Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 26(6): 81 – 94 (2022)
www.ejabf.journals.ekb.eg

Characteristics of Bottom Sediments of Different Marine Ecosystems of Egyptian coast sides

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ARTICLE INFO
Article History:
Received: Oct. 17, 2022
Accepted: Nov. 11, 2022
Online: Nov. 17, 2022

Keywords:
Mediterranean,
Gulf of Suez,
coastal ecosystem,
Short-cores
sediment textures

ABSTRACT

Cross correlation of coastal ecosystem alteration among three areas was investigated; two of them located along the Egyptian Mediterranean coast and the third one along the Gulf of Suez. Sediment textures, phosphorus forms, organic carbon, total carbonate content, water content, and pH were analyzed for collected short-core samples to reveal the variations and the relevant factors influencing the coastal depositional environments at the three sites. Geographic locations and relevant conditions combined with the anthropogenic stressors, corresponding to associated sources and magnitude of pollution, are considered as major affected elements in bottom habitats. The regional comparison between the two sites located along the Mediterranean Sea indicates a distinct gradient in the ecosystem and controlling factors from the west to the east. Alexandria site is represented as a typical near-shore oligotrophic, well-ventilated and unpolluted environment, attributed to an increase in water activity revealing a high-energy erosive environment. While, the site of Port Said is reflected as a highly stressed coastal environment, influenced by freshwater flush discharged from the nearby local outlet, developing strong and continuous wash out of seabed sediment. The Suez site is induced by tense industrial and domestic pollution, corresponding to the propagation of the anthropogenic impact, coupled with the significant effect of a hypersaline environment.

INTRODUCTION

The Egyptian coastal ecosystem exhibits extraordinary influence on ecological attributes and biodiversity, which are related to the different climatic conditions, in particular wind intensity, sea-level changes and erosion, in addition to anthropogenic stressors, especially large-scale use, human population growth and tourism **(Badawi & El-Menhawy, 2016; Badawi *et al.*, 2021, 2022)**. The Egyptian Mediterranean coast has recently suffered from severe erosion, in particular after the construction of the Aswan High Dam in 1964 **(Frihy *et al.*, 1991; Hamouda & Abdel-Salam, 2010b; Hamouda *et al.*, 2014)**. Significant coastal changes have been reported due to the reduction in the Nile sediment discharge, which diminished to near zero, combined with natural factors, including delta subsidence, sea level rise and strong coastal current processes **(Stanley,**

1990; Stanley & Warne, 1993; Fanos *et al.*, 1995; El-sherif *et al.*, 2020). The Red Sea and the Mediterranean linked through the artificial Suez Canal constructed in 1869 created the first salt-water passage between the Red Sea and Mediterranean, allowing the faunal migration through it **(Badawi, 2015, 2016)**. Phosphorus is commonly the limiting nutrient for primary productivity in coastal marine environments, and has been cited as the ultimate limiting nutrient for primary productivity in marine ecosystems over geologic time scale **(Toggweiler, 1999; Tyrell, 1999)**. The largest source of phosphorus is the riverine input of weathered particulate matter and dissolved phosphorus species. Up to 99% of particulate phosphorous and 25% of dissolved phosphate delivered by rivers are buried in the deltas and continental shelves **(Paytan, 2007)**. As the main repository of oceanic phosphorus, sediment phosphorous cycling commonly plays a large role in controlling the concentration of phosphorus in overlying waters. Phosphorus (P) is an essential nutrient element limiting the biological productivity **(Codispoti, 1989)**. Although it lacks a volatile form to facilitate transfer between the ocean, atmosphere and terrestrial biosphere **(Broecker, 1982)**, it is a key element in global biogeochemical cycles **(Sanudo-Wilhelmy *et al.*, 2001)**. The sediments are a major P sink for the overlying waters, including the well-mixed surface waters **(Stabel, 1984)**. The eastern Mediterranean coast is at present a phosphate limited environment **(Krom *et al.*, 1991)** due to the limited Nile flood mud post Aswan Dam establishement.

The objective of this study was to generate cross correlation of the coastal ecosystem variations along the three selected significant sites on the Mediterranean coast (Alexandria and Port Said) and in the Gulf of Suez, in terms of grain size analysis, and vertical variation of sedimentary total phosphorus, inorganic and organic phosphorus (TP, IP, OP). In addition, the organic carbon (OC) and total carbonate content in the cores sediments were addressed. Correlation between the three different coastal ecosystems was considered since the environmental status between the three selected locations is significantly different. An integrated approach of conducted geochemical studies was followed to generate a data set to figure out the possible controlling parameter(s) in each location.

MATERIALS AND METHODS

Three sites were selected for the current study; the first site is along the Alexandria coast, the second site is on Port Said coast and the third one is located on the Suez coast. Three short cores have been collected from the three selected locations (Fig. 1, Table 1).

