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Impact of Contaminants in Marine Sediment Assemblages in El-Hamrawein Harbour, Red Sea Coast, Egypt

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Abstract:
Thirty-four sediment samples were gathered from El-Hamrawein Harbour area. The investigating area sediments are composed of 84.86% sand fraction. The gravel fraction ranged from 0.00 to 46.54% and averaged 6.71%. Mud fraction varied from 0.00 to 32.39% and averaged 8.44%. The majority of samples were gathered from deep depths of the area contain a significant amount of mud fraction. This is a result of landfilling and dredging in the harbour area, additional to phosphate ore shipment activities. The carbonate content ranged from 22.10% to 85.78%, averaging 63.43%, indicating impure carbonate content. The sediment's organic matter content ranged from 1.35% to 4.22%, averaging 2.71%. El-Hamrawein Harbour has values of total phosphorus ranged from ND to 11120.71 ppm and averaged 4555.59 ppm. These values are due to phosphate shipment activities at the harbour. The distribution of heavy metals at El-Hamrawein Harbour's marine sediments has been carried out. The overall average concentrations of the metals Fe, Mn, Zn, Pb, Cu, Cd, Ni, and Hg were recorded at 0.31%, 126.32 ppm, 20.55 ppm, 7.77 ppm, 6.35 ppm, 0.30 ppm, 21.57 ppm, and 0.08 ppm, respectively. These concentrations are related to dredging, landfilling, and phosphate ore shipping, additional to terrigenous flux from Wadi Hamrawein. The assessment of sediment contamination was conducted using various metrics, including the pollution load index, contamination factor, modified degree of contamination, contamination degree, and enrichment factor. Statistical methods, including principal component analysis, correlation coefficients, and cluster analysis, have been utilized to uncover potential relationships among different variables. Maps of the spatial distribution of the different variables were also produced using an arcGIS approach.
***Key Word**: Sediments, Geochemical, El-Hamrawein Harbour, Red Sea, Egypt..*

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I. Introduction

The main threat to the health, productivity and biodiversity of the marine ecosystem is human activities on land in inland and coastal locations. Land-based sources account for around 80% of marine pollution, in various kinds of pollutants, primarily as a result of human activity. El-Hamrawein Harbour is under impact of shipping of phosphate processes, along with the materials that were derived from the surrounding wadis, such as Wadi Hamrawein. Phosphate dust generally has elevated concentrations of lead (Pb), zinc (Zn), and cadmium (Cd) as contaminants [1]. Examining the distribution and behavior of surface sediments's metals at El-Hamrawein Harbour area is the study's objective, to evaluate the empacts of human activities on the marine ecosystem and assessing the sediment contamination condition through various environmental indices for instance contamination factor, pollution load index, modified degree of contamination, contamination degree, and enrichment factor as powerful mathematical tools for processing, analyzing, interpreting, and simplifying complex ecological information.

II. Material And Methods

2.1 Study Area: El-Hamrawein Harbour is a specialized mining harbour located on the Egyptian Red Sea coast in Quseir City (Fig. 1). It is lying at 26° 15' 15" N to 26° 15' 21" N and 34° 12' 13" E to 34° 12' 22" E. El-Hamrawein Harbour is a harbour for shipping and exporting mineral ores (phosphate, ilmenite, gypsum and quartz).

2.2 Field Work: The El-Hamrawein Harbour area has been divided into four distinct transects, labeled HH4, HH1, HH2, and HH3, arranged from north to south. Transect HH4 is located to the north of the phosphate ore shipment berth, while transect HH1 is situated directly beneath the berth itself. Transect HH2 is positioned in front of Wadi Hamrawein, and transect HH3 represents the southernmost section of the El-Hamrawein Harbour area. A total of thirty-four sediment samples were collected from these transects, with water depths ranging from 0 to 29 meters below sea level, extending up to 574 meters from the coastline.

2.3 Laboratory Methods: The sediment samples were dried in ambient air by spreading them on glass sheets. Grain size analysis was performed on a series of sieves of different mesh sizes [2]. The heavy metals were determined in the sediments as stated by Chester et al. [3] to obtain Fe, Mn, Zn, Pb, Cu, Cd, Ni, and Hg concentrations by spectrophotometer of atomic absorption fitted with self-reversing lamp for background rectification (GBC-932 Ver. 1.1). 1N HCL acid was used to treat one gram of each prepared sample, was filtered, and repeatedly rinsed with distilled water, then dried and reweighed to determine the percentage of sediments' carbonate content. The loss on ignition method at 550°C was utilized to measure the content of total organic materials [4]. The persulfate digestion method was used to quantify the concentration of total phosphorus [5] using ultraviolet double beam spectrophotometer.

