

1 **Synergetic approach for the harbor sediment**
2 **management: The Damietta harbor (Egypt) case**
3 **study**

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8 **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 ϕ (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.

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

14 **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.

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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

33 domestic supply to Egypt (Luis and Moncayo 2005). The most important competition for
34 Damietta on container transshipment activities on the international route can be found in
35 the port of Tauro, Port Piraeus, and Port Said. The monthly value of exports from Damietta
36 port in Egypt stood at close to 170.2 million U.S. dollars in July 2020, a drastic increase of
37 around 53 percent from the preceding month. Between January 2019 and July 2020, the
38 portion of Egyptian exports leaving via Damietta port ranged between approximately 4.19
39 and 8.29 percent of the nation's total exports. Moreover, the export value ranged between
40 181.4 million U.S. dollars and 101.9 million U.S. dollars in March and November 2019,
41 respectively (<https://www.statista.com>, 2022).

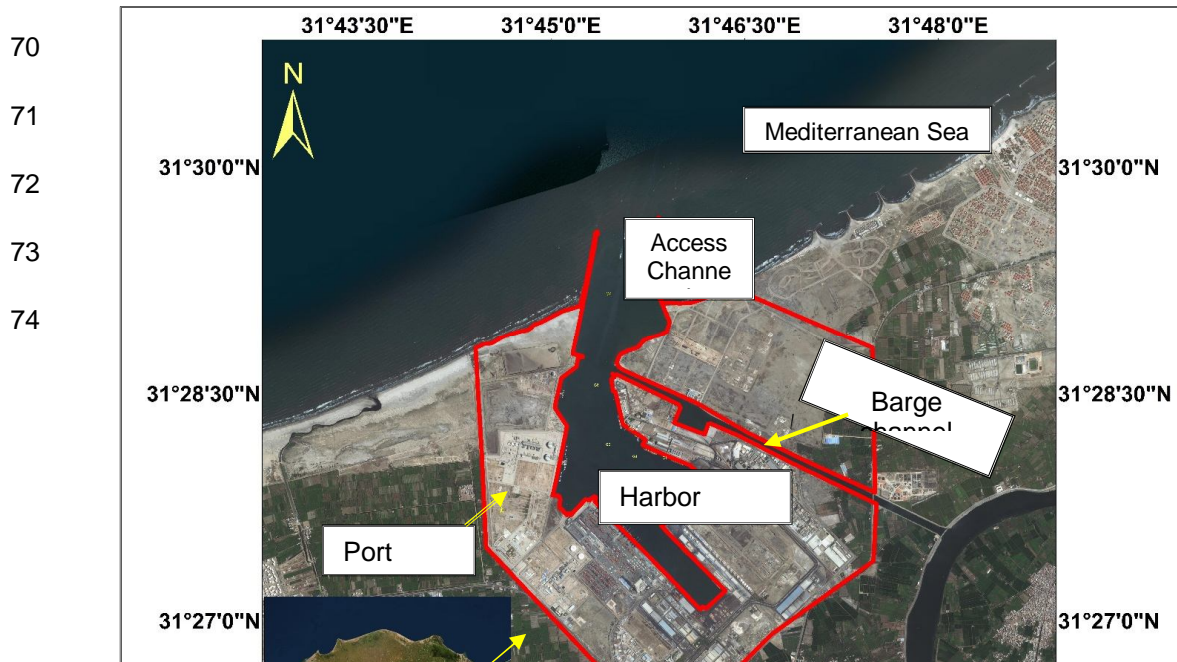
42 The port is subdivided into two main parts; the shipping area, which is an inland section
43 containing 16 berths and quays, and the water area which is composed of an access
44 channel connecting the shipping area with the Mediterranean Sea and the main basin. To
45 ease access to inland navigation,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

51 Although there are several studies were carried out and published on the sedimentation
52 problem of Damietta harbors such as El-Asmar & White (2002), Frihy et al. (2002), Abo Zed
53 (2007), Gad et al.(2013), and El-Asmar et al. (2016); the management of dredged sediments
54 in a sustainable perspective has not addressed yet. Thus, the beneficial placement of
55 sediment calls for putting those materials where they are most needed or where they would
56 have the least potential for adversely affecting the harbor's environment. While there is an
57 extensive body of literature that describes potential beneficial uses of dredged material,
58 relatively few plans were found that appear to implement the practice. Therefore, the
59 objectives of the present study are to provide an example of the best management of the
60 dredged harbor sediment from the navigational channel deepening and the expansion of the
61 harbor basin through a comprehensive study of the harbor sediment characteristics. In
62 addition to proposing a new offshore dumping site that will solve the problem of redispersing
63 of the dumped sediment and re-shoaling of the harbor entrance.
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65 2. MATERIAL AND METHODS

66 2.1 Study area

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



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82 **Fig 1. Location map of the study area**

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84 The Damietta harbor is about 8.5 km west of the Damietta branch of the River Nile
85 on the Mediterranean Sea west and about 70 km west of Port-Said Port. The
86 construction area covers about 25 km. The navigational channel (canal entrance) is
87 about 11.3 km long and 300 m wide which gradually decreases till it reaches 250 m
88 at water break and 15 m depth.

89 The harbor is protected by water breaks, the western water break is about 1500 m
90 seaward long and its landward is about 140 m with a total of 1640 m and the Eastern
91 water break is about 538 m long seaward and about 200 landward with a total of 738
92 m. The water breaks are protected from the external side of the industrial acrid
93 bocks, and they are topped by a cement layer.

94 The barge channel consists of two ports one is 1350 m which links the barges dock
95 to the sea and the other is 3750 m which links the dock to the Nile branch. The area
96 of the barge dock is 250 x 250 m and it is equipped with a berth of 250 m long where
97 the water depth is 5 m deep. The diameter of the rotation dock is 500 m and its depth
98 is 14.5 m in front of the containers broth and 12 m in front of the general cargo
99 berths.

100 The seafloor of the study area and its surroundings is dominated by patches of sand,
101 silt, and **silty clayey** (mud) (El Sammak, 1995). The study area is fronted by a series
102 of protection works including the shore parallel detached breakwaters and the 6-km
103 long Damietta seawall.

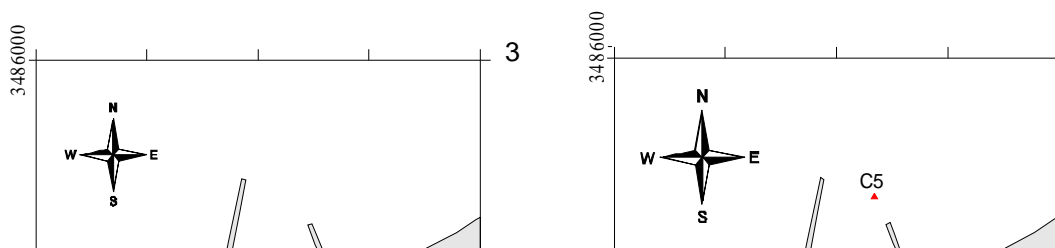
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105 **2.2 SEDIMENT SAMPLING**

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

109 The samples were collected during 2017 from the harbor basin while the core and offshore
110 sediments of the study area were obtained during June 2007. It is worth to note that the
111 present study depends on offshore sediments collected during 2007. The present work
112 depends on the sediments were collected during the year 2007 for core sediments and the



113 offshore survey to reduce the high cost of resampling in the open sea for the year 2017.
114 Figures 2 and 3 and Table. 1 shows the sampling positions of the harbor basin and offshore
115 areas.

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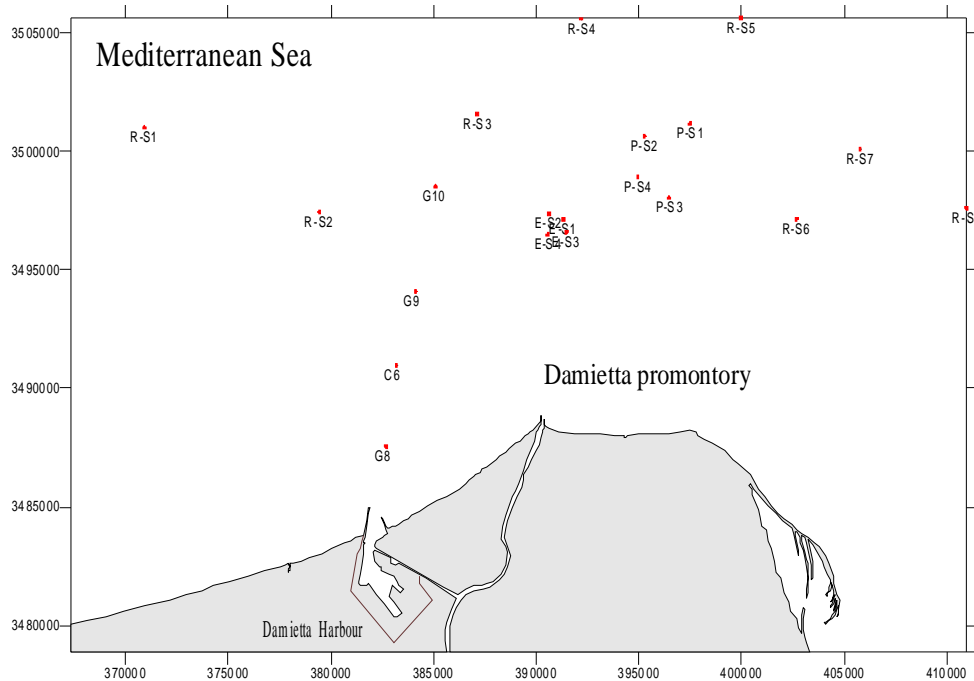
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131 **Fig 3. Study area showing locations of the followings: a) Grab sediment samples (G1**
132 **to G7 and RS) in the Damietta Harbor basin, and b) Sediment cores (Core 1 to Core 6).**



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

138 Table 1. The geographic locations of seabed samples and cores are examined in the present
 139 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	31 27 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

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141 Surficial sediments were collected using a **galvanized Van Veen grab sampler** whereas a 3-
 142 m long gravity corer was used to recover subsea samples. The recovered sediment cores of
 143 approximately 3-m length are vertically sub-sampled at approximately 20 to 50 cm intervals.
 144 The surficial samples were collected in plastic containers whereas the core samples were in
 145 PVC tubes.