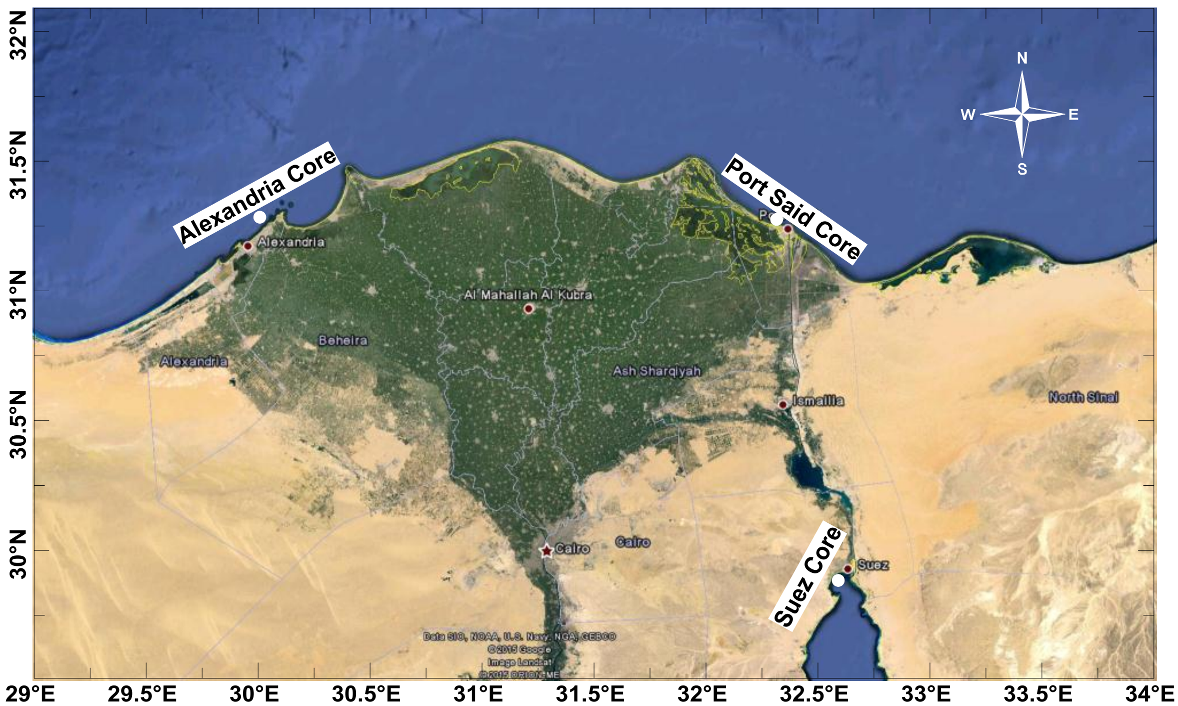


Fig. 1. The location of the collected short cores samples along the study area

Table 1. Locations, water depth and core length of the investigated short-cores

Core site	Location		Water depth (cm)	Core length (cm)
	Latitude	Longitude		
Alexandria core	31.28701°N	30.0187°E	15	79
Port Said core	31.27858°N	32.3268°E	2.5	80
Suez core	29.88322°N	32.60167°E	15	60

The recovered sediment cores were sampled at 5cm intervals with the top of 1cm for each interval. For grain size analysis, combined technique of dry sieving and pipette analysis were carried out for the sediment samples of the three cores according to **Folk (1974)**. The procedure involves pipetting a weighed portion of sediment sample using 0.01N sodium oxalate, followed by sieving through the 4 Φ (63µ) mesh screen to separate the sand from the silt and clay fractions. The fractions retained on the sieve were washed, dried and sieved on electrical shaker for 15 minutes. The sieves were arranged from top to bottom in one phi order as follows: -2, -1, 0, 1, 2, 3, 4 Φ, corresponding to 4, 2, 1, 0.5, 0.25, 0.125 and 0.063mm, respectively. The graphic measures were employed for the results of the grain size analysis using the phi notation, where Φ= - log x (x= given value in mm). The results of sand, silt and clay were combined in smooth continuous cumulative curves, from which grain size data (percentiles) were obtained. These percentiles were used in calculating the graphic mean size (MZ) and degree of sorting (σ) for each sample, using the formulas of **Folk (1974)**. For geochemical analysis, total phosphorus (TP) in sediment was based on treatment at 500°C (2 h), followed by HCl (1 N) extraction (16 h). For inorganic P (IP), samples were extracted (16 h) with HCl (1 N). Organic P (OP) concentrations in the sediments were calculated as the difference between TP and IP **(Aspila *et al.*, 1976)**. The P in the respective extracts was measured by molybdate colorimetry **(Murphy & Riley, 1962)**.