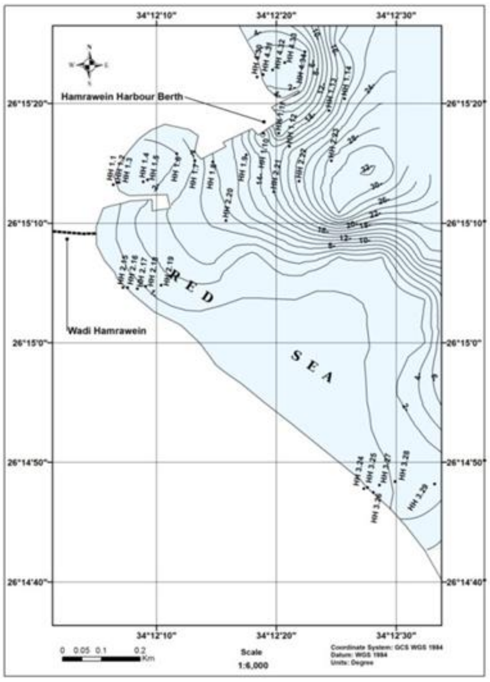


Fig. 1: Map showing the study area's location on the Red Sea Coast

III. Result

3.1 Facies of study area:

Coarse sand sediments constitute the area's bottom topography, mostly biogenic in the southern and northern transects of El-Hamrawein Harbour and dark, light grey, medium to fine sand at El-Hamrawein harbour berth transect**,** while it is covered with muddy sand and mud at offshore area of the harbour (Fig. 2).

3.2 Sediments texture of the area:

The area of current study is covered by a blanket composed of 84.86% sand fraction. Gravel fraction varies from 0.00 to 46.54%, averaging 6.71% (Table 1). The highest content of gravel fraction is recorded in samples that were taken close to coral reefs because they are mostly composed of biogenic fragments (Fig. 2). Mud fraction varies from 0.00 to 32.39%, averaging 8.44%. Most samples taken from the high depths of this area have a high content of mud fraction. Therefore, mud increases with water depth. The elevated amount of mud fraction was found in the samples south and southeast of the berth because of shipping of phosphate ore and the harbor's dredging and landfilling

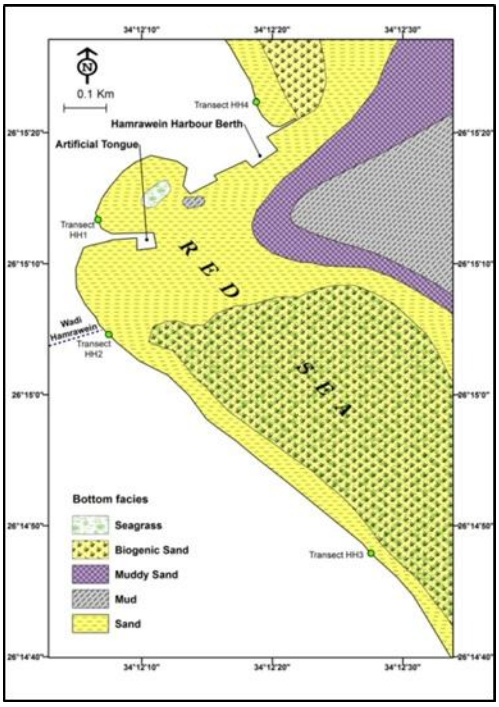


Fig. 2: Distribution of bottom facies at El-Hamrawein Harbour

3.3 Geochemical characteristics of marine sediments:

Carbonates: The amount of carbonate within the examined area's sediments varies between 22.10% and 85.78%, averaging 63.43% (Table 1). The sediments' carbonate content below the shipping wharf, as well as southeastward from the berth, are high and impure carbonates. This is probably due to carbonate precipitation as a result of excessive calcium or magnesium carbonate originating from chemical compounds associated with phosphate ore. On the contrary, the carbonate composition found in the supratidal, beach, and intertidal sediment samples from transects HH1 and HH2 is primarily composed of terrigenous and transitional carbonates, which suggests that these carbonates originate from terrestrial sources influenced by the contributions from Wadi Hamrawein. The findings presented in the correlation matrix (Table 2) reveal a strong negative correlation between carbonate content and iron (-0.72), as well as moderate negative correlations with nickel (-0.66) and copper (-0.51).