146 The core length and its percentage recovery are listed in Table 2. Each core was cut into 6
 147 parts. Starting from the top these parts were taken at successive core intervals: 0-0.25,
 148 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
 149 400 ml. To meet the required sediment volumes, the corer device was released twice in
 150 each oceanographic station. Sampling and cutting of the core were made on board the
 151 research vessel. The recovered core intervals were marked and capped and placed into ice
 152 boxes.

153 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

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155 2.3 SEDIMENT CHARACTERISTICS AND CHEMICAL ANALYSES

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157 2.3.1 Grain size analysis (G. S. A.)

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159 About 15 to 50 gm of the oven-dried samples were subjected to grain size analysis. The
 160 mechanical technique was used for coarse fractions (less than 4 Ø); by sieving through a
 161 standard set of sieves (Prüfsiebring A TGL 7354) mounted on an electric shaker machine

162 (Test Sieve Shaker). The standard applied time of sieving was 20 minutes. The sieves were
163 arranged in 1 ϕ class interval from top to bottom. The pipette analysis was used for the fine
164 fractions (more than 4 ϕ) using the technique described by Krumbein and Littlejohn (1938).
165 In the present work, the graphic measures given by Folk (1980) were employed for the
166 results of grain size analysis using phi notation, where $\phi = -\log_2 d$ (d given diameter value in
167 mm). Cumulative percentages were plotted against grain size interval (ϕ) on a probability
168 paper. The 5 ϕ , 16 ϕ , 50 ϕ , 84 ϕ , and 95 ϕ values were directly interpolated from the
169 cumulative curves. From these percentiles, the inclusive graphic mean size (Mz) and
170 inclusive graphic standard deviation (sorting, σ_1) were calculated.

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

$$\text{Inclusive graphic standard deviation } (\sigma_1) = (\phi_{84} - \phi_{16}/4) + (\phi_{95} - \phi_5 / 6.6)$$

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174 **2.3.2 Determination of total solids**

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

179 The total solids content was determined as follows:

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

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

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184 **2.3.3 Determination of total carbonates**

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

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

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192 **2.3.4 Determination of total organic matter content**

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

199 1 ml 0.2 Ferrous Ammonium Sulphate \equiv 1.15 x 0.6 mg organic carbons

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

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202 **3.3.5 Determination of density or specific gravity**

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

$$\text{SG} = W_s / (W_s - (W_{ws} - W_w))$$

211 where SG is the specific gravity of sediment particles; W_s is the weight of the
212 sediment; W_{ws} is the weight of the flask filled with the water-sediment mixture; W_w is the weight of the
213 flask filled with distilled water.

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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.

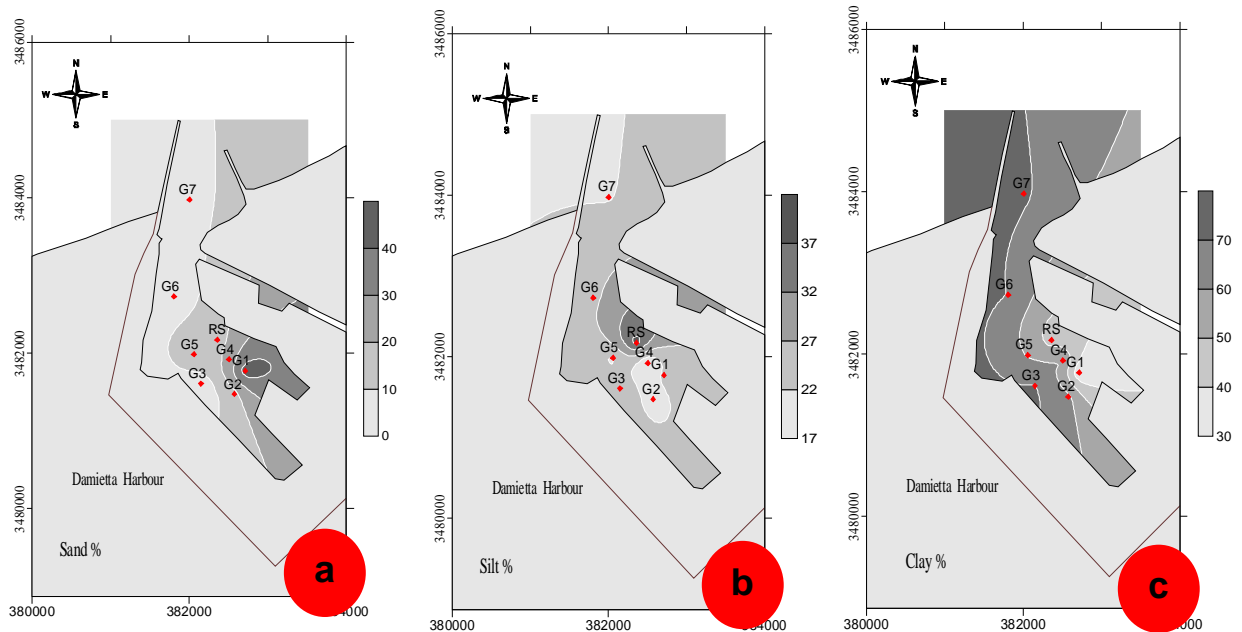
3. RESULTS AND DISCUSSION

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 ϕ (coarse silt, medium silt, fine silt & very fine silt) and 4.43-8.85 ϕ (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 ϕ (poorly & very poorly sorted) and 1.24-3.27 ϕ (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.



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

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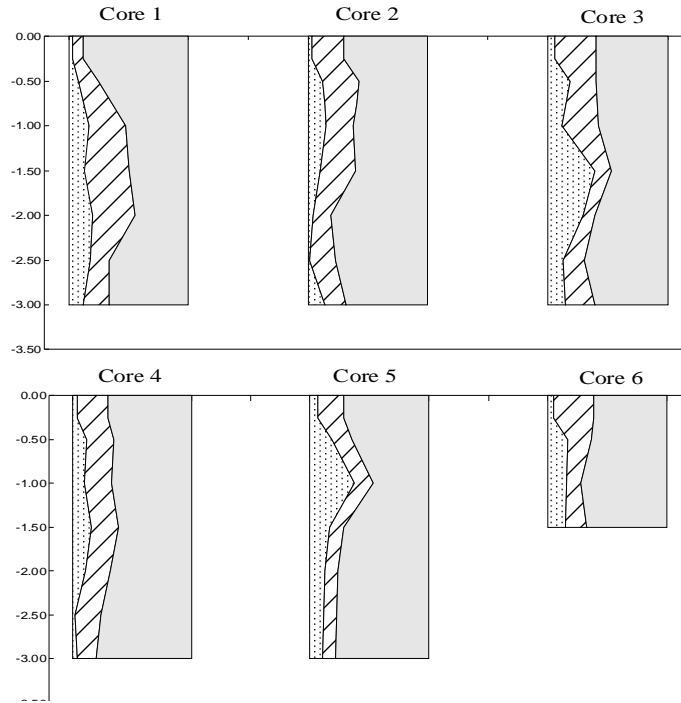


Fig 5. Vertical distribution of sand %, silt%, and clay% in the examined cores.