The total carbonate contents calculated as $CaCo_3$ was determined by oxidation with 1 N $K_2Cr_2O_7$, acidified with concentrated H_2SO_4 and titration, with 0.5N Fe $(NH_4)^2(SO_4)^2$ **(Loring & Rantala, 1992)**. Total carbonate was determined by titration technique **(Herrin *et al.*, 1957; Black, 1965)**. About 1g of each sample was digested in standardized HCl, and the released amount of CO_2 was determined by back titration with previously standardized NaOH solution using a phenolphthalein indicator. The water content, pH and the porosity of the sediment samples were measured.

RESULTS

The sediments of the three cores consisted primarily of grey to pale brown fine grain sediments with high carbonate content. Lithological changes were minor along the studied cores from visual observation. Alexandria short core (water depth: 15m; core length: 79cm) is composed of a mixture of shell, shell fragments (mollusks and pelecypods), foraminifera and quartz grains of coarse sands size (typical buff color of Alexandria beach sands). While, Port Said short core (depth: 2.5m; core length: 80cm) composed of silts of grey color, mixed with few pelecypod shell and shell fragments (typical of Nile Delta deposits). Port Said core is characterized by thickness of 3- 6cm common with Pteropod ooze, pelecypod (bivalve) shells and shell fragments at a depth of 53cm from the top of the core. Suez short core (water depth: 15m; core length: 60cm) is composed of light grey mud mostly clays. No variation in the lithology of the core was detected from top to bottom. Cross correlations of the vertical variation of grain size analysis, pH, water content, organic carbon, total carbonate content, and phosphorus forms (TP, IP, OP) among the core sediments of the three investigated sites were discussed in this study as illustrated in Tables (2, 3).

Graphic mean size (Mz) was used as an indicator for the grain size distribution. According to **Folk (1974)**, it is the best graphic measure for determining the overall size of the sediments.

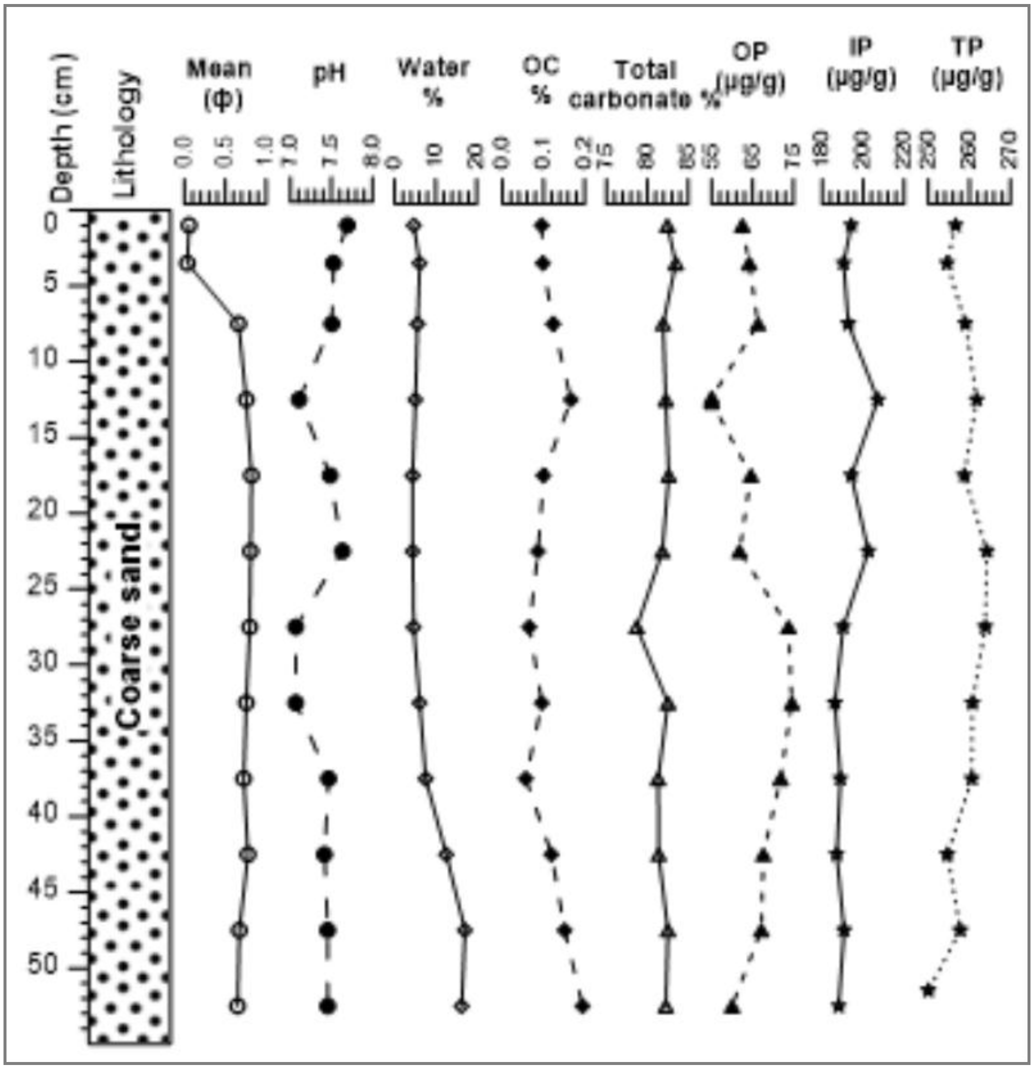
Table 2. The mean size and sorting of the investigated short sediment cores