Total organic matter: The organic matter concentration in the sediments of El-Hamrawein Harbour ranges from 1.35% to 4.22%, with a mean value of 2.71%, as shown in Table 1. The elevated levels of organic matter in certain regions can be attributed primarily to the presence of sea grass, seaweed, and algae, which significantly contribute to the overall organic matter found in the most of sediment samples from the harbour.

Total phosphorus: Sediments sampled at El-Hamrawein Harbour have values of total phosphorus ranged from ND to 11120.71 ppm, averaging 4555.59 ppm (Table 1). These values are due to phosphate shipment activities, as fine particulates fly out from the ore conveying belts, especially during direct unloading of the belt load in the shipping boat, which causes fine dust to spread with the wind direction southeastward from the loading berth, precipitated in the marine environment. As well, the coarser particulates fall under the shipping berth in the marine environment.

The spatial distribution map of total phosphorus (Fig. 3a) illustrates that the concentration of total phosphorus diminishes with increasing distance from the loading berth. From another point of view, total phosphorus's average value (4555.59 ppm) in El-Hamrawein Harbour is more than double the probable effect concentration (2000 ppm) regulated by the sediment quality evaluation standard of Environment Ministry of Ontario [6]. Total phosphorus exhibits a moderate positive correlation with manganese (0.68), mercury (0.61), zinc (0.58), and mud (0.52). Additionally, its concentration rises with increasing depth (0.66) and greater distance from the shoreline (0.60) as indicated in Table 2.

Table 1: Shows grain size and geochemical analysis results of marine sediments at El-Hamrawein Harbour.