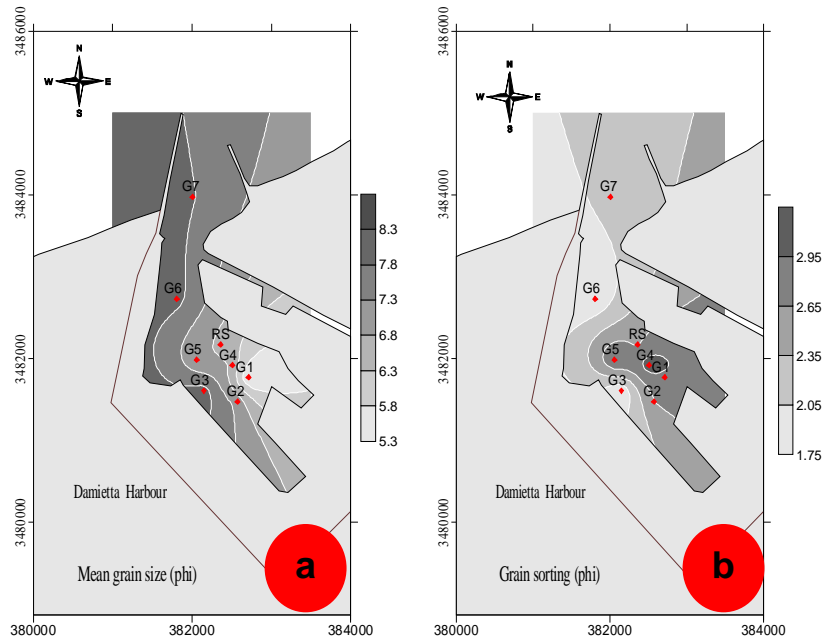
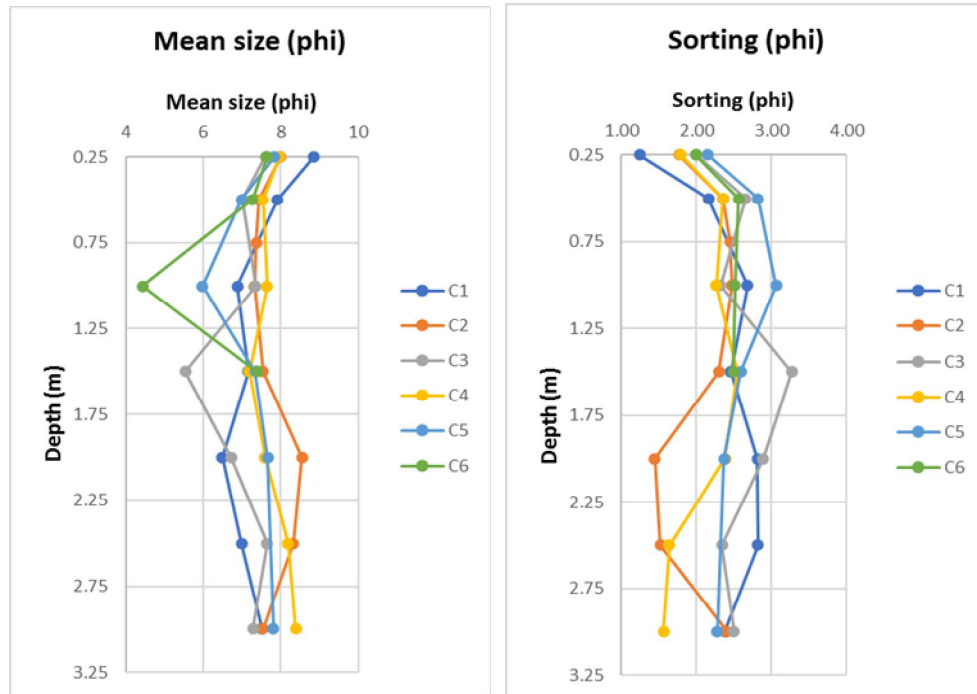


Fig 6. Geographical distribution of a) mean grain size (phi unit) and b) grain sorting (phi unit) of Grab samples in the Damietta harbor basin.



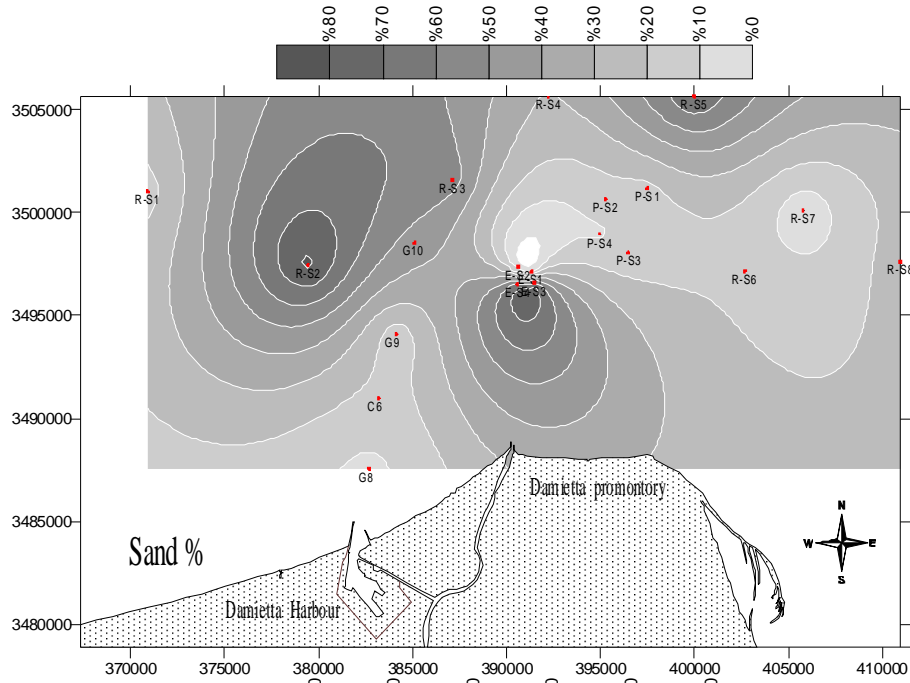
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Fig 7. Geographical distribution of a) mean grain size (phi unit) and b) grain sorting (phi unit) of Core samples (C1 to C6).

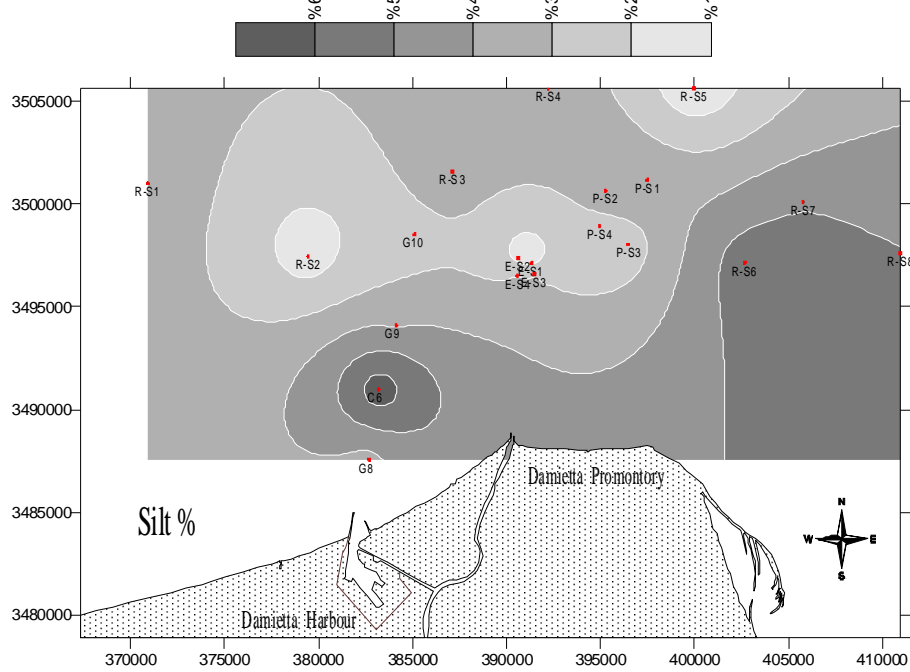
3.1.1.2 Offshore surface sediments

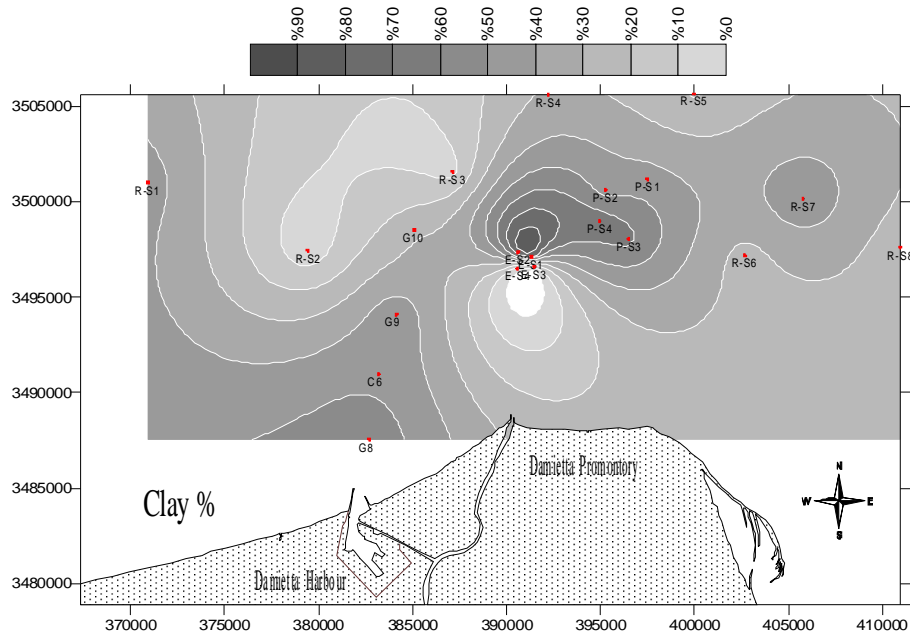
The offshore spatial distribution of percentages of sand, silt, and clay are shown in Figures 8 while, mean grain size (in phi unit) and sorting (in phi unit) are demonstrated in Figures 9 to 11, respectively. This geographic distribution includes samples from offshore (existing and proposed dumping 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 ϕ 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 ϕ and is defined as poorly sorted and very poorly sorted (Figure 10).

