Synergetic approach for the harbor sediment management: The Damietta harbor (Egypt) case study

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ABSTRACT

Dredged material dumping is one of the most important locally generated problems to be considered in harbors' management. The present work was carried out to assess the physical and particle size characteristics of the seabed and core sediments of the Damietta harbor basin and offshore sediments, with the main aim of establishing a synergetic approach to harbor sediment management. In addition to proposing a new offshore dumping site that will solve the problem of redispersing of the dumped sediment and re-shoaling of the harbor entrance. Thirty three sediment samples were collected from the harbor basin and offshore during the years 2007 and 2017.To achieve the study objectives, sediments were subjected to grain size analysis, total solids determination, and estimation of carbonate and organic matter contents. In addition to, marine bottom communities' analysis. Results show that the mean grain size of samples ranged between 4.75-7.99 Ø (coarse silt, medium silt, fine silt & very fine silt). While carbonate content in samples ranged from 0.41 to 3.13% and the total organic matter in samples reached a value of 2.95%. These results would help in assessing sediments that will be dredged from this area to be dumped in the middle shelf off the Damietta promontory. Management measures proposed by the present study consider the harbor basin deepening, extension of the harbor basin and the beneficial use of the dredged sediment. In addition, sediment bypassing supposed to mitigate scour problem and acting as a feeder to the adjacent shorelines and the littoral cell in the study area.

Keywords: Harbor sediment management, Dredged materials, Dumping site, Synergetic approach, Sediment characteristics.

1. INTRODUCTION

Management of dredged material requires careful planning of dredging needs and disposal alternatives, comprehensive evaluation of environmental consequences of specific proposed dredging and disposal actions, and short- and long-term monitoring of dredged material disposal sites utilizing.
Dredging is necessary to create and maintain navigation channels to the ports, harbors, marinas, and naval facilities. Dredged sediments can be isolated, directly reused (e.g., for rehabilitation of dykes or beach nourishment), or deposited on land for construction and public works. The beneficial use of dredge sediments from ports and harbors to maintain navigable waterways is central to their operation, particularly for an economically important one as Damietta harbor.

The New Damietta port has been established in the early eighties to improve trade facilities and foster the flow of trade traffic across the Mediterranean coast of Egypt. The port is situated on the Egyptian Mediterranean coast, about 37 km west of Port Said and about 9 km of Dumyat city (Sarhan and Negm 2017). It handles the export of agricultural products, fertilizers, and furniture and receipt imported goods such as petrochemicals, cement, grains, flour, and general cargo with a total capacity of about 5.6 million tons annually. The Port of Damietta is strategically located on the international transport lane as well as for domestic supply to Egypt (Luis and Moncayo 2005). The most important competition for Damietta on container transshipment activities on the international route can be found in the port of Tauro, Port Piraeus, and Port Said. The monthly value of exports from Damietta port in Egypt stood at close to 170.2 million U.S. dollars in July 2020, a drastic increase of around 53 percent from the preceding month. Between January 2019 and July 2020, the portion of Egyptian exports leaving via Damietta port ranged between approximately 4.19 and 8.29 percent of the nation's total exports. Moreover, the export value ranged between 181.4 million U.S. dollars and 101.9 million U.S. dollars in March and November 2019, respectively (https://www.statista.com, 2022).

The port is subdivided into two main parts; the shipping area, which is an inland section containing 16 berths and quays, and the water area which is composed of an access channel connecting the shipping area with the Mediterranean Sea and the main basin. To ease access to inland navigation, the port's basin has been connected to the Rosetta branch of the River Nile through a man-made barge canal of 4.5 km long and 5 m in depth. The harbor basin was dredged inland, and its entrance was protected by two breakwaters. These breakwaters were designed to avoid easterly and westerly sediment transport from bypassing the navigation channel. The harbor's navigation channel has experienced sedimentation and subsequently threatened navigation activities.

Although there are several studies were carried out and published on the sedimentation problem of Damietta harbors such as El-Asmar & White (2002), Frihy et al. (2002), Abo Zed (2007), Gad et al.(2013), and El-Asmar et al. (2016); the management of dredged sediments in a sustainable perspective has not addressed yet. Thus, the beneficial placement of sediment calls for putting those materials where they are most needed or where they would have the least potential for adversely affecting the harbor's environment. While there is an extensive body of literature that describes potential beneficial uses of dredged material, relatively few plans were found that appear to implement the practice. Therefore, the objectives of the present study are to provide an example of the best management of the dredged harbor sediment from the navigational channel deepening and the expansion of the harbor basin through a comprehensive study of the harbor sediment characteristics. In addition to proposing a new offshore dumping site that will solve the problem of redispersing of the dumped sediment and re-shoaling of the harbor entrance.

2. MATERIAL AND METHODS

2.1 Study area

The study area includes the Damietta harbor basin and its navigation channel as well as the offshore area between the harbor and Damietta promontory (figure 1).

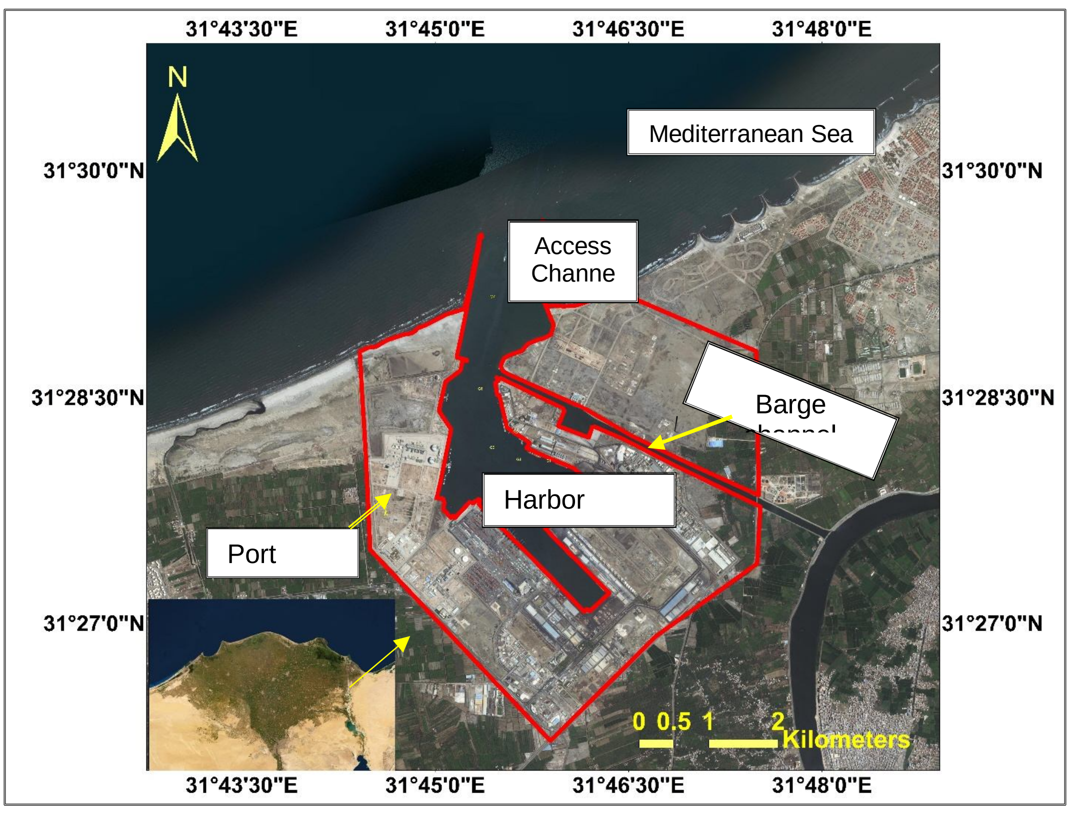


Fig 1. Location map of the study area

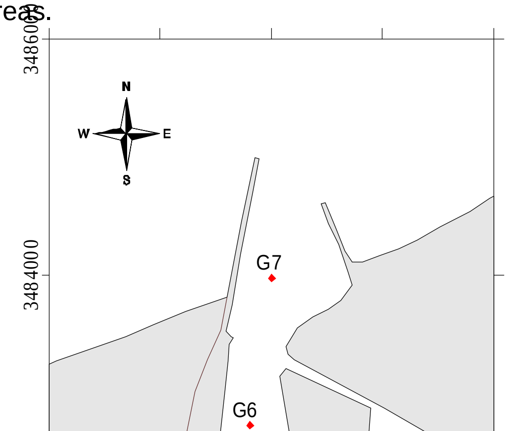
The Damietta harbor is about 8.5 km west of the Damietta branch of the River Nile on the Mediterranean Sea west and about 70 km west of Port-Said Port. The construction area covers about 25 km. The navigational channel (canal entrance) is about 11.3 km long and 300 m wide which gradually decreases till it reaches 250 m at water break and 15 m depth.
The harbor is protected by water breaks, the western water break is about 1500 m seaward long and its landward is about 140 m with a total of 1640 m and the Eastern water break is about 538 m long seaward and about 200 landward with a total of 738 m. The water breaks are protected from the external side of the industrial acrid bocks, and they are topped by a cement layer.

The barge channel consists of two ports one is 1350 m which links the barges dock to the sea and the other is 3750 m which links the dock to the Nile branch. The area of the barge dock is 250 x 250 m and it is equipped with a berth of 250 m long where the water depth is 5 m deep. The diameter of the rotation dock is 500 m and its depth is 14.5 m in front of the containers broth and 12 m in front of the general cargo berths.
The seafloor of the study area and its surroundings is dominated by patches of sand, silt, and silty clayey (mud) (El Sammak, 1995). The study area is fronted by a series of protection works including the shore parallel detached breakwaters and the 6-km long Damietta seawall.

2.2 SEDIMENT SAMPLING

To achieve the objectives of the present work, a comprehensive study of the harbor basin and the offshore sediments were applied through the following methods and approaches.

The samples were collected during 2017 from the harbor basin while the core and offshore sediments of the study area were obtained during June 2007. It is worth to note that the present study depends on offshore sediments collected during 2007. The present work depends on the sediments were collected during the year 2007 for core sediments and the offshore survey to reduce the high cost of resampling in the open sea for the year 2017. Figures 2 and 3 and Table. 1 shows the sampling positions of the harbor basin and offshore areas.