Sa. No.	Gravel	Sand	Mud	Carb. %	TOM %	TP*	Fe %	Mn*	Zn*	Cu*	Pb*	Ni*	Cd*	Hg*	Depth (m)	D. sh (m)
HH 1.1	1.87	89.09	9.04	55.28	4.12	4893.35	0.14	192.65	26.27	4.61	22.02	25.46	0.28	0.10	0	0
HH 1.2	1.31	97.38	1.31	38.30	2.06	1905.00	0.49	189.44	18.05	6.30	24.05	30.93	0.20	0.04	0	0
HH 1.3	0.05	96.87	3.08	44.60	2.81	5555.41	0.38	174.09	20.90	5.13	19.17	25.13	0.23	0.09	0.3	55
HH 1.4	0.65	91.06	8.29	54.24	2.87	4819.10	0.26	132.68	16.89	4.20	12.21	19.92	0.26	0.10	0.5	61
HH 1.5	0.00	84.00	16.00	61.91	2.85	5699.22	0.32	103.81	20.05	4.95	8.49	14.62	0.31	0.16	1	71
HH 1.6	1.29	87.53	11.17	67.38	3.68	2120.56	0.17	86.87	17.11	3.91	7.10	18.64	0.28	0.06	1.2	157
HH 1.7	0.23	77.18	22.60	64.31	3.14	8033.72	0.29	126.11	28.36	6.58	11.75	20.04	0.28	0.09	4	188
HH 1.8	2.78	68.14	29.08	58.32	2.65	3465.98	0.50	93.39	13.52	5.28	5.67	19.59	0.40	0.14	8	228
HH 1.9	0.10	87.52	12.38	71.70	2.43	8005.82	0.20	172.17	33.59	7.58	6.71	20.33	0.28	0.24	11	308
HH 1.10	5.00	92.43	2.57	77.69	1.79	9009.81	0.39	180.27	37.52	7.29	4.24	19.35	0.28	0.17	19	361
HH 1.11	1.83	94.21	3.96	73.48	1.73	11120.71	0.22	256.86	37.55	7.49	4.86	18.57	0.41	0.10	10	395
HH 1.12	0.00	80.00	20.00	76.74	2.88	7915.36	0.23	163.06	37.95	8.45	6.60	21.59	0.30	0.19	19	410
HH 1.13	0.00	82.56	17.44	80.33	2.55	9557.65	0.09	153.52	33.40	7.12	8.05	26.06	0.39	0.02	17	225
HH 1.14	0.00	89.07	10.94	77.78	2.45	8152.20	0.08	108.76	31.80	5.93	8.45	26.13	0.43	0.01	21	570
HH 2.15	0.06	80.13	19.81	42.52	3.78	5328.40	0.80	132.79	59.22	10.99	14.46	39.87	0.35	0.03	0	0
HH 2.16	8.65	91.32	0.03	22.10	1.35	976.44	2.16	168.39	50.34	23.64	11.79	47.22	0.11	0.06	0	0
HH 2.17	46.54	51.70	1.77	27.64	2.00	3480.75	0.77	103.13	22.83	8.47	7.44	31.92	0.16	ND	0.3	22
HH 2.18	17.50	81.45	1.06	53.93	1.97	1162.94	0.35	78.11	8.80	4.27	5.42	19.49	0.18	0.04	0.3	42
HH 2.19	6.58	90.50	2.92	72.22	3.12	1493.75	0.13	79.59	12.28	3.15	2.24	14.03	0.10	ND	0.4	78
HH 2.20	0.02	94.98	5.00	37.54	1.96	2381.27	0.52	170.39	15.40	7.50	5.71	24.84	0.24	0.10	7	285
HH 2.21	0.00	80.00	20.00	64.32	1.99	7258.99	0.16	168.77	24.30	10.59	3.12	23.12	0.27	0.16	16	419
HH 2.22	0.00	75.00	25.00	71.46	3.80	6217.07	0.16	194.11	32.12	6.60	3.58	25.21	0.38	0.20	23	482
HH 2.23	0.01	67.60	32.39	67.70	2.46	9457.90	0.28	211.67	32.14	8.12	2.10	21.56	2.09	0.16	29	574
HH 3.24	6.89	90.11	3.01	43.54	2.73	1465.30	0.17	111.93	7.69	5.28	0.88	17.29	0.36	0.02	0	0
HH 3.25	24.71	75.25	0.04	52.63	1.88	750.37	0.33	94.37	7.81	5.95	2.84	16.08	0.10	0.01	0	0
HH 3.26	25.00	74.60	0.40	64.35	2.42	1162.47	0.10	90.25	6.79	3.92	2.81	16.15	0.25	ND	0.3	3
HH 3.27	5.84	91.66	2.50	75.70	3.43	1268.69	0.11	60.12	4.20	3.05	4.00	14.23	0.13	ND	0.3	35
HH 3.28	4.18	94.09	1.73	74.82	3.37	687.35	0.10	45.10	3.47	2.80	4.44	13.20	0.11	0.02	0.5	80
HH 3.29	0.86	98.84	0.31	81.85	4.22	665.46	0.09	33.18	2.87	2.67	5.43	12.42	0.08	0.03	0.8	165
HH 4.30	5.65	91.42	2.93	79.49	2.22	8275.80	0.06	112.06	5.26	8.40	7.22	21.70	0.31	0.09	0	0
HH 4.31	15.34	84.65	0.02	80.23	2.69	5959.02	0.30	124.10	3.34	4.25	7.00	19.50	0.30	0.08	0	0
HH 4.32	19.76	80.24	0.00	76.30	2.65	6644.28	0.15	111.73	18.53	5.48	7.98	19.25	0.28	0.11	0.3	40
HH 4.33	13.83	86.15	0.03	80.31	3.07	0.00	0.03	33.74	3.12	2.74	6.90	16.98	0.15	ND	0.5	73
HH 4.34	11.51	88.47	0.02	85.78	3.11	0.00	0.002	37.60	5.06	3.28	9.39	12.94	0.07	ND	1.3	131
Stdev	10.18	9.94	9.55	16.69	0.71	3326.75	0.38	55.00	14.45	3.75	5.41	7.42	0.33	0.07	8	179
Min	0.00	51.70	0.00	22.10	1.35	ND	0.002	33.18	2.87	2.67	0.88	12.42	0.07	ND	0	0
Max	46.54	98.84	32.39	85.78	4.22	11120.71	2.16	256.86	59.22	23.64	24.05	47.22	2.09	0.24	29	574
Avg.	6.71	84.86	8.44	63.43	2.71	4555.59	0.31	126.32	20.55	6.35	7.77	21.57	0.30	0.08	6	161

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

Table 2: Shows the correlation coefficient among sediment texture, geochemical components, depth and distance from the shoreline of marine sediments at El-Hamrawein Harbour.