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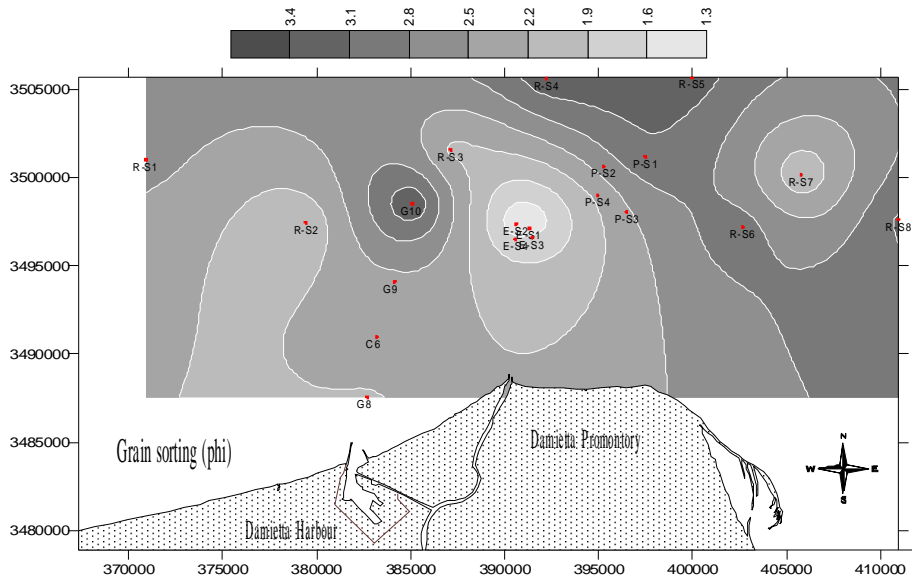
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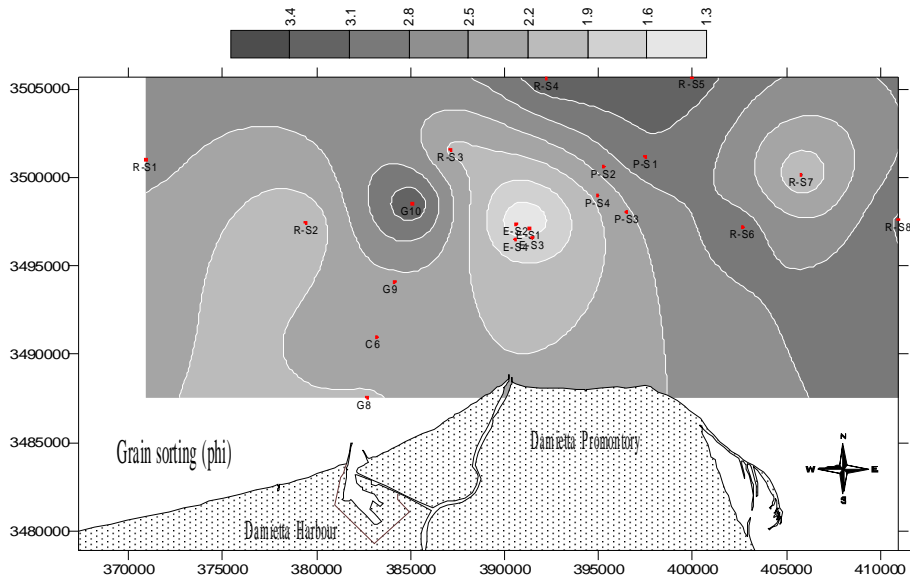
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Fig 8.Offshore geographical distribution of a) sand%, b) silt% and c) clay% of Damietta.



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



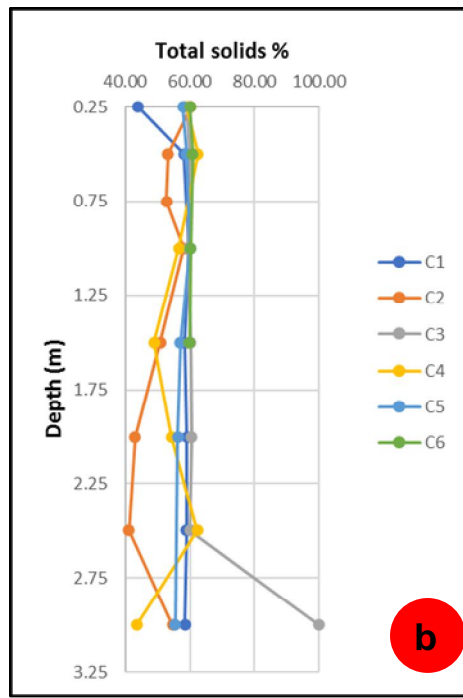
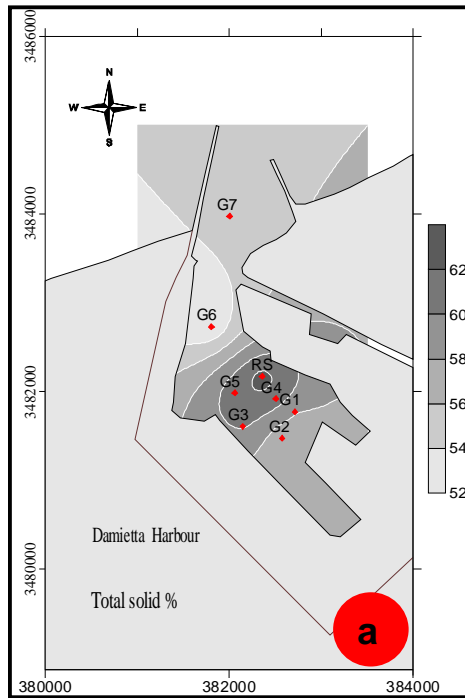
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Fig 10.Offshore geographical distribution of grain sorting (standard deviation) in phi unit.

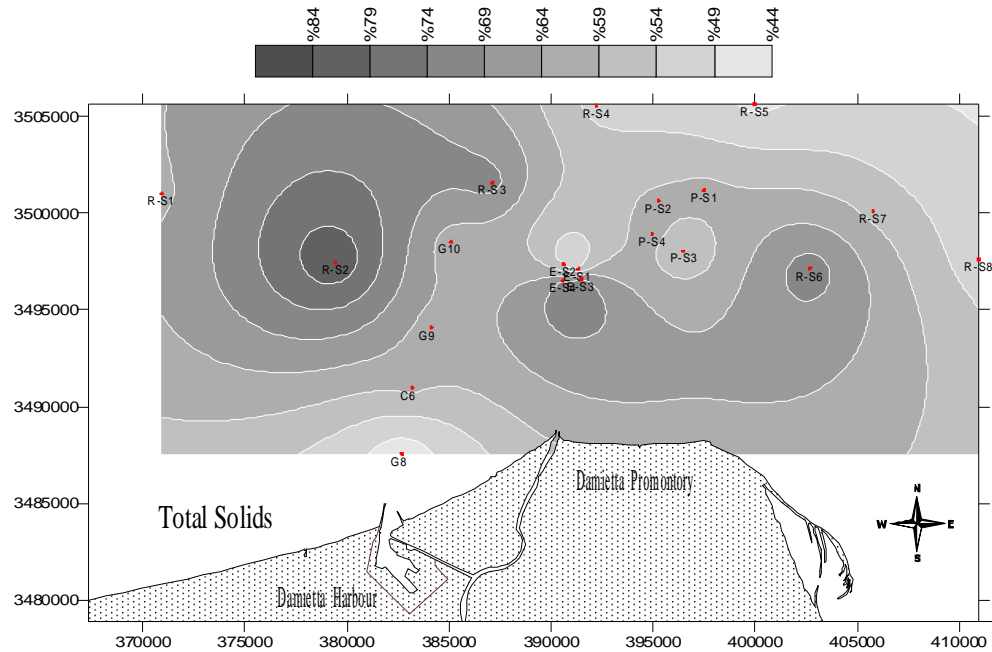
3.1.2 Total solids

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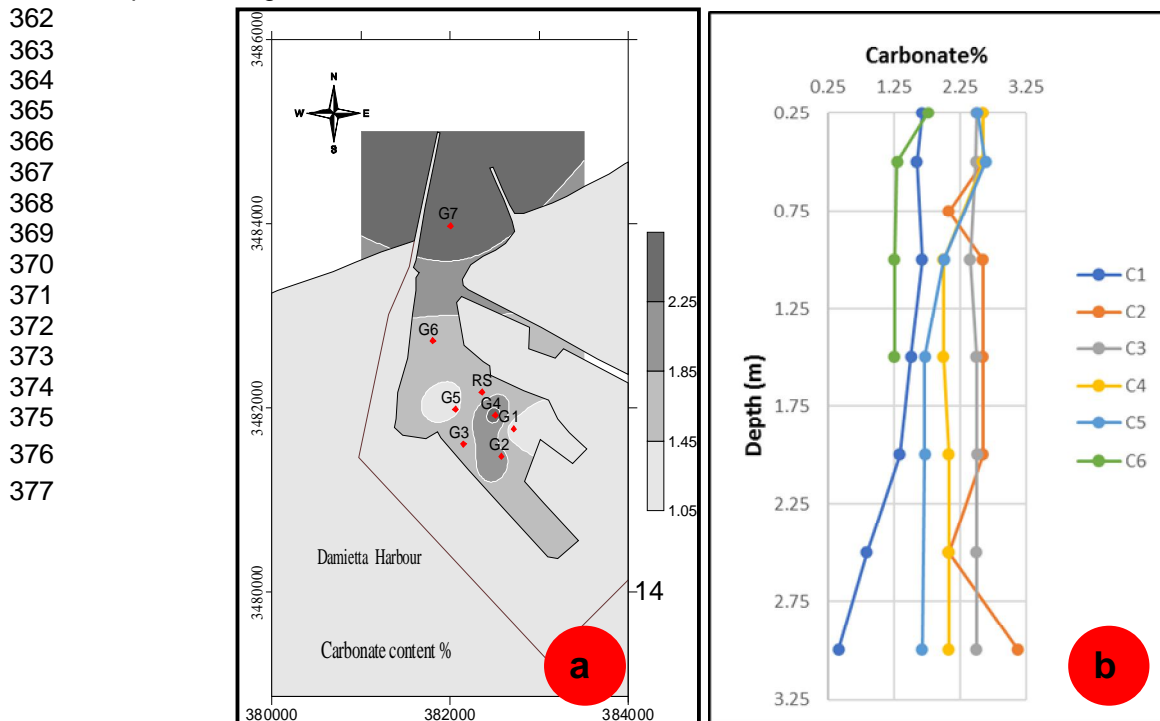
348 **Fig 11. Geographical distribution of total solids % (a. the Grab samples in the**
 349 **Damietta harbor basin, and b. Total solids % distribution of the Core samples).**