Alexandria core					Port Said core				Suez core			
Interval (cm)	**Mean Size**		**Sorting**		**Mean Size**		**Sorting**		**Mean Size**		**Sorting**	
0-2	0.06	Coarse Sand	0.74	Moderately sorted	2.51	Fine sand	0.67	Moderatly well sorted	7.49	Very fine silt	0.32	Very well sorted
2-5	0.04	Coarse Sand	0.72	Moderately sorted	2.27	Fine sand	1.08	Poorly sorted	7.46	Very fine silt	0.84	Moderately sorted
5-10	0.63	Coarse Sand	0.77	Moderately sorted	2.37	Fine sand	0.75	Moderately sorted	7.46	Very fine silt	0.86	Moderately sorted
10-15	0.72	Coarse Sand	0.79	Moderately sorted	2.49	Fine sand	0.58	Moderatly well sorted	7.45	Very fine silt	0.87	Moderately sorted
15-20	0.78	Coarse Sand	0.79	Moderately sorted	2.65	Fine sand	0.79	Moderately sorted	7.41	Very fine silt	0.91	Moderately sorted
20-25	0.77	Coarse Sand	0.79	Moderately sorted	2.42	Fine sand	0.89	Moderately sorted	6.31	Fine silt	1.73	Poorly sorted
25-30	0.76	Coarse Sand	0.78	Moderately sorted	2.54	Fine sand	0.67	Moderatly well sorted	6.30	Fine silt	1.74	Poorly sorted
30-35	0.72	Coarse Sand	0.77	Moderately sorted	2.64	Fine sand	0.67	Moderatly well sorted	6.29	Fine silt	1.75	Poorly sorted
35-40	0.69	Coarse Sand	0.80	Moderately sorted	2.58	Fine sand	0.72	Moderately sorted	6.23	Fine silt	1.78	Poorly sorted
40-45	0.74	Coarse Sand	0.77	Moderately sorted	1.48	Medium sand	1.50	Poorly sorted	6.16	Fine silt	1.80	Poorly sorted
45-50	0.64	Coarse Sand	0.83	Moderately sorted	2.69	Fine sand	0.71	Moderatly well sorted	6.14	Fine silt	1.81	Poorly sorted
50-55	0.62	Coarse Sand	0.82	Moderately sorted	2.78	Fine sand	0.60	Moderatly well sorted				
55-60					2.74	Fine sand	0.59	Moderatly well sorted				

The distribution of the average graphic mean size of the sediments in Alexandria core showed that, the mean size ranged from 0.04 to 0.78 Φ, with an average of 0.5975. The average of the mean size range in Port Said sediments was 2.5 with vertical distribution ranging from 1.48 to 2.78 Φ. Suez core sediment recorded vertical distribution that ranged from 6.14 to 7.49 Φ, with an avenge of 6.79. Most of the studied sediments recorded a standard deviation ranging from 0.58 to 0.91 Φ reflecting general moderate sorting, except for two samples from Port Said core at intervals of 5- 6 and 45-46cm, and samples that started from 25-26 cm downward to the core end at 50-51cm were poorly sorted with standard deviation ranging from 1.08 to 1.81 Φ. Only one sample recorded very well sorted (0.32 Φ) at the top first cm of Suez core.

The recorded pH values of the investigated cores showed minor vertical variation throughout the cores length. Port Said core registered the minimum average values of 7.23, followed by Alexandria core with an average of 7.40, while the highest average pH value (7.82) was recorded in Suez core. The water content percentage well reflects the sediment textures of the investigated cores samples; the vertical variation throughout the investigated cores length were relatively minor; while, a significant variation was detected between the three studied cores. Alexandria core sediments recorded vertical average water content of 7.81 %. In Port Said core, the vertical average water content was 17.76, while for Suez core it was 38.54.

The TP content of Alexandria core was low, with an average of 258 µg/g with a slightly increasing trend from bottom to top. IP recorded a slight fluctuation from bottom to top with an average of 193µg/ g, and a sharp increase from 30- 10cm was recorded with a maximum value of 207µg/ g at depth of 15cm. OP showed a consistent variation trend, it showed little change from bottom to top with an average of 66µg/ g.