	Gravel	Sand	Mud	Carb.	TOM	TP	Fe	Mn	Zn	Cu	Pb	Ni	Cd	Hg	Depth	D. sh
Gravel	1.00															
Sand	**-0.55**	1.00														
Mud	-0.49	-0.46	1.00													
Carb.	-0.22	0.16	0.07	1.00												
TOM	-0.31	0.12	0.20	0.33	1.00											
TP	-0.36	-0.13	**0.52**	0.28	-0.19	1.00										
Fe	0.14	-0.09	-0.05	**-0.72**	-0.41	-0.14	1.00									
Mn	-0.36	0.01	0.37	-0.26	-0.36	**0.68**	0.25	1.00								
Zn	-0.32	-0.14	0.48	-0.27	-0.16	**0.58**	**0.50**	**0.68**	1.00							
Cu	-0.04	-0.11	0.16	**-0.51**	**-0.50**	0.22	**0.85**	0.48	**0.69**	1.00						
Pb	-0.20	0.27	-0.06	-0.38	0.15	0.02	0.25	0.27	0.26	0.13	1.00					
Ni	-0.01	-0.14	0.15	**-0.66**	-0.28	0.15	**0.79**	0.47	**0.71**	**0.82**	0.49	1.00				
Cd	-0.23	-0.34	**0.59**	0.07	-0.07	0.47	-0.06	0.42	0.27	0.10	-0.17	0.05	1.00			
Hg	-0.44	-0.09	**0.56**	0.11	-0.09	**0.61**	0.00	**0.60**	0.41	0.23	-0.04	0.04	0.33	1.00		
Depth	-0.38	-0.24	**0.65**	0.31	-0.15	**0.66**	-0.15	**0.52**	0.48	0.18	-0.31	0.08	**0.61**	**0.55**	1.00	
D. sh	-0.45	-0.12	**0.60**	0.35	-0.10	**0.60**	-0.20	0.45	0.41	0.10	-0.33	-0.03	**0.52**	**0.54**	**0.94**	1.00

Carb. = carbonate content TOM = total organic matter TP = total phosphorus D.sh.= distance from the shoreline

Metals concentration:

Heavy metals in the crust of the earth are found as natural constituents. Excessive quantities of important metals, in contrast, might be harmful to the organism. Heavy metals are recognized as significant pollutants in aquatic environments due to their persistence, toxicity, and tendency to bioaccumulate [7]. El-Hamrawein Harbour's sediments' levels of heavy metals range from 0.002 to 2.16% for Fe, 33.18 to 256.86 ppm for Mn, 2.87 to 59.22 ppm for Zn, 2.67 to 23.64 ppm for Cu, 0.88 to 24.05 ppm for Pb, 12.42 to 47.22 ppm for Ni, 0.07 to 2.09 ppm for Cd, and ND to 0.24 ppm for Hg (Table 1). The spatial distribution maps of Mn, Zn, Cd, and Hg of study area (Fig. 3c, d, h, and i) show that the highest concentrations are located close to the phosphate shipping berth, which decreases as the distance from the berth increases, indicating that phosphate ore loading activities have a significant effect on Mn, Zn, Cd, and Hg distribution in surface sediments, as indicated by the positive relationship between total phosphorus and these metals in the area. Rock phosphate includes significant quantities of cadmium and zinc as impurities, according to study by Al-Sheikh and Fathi (2010). From Fe, Cu, and Ni spatial distribution maps (Fig. 3b, e, and g), it is noticed that the supratidal, beach and intertidal area of transect HH2 show highest concentration of Fe, Cu, and Ni. It is because of the natural inputs from Wadi Hamrawein.

El-Hamrawein Harbour sediments recorded lower levels of heavy metals than those recorded in the same area by Madkour et al.[8]. Also, the concentrations found in the present study were higher than those measured in Hurghada area [9]. The Red Sea coast sediments investigated by El-Metwally et al. [10] show higher concentrations of heavy metals than those in the present work as well as those investigated by Badawy et al. [11] except for Cu, Pb, and Ni, which showed similar values compared to the current study. Elgendy et al. [12] recorded higher average concentrations at El Zaitiya Harbour, except for Cd, which revealed a similar average value compared to the current study (Table 3). Most of heavy metals correlated negatively with carbonate, especially Fe (-0.72), Ni (-0.66), and Cu (-0.51). In contrast, they are positively correlated with total phosphorous, especially Mn (0.68), Hg (0.61), and Zn (0.58). The present average concentrations of heavy metals are significantly below the threshold effect levels, with the exception of nickel, which marginally exceeds the threshold effect level as indicated in Table 3.

Table 3: shows comparison of heavy metals in the current study with other studies of the Egyptian Red Sea coast (values in ppm unless otherwise noted).