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 351 **Fig 12. Offshore geographical distribution of total solids %.**

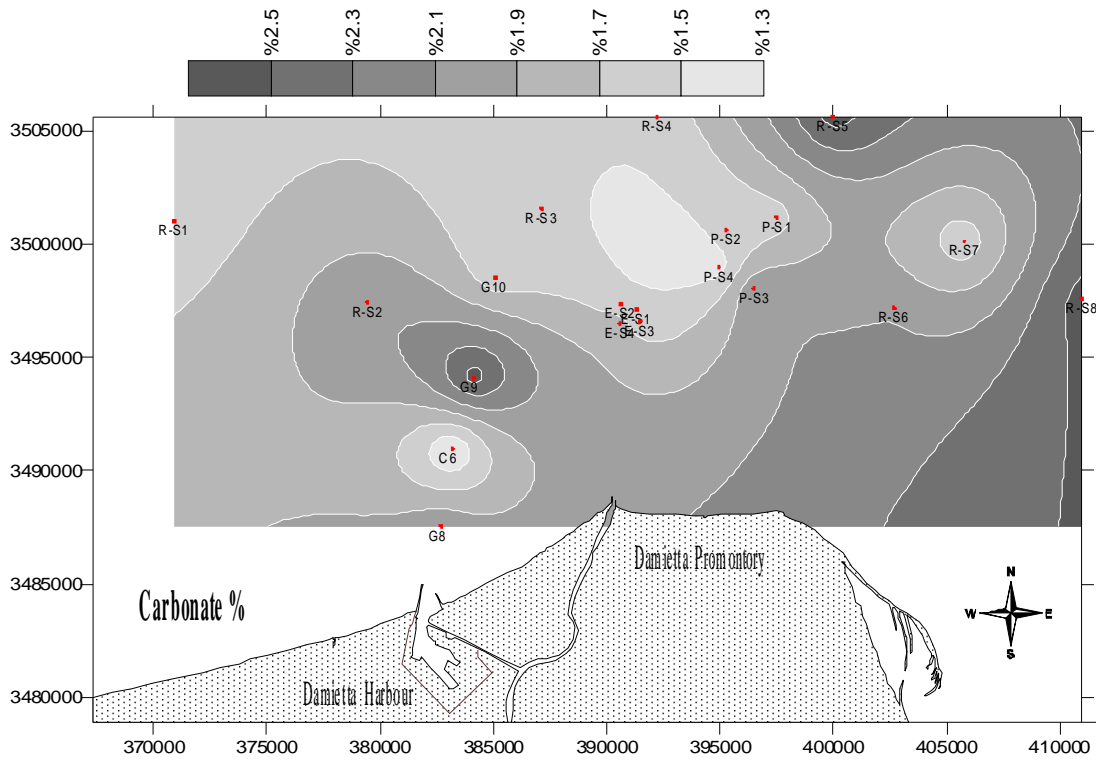
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 353 **3.1.3 Total Carbonate content**

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



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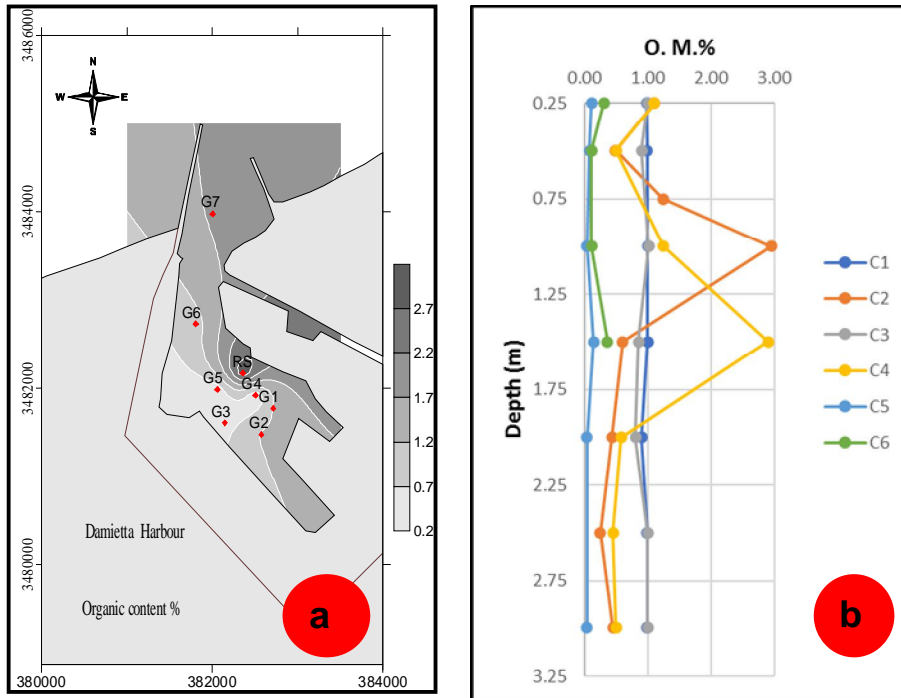
378 **Fig 13. Geographical distribution of carbonate content % (a. Grab samples in**
 379 **the Damietta harbor basin and b. Carbonate content % distribution of the core**
 380 **samples).**



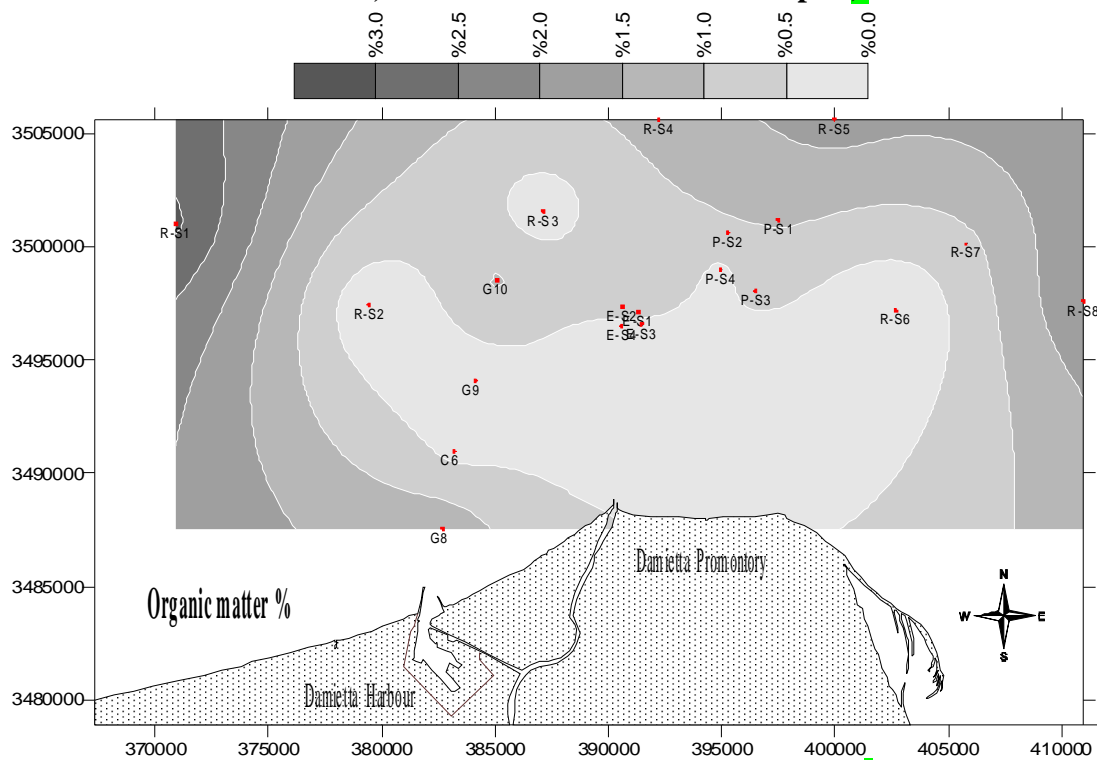
381 **Fig 14. Offshore geographical distribution of carbonate %.**

383 **3.1.4 Organic matter content**

386 Results of total organic matter are shown in Figures 15& 16. The total organic matter in
 387 samples (G1 to G10 samples) and core (C1 to C6) sediments ranged between 0.29-1.76
 388 and 0.04-2.95%, respectively. Total organic matter in the offshore samples varies from 0.0 to
 389 3.2%. Microscopic examination indicates that organic matter exists is mainly related to the
 390 plant remains exist in the total sediment samples.