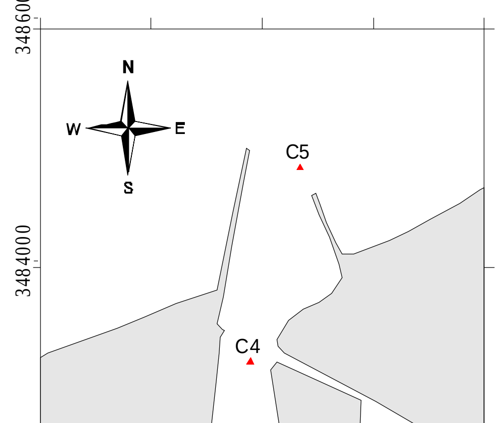


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Fig 3. Study area showing locations of the followings: a) Grab sediment samples (G1 to G7 and RS) in the Damietta Harbor basin, and b) Sediment cores (Core 1 to Core 6).

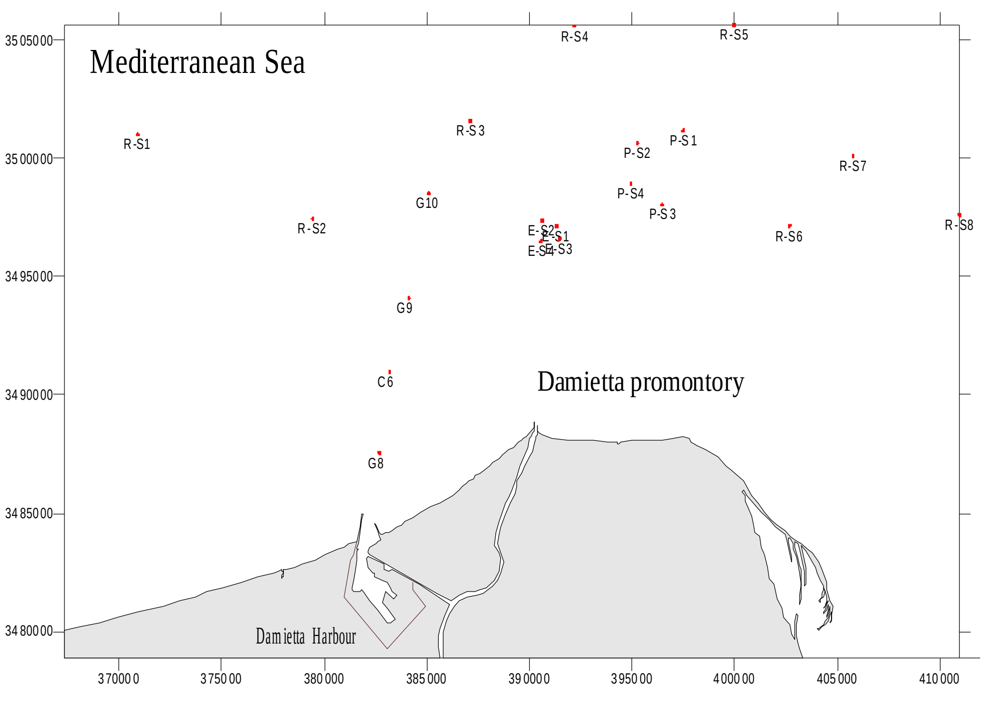


Fig 3. Study area showing locations of surficial sediment samples of the continental shelf between the Damietta Harbor and Damietta promontory. R-S = disposal site reference samples, E-S = existing disposal site, P-S = proposed disposal site, G8-G10 = grab sample and C6 = core position.

Table 1. The geographic locations of seabed samples and cores are examined in the present study.

Sample Type	**Label**	**Lat (DMS)**	**Long (DMS)**
Disposal Site reference	R-S1	31° 38' 13.043"	31° 38' 19.416"
Disposal Site reference	R-S2	31° 36' 20.981"	31° 43' 44.555"
Disposal Site reference	R-S3	31° 38' 37.498"	31° 48' 34.675"
Disposal Site reference	R-S4	31° 40' 49.829"	31° 51' 46.259"
Disposal Site reference	R-S5	31° 40' 53.724"	31° 56' 41.287"
Disposal Site reference	R-S6	31° 36' 19.638"	31° 58' 26.010"
Disposal Site reference	R-S7	31° 37' 56.419"	32° 0' 22.940"
Disposal Site reference	R-S8	31° 36' 36.539"	32° 3' 40.805"
Existing Disposal Site	E-S1	31° 36' 14.502"	31° 51' 15.896"
Existing Disposal Site	E-S2	31° 36' 22.050"	31° 50' 48.584"
Existing Disposal Site	E-S3	31° 35' 57.489"	31° 51' 21.346"
Existing Disposal Site	E-S4	31° 35' 54.040"	31° 50' 47.493"
Proposed Disposal site	P-S1	31° 38' 28.112"	31° 55' 8.400"
Proposed Disposal site	P-S2	31° 38' 9.784"	31° 53' 43.880"
Proposed Disposal site	P-S3	31° 36' 45.966"	31° 54' 31.513"
Proposed Disposal site	P-S4	31° 37' 15.469"	31° 53' 32.443"
Reference sample	R-S	31° 39' 40.180"	31° 32' 9.837"
Sediment grab	G1	3127 53.109	31 45 55.632
Sediment grab	G2	31 27 43.428	31 45 50.486
Sediment grab	G3	31 27 47.631	31 45 34.280
Sediment grab	G4	31 27 57.854	31 45 47.733
Sediment grab	G5	31 27 59.852	31 45 30.739
Sediment grab	G6	31 28 23.862	31 45 20.863
Sediment grab	G7	31 29 4.429	31 45 27.829
Sediment grab	G8	31 13 1.065	31 45 52.379
Sediment grab	G9	31 34 33.617	31 46 44.124
Sediment grab	G10	31 36 57.608	31 47 18.916
Sediment core	C1	31 27 50.132	31 46 10.523
Sediment core	C2	31 27 52.129	31 45 41.103
Sediment core	C3	31 28 13.602	31 45 28.764
Sediment core	C4	31 28 39.564	31 45 23.894
Sediment core	C5	31 29 32.720	31 45 40.190
Sediment core	C6	31 32 51.676	31 46 09.705

Surficial sediments were collected using a galvanized Van Veen grab sampler whereas a 3-m long gravity corer was used to recover subsea samples. The recovered sediment cores of approximately 3-m length are vertically sub-sampled at approximately 20 to 50 cm intervals.

The surficial samples were collected in plastic containers whereas the core samples were in PVC tubes.

The core length and its percentage recovery are listed in Table 2. Each core was cut into 6 parts. Starting from the top these parts were taken at successive core intervals: 0-0.25, 0.25-0.5m, 0.5-1m, 1-1.5m, 1.5-2, and 2-3m. The volume of each core section is more than 400 ml. To meet the required sediment volumes, the corer device was released twice in each oceanographic station. Sampling and cutting of the core were made on board the research vessel. The recovered core intervals were marked and capped and placed into ice boxes.

Table (2): The Cores' lengths and the percentage cover.

Core #	Total Length	Actual length	% Recovery
Core # 1	270	300	90
Core # 2	255	300	85
Core # 3	260	300	86.7
Core # 4	264	300	88
Core # 5	275	300	91.7
Core # 6	264	300	88

2.3 SEDIMENT CHARACTERISTICS AND CHEMICAL ANALYSES

2.3.1 Grain size analysis (G. S. A.)

About 15 to 50 gm of the oven-dried samples were subjected to grain size analysis. The mechanical technique was used for coarse fractions (less than 4 Ø); by sieving through a standard set of sieves (Prűfsiebring A TGL 7354) mounted on an electric shaker machine (Test Sieve Shaker). The standard applied time of sieving was 20 minutes. The sieves were arranged in 1 Ø class interval from top to bottom. The pipette analysis was used for the fine fractions (more than 4 Ø) using the technique described by Krumbein and Littlejohn (1938).

In the present work, the graphic measures given by Folk (1980)were employed for the results of grain size analysis using phi notation, where Ø =-$\log_2$ d (d given diameter value in mm). Cumulative percentages were plotted against grain size interval (Ø) on a probability paper. The 5 Ø, 16 Ø, 50 Ø, 84 Ø, and 95 Ø values were directly interpolated from the cumulative curves. From these percentiles, the inclusive graphic mean size (Mz) and inclusive graphic standard deviation (sorting, σ_I) were calculated.

$$\text{Inclusive graphic mean size (Mz)} = (Ø_{16} + Ø_{50} + Ø_{84})/3$$

$$\text{Inclusive graphic standard deviation } (\sigma_I) = (Ø_{84} - Ø_{16}/4) + (Ø_{95} – Ø_{5} / 6.6)$$

2.3.2 Determination of total solids

Total solids (the organic and inorganic materials remaining after a sample has been dried completely) were determined according to Sluiter et al (2008). This variable is commonly used to convert sediment concentrations of substances from a wet-weight to a dry-weight basis.

The total solids content was determined as follows:

$$\text{Total solids (\%)} = (A\text{-}B)\ (100)/C\text{-}B$$

Where: A = weight (g) of the dish and dry sample residue, B = weight (g) of the dish, and C = weight (g) of the dish and wet sample.

2.3.3 Determination of total carbonates

Total carbonates were determined in the samples using the indirect method described by (Heidelberger and Treffers, 1989). Exactly 0.5 gm of the sample was treated with hydrochloric acid (10%) until the reaction stops. The residue was filtered on pre-weighed filter paper (W1) and then dried in an oven for 2- minutes. The weight was then determined (W2) and the total carbonate percent was calculated as follows:

$$\text{Total carbonate \%} = (0.5-(W1-W2)/0.5) * 100$$

2.3.4 Determination of total organic matter content

The organic matter content was determined by the direct method described by El Wakeel and Riley (1957) the method is based on the oxidation of about 200 mg of dry sediment sample with 10 ml of chromic acid in a boiling tube. Heat in a bath of boiling water for 15 minutes, cool, and pour the contents of the tube into distilled water. Titrate against Ferrous Ammonium Sulphate using Phenanthroline indicator until pink color persists.

