 0.17 | **0.67** | **0.70** | 1 | | | | | | |
| Sr % | 0.28 | 0.03 | -0.25 | -0.27 | **0.74** | **0.78** | **0.51** | 1 | | | | | |
| TP* | 0.22 | -0.31 | 0.01 | -0.06 | -0.23 | -0.16 | -0.06 | -0.01 | 1 | | | | |
| TN* | -0.31 | -0.02 | 0.27 | 0.34 | 0.23 | 0.15 | 0.03 | -0.07 | -0.20 | 1 | | | |
| TOM % | -0.31 | -0.15 | 0.35 | 0.36 | 0.49 | 0.43 | **0.80** | 0.26 | -0.03 | 0.12 | 1 | | |
| Depth | **-0.70** | -0.09 | **0.64** | **0.68** | 0.45 | 0.35 | 0.34 | 0.09 | -0.44 | 0.27 | 0.45 | 1 | |
| D.sh | -0.17 | 0.03 | 0.12 | 0.20 | **0.68** | **0.64** | **0.52** | **0.59** | -0.46 | 0.21 | 0.37 | **0.54** | 1 |

Mz = mean size Carb.% = carbonate content TP = total phosphorus TN = total nitrogen * values = ppm TOM = total organic matter D. sh = distance from the shoreline.

**Table 6:** Comparison of carbonate, total organic matter, organic carbon, total phosphorous and total nitrogen in the current study with other studies of the Egyptian Red Sea coast (values in percent unless otherwise noted).

| Parameter | Other studies of the Egyptian Red Sea coast | | | | | | | | The present Study |
|---|---|---|---|---|---|---|---|---|---|
| | Mansour *et al.*, (2000) | Madkour (2004) | | | | Madkour *et. al.*, (2012) | Mansour *et. al.*, (2013) | Youssef *et. al.*, (2020) | Safaga |
| | Safaga Harbour | Qusier Harbour | Safaga Harbour | Hurghada Harbour | El-Esh area | El-Hamrawein Harbour | Hurghada area | Makadi Bay area | Harbour |
| **Carbonate** | | | | | | | | | |
| Range | ~~~~ | 3.9 - 63.3 | 7.9 - 96.4 | 4.4 - 96.8 | 24.6 - 96.0 | 23 - 86 | 11.72 - 87.98 | ~~~~ | 8.14 - 88.87 |
| Avg. | 78.02 | 33.1 | 53.7 | 78.6 | 73.4 | 49 | 66.3 | ~~~~ | 41.14 |
| **TOM** | | | | | | | | | |
| Range | ~~~~ | 0.9 - 5.9 | 0.8 - 5.4 | 1.0 - 4.3 | 1.1 - 6.6 | 1.9 - 7.7 | 1.60 - 8.63 | 0.19 - 6.22 | 0.44 - 6.27 |
| Avg. | 4.89 | 2.0 | 3.4 | 3.0 | 3.2 | 3.8 | 5.25 | 3.04 | 2.08 |
| **Organic Carbon** | | | | | | | | | |
| Range | ~~~~ | 0.5 - 3.3 | 0.4 - 3.0 | 0.5 - 2.4 | 0.6 - 3.7 | 1.1 - 4.3 | 0.89 - 4.79 | ~~~~ | 0.24 - 3.48 |
| Avg. | 2.71 | 1.1 | 1.9 | 1.7 | 1.8 | 2.1 | 2.91 | ~~~~ | 1.16 |
| **TP*** | | | | | | | | | |
| Range | ~~~~ | 632 - 10974 | 1200 - 9630 | 830 - 3708 | 232 - 4408 | 4010 - 6954 | ~~~~ | ~~~~ | ND - 5379.52 |
| Avg. | 129.00 | 6303.2 | 5125.8 | 2472.3 | 3170.3 | 5011 | ~~~~ | ~~~~ | 757.60 |
| **TN*** | | | | | | | | | |
| Range | ~~~~ | ~~~~ | ~~~~ | ~~~~ | ~~~~ | ~~~~ | ~~~~ | ~~~~ | ND - 1606.85 |
| Avg. | ~~~~ | ~~~~ | ~~~~ | ~~~~ | ~~~~ | ~~~~ | ~~~~ | ~~~~ | 478.25 |