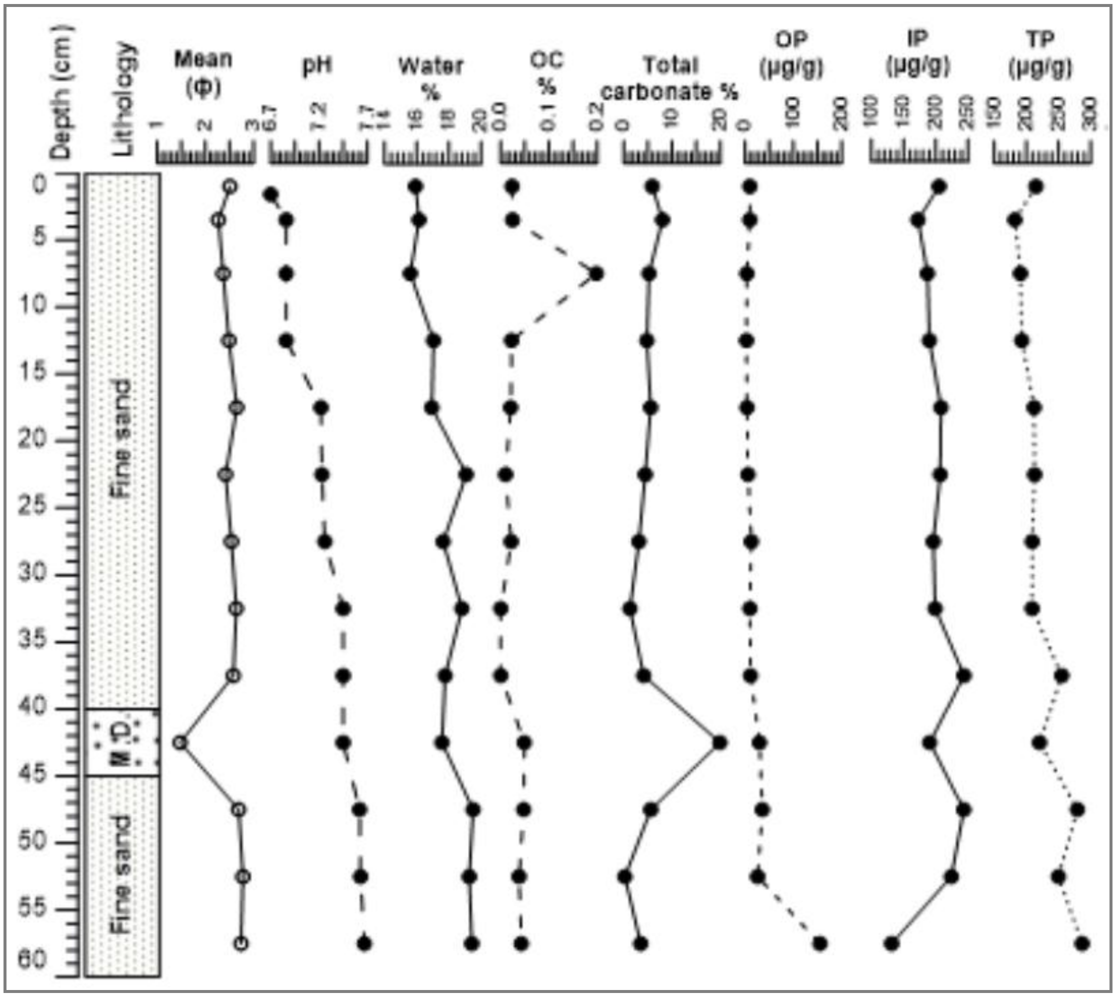


W%=Water content, OC=Organic carbon, Total carbonate= $CaCo_3$, OP=Organic Phosphorus, IP=Inorganic Phosphorus & TP=Total Phosphorus.

Fig. 2. Grain size and geochemical analysis in Alexandria core.

OC percentage has minor variation throughout the core length with an average of 0.09 % while $CaCO_3$ has fluctuation trend with an average value of 82 %, minimum value of 79 % was recorded at 30 cm depth.

TP content of Port Said core is significantly low, with an average of 224 µg/g with obvious decreasing trend from the bottom to top, recorded minimum value of 191 at 10 cm depth. Slight variation in IP throughout the core was observed with an average value of 200 µg/g.