1 ml 0.2 Ferrous Ammonium Sulphate ≡1.15 x 0.6 mg organic carbons

A factor of 1.8 proposed by Trask (1939) was used for the calculation of total organic matter.

3.3.5 Determination of density or specific gravity

Specific gravity is an important physical property of a sediment particle, which may be measured with a specific-gravity flask. A sample with a dry weight W is transferred into the flask filled with distilled water. Air bubbles are removed from the flask by vacuum pumping or boiling. The weight of the flask filled with the water-sediment mixture Wws and the weight of the flask filled with distilled water Ww are measured by a sensitive balance. The specific gravity of sediment particles may be calculated by:

$$SG=Ws/\ Ws-(WWs-Ww)$$

where SG Ws Wws Ww is the specific gravity of sediment particles; is the weight of the sediment; is the weight of the flask filled with the water-sediment mixture; is the weight of the flask filled with distilled water.

2.4 MARINE BOTTOM COMMUNITIES' ANALYSIS

The bottom fauna samples are collected using a grab sampler (15x15 cm). The grab samples were sieved through sieves of 0.5 mm. mesh size was provided with continuous spray water and agitated to accelerate the sieving processes. Organisms are separated from bottom sediments such as silt and clay then sorted and separated into different taxa.

3. RESULTS AND DISCUSSION

3.1 SEDIMENT CHARACTERISTICS AND DISTRIBUTION

3.1.1 Grain size analysis

3.1.1.1 Harbor sediment (surface and core sediments)

Mean grain size of samples (G1 to G10) and core sediments (C1 to C6) ranged between 4.75-7.99 Ø (coarse silt, medium silt, fine silt & very fine silt) and 4.43-8.85 Ø (medium silt, fine silt, very fine silt & clay), respectively. Sorting of these samples (G1 to G10) and core sediments (C1 to C6) ranged between 1.77-3.42 Ø (poorly & very poorly sorted) and 1.24-3.27 Ø (poorly & very poorly sorted), respectively. It was found that most sediments consist mainly of very poorly silt fractions covering the bottom indicating troubling conditions. The geographic distribution of sand%, silt%, clay%, mean grain size, and sorting patterns of grab samples "G samples" in the harbor basin is shown in Figures 4, 5,6&7.

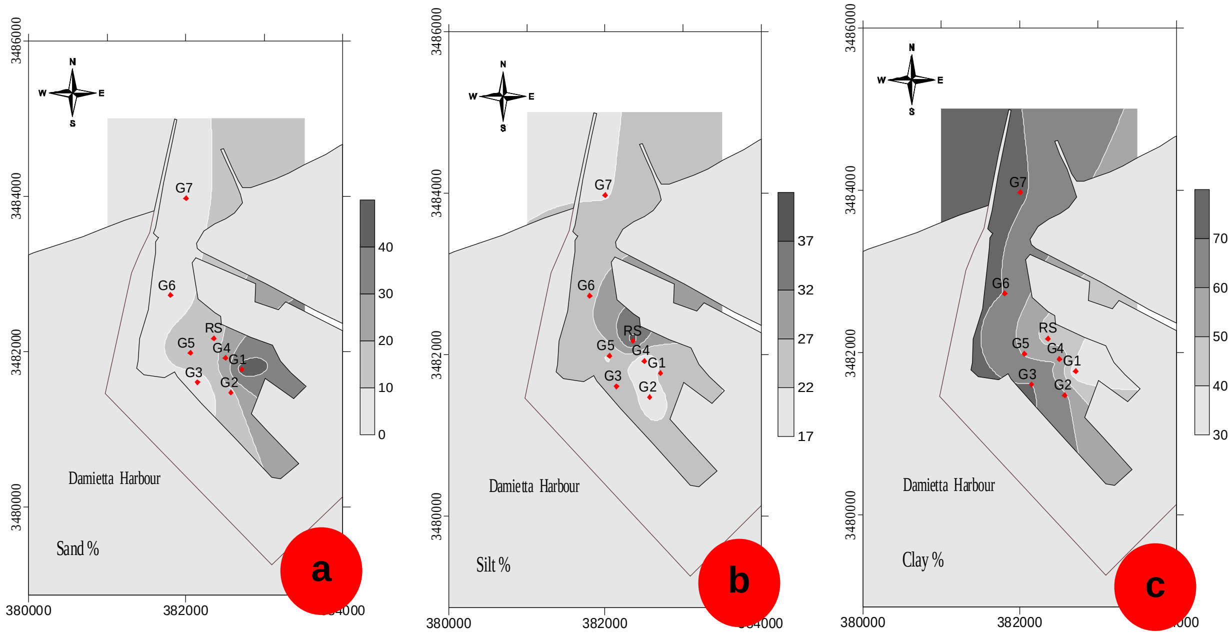


Fig 4. Geographical distribution of a) sand%, b) silt% and c) clay% of Grab samples in the Damietta harbor basin.

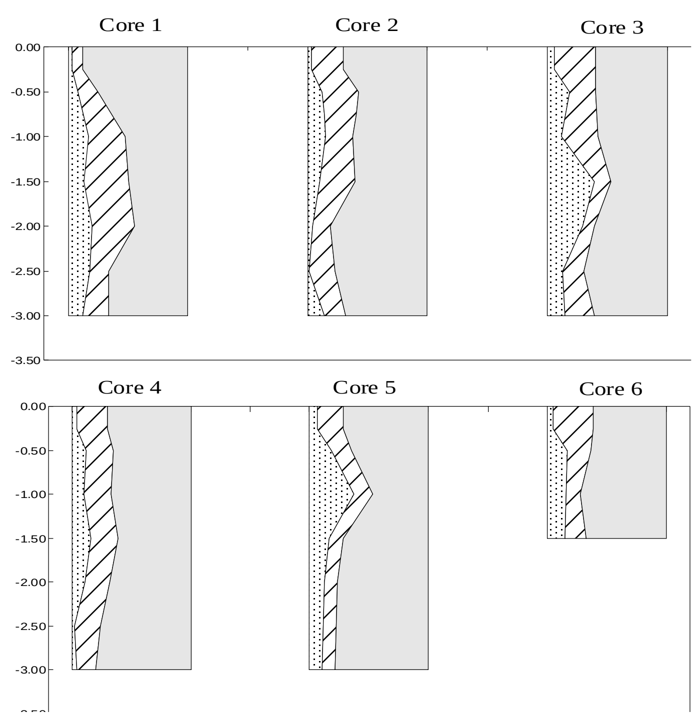


Fig 5. Vertical distribution of sand %, silt%, and clay% in the examined cores.

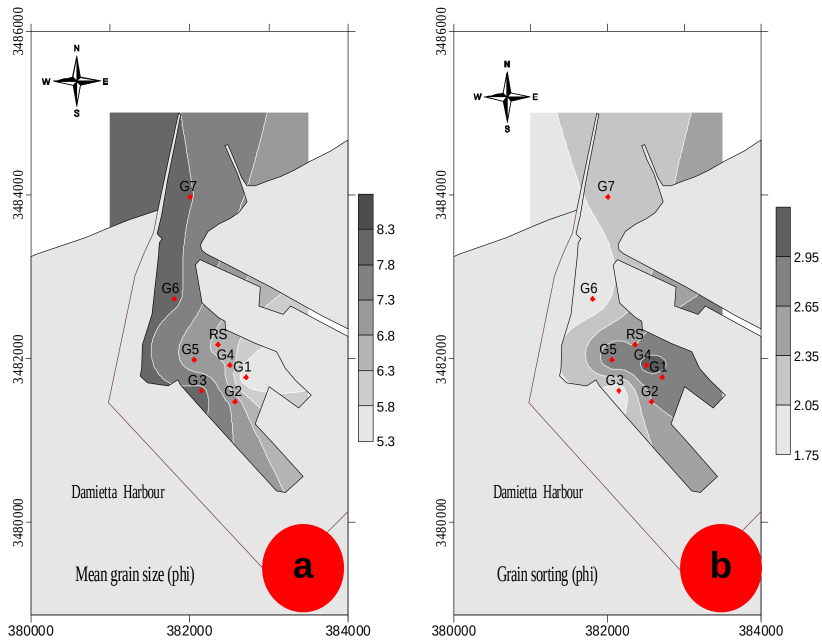


Fig 6. Geographical distribution of a) mean grain size (phi unit) and b) grain sorting (phi unit) of Grab samples in the Damietta harbor basin.