391
 392 **Fig 15. Geographical distribution of organic matter % (a. The Grab samples in**
 393 **the Damietta harbor basin, and b. the core sediments samples).**



394 **Fig 16. Offshore geographical distribution of organic matter %.**

396 Generally, the value fluctuations are dominant as proceeding in the southward direction
397 inside the harbor. The maximum value is computed at the surface sediments of station 8
398 located at the southmost zone of the harbor, while the minimum is found at station 1 located
399 just beyond the left jetty at the mouth of the harbor in the open waters. The riverine input or
400 terrestrial discharge that characterizes the study area is regarded as the main contributor of
401 the organic detritus to the marine environment.

402 These results are recognized from the nature and characteristics of the samples themselves.
403 Such findings coincide with Marmin *et al* (2014), which suggested that the input of organic
404 carbon is not only due to settling but also through the incorporation of organisms.
405 Decomposition and mineralization of the organic contents help the important elements,
406 carbon, nitrogen, and phosphorus into circulation in the water in the form of carbon dioxide,
407 ammonia, and phosphoric acid, thus they are rendered available for the photosynthesis and
408 growth of the phytoplankton. Due to the sampling time during the summer season, the warm
409 temperature of the surface sediments may exert a great influence on the activities of the
410 living microorganisms, where high temperature increases the rate of mineralization and the
411 active decomposition of the organic matter and prevents its accumulation on the bottom. The
412 gradual renewal of the harbor water by drainage water, or through the exchange with the
413 marine waters at the opening increases the nutrient concentrations are favorable for
414 plankton productivity consequently, the supply of organic matter would be abundant.

415
416 The spatial distribution of TOC in the Damietta harbor surface sediments indicates the
417 expected pattern of the such harbor. Minimum values always characterize the marine
418 environments just outside the harbor, while directed in the southward direction, the TOC
419 concentration increase in a horizontal strip, reaching its maximum limit at the southmost part
420 of the harbor. In such environments with high photosynthetic activities, the shallow depth
421 prevents the falling biogenic particles from effective oxidation, which increase the
422 accumulation of organic matter on the bed sediments.

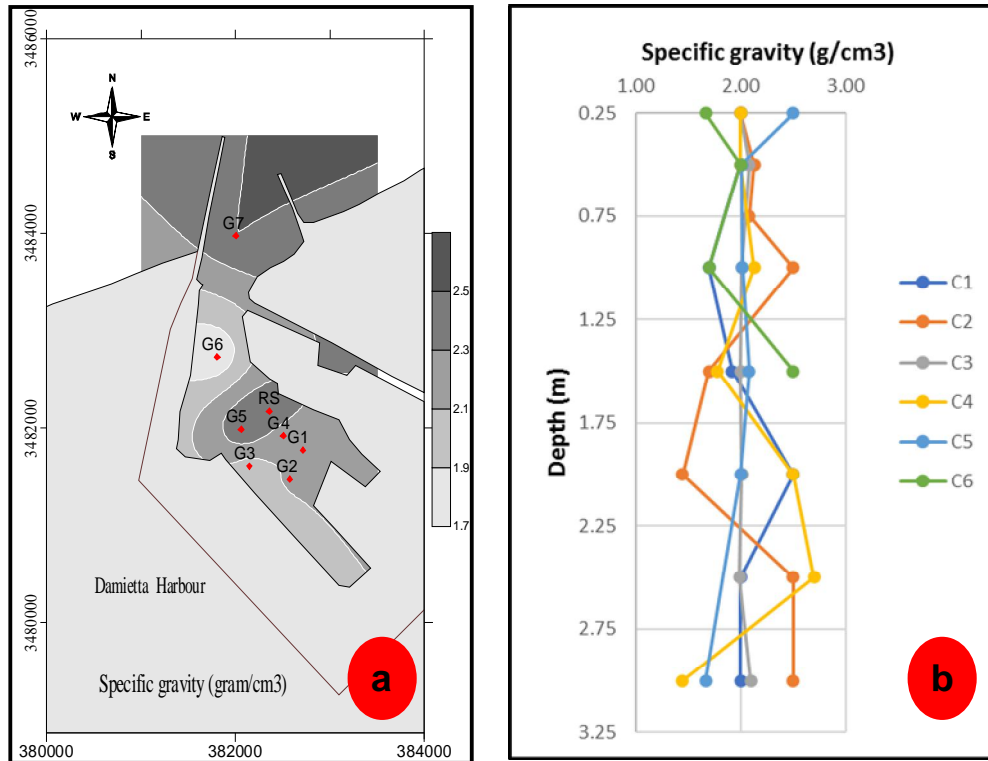
423 The sediments of the internal canal can be categorized in the high TOC contents areas at
424 the harbor, which may be due to the contribution of terrigenous materials and the
425 decomposition of plant and animal remains at the bottom of the water bodies through the
426 action of bacteria at the mixing zone in the drain. Particularly the oxygen content, bacterial
427 activity and movement in the chemical nature of the overlying water affect the character of
428 the organic substance (Shmeis 2018).

429

430 **3.1.5 Specific gravity**

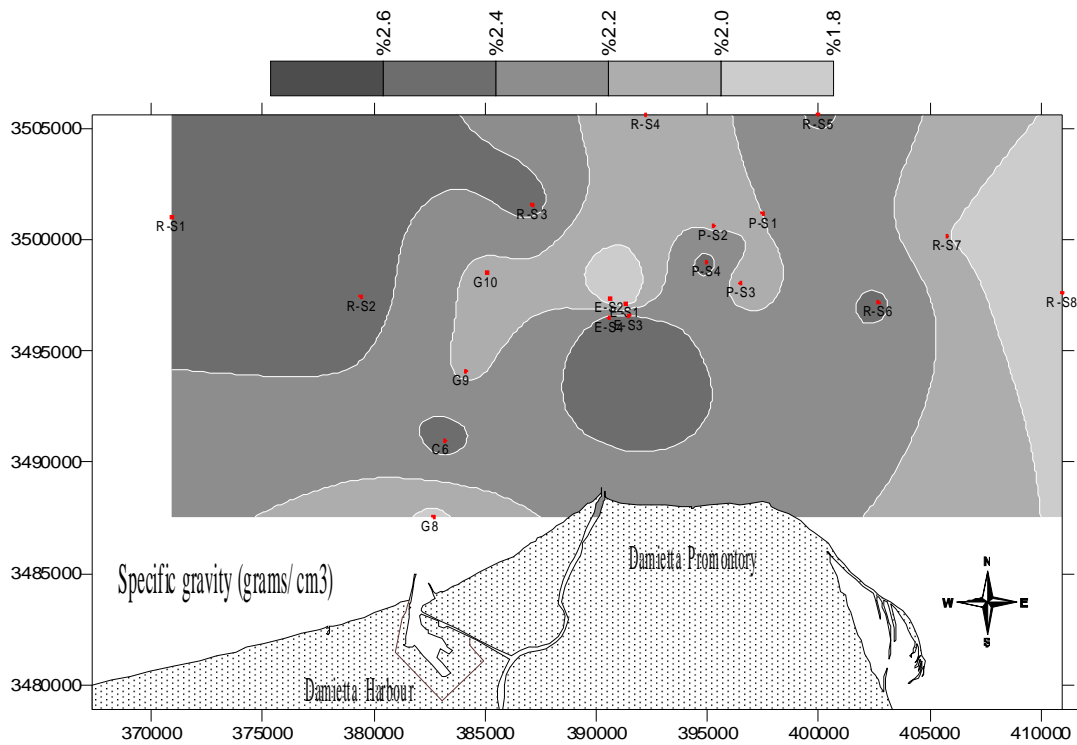
431

432 The specific gravity of a dredged-material sample helps to predict the behavior (i.e.,
433 dispersal and settling characteristics) of dredged material after disposal. Results of specific
434 gravity are listed. Specific gravity in samples (G1 to G10 samples) and core (C1 to C6)
435 sediments ranged between 1.7-2.5 and 1.45-2.70 gram/cm³, respectively. The geographic
436 distribution of the percentage of specific gravity of "G and R-S" samples in the harbor basin is
437 shown in Figure 17. Specific gravity in the offshore samples varies from 1.8 to 2.6
438 grams/cm³, and their geographical distribution is depicted in Figure 18.



439
440
441
442

Fig 17. Geographical distribution of specific gravity (gram/cm³) of the Grab samples in the Damietta harbor basin.



443 **Fig 18.Offshore geographical distribution of specific gravity (gram/cm³).**

444

445 **3.2 MARINE BOTTOM COMMUNITIES**

446

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

455 Among many factors which affect the successful settlement of the pelagic larvae of bottom
456 invertebrates (temperature, salinity, food supplyetc), is the suitable substratum which is
457 a predominant factor, Consequently, the nature of the bottom may determine a great extent
458 the kinds and abundance of bottom animals. The type of bottom sampled was dark clayed
459 silt or muddy. Generally, the diversity of species was low and only 4 major taxa were
460 recorded and represented by Polychaeta (13 species) Mollusca: bivalves 9 sp. Gastropods 2
461 sp. Crustaceais represented by several orders: Amphipoda 2 sp., Tanaidacea 2 sp., Isopoda
462 1 sp., Cumacea 1 sp., and the last taxa was Nematoda.