TOM = total organic matter  TP = total phosphorus  TN = total nitrogen  * values = ppm  Avg. = average

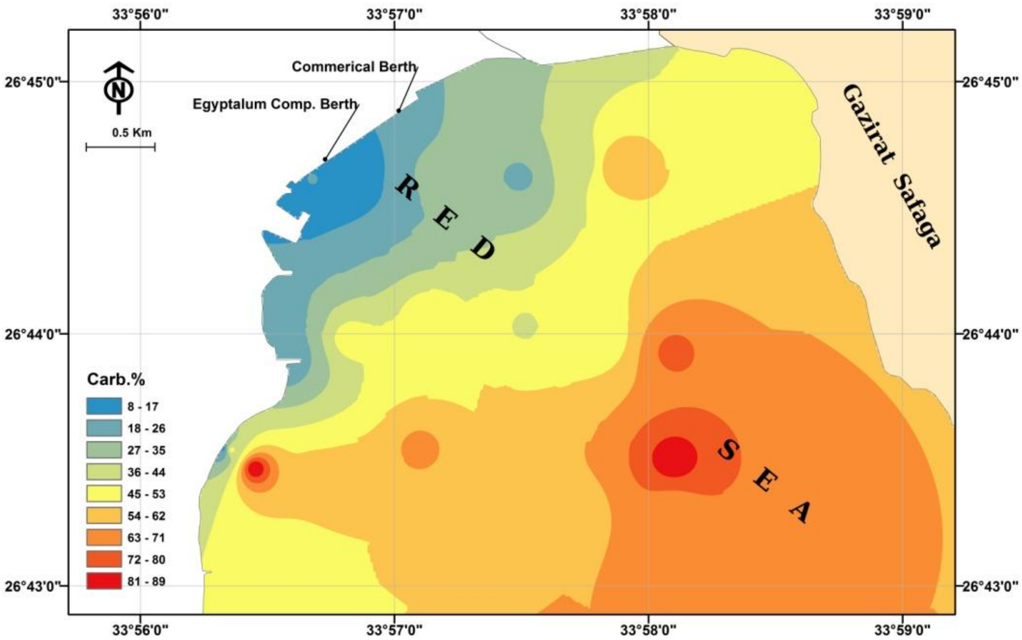


**Fig. 8:** Spatial distribution of carbonate content at Safaga Harbour.

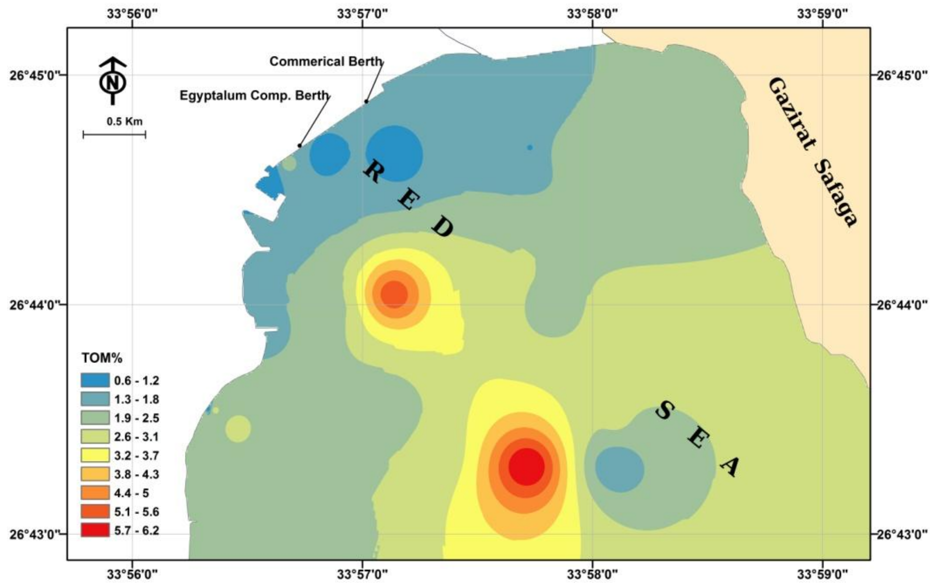


**Fig. 9:** Spatial distribution of total organic matter at Safaga Harbour.

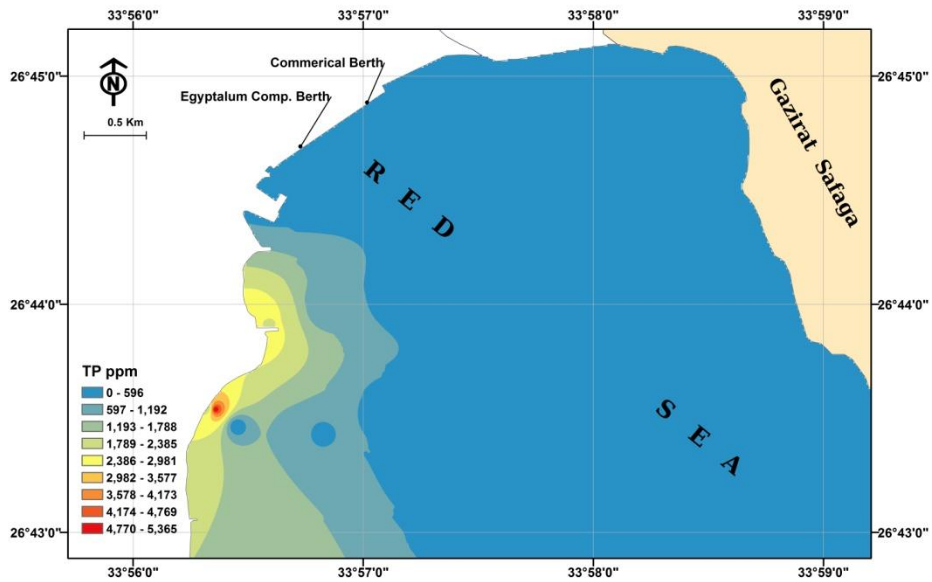


**Fig. 10:** Spatial distribution of total phosphorus at Safaga Harbour.

## IV. Conclusions And Recommendations

The sand fraction represents the highest fraction with an average of 77.91%, followed by mud fraction (13.78%), whereas the gravel fraction recorded the lowest content with an average of 8.30%. The mud content recorded the highest values at the deepest parts of the area. The high content of mud fraction is related to landfilling and dredging in the harbour area, unloading of green petroleum coke and phosphate ore shipment. The mean size of the sediments ranged from coarse sand to coarse silt, averaging medium sand. Additionally, the mean size increases from the shore and high topographic areas with increasing water depth. The sorting shows the same pattern as the mean size, with an average of poor sorting. This is illustated by the positive relationships between mud, mean size, sorting and depth. The skewness generally changed from strongly coarse to coarse skewness, with strongly coarse and fine skewness close to Gazirat Safaga. The kurtosis ranged from very platykurtic to very leptokurtic.

Ca, Mg, and Sr recorded the lowset values close th the harbour berth. This is due to the human impacts resulting from the activities of green petroleum coke unloading and landfilling and dredging operations in the area. In contrast, the samples close to Gazirat Safaga recorded higher values due to the abundance of biogenic fragments of coral reefs. The samples close to the harbour berth are very terrigenous, terrigenous and transitional carbonates, whereas the carbonate content increases in the samples close to Gazirat Safaga, where coral fragments are abundant. The organic matter recorded an average of 2.08%, this is probably due to direct discharge of domestic waste and the organic productivity in some areas due to seagrass bottom facies. The total phosphorous recorded an average value of 757.60 ppm, which is slightly higher than the threshold effect level. This is attributed to phosphate shipment activities in the past. The total nitrogen in marine sediments of the current study recorded an average of 478.25 ppm.