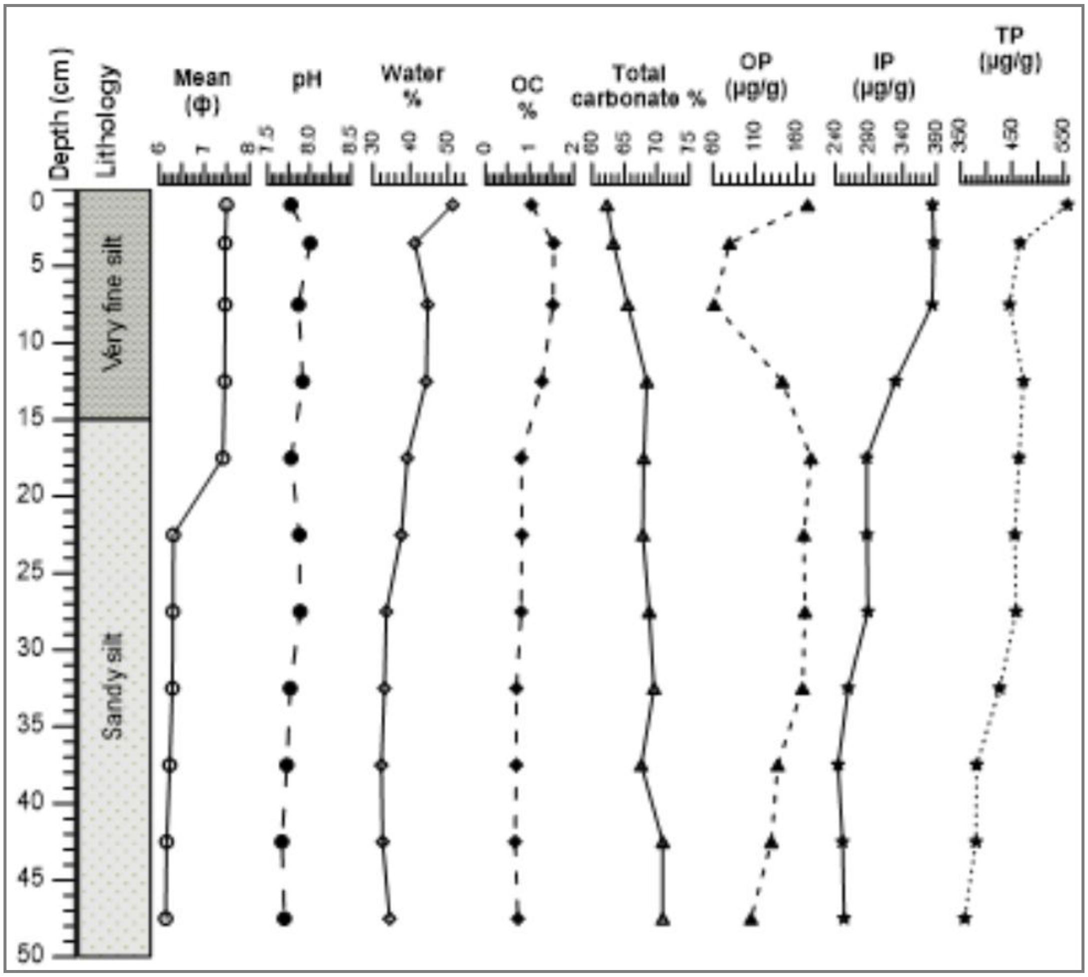


W%=Water content, OC=Organic carbon, Total carbonate= $CaCo_3$, OP=Organic Phosphorus, IP=Inorganic Phosphorus & TP=Total Phosphorus.

Fig. 3. Grain size and geochemical analysis in Port Said core.

Dramatic decline in OP was detected in this core which reported an average value of 25 µg/g, the values ranged from 3-36 µg/g throughout the core, except the bottom sample, which recorded 155 µg/g at 60 cm. Percentage of OC was very low throughout the core, and ranges from 0 - 0.05 % with an average of 0.04 %. $CaCO_3$ also showed significant low values with 6 % average.

Suez core has the highest TP value within the investigated cores, it recorded an average value of 442 µg/g with a consistent increasing trend from the bottom to top. Lowest value of 358 µg/g was recorded at the deepest sample (50 cm) while the highest value (557 µg/g) was recorded at the surface sample at 2 cm.



W%=Water content, OC=Organic carbon, Total carbonate= $CaCo_3$, OP=Organic Phosphorus, IP=Inorganic Phosphorus & TP=Total Phosphorus.

Fig. 4. Grain size and geochemical analysis in Suez core.

IP follows TP increasing trend with an average value of 253 µg/g. Strong fluctuation trend in OP distribution was observed throughout the core with an average value of 137µg/g. Highest OC as well as $CaCo_3$ was recorded in Suez core comparing with the other two cores with average values of 0.97 and 68, respectively. OC has slight increasing trend from the bottom to top, while $CaCO_3$ has obvious increasing trend from the bottom to up.

As demonstrated from the correlation matrix in Table 3, TP in Alexandria core was highly correlated with IP and respectively). On the other hand, IP has positive correlation with OC and $CaCO_3$ (0.161 and 0.112, respectively), whereas significant negative correlation between OP and OC as well as $CaCO_3$ was noticed (-0.64 and -0.463, respectively). TP in Port Said core showed positive correlation with IP (0.159), there is significant strong positive correlation between TP and OP (0.7). Negative correlation between TP and both OC and $CaCO_3$ was recorded (-0.157 and -0.165, respectively). IP was negatively correlated with both OC and CaCO3 (-0.196 and -0.137, respectively). OP has positive correlation with OC and negative correlation with CaCO3 (0.013 and 0.036, respectively.