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

469 1. station G6 (166 organisms),

470 2. station G2 (141 organisms),

471 3. station G 3 (78 organisms),

472 4. station G1 (46 organisms),

473 5. station G7 has a number of 58 organisms, while

474 6. Offshore stations show a very poor number of organisms ranged from (7-13
475 organisms/sample).

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

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

489

490 **3.3 PROPOSED MANAGEMENT MEASURES FOR DAMIETTA NEW HARBOR**

491

492 Since the Damietta Harbor was constructed in 1986, the average annual maintenance
493 dredging volume has been 1,180,000 m³ (Damietta Port Authority, 2022). The preferred
494 disposal method for dredged sediment is open water disposal. Dredging activities in
495 Damietta harbor are - in general - periodic maintenance dredging on regular basis to

496 maintain the existing facilities. The main purpose of this process is to deepen the main
497 access channel and the main harbor basin.
498 However, offshore disposal is contingent on the sediment's suitability. Although spacing
499 between samples of the present study was relatively wide, this distribution indicates that the
500 seafloor of the study area and its surroundings are dominated by patches of sand, silt, and
501 silty clayey (mud). Different regulatory agency requirements apply to disposal permits for the
502 existing offshore site. Permitted upland wetland reuse/disposal and upland landfill disposal
503 sites have their regulatory requirements, which are the responsibility of the site operators
504 and not of the dredger.

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

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

513

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

516

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

518 Damietta harbor has been protected by two breakwaters built in 1982 to prevent the
519 prevailing easterly and westerly sediment transport from shoaling the navigation channel,
520 which extends about 20 km offshore. **Although this protection, the navigation channel has**
521 **experienced continued seabed sedimentation which has negatively affected navigation**
522 **safety.** Sedimentation is concentrated in the harbor entrance near the head of the western
523 breakwater. As a result, periodic annual dredging of the channel has been carried out since
524 1986, with an average of $1.18 \times 10^6 \text{ m}^3/\text{yr}$. This amount is much higher than expected in the
525 early impact assessment of breakwaters on the beach morphology. The sedimentation process
526 is complex and is influenced by the temporal variability in the direction and intensity of the
527 incoming waves, currents, and the orientation of coastline and seafloor morphology.
528 Sediments are transported to the sink area including the navigation channel from adjacent
529 coastal sources at Burullus and Ras **El Bar** as well as from the Damietta offshore shoals by
530 several pathways comprising the opposing easterly and westerly littoral drift, north-northwest
531 and north-northeast offshore currents as well as from onshore sediment movement.
532 Sediments are dispersed primarily away from sediment sources toward the sink area by both
533 contour-flowing bottom and cross-shelf (seaward-trending currents). Together with these
534 sediment sources is the continuing bypassing of sediment around the head of the western
535 jetty into the harbor entrance.

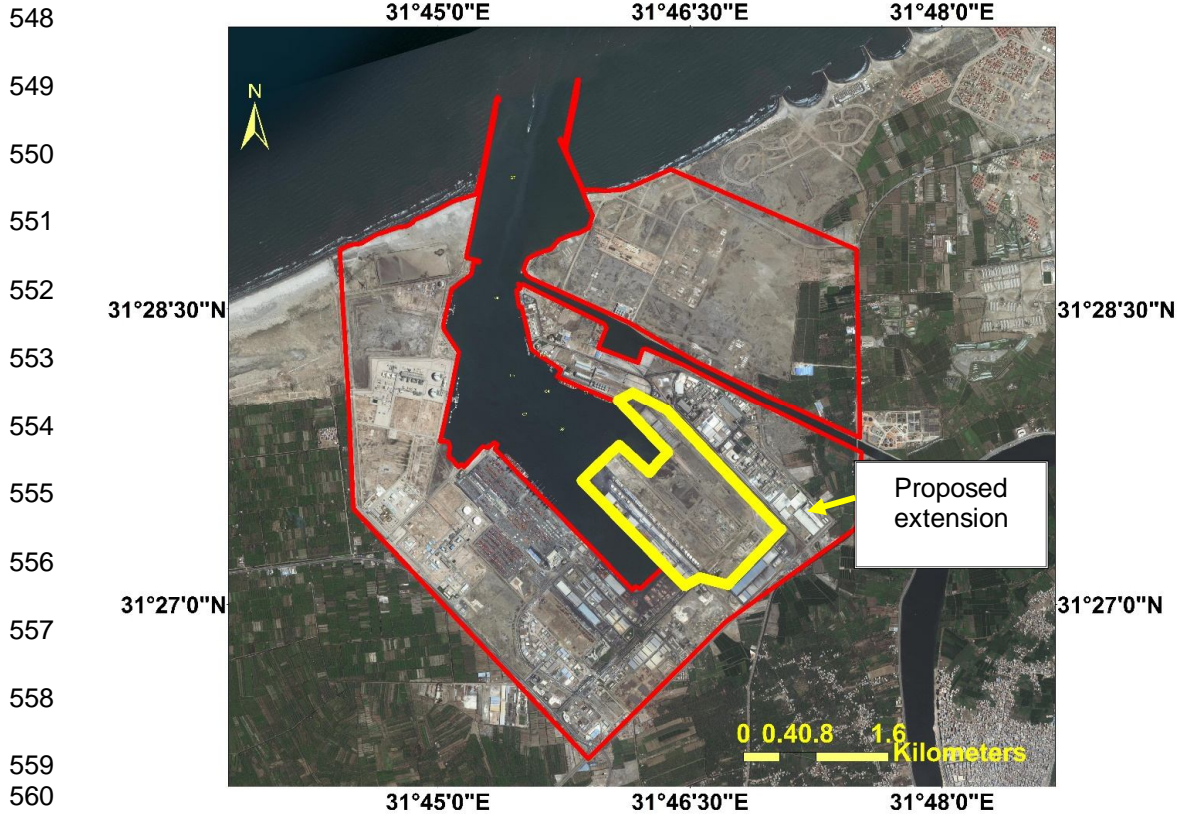
536 The harbor deepening and expansion component require significant dredging of
537 maintenance material above the current 15 m depth, deepening to the proposed depths of
538 up to 18 m, and dredging of the expansion area that is currently upland. The total volume of
539 material to be dredged is approximately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

541

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

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

547



561 **Fig 19. The proposed extension of the harbor.**

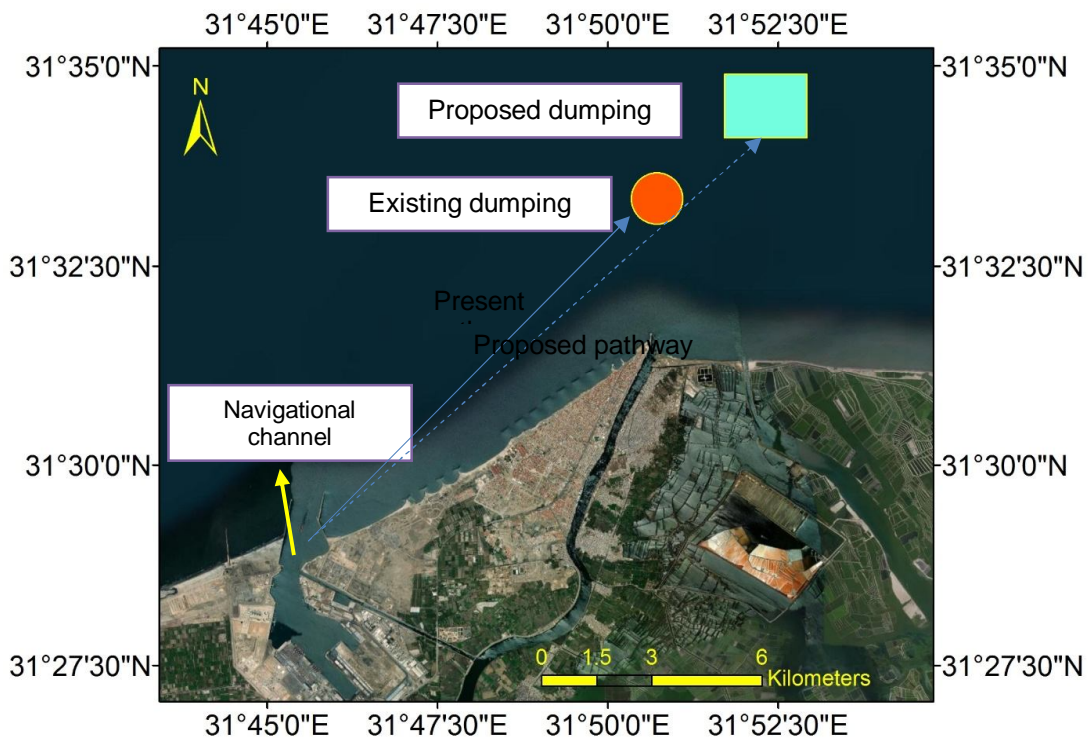
562 *Issue III: Management of the dredged sediments*

563 a) Dredged sediments from the deepening of the navigational channel

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

570 Current annual dredge maintenance in Damietta Harbor results in the disposal of a
 571 considerable amount of sediment layer. The aquatic existing dredged material disposal site
 572 is operated as a dispersive site; that is, material disposed at the site tends to disperse and
 573 be carried by currents. Reversed westward currents in part rework and disperse dumped
 574 sediments once again to the navigation channel. Because of mitigation, studies have
 575 proposed measures to overcome this undesired channel sedimentation. The west and east
 576 breakwaters have to be extended respectively, 1.7 and 1.5 km offshore to reach an 8 m depth
 577 of closure, i.e., a water depth of little sediment transport. Dispersal is dependent upon the
 578 material type, disposal volume, and frequency. Among recent questions, there is the issue of
 579 depositing sediment dredged from the navigation channel of the harbor. The current
 580 dumping site is known to have contributed over the last decades to maintaining the silting up
 581 of the channel. For that reason, the present study works to find a less detrimental dumping
 582 area to minimize the reversed impact of dredged sediment dumping.