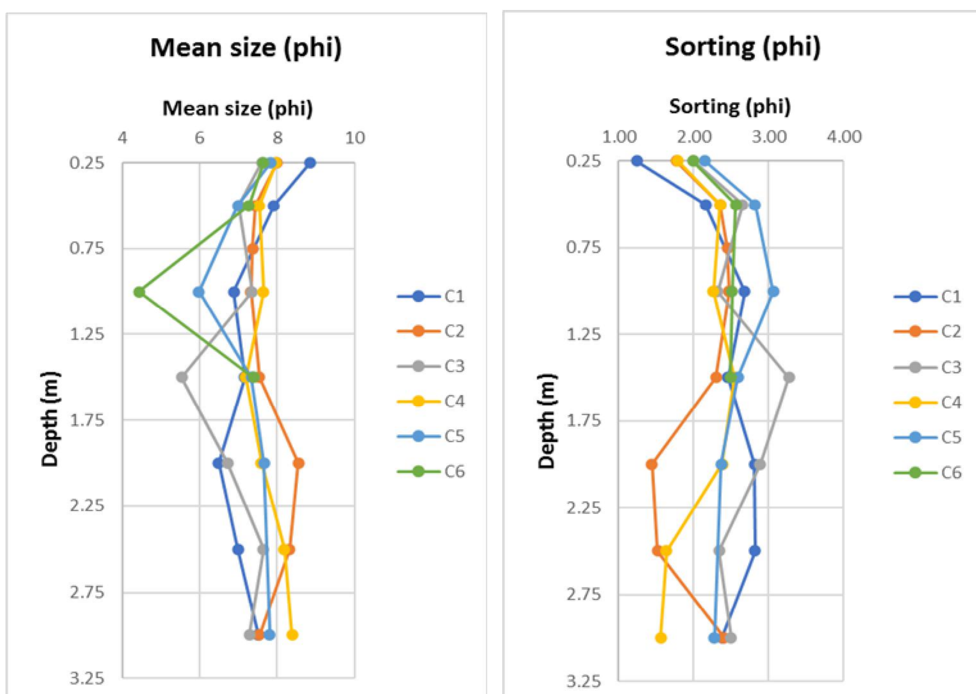
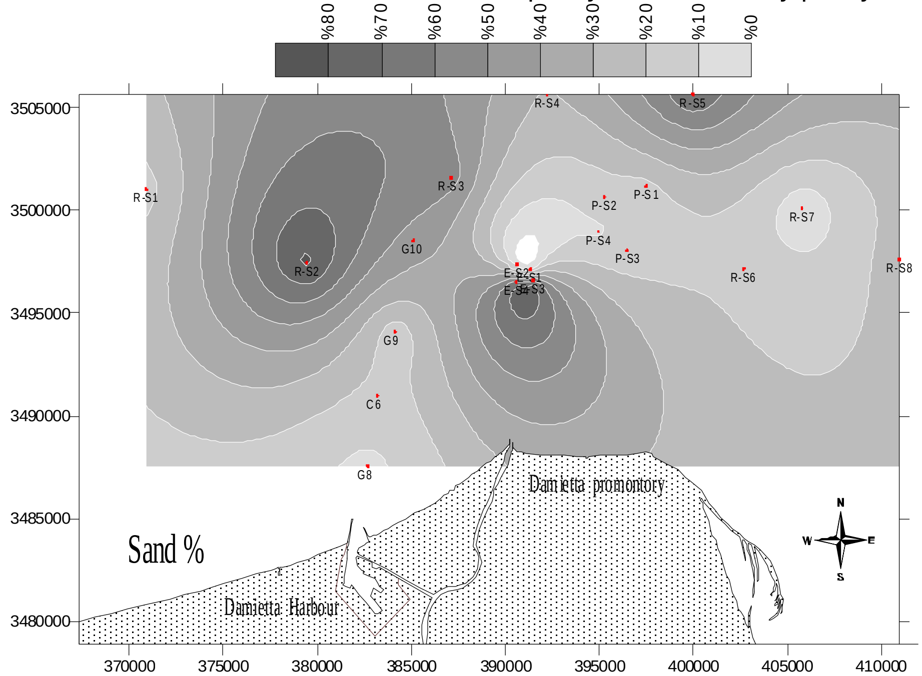


Fig 7. Geographical distribution of a) mean grain size (phi unit) and b) grain sorting (phi unit) of Core samples (C1 to C6).

3.1.1.2 Offshore surface sediments

The offshore spatial distribution of percentages of sand, silt, and clay are shown in Figures 8 while, mean grain size (in phi unit) and sorting (in phi unit) are demonstrated in Figures 9 to 11, respectively. This geographic distribution includes samples from offshore (existing and proposed dumping sites), navigation channels, and the upper 0-25 cm layer of core #6. The mean grain size of offshore samples ranges from 2.06 to 8.59 Ø and incorporated fine sand, very fine sand, coarse silt, medium silt, and very fine silt. The grain sorting (σI) ranges between 1.31 and 3.32 Ø and is defined as poorly sorted and very poorly sorted (Figure 10).



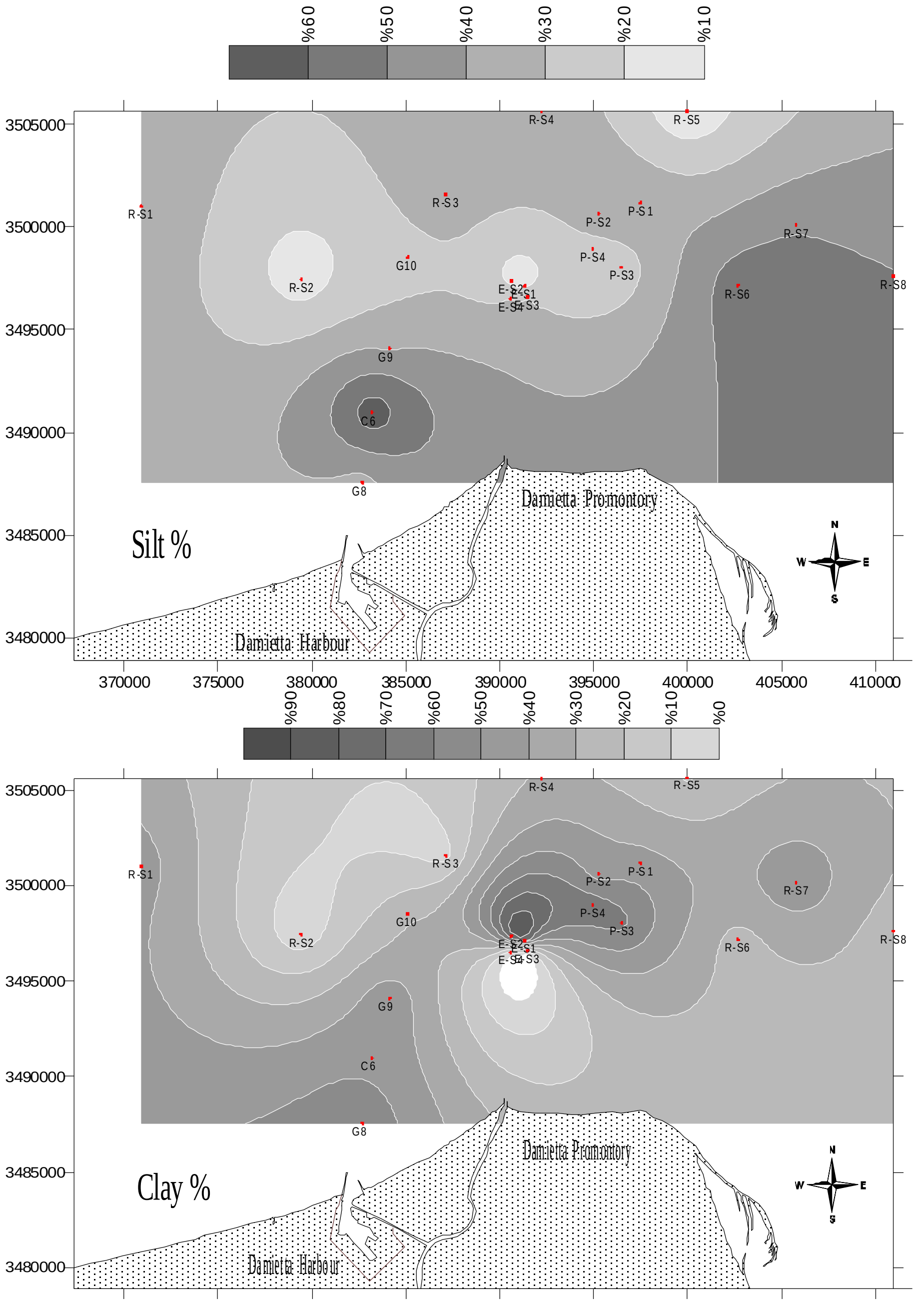


Fig 8. Offshore geographical distribution of a) sand%, b) silt% and c) clay% of Damietta.

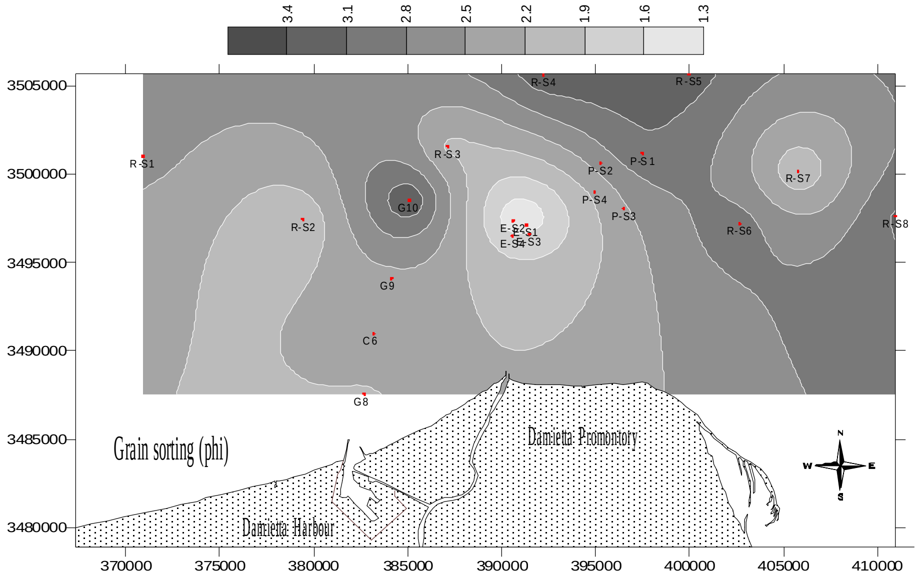


Fig 9. Offshore geographical distribution of mean grain size in phi units of Damietta.