Table 3. Correlation matrix of the investigated short sediment cores.

	Mean	*pH*	*W%*	*OC*	*CaCO₃*	*OP*	*IP*	*Mean*	*pH*	*W%*	*OC*	*CaCO3*	*OP*	*IP*	*Mean*	*pH*	*W%*	*OC*	*CaCO3*	*OP*	*IP*
Alex Core								**Port Said Core**							**Suez Core**						
pH	-0.5	1						0.19	1						0.54	1					
WC	0.12	0.09	1					0.35	0.88	1					0.87	0.41	1				
OC	0.06	-0	0.63	1				-0.2	-0.2	-0.4	1				0.8	0.76	0.69	1			
CaCO3	-0.5	0.42	0.13	0.39	1			-0.9	-0.1	-0.3	0.12	1			-0.7	-0.5	-0.8	-0.7	1		
OP	0.21	-0.3	-0	-0.6	-0.5	1		0.18	0.52	0.49	0.01	-0	1		-0.2	-0.2	-0.1	-0.6	0.19	1	
IP	0.09	0.04	-0.4	0.16	0.11	-0.7	1	0.17	0.16	0.15	-0.2	-0.1	-0.6	1	0.86	0.67	0.88	0.9	-0.9	-0.4	1
TP	0.4	-0.3	-0.7	-0.6	-0.4	0.28	0.46	0.37	0.78	0.73	-0.2	-0.2	0.7	0.16	0.72	0.52	0.82	0.46	-0.8	0.33	0.74

W%=Water content %, OC=Organic carbon, Total carbonate= $CaCo_3$, OP=Organic Phosphorus, IP=Inorganic Phosphorus & TP=Total Phosphorus

Suez core showed significant strong positive correlation between TP and IP (0.74) and positive correlation with OP (0.33). TP and OC has positive correlation (0.46), while TP and CaCO3 has negative one (-0.76). IP has the same relationship as TP with OC and CaCO3 (0.90 and -0.87, respectively). Opposite correlation between OP and both OC and CaCO3 compared with TP was recorded (-0.64 and 0.19, respectively).

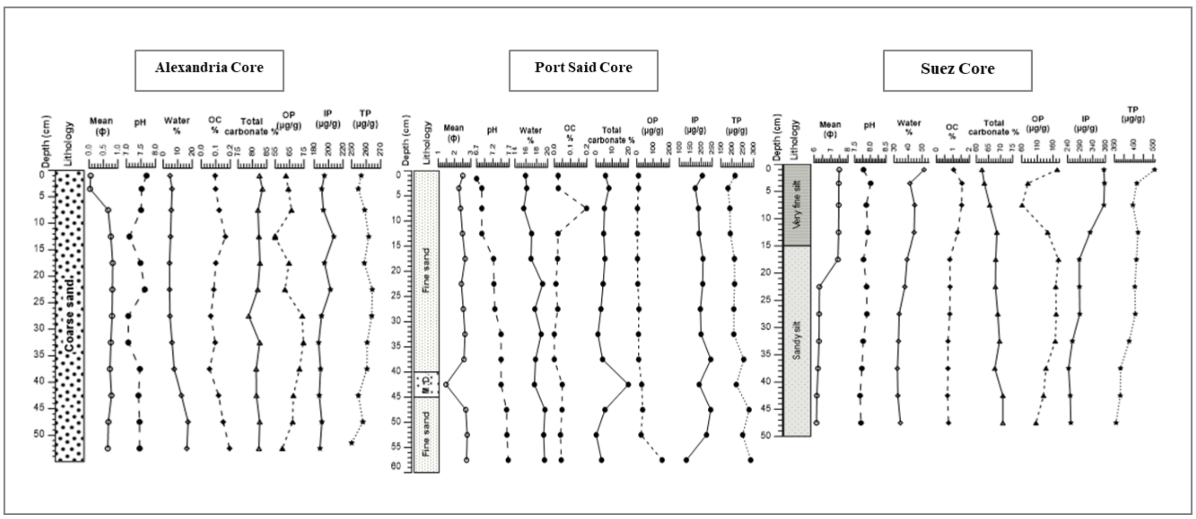
DISCUSSION

Cross correlation of the grain size analysis and geochemical results of the investigated core samples that were collected from three sites, demonstrate significant different ecosystem (Fig. 5).