Location	Heavy metal								Reference
	Fe (%)	Mn	Zn	Cu	Pb	Ni	Cd	Hg	
El-Hamrawein Harbour	0.31	126.3	20.55	6.35	7.77	21.57	0.3	0.08	Present study
El-Hamrawein Harbour	0.18	592	73	18	39	42	2.3	----	[8]
Hurghada area	0.26	49	12.41	4.57	1.51	7.21	0.11	0.02	[9]
Red Sea coast	1.06	277.4	58.4	41.3	46.7	32	3.5	----	[10]
Red Sea coast	1.46	291.94	27.55	7.7	4.89	15.37	----	----	[11]
El Zaitiya Harbour	2.72	182.43	180.47	67.02	31.11	46.47	0.02	----	[12]
Gulf of Suez	0.41	----	47.59	4.11	31.11	46.47	0.96	0.065	[13]
Threshold effect level	2	640	124	18.7	30.2	16	0.7	0.13	[6, 14]
Probable effect level	4	1100	271	108	112	75	4.2	0.7	

3.4 Metals cluster: The levels of heavy metals (Fe, Mn, Cu, Zn, Ni, Pb, Cd, and Hg) were analyzed through cluster analysis employing Ward's method, resulting in the categorization of the samples from the area into four primary groups based on ascending concentrations (Fig. 4). The first cluster shows the lowest concentrations of metals, comprising 16 samples, which constituting 47.05% of the total sample set. The second cluster consists of 12 samples, representing 35.29% of the total, and is characterized by elevated levels of manganese (Mn), cadmium (Cd), and mercury (Hg), likely due to shipping activities related to phosphate ore. The third cluster contains 5 samples, making up 14.71% of the overall sample collection, and is notable for its high concentrations of iron (Fe), copper (Cu), zinc (Zn), nickel (Ni), and lead (Pb). This attributed to the terrigenous flux from Wadi Hamrawein rich in these metals. Cluster 4 consists of only one sample (HH 2.16), which is located at the beach area of HH2 transect at at Wadi Hamrawein's mouth. The sample exhibits the highest levels of Fe, Cu, and Ni.

3.5 Analysis of principal component (PCA): PCA identified three principal components that collectively accounted for around 74.47% of the total variance (Table 4; Fig. 5). Factor 1 explains 38.60% of the total variance. Its loading is strongly positive with Fe, Ni, Cu, and partially Zn, with a significant negative loading for carbonate. The site associated with this factor was mainly that which experienced detrital contributions from Wadi Hamrawein (HH2 transect), which suggests the anthropogenic source of these metals. Evidently, the second factor has a stronger correlation with the variables than the other factors. Factor 2 possesses a significant positive relationship with TP, mud, Hg, Mn, Cd, and partially Zn, with weak loading for carbonate. This factor explains 24.96% of the total variance. The site associated with this factor is mainly subjected to human impacts resulting from phosphate ore sedimentations, suggesting the anthropogenic source of these elements. Factor three exhibits robust positive factor loadings for both lead (Pb) and total organic matter (TOM), while showing no significant loadings from other elements.