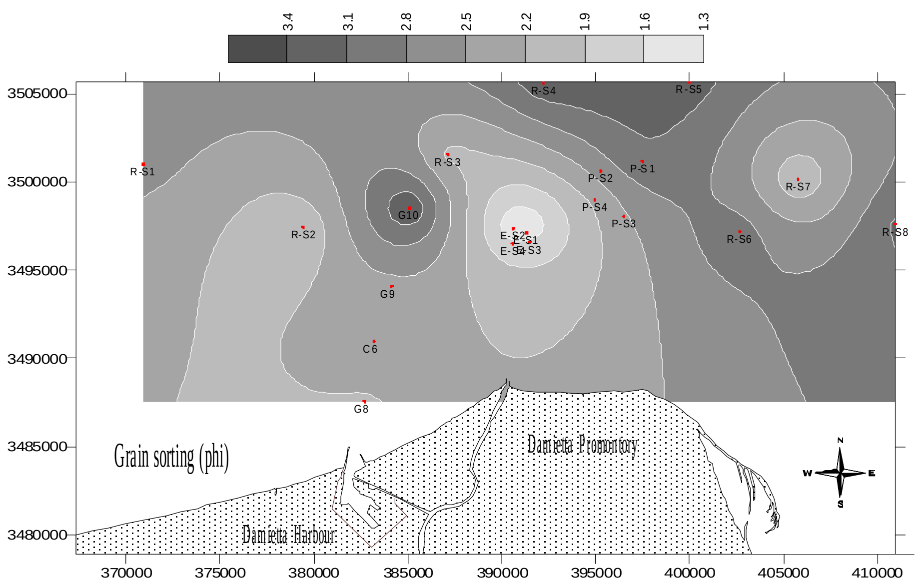
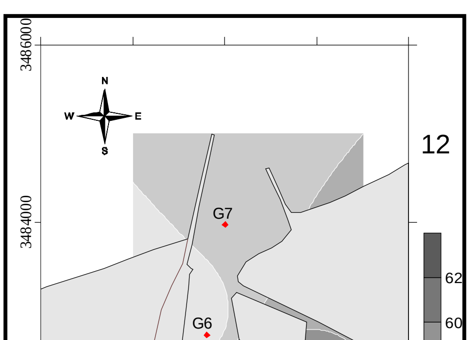


Fig 10. Offshore geographical distribution of grain sorting (standard deviation) in phi unit.

3.1.2 Total solids

Results of total solids for all samples are shown in Figure 11. Total solids in samples (G1 to G10 samples) and core (C1 to C6) sediments ranged between 45.2-95.1% and 41.1-62.4%, respectively. In the offshore samples, total solids vary from 44 to 84 %, and their geographical distribution is shown in Figure 12.



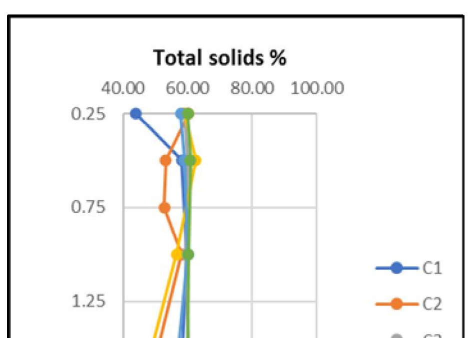


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Fig 11. Geographical distribution of total solids % (a. the Grab samples in the Damietta harbor basin, and b. Total solids % distribution of the Core samples).

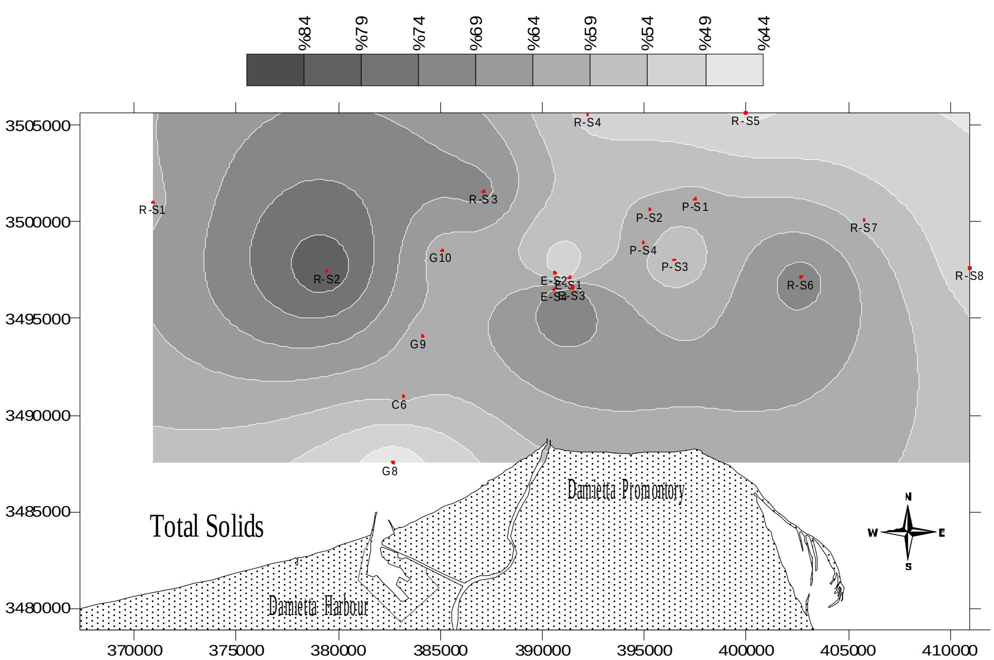


Fig 12. Offshore geographical distribution of total solids %.

<u>3.1.3 Total Carbonate content</u>

Surficial and core sediment samples indicated that carbonate content is related to the shell fragments and entire shells exist in the total sediment samples. Carbonate content in samples (G1 to G10 samples) and core (C1 to C6) sediments ranged between 1.04-2.61 and 0.41-3.13%, respectively. The geographic distribution of the percentage of carbonate content of "G and R-S" samples in the harbor basin is shown in Figure 13. The carbonate content of offshore samples varies from 1.3 to 3.6 %, and their geographical distribution is depicted in Figure 14.

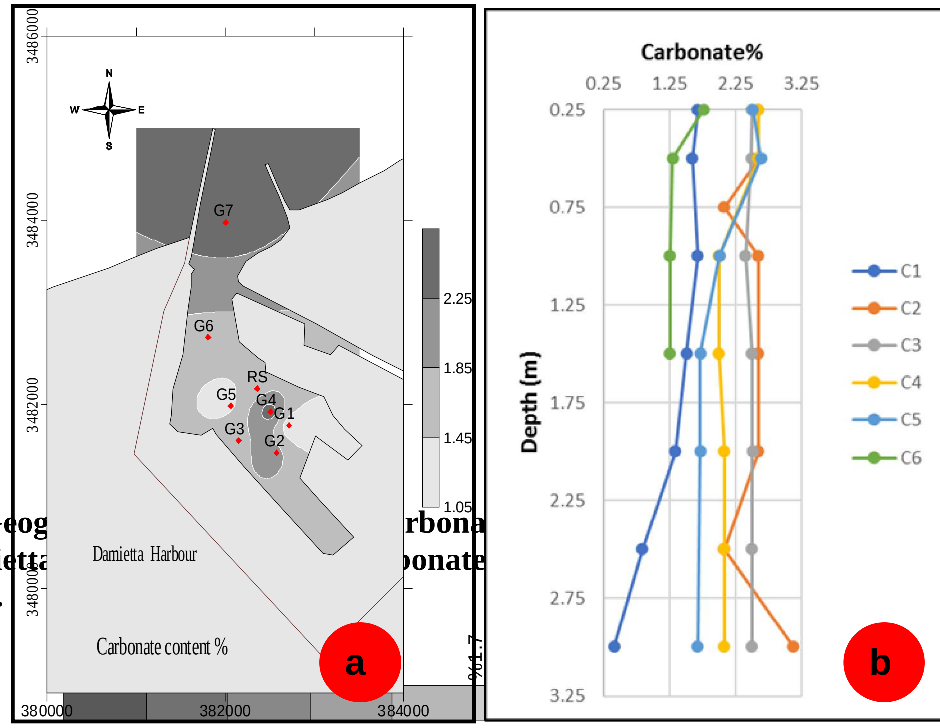


Fig 13. Geog… rbona… the Damietta… bonate… e samples).

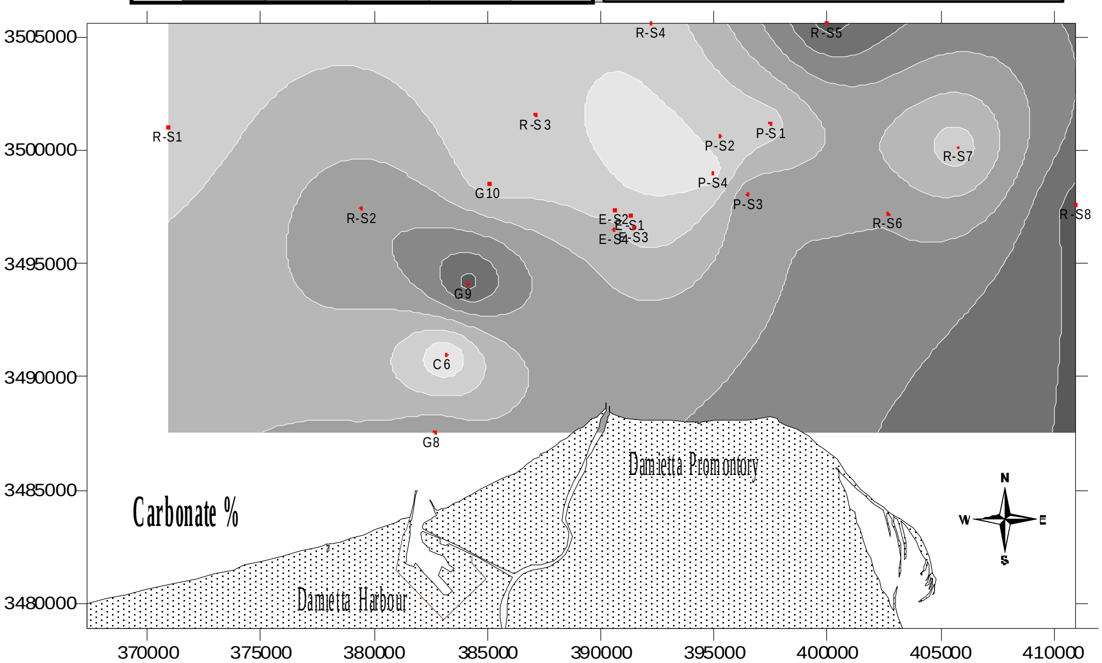


Fig 14. Offshore geographical distribution of carbonate %.

3.1.4 Organic matter content

Results of total organic matter are shown in Figures 15 & 16. The total organic matter in samples (G1 to G10 samples) and core (C1 to C6) sediments ranged between 0.29-1.76 and 0.04-2.95%, respectively. Total organic matter in the offshore samples varies from 0.0 to 3.2%. Microscopic examination indicates that organic matter exists is mainly related to the plant remains exist in the total sediment samples.