It is recommended that the harbour should be equipped with facilities to receive grabage and wastewater from ships. Using modern technology in coal unloading operations to prevent any emissions as a result of unloading activities.

## References:


[1]. P. M. James, "Principles, methods, and applications of particle size analysis," *Cambridge University Press*. Cambridge, vol. 3, no. 5, 229p., 1991, do: org/10.1017/CBO9780511626142.

[2]. R. L. Folk, and W. C. Ward, "Brazos River bar: a study in the significance of grain size," *Jour. Sed. Petrol.*, vol. 27, no. 1, pp. 3-26, 1957, doi: org/10.1306/74D70646-2B21-11D7-8648000102C1865D.

[3]. R. Chester, F. Lin, and A. Basaham, "Trace metals solid-state speciation changes associated with the down-column fluxes of oceanic particulates," *Journal of the Geological Society*, vol. 151, pp. 351-360, 1994, doi: org/10.1144/gsjgs.151.2.0351.

[4]. W. E. Dean, "Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss in ignition: comparison with other methods," *J. sediment. Petrol.*, vol. 44, pp. 242-248, 1974, doi: org/10.1306/74D729D2-2B21-11D7-8648000102C1865D.

[5]. M. S. Flannery, R. D. Snodgrass, and T. J. Whitmore, "Deepwater sediments and trophic conditions in Florida Lakes," *Hydrobiologia*, vol. 92, pp. 597-602, 1982.

[6]. M. Brenner, and M. W. Binford, "Relationships between concentrations of sedimentary variables and trophic state in Florida Lakes," *Can. J. Fish. Aquat. Sci.*, vol. 45, pp. 294-300, 1988, doi: org/10.1139/f88-035.

[7]. S. Nelson, "An acid-persulfate digestion procedure for determination of phosphorous in sediments," *Communications in soil science and plant analysis*, vol. 18, pp. 359-369, 1987, doi: org/10.1080/00103628709367826.

[8]. M. M. Smart, R. G. Rada, and G. N. Donnermeyer, "Determination of total nitrogen in sediments and plants using persulfate digestion," *Water Res*., vol. 17, pp. 1207-1211, 1983, doi: org/10.1016/0043-1354(83)90063-5.

[9]. R. L. Folk, "Petrology of sedimentary rocks," *Hemphill Pub. Co., Texas*, 182p., 1980.

[10]. Y. A. Ali, A. I. Beltagy, and I. H. Lotfy, "Grain size analysis and environmental of deposition of tidal and bottom sediment from Gharadaqa region, Red Sea area," *Bull. Inst. Oceanogr. & Fish. ARE*, vol. 13, no. 2, pp. 147-167, 1987.

[11]. G. S. Visher, "Grain size distribution and depositional processes," *Jour. Sed. Petrol.*, vol. 39, no. 3, pp. 1074-1106, 1969, doi: org/10.1306/74D71D9D-2B21-11D7-8648000102C1865D.

[12]. S. M. Madian, "Impacts of constructions on the sedimentary parameters and the environment, Hurghada, Red Sea, Egypt," *M. Sc. Thesis, Fac., of Sci., South Valley University*, 120p., 2005.

[13]. L. Irving, "The precipitation of calcium and magnesium from sea water," *Journal of the marine biological association*, 14(2): 441-446, 1926.

[14]. A. M. Dar, "Geological basis to study the environmental defect in the marine ecosystem as a result of tourist activities in Hurghada area and surroundings, Red Sea, Egypt," *Ph.D. Thesis, Suez Canal Univ. Egypt*, 218p., 2002.