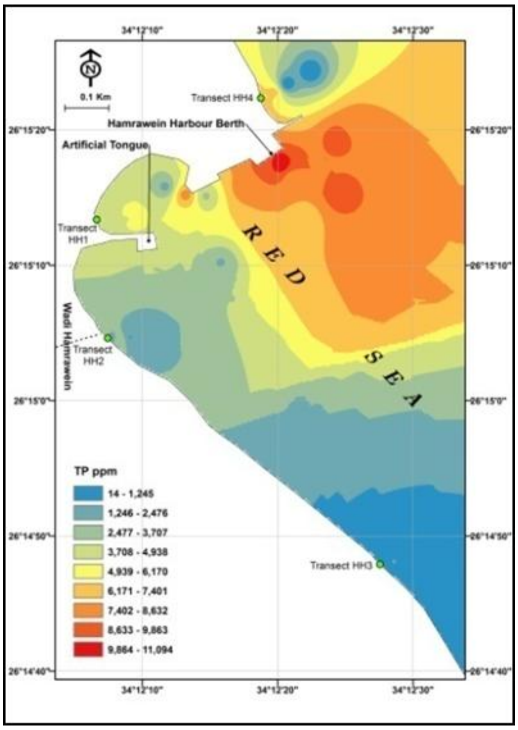
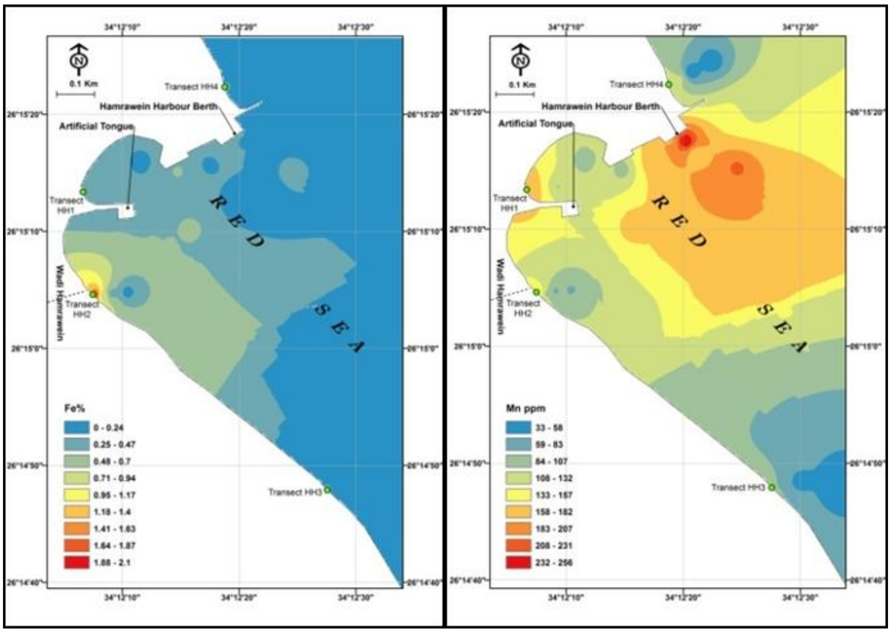
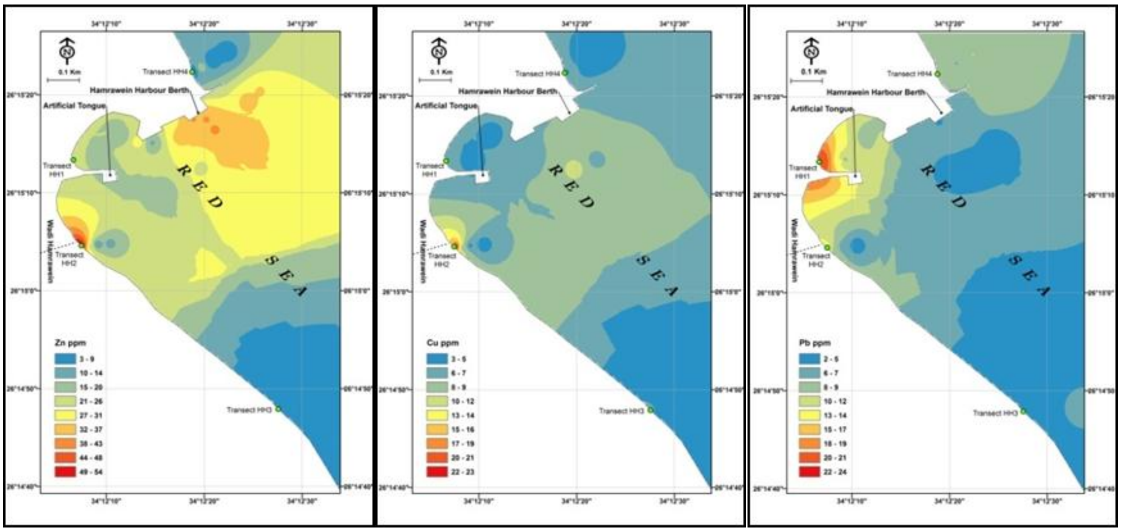


Fig. 3a: Spatial distribution of TP at El-Hamrawein Harbour using GIS technique.



b c

Fig. 3: Spatial distribution of Fe (a), and Mn (b) at El-Hamrawein Harbour using GIS technique.



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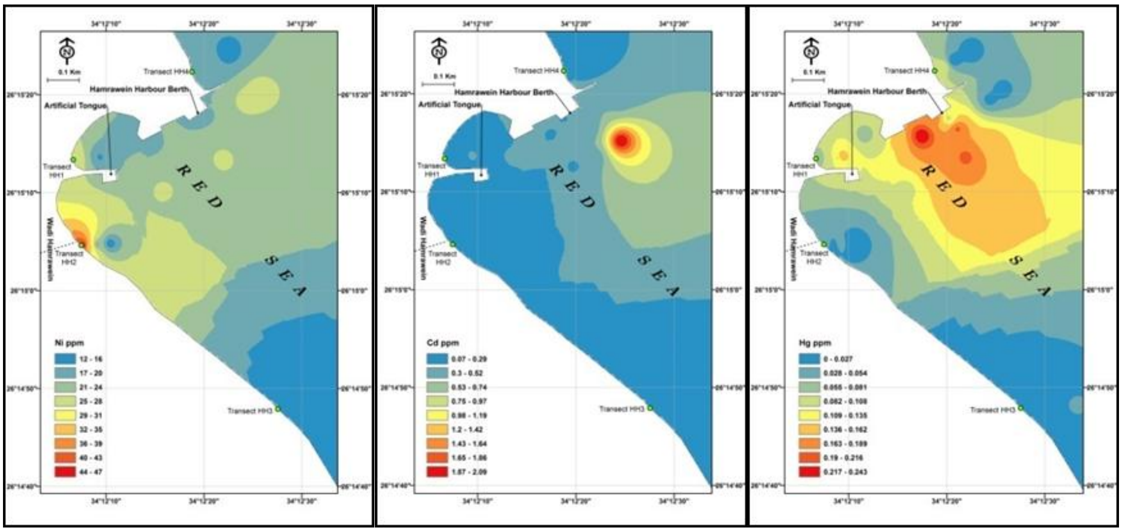