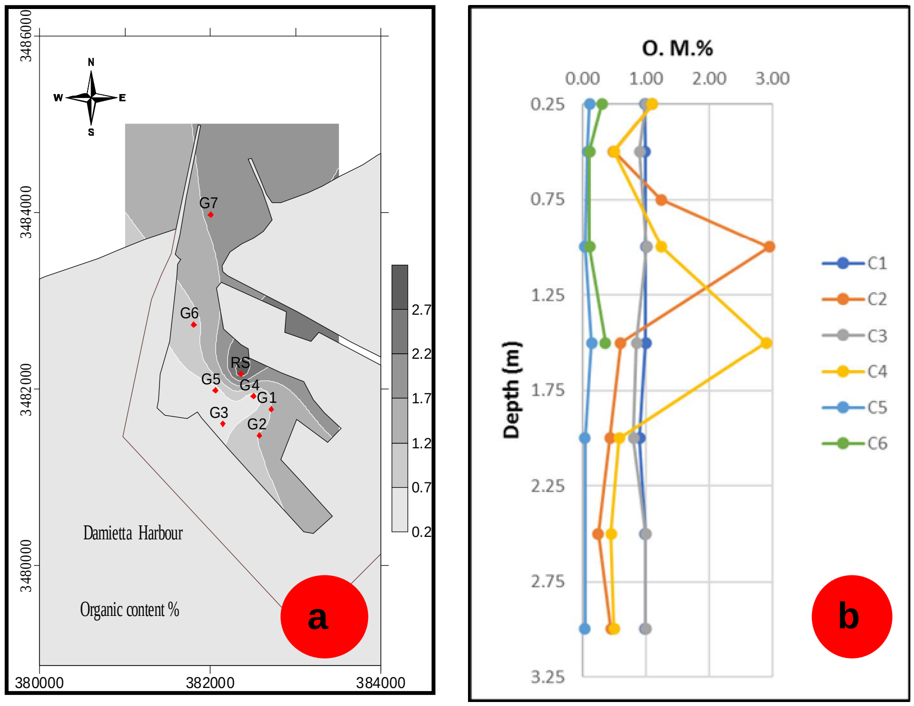


Fig 15. Geographical distribution of organic matter % (a. The Grab samples in the Damietta harbor basin, and b. the core sediments samples).

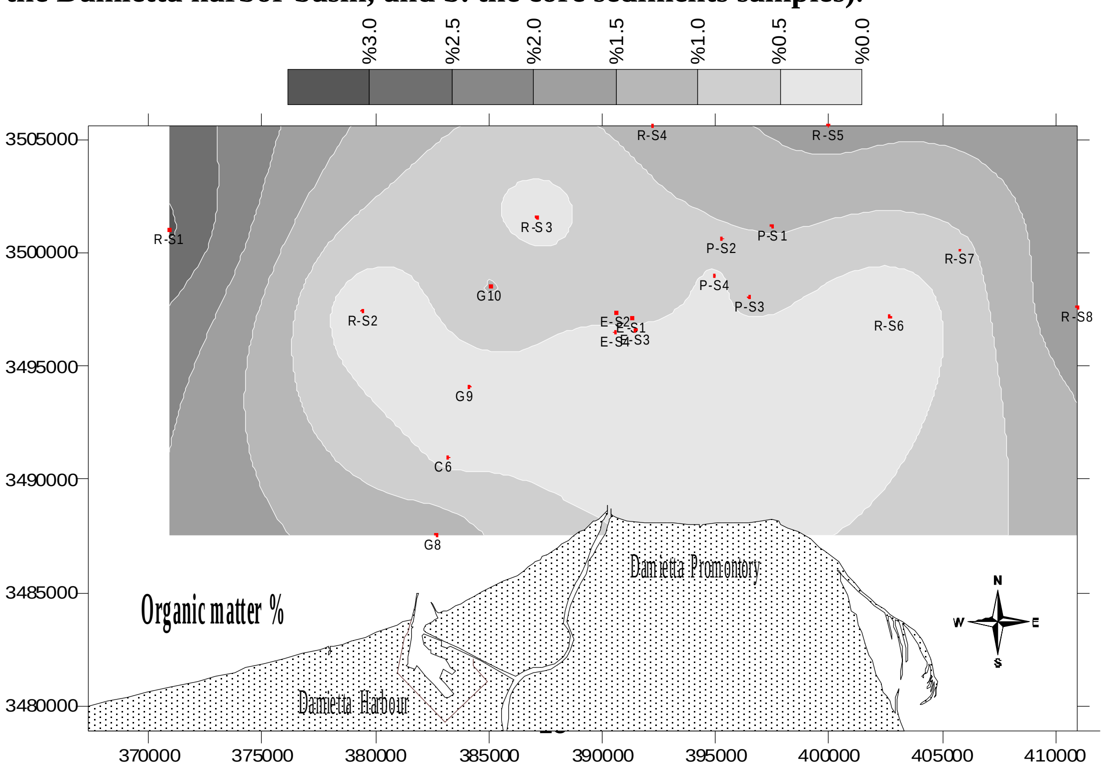


Fig 16. Offshore geographical distribution of organic matter %.

Generally, the value fluctuations are dominant as proceeding in the southward direction inside the harbor. The maximum value is computed at the surface sediments of station 8 located at the southmost zone of the harbor, while the minimum is found at station 1 located just beyond the left jetty at the mouth of the harbor in the open waters. The riverine input or terrestrial discharge that characterizes the study area is regarded as the main contributor of the organic detritus to the marine environment. These results are recognized from the nature and characteristics of the samples themselves. Such findings coincide with Marmin *et al* (2014), which suggested that the input of organic carbon is not only due to settling but also through the incorporation of organisms. Decomposition and mineralization of the organic contents help the important elements, carbon, nitrogen, and phosphorus into circulation in the water in the form of carbon dioxide, ammonia, and phosphoric acid, thus they are rendered available for the photosynthesis and growth of the phytoplankton. Due to the sampling time during the summer season, the warm temperature of the surface sediments may exert a great influence on the activities of the living microorganisms, where high temperature increases the rate of mineralization and the active decomposition of the organic matter and prevents its accumulation on the bottom. The gradual renewal of the harbor water by drainage water, or through the exchange with the marine waters at the opening increases the nutrient concentrations are favorable for plankton productivity consequently, the supply of organic matter would be abundant.

The spatial distribution of TOC in the Damietta harbor surface sediments indicates the expected pattern of the such harbor. Minimum values always characterize the marine environments just outside the harbor, while directed in the southward direction, the TOC concentration increase in a horizontal strip, reaching its maximum limit at the southmost part of the harbor. In such environments with high photosynthetic activities, the shallow depth prevents the falling biogenic particles from effective oxidation, which increase the accumulation of organic matter on the bed sediments. The sediments of the internal canal can be categorized in the high TOC contents areas at the harbor, which may be due to the contribution of terrigenous materials and the decomposition of plant and animal remains at the bottom of the water bodies through the action of bacteria at the mixing zone in the drain. Particularly the oxygen content, bacterial activity and movement in the chemical nature of the overlying water affect the character of the organic substance (Shmeis 2018).

3.1.5 Specific gravity

The specific gravity of a dredged-material sample helps to predict the behavior (i.e., dispersal and settling characteristics) of dredged material after disposal. Results of specific gravity are listed. Specific gravity in samples (G1 to G10 samples) and core (C1 to C6) sediments ranged between 1.7-2.5 and 1.45-2.70 gram/cm^3, respectively. The geographic distribution of the percentage of specific gravity of "G and R-S" samples in the harbor basin is shown in Figure 17. Specific gravity in the offshore samples varies from 1.8 to 2.6 grams/cm^3, and their geographical distribution is depicted in Figure 18.

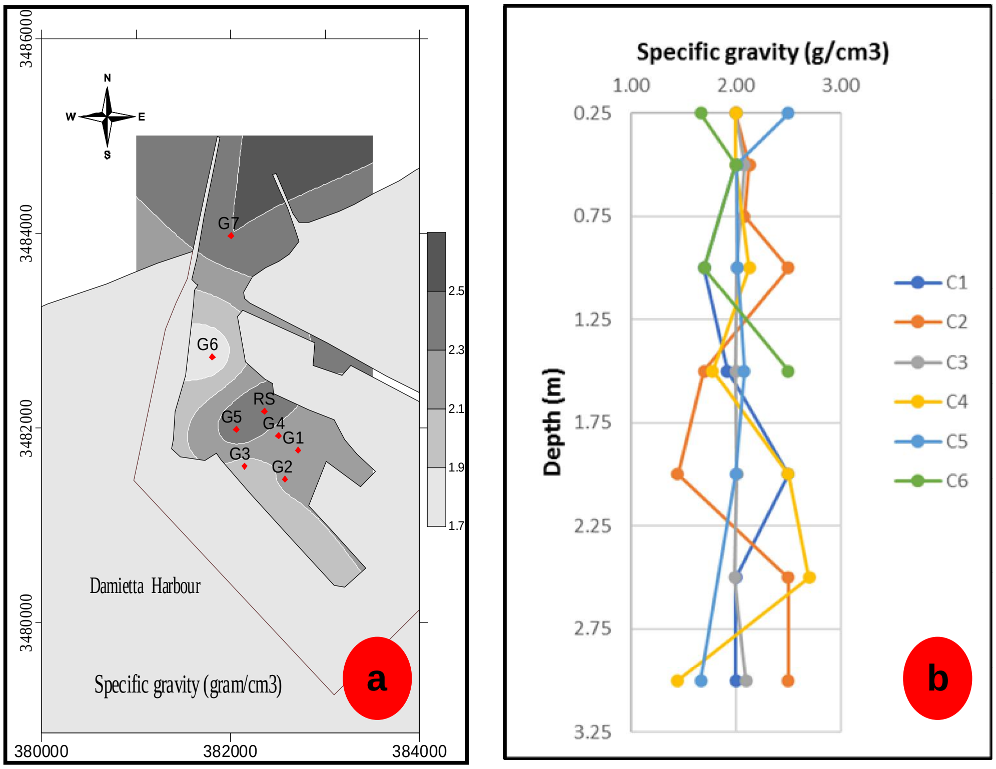


Fig 17. Geographical distribution of specific gravity (gram/cm^3) of the Grab samples in the Damietta harbor basin.