[15]. J. D. Milliman, "Marine carbonates," *Springer, Berlin Heidelberg New York*, 375p., 1974, doi: 10.4319/lo.1974.19.5.0876b.

[16]. W. G. H. Maxwell, "Atlas of the great barrier reef," *Elsevier Amsterdam. Mari. Poll. Bull*., vol. 28, no. 4, 268p., 1968.

[17]. A. M. Mansour, "Quaternary reef terraces and their relation to tectonics/eustatics of the Red Sea region, Egypt," *Sedimentology of Egypt*, vol. 8, pp. 19-33, 2000.

[18]. H. A. Madkour, "Geochemical and environmental studies of recent marine sediments and some invertebrates of the Red Sea, Egypt," *Ph. D. Thesis, Fac., of Sci., South Valley University*, 317p., 2004.

[19]. A. M. Mansour, M. S. Askalany, H. A. Madkour, and B. B. "Assran, Assessment and comparison of heavy-metal concentrations in marine sediments in view of tourism activities in Hurghada area, northern Red Sea, Egypt," *Egyptian Journal of Aquatic Research*, vol. 39, pp. 91-103, 2013, doi: org/10.1016/j.ejar.2013.07.004.

[20]. H. A. Madkour, A. El-Taher, A. N. Ahmed, A. W. Mohamed, and T. M. El-Erin, "Contamination of Coastal Sediments in El-Hamrawein Harbour, Red Sea, Egypt," *Journal of Environmental Science and Technology*, vol. 5, no. 4, pp. 210-221, 2012, doi: 10.3923/jest.2012.210.221.

[21]. M. Youssef, H. Madkour, R. El Attar, A. Mansour, and A. Badawi, "Assessment of metal contamination in coastal marine sediments of Makadi Bay on the Red Sea, Egypt," *Marine and Freshwater Research*, vol. 71, no. 10, pp. 1241-1251, 2020, doi: org/10.1071/MF19306.

[22]. H. Xu, H. Paerl, B. Qin and G. Zhu, "Nitrogen and phosphorus inputs control phytoplankton growth in eutrophic Lake Taihu, China," *Limnology and Oceanography*, vol. 55, no. 1, pp. 420-432, 2010, doi:10.4319/lo.2010.55.1.0420.

[23]. T. J. Smayda, "Harmful algal blooms: Their ecophysiology and general relevance to phytoplankton blooms in the sea," *Limnology Oceanography*, vol. 42, pp. 1137-1153, 1997, doi: 10.4319/lo.1997.42.5_part_2.1137.

[24]. E. M. Bennett, S. R. Carpenter, and N. F. Caraco, "Human impact on erodable phosphorus and eutrophication: A global perspective: Increasing accumulation of phosphorus in soil threatens rivers, lakes, and coastal oceans with eutrophication," *Bioscience*, vol. 51, no. 3, pp. 227-234, 2001, doi: org/10.1641/0006-3568(2001)051[0227:HIOEPA]2.0.CO;2.

[25]. D. Persaud, R. Jaagumagi, and A. Hayton, "Guidelines for the protection and management of aquatic sediments in Ontario," *Standards Development Branch, Ontario Ministry of Environment and Energy. Toronto, Canada*, 27p., 1993.

[26]. X. Liang, X. Sun, T. Huang, H. Huang and H. Zhang, "Spatial distribution characteristics of total nitrogen, total phosphorus and organic matter in surface sediments of Duliujianhe River," *IOP Conf. Ser.; Materials Science and Engineering*, vol. 392, no. 4, 5p., 2018, doi: 10.1088/1757-899X/392/4/042044.

[27]. E. Escobar-Briones, and F. J. García-Villalobos, "Distribution of total organic carbon and total nitrogen in deep-sea sediments from the southwestern Gulf of Mexico," *Boletín de la Sociedad Geológica Mexicana*, vol. 61, no. 1, pp. 73-86, 2009.