583 From the present study results of the bathymetry obtained from “The National Center For
 584 Environmental Information, NOAA” for the Mediterranean Sea, it appears that a site with
 585 fine-to-medium clean sand offshore from the mouth of the Seine estuary would be a good
 586 candidate in view of the biological and economic perspectives. Dumped material that comes
 587 from the navigation channel is composed of fine sand containing a significant proportion of
 588 shell debris. The fine fraction (<63 mm) makes up between 30% and 50% of the bulk
 589 sediment. Thus, the similarity between dredged material and sediments in the dumping area
 590 will play an essential role in controlling the type and severity of the impact on the
 591 marine environment. The proposed dumping sites for the dredged materials are considered
 592 offshore located north of the initial one (Figure 20). Accordingly, the proposed dumping area
 593 is supposed to have double benefits which are the reduction of the navigational channel re-
 594 shoaling and the protection of the adjacent beaches from erosion (as a mitigating tool).
 595
 596
 597



623
 624 **Fig 20. Offshore existing and proposed offshore dumping sites.**
 625

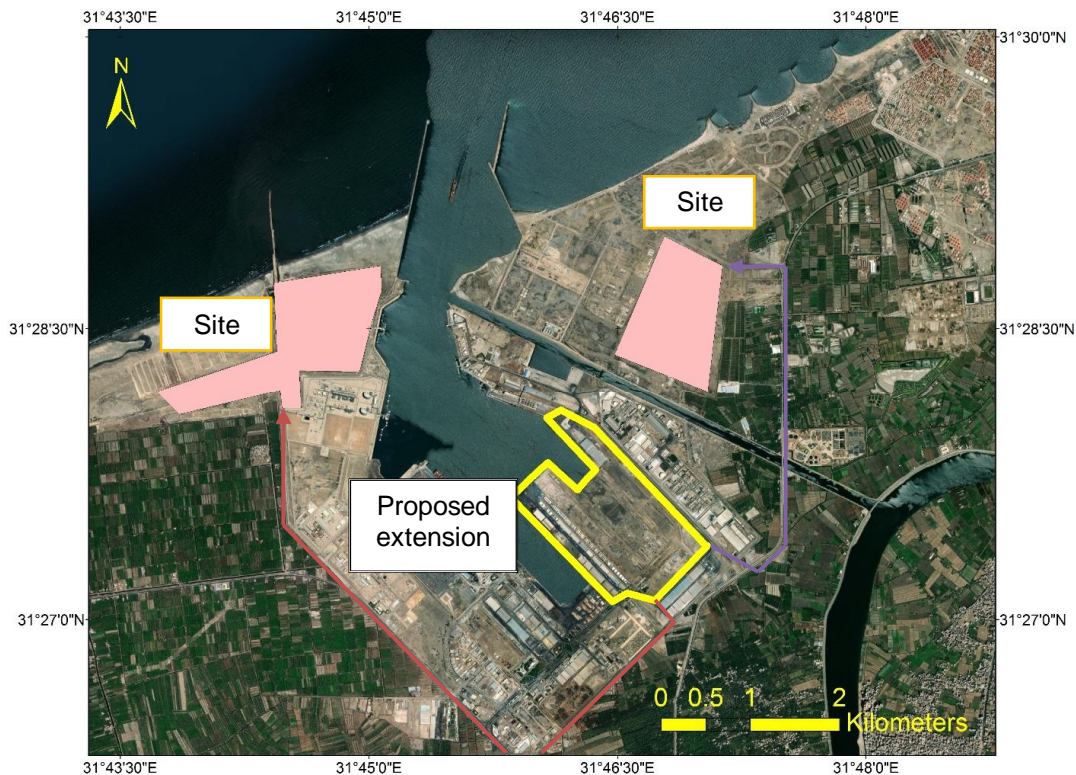
626 b) Disposing sediments dredged from the harbor’s extension

627 An amount of $12.63 \times 10^6 \text{ m}^3$ deltaic sediment is expected to be dredged from the excavation
 628 of the harbor-basin extension project. In this study we propose disposing of this sediment
 629 volume in two dumping sites. Site #1 is a low-lying area that lies northwest of the project site
 630 and is fronted by an accretionary coastline. To avoid possible wave overtopping, this site
 631 requires a landfill elevation of ~3 m above mean sealevel that is corresponding to a volume
 632 capacity of $2.98 \times 10^6 \text{ m}^3$. Environmentally, the created landfill **planform** can provide a
 633 sustainable area for future beach development and in turn improve the project outcomes.
 634 Site #2 is located northeast of the basin in a place previously used for dumping sediment

635 dredged from the navigation canal connecting the main basin and the Damietta Nile branch.
636 This site has a large surface area and can efficiently receive the remaining sediment volume,
637 amounting to $9.65 \times 10^6 \text{ m}^3$
638

639 *c) Disposing sediments dredged from the extension basin*

640
641 Previous studies have indicated that basin-dredged material has been wrongly called "spoil"
642 for years and they are commonly carried to dumping or disposing of sites. In a few cases
643 worldwide, dredged material is practically **used for much** beneficial inland and coastal uses
644 **mostly landfill** of wetlands and low-relief areas (Welch et al. 2016). Beneficial uses of
645 dredged material as borrowed sediment for landfill are widely applied worldwide (Carter and
646 Akerman 2018). In a few cases, they are used to manufacture bricks, glass containers, and
647 cement. According to the EEA guidelines (2009), engineering structures built on the
648 coastline that may significantly change the beach morphology must require environmental
649 impact analysis and mitigation. In our case study, the inland dredging of the new harbor
650 basin would not impact the adjacent coastline and thus no environmental impact analysis is
651 required. However, the only impact **may be resulted** from the improper management of the
652 dredged sediment resulted from dredging activities. Therefore, dredged sediment must be
653 managed in economically and environmentally **sustainable disposing** sites. It has been
654 estimated that a total of $12.63 \times 10^6 \text{ m}^3$ sediment volume is expected to be dredged from the
655 extension basin project. This sediment volume is yielded by multiplying **surface**
656 **area** (789510 m^2) by the dredged basin depth (16 m). Therefore, it is necessary to assure suitable
657 area to place dredged material **resulted** from **excavation** of the project site.
658 The following figure presents the proposed sites for landfill materials disposed **from**
659 the harbor extension (Figure 21). It is worth **noted** that there are buffer areas between the
660 proposed dumping site and the adjacent cultivated area to avoid their adverse impact on the
661 plants.
662



688 **Fig 21. Two sites proposed to dispose sediment dredged from the extension harbor**
689 **basin (project area).** Site #1 is identified in this study as a low-lying area suitable for **land**
690 **filling** whereas Site #2 has been previously used for dumping sediment excavated from the
691 navigation canal connecting **between** the main basin and the Damietta Nile branch whereas.
692 General pathways connecting **between** the proposed dumping sites and the excavated basin
693 are also denoted as lines.
694

695 **4. CONCLUSIONS**

696
697 Planned dredging operations in Damietta Harbor require sediment investigations to
698 understand the possible disposal or re-use considerations. The purpose of this study is to
699 characterize sediments that will be dredged to determine their suitability for placement in
700 either an upland, an offshore disposal site, or at an existing beach for re-nourishment.

701 **Data of** the examined samples were used to assess the feasibility of the environmental
702 implications of the proposed disposal sites on the continental shelf of the study area. It is
703 proposed to place the material dredged from deepening the navigation channel within a
704 disposal site proposed on the middle shelf off the Damietta promontory, approximately
705 between 15 and 20m water depth off the Damietta promontory. As would be expected the
706 southward (landward) current occasionally occurring in winter can bypass coarse-grained
707 sediment dumped in the proposed disposal site toward scoured seabed areas fronting the 6-
708 km long Damietta seawall built to protect the Damietta promontory from shore erosion. We
709 believe that sediment bypassing can mitigate scour problem and **acting** as a feeder to the
710 adjacent shorelines and the littoral cell in the study area. On the other hand, precautions
711 must be considered to reduce probable sedimentation in the Damietta Nile estuary.
712 Furthermore, the subsequent plume of suspended sediments **which** may lead to altering
713 seafloor habitats.
714

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716
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720

721 **Competing interests**

722
723 The authors declare no conflict of interest.
724

725 **AUTHORS' CONTRIBUTIONS**

726
727 **??**
728

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