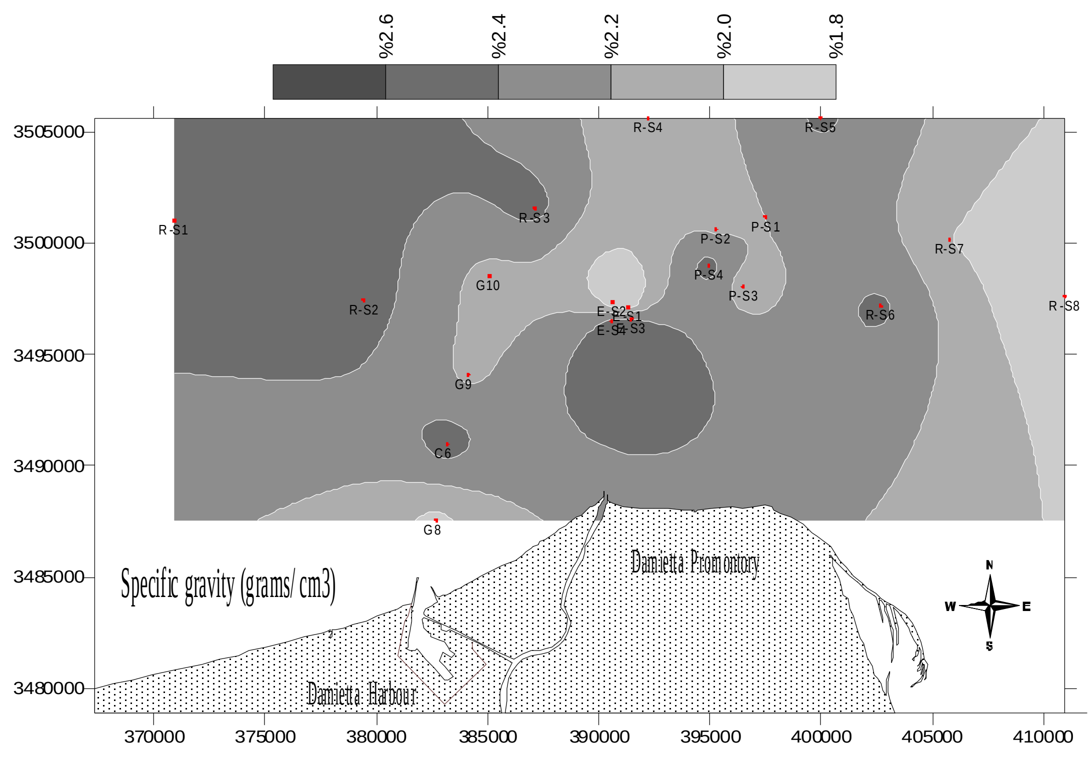


Fig 18. Offshore geographical distribution of specific gravity (gram/cm^3).

3.2 MARINE BOTTOM COMMUNITIES

Benthic organisms play an important role in the economy of the natural water systems. They act as a link in the energy flow from the primary producers to fish. They affect the structure of fish and invertebrates' communities that act as benthic predators. Microfauna are important in benthic communities: both as competitors with the macrofauna for food resources and as prey for benthic invertebrates and fish. Mollusks constitute the food requirements for some bottom invertebrates and some demersal fishes. The bottom fauna by itself is a good indicator of the trophic state of the sea through their natural habitats that is triggered by the combined action of various physical and chemical factors.

Among many factors which affect the successful settlement of the pelagic larvae of bottom invertebrates (temperature, salinity, food supply …..etc), is the suitable substratum which is a predominant factor, Consequently, the nature of the bottom may determine a great extent the kinds and abundance of bottom animals. The type of bottom sampled was dark clayed silt or muddy. Generally, the diversity of species was low and only 4 major taxa were recorded and represented by Polychaeta (13 species) Mollusca: bivalves 9 sp. Gastropods 2 sp. Crustacea is represented by several orders: Amphipoda 2 sp., Tanaidacea 2 sp., Isopoda 1 sp., Cumacea 1 sp., and the last taxa was Nematoda.

Stations number G6, G2, G3, and G1 represent the richest stations compared with the other stations, while stations 8 and 7 have a very poor diversity of species and a very low total number of individuals. Polychaetes dominated all stations except station 7 where no organisms were represented, followed by Molluscan bivalves and then crustaceans which dominated station 4. According to the total number of individuals recorded the richness of species was as follows:

1. station G6 (166 organisms),
2. station G2 (141 organisms),
3. station G 3 (78 organisms),
4. station G1 (46 organisms),
5. station G7 has a number of 58 organisms, while
6. Offshore stations show a very poor number of organisms ranged from (7-13 organisms/sample).

The polychaetes were not present in station G7 which represents the area of the grain berth and hence it could be attributed to the instability of the bottom sediments due to the traffic of the major containers and large ships in the Port.

Generally, the literature shows that the impact of depositing dredged material in the marine environment depends on the amount of sediment deposited, the resulting turbidity, the particle size, dumping date, water depth, and currents, as well as the similarity between the dredged material and the initial natural sediment at the dumping site ((Essink 1999; Powilleit et al., 2006; Hermand 2008). However, the effects of offshore sediment dumping on benthic assemblages differ greatly from one site to another (Harvey *et al* 1998; Collins 2004; Powilleit et al., 2006; Hermand, 2008). Thus, general conclusions are difficult to draw, suggesting that assessments must be established on a case-by-case basis (Harvey et al., 1998). From the results of the present study, it is clear that the proposed dumping site sediments characteristics have coincided with the majority of the harbor basin sediments.

3.3 PROPOSED MANAGEMENT MEASURES FOR DAMIETTA NEW HARBOR

Since the Damietta Harbor was constructed in 1986, the average annual maintenance dredging volume has been 1,180,000 m^3 (Damietta Port Authority, 2022). The preferred disposal method for dredged sediment is open water disposal. Dredging activities in Damietta harbor are - in general - periodic maintenance dredging on regular basis to maintain the existing facilities. The main purpose of this process is to deepen the main access channel and the main harbor basin.

However, offshore disposal is contingent on the sediment's suitability. Although spacing between samples of the present study was relatively wide, this distribution indicates that the seafloor of the study area and its surroundings are dominated by patches of sand, silt, and silty clayey (mud). Different regulatory agency requirements apply to disposal permits for the existing offshore site. Permitted upland wetland reuse/disposal and upland landfill disposal sites have their regulatory requirements, which are the responsibility of the site operators and not of the dredger.

The management aim for the dredged material from the Damietta Harbor and the navigation channel area is to address the followings:

- Maintain in an economically and environmentally sound manner the access channel necessary for navigation in the area.
- Eliminate unnecessary future dredging activities in the area.
- Conduct dredged material disposal in the most environmentally sound manner.
- Maximize the use of dredged material as a resource; and
- Establish a synergetic framework for dredging and disposal applications.

The following section presents the proposed sediment management measures to protect, improve and support rational uses of Damietta New Harbor.

***Issue I**: Deepening the harbor navigational channel*

Damietta harbor has been protected by two breakwaters built in 1982 to prevent the prevailing easterly and westerly sediment transport from shoaling the navigation channel, which extends about 20 km offshore. Although this protection, the navigation channel has experienced continued seabed sedimentation which has negatively affected navigation safety. Sedimentation is concentrated in the harbor entrance near the head of the western breakwater. As a result, periodic annual dredging of the channel has been carried out since 1986, with an average of 1.18 x 10^6 m^3/yr. This amount is much higher than expected in the early impact assessment of breakwaters on the beach morphology. The sedimentation process is complex and is influenced by the temporal variability in the direction and intensity of the incoming waves, currents, and the orientation of coastline and seafloor morphology. Sediments are transported to the sink area including the navigation channel from adjacent coastal sources at Burullus and Ras El Bar as well as from the Damietta offshore shoals by several pathways comprising the opposing easterly and westerly littoral drift, north-northwest and north-northeast offshore currents as well as from onshore sediment movement. Sediments are dispersed primarily away from sediment sources toward the sink area by both contour-flowing bottom and cross-shelf (seaward-trending currents). Together with these sediment sources is the continuing bypassing of sediment around the head of the western jetty into the harbor entrance.

The harbor deepening and expansion component require significant dredging of maintenance material above the current 15 m depth, deepening to the proposed depths of up to 18 m, and dredging of the expansion area that is currently upland. The total volume of material to be dredged is approximately 20 million m^3. Future dredging will also be required to maintain the proposed depths.

***Issue II:** The proposed harbor extension*

The area of the proposed harbor extension is about 300 m wide and about 1.5 kilometers long and 17 meters deep. It will occupy approximately 130 hectares of land at the port. There will be dredged but with no changes on its inlet. The area has witnessed high amounts of siltation (Figure 19).

Fig 19. The proposed extension of the harbor.

Issue III: Management of the dredged sediments

a) Dredged sediments from the deepening of the navigational channel

Dredged materials are disposed of at the existing site to move sediments away and out of the area. Dredged materials are disposed of in a dumping site, ~2-3 km east of the harbor, in water depths of 15m, approximately 11 km offshore from the coastline. This site was mostly designated at the start of the operation phase of Damietta Harbor (1985) and was approved by the Egyptian ministry of transport (MOT) and the Egyptian Navy. Ever since this area was receiving all the dredged material from both the main port basin and the access channel.