Alexandria site, which is located along the Mediterranean Sea, represents typical near-shore environments that is clear from industrial pollution while impacted by domestic wastes. Phosphorous limitation associated with relatively $CaCO_3$-rich sediments and exclusively calcareous type of the core sediments, have been noted in Alexandria site compared with the other two investigated sites. The low concentration of PO4 in $CaCO_3$-rich sediments is typical for subtropical/tropical marine environments **(Short, 1985; Short, 1990; Jensen, 1998 and Nielsen, 2007)**. This process is largely influenced by the chemisorption of P onto $CaCO_3$ surfaces and the conversion into more stable apatite phases **(DeKanel and Morse, 1978; Millero, 2001)**. Thus, tropical $CaCO_3$-dominated sediments have an additional sink of bioavailable phosphorous, which may cause P-limited primary productivity where sea grasses or other macroalgae are P-limited **(Short,**

1985; Short, 1990; Fourqurean and Zieman, 1992; Jensen, 1998; Fourqurean and Zieman, 2002). As such, Phosphorus limitation of primary productivity in relatively carbonate-rich sediments, leading to oligotrophic environment, is obviously exhibited in core sediment from the Alexandria site reflected un-polluted, oligotrophic and well-ventilated environment.

Port Said study area has specific characters, it is very shallow, under the direct influence of Manzalla lake fresh water discharge via Bougaz El Gamel outlet. Consequently, Port Said core sediments, formed mainly by moderately well sorted sands and recorded the lowest PH value along the investigated core. In addition, This core exhibit the lowest values in terms of Phosphorus content (TP, IP, OP) as well as OC and $CaCO_3$, indicative for fresh water discharge resulting in strong and continuous wash out of sea bed sediment. Meanwhile, the bottom section of Port Said core indicates hypersaline environment before the effect of industrial and domestic pollution. This site could be considered as highly stressed environment influenced by fresh water flush, rapid sedimentation, temperature and salinity fluctuations associated with low organic matter content.



W%=Water content, OC=Organic carbon, Total carbonate= $CaCo_3$, OP=Organic Phosphorus, IP=Inorganic Phosphorus & TP=Total Phosphorus.

Fig. 5. Cross correlations of the measured parameters of the investigated short sediment cores.

Suez site is considered as the most polluted areas along the investigated sites, it receives substantial amounts of pollutants from the surrounding industrial area, agricultural and domestic effluents. The sediments are formed mainly by poorly to moderately sorted fine to very fine silt associated with high water content and Ph. The core sediments demonstrated the highest values of nutrient content compared with the other two cores, represented by Phosphorus forms (TP, IP, OP), OC as well as $CaCO_3$ content, with common increasing trend from the bottom to top, indicated for prompt propagation of anthropogenic influence time ahead. Suez core, reflect warm, shallow, and hypersaline inner shelf environment with high levels of nutrients. The significant increase in nutrients availability associated with high organic matter in clay sediments of Suez core linked to intensified levels of industrial and domestic pollution leads to enhanced organic matter fluxes and low bottom and pore water oxygen. This is characteristic of confined environment under stress, where grain size, TOC, nutrient, and the influence of industrial pollution are the controlling factors. Maximum intensification of anthropogenic impact is detected in the uppermost section of Suez core (from 25 cm to surface sample), while, hypersaline environment is significant parameter through the bottom section of the core. Hypersaline environment could consider as a major environmental parameter prior to industrial and domestic discharge onset.

CONCLUSION

Sediment texture and geochemical analysis of short-cores samples demonstrated the variations of coastal depositional environments, along the three selected sites, two sites along the Egyptian Mediterranean coast and one site from the Gulf of Suez.

Sediment texture of Alexandria site represented typical near-shore environments. Low Phophorus concentration associated with $CaCO_3$-rich sediments is typical subtropical/tropical marine environments, reflected low primary productivity in relatively carbonate-rich sediments, attributed to oligotrophic well-ventilated environment. Alexandria site recorded as the lowest site exposed to industrial pollution, comparing with other two sites, while impacted by domestic wastes.

Port Said site is subjected directly to fresh water discharge from Manzalla lake via Bougaz El Gamel outlet. Port Said sediments characterized by moderately well sorted sands and recorded the lowest values in terms of Phosphorus content, OC, $CaCO_3$ and PH, comparing with other two sites. The fresh water flux leading to strong and continuous wash out of sea bed sediment. This site could be considered as highly threaten environment, influenced by fresh water flush, rapid sedimentation, temperature and salinity fluctuations and low organic matter content.

Suez site is represented shallow-hypersaline inner shelf environment, encountered high levels of nutrients and considered as the most polluted areas along the investigated sites. The upper core section suggested confined environment under stress, with increasing trend from the bottom to top, indicated continous propagation of anthropogenic influence through time. The sediments exhibits poorly to moderately sorted fine to very fine silt. The significant increase in nutrients associated with high organic matter in clay sediments are corresponding to intensified levels of industrial and domestic pollution, due to enhanced organic matter fluxes, leading to low bottom water oxygen, while core bottom section reveals hypesaline environment.

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