Current annual dredge maintenance in Damietta Harbor results in the disposal of a considerable amount of sediment layer. The aquatic existing dredged material disposal site is operated as a dispersive site; that is, material disposed at the site tends to disperse and be carried by currents. Reversed westward currents in part rework and disperse dumped sediments once again to the navigation channel. Because of mitigation, studies have proposed measures to overcome this undesired channel sedimentation. The west and east breakwaters have to be extended respectively, 1.7 and 1.5 km offshore to reach an 8 m depth of closure, i.e., a water depth of little sediment transport. Dispersal is dependent upon the material type, disposal volume, and frequency. Among recent questions, there is the issue of depositing sediment dredged from the navigation channel of the harbor. The current dumping site is known to have contributed over the last decades to maintaining the silting up of the channel. For that reason, the present study works to find a less detrimental dumping area to minimize the reversed impact of dredged sediment dumping.
From the present study results of the bathymetry obtained from "The National Center For Environmental Information, NOAA" for the Mediterranean Sea, it appears that a site with fine-to-medium clean sand offshore from the mouth of the Seine estuary would be a good candidate in view of the biological and economic perspectives. Dumped material that comes from the navigation channel is composed of fine sand containing a significant proportion of shell debris. The fine fraction (<63 mm) makes up between 30% and 50% of the bulk sediment. Thus, the similarity between dredged material and sediments in the dumping area will play an essential role in controlling the type and severity of the impact on the marine environment. The proposed dumping sites for the dredged materials are considered offshore located north of the initial one (Figure 20). Accordingly, the proposed dumping area is supposed to have double benefits which are the reduction of the

navigational channel re-shoaling and the protection of the adjacent beaches from erosion (as a mitigating tool).

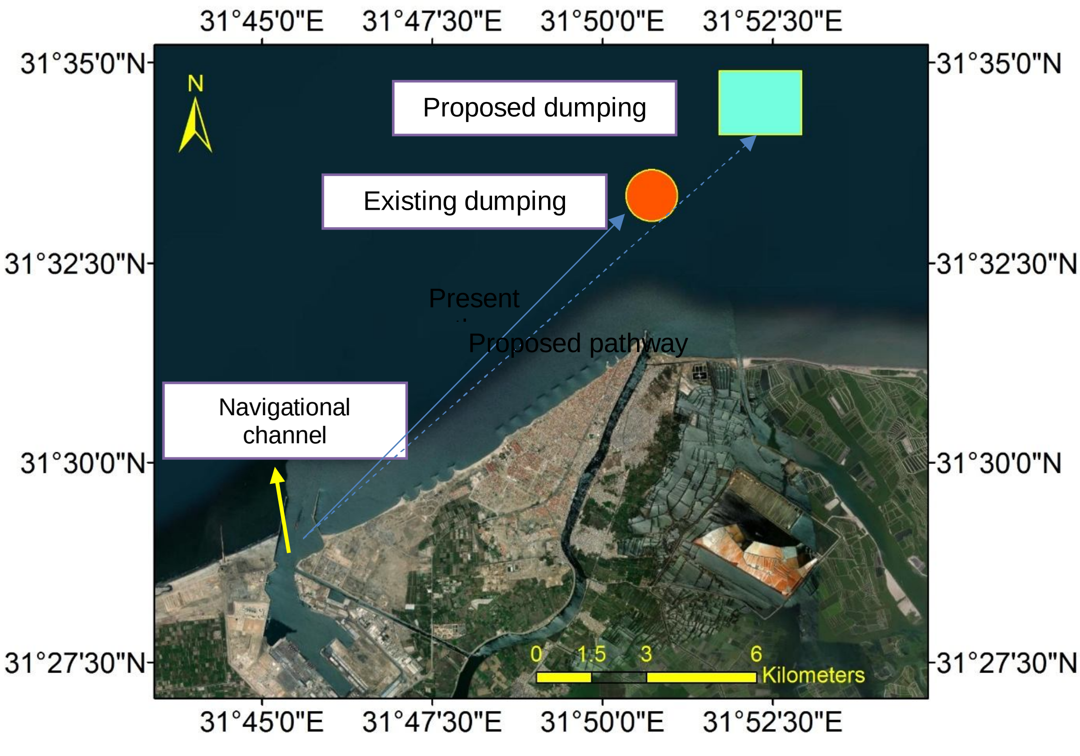


Fig 20. Offshore existing and proposed offshore dumping sites.

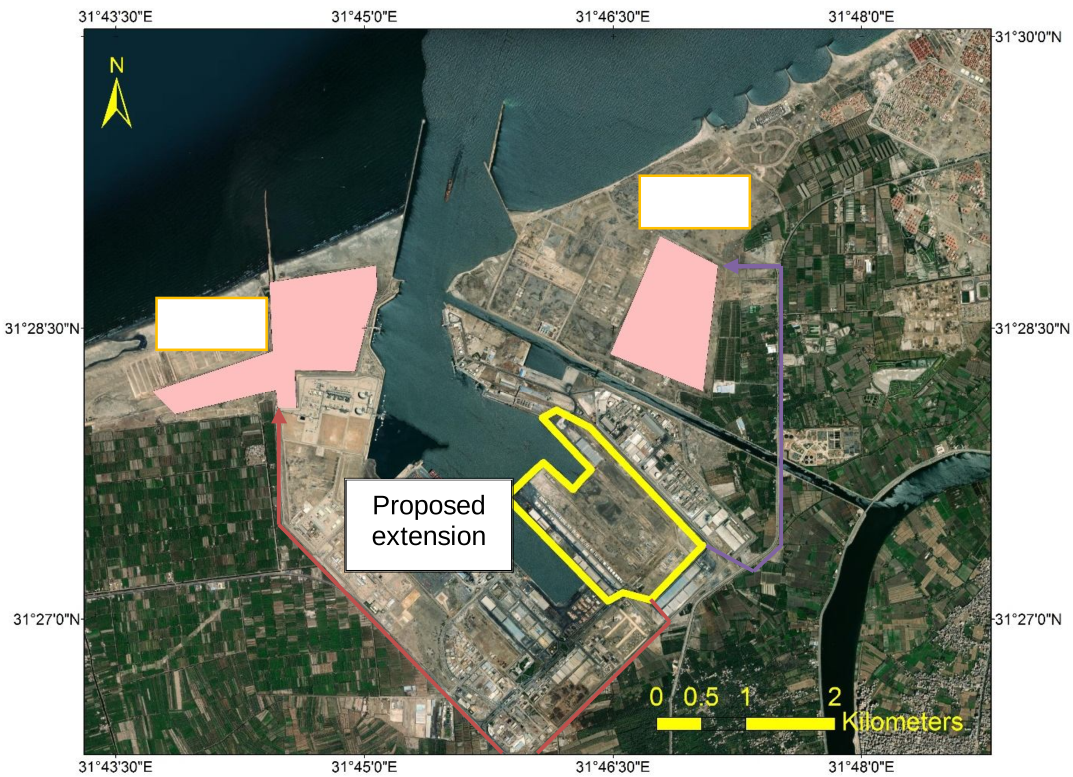
b) Disposing sediments dredged from the harbor's extension

An amount of 12.63 $x10^6$ m^3 deltaic sediment is expected to be dredged from the excavation of the harbor-basin extension project. In this study we propose disposing of this sediment volume in two dumping sites. Site #1 is a low-lying area that lies northwest of the project site and is fronted by an accretionary coastline. To avoid possible wave overtopping, this site requires a landfill elevation of ~3 m above mean sea level that is corresponding to a volume capacity of 2.98 $x10^6$ m^3. Environmentally, the created landfill planform can provide a sustainable area for future beach development and in turn improve the project outcomes. Site #2 is located northeast of the basin in a place previously used for dumping sediment dredged from the navigation canal connecting the main basin and the Damietta Nile branch. This site has a large surface area and can efficiently receive the remaining sediment volume,
amounting to 9.65 $x10^6$ m^3

c) *Disposing sediments dredged from the extension basin*

Previous studies have indicated that basin-dredged material has been wrongly called "spoil" for years and they are commonly carried to dumping or disposing of sites. In a few cases worldwide, dredged material is practically used for much beneficial inland and coastal uses mostly landfill of wetlands and low-relief areas (Welch et al. 2016). Beneficial uses of dredged material as borrowed sediment for landfill are widely applied worldwide(Carter and Akerman 2018). In a few cases, they are used to manufacture bricks, glass containers, and cement. According to the EEAA guidelines (2009), engineering structures built on the coastline that may significantly change the beach morphology must require environmental impact analysis and mitigation. In our case study, the inland dredging of the new harbor basin would not impact the adjacent coastline and thus no environmental impact analysis is required. However, the only impact may be resulted from the improper management of the dredged sediment resulted from dredging activities. Therefore, dredged sediment must be managed in economically and environmentally sustainable disposing sites. It has been estimated that a total of 12.63 x10^6 m^3 sediment volume is expected to be dredged from the extension basin project. This sediment volume is yielded by multiplying surface area (789510 m^2) by the dredged basin depth (16 m). Therefore, it is necessary to assure suitable area to place dredged material resulted from excavation of the project site.

The following figure presents the proposed sites for landfill materials disposed from the harbor extension (Figure 21). It is worth noted that there are buffer areas between the proposed dumping site and the adjacent cultivated area to avoid their adverse impact on the plants.



F ct area). Site #1 is identified in this study as a low-lying area suitable for land filling whereas Site #2 has been previously used for dumping sediment excavated from the navigation canal connecting between the main basin and the Damietta Nile branch whereas. General pathways connecting between the proposed dumping sites and the excavated basin are also denoted as lines.

4. CONCLUSIONS

Planned dredging operations in Damietta Harbor require sediment investigations to understand the possible disposal or re-use considerations. The purpose of this study is to characterize sediments that will be dredged to determine their suitability for placement in either an upland, an offshore disposal site, or at an existing beach for re-nourishment.

Data of the examined samples were used to assess the feasibility of the environmental implications of the proposed disposal sites on the continental shelf of the study area. It is proposed to place the material dredged from deepening the navigation channel within a disposal site proposed on the middle shelf off the Damietta promontory, approximately between 15 and 20 m water depth off the Damietta promontory. As would be expected the southward (landward) current occasionally occurring in winter can bypass coarse-grained sediment dumped in the proposed disposal site toward scoured seabed areas fronting the 6-km long Damietta seawall built to protect the Damietta promontory from shore erosion. We believe that sediment bypassing can mitigate scour problem and acting as a feeder to the adjacent shorelines and the littoral cell in the study area. On the other hand, precautions must be considered to reduce probable sedimentation in the Damietta Nile estuary. Furthermore, the subsequent plume of suspended sediments which may lead to altering seafloor habitats.

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Competing interests

The authors declare no conflict of interest.

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