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Cont. **Fig. 3:** Spatial distribution of Zn (c), Cu (d), Pb (e), Ni (f), Cd (g), and Hg (h) at El-Hamrawein Harbour using GIS technique.

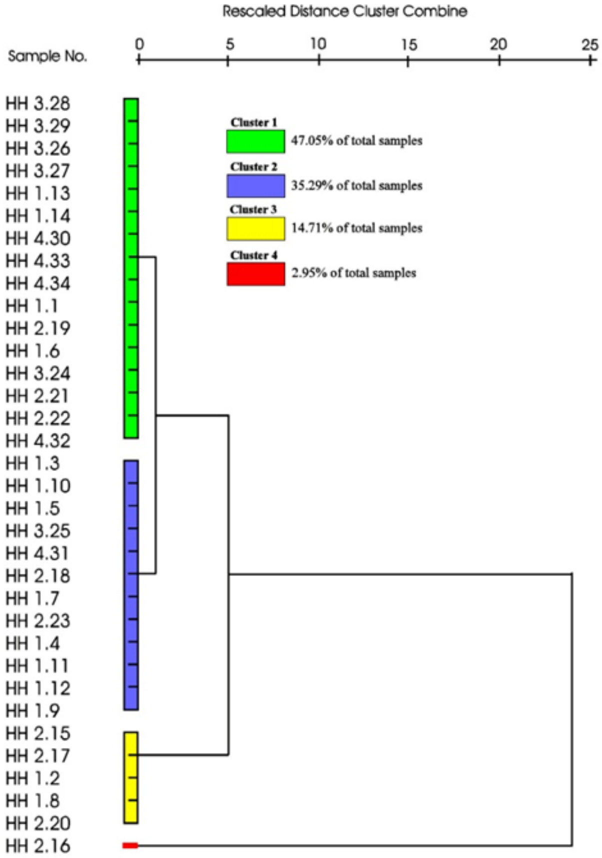

Fig. 4: Dendrogram of heavy metals cluster analysis using Ward's method.

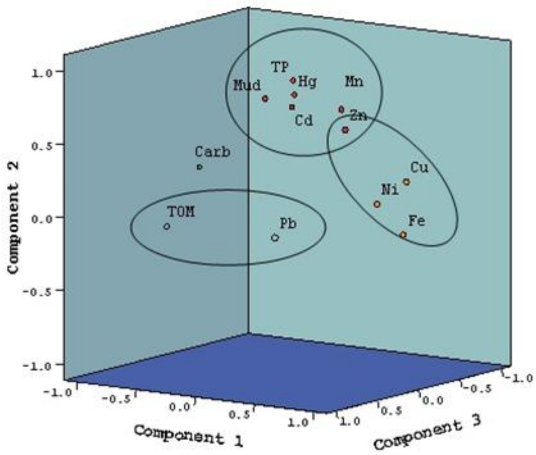

Fig. 5: Principal component analysis plot of heavy metals, TP, mud, TOM and Mud of the samples at El-Hamrawein Harbour.

3.6- Ecological risk assessment associated with heavy metal contamination.

The pollution indices serve as a common metric for assessing the contamination levels of surface sediments in aquatic ecosystems [15].

3.6.1- Contamination factor (CF)

The contamination factor C_f^i was employed to assess levels of sediment contamination. The contamination factor equation is expressed by Hakanson [16] as follows:

$$C_f^i = C_s^i / C_b^i$$

In this context, Cs represents the concentration of metals within the sample, while Cb denotes the corresponding background or reference value. The values for the contamination factor (CF) of heavy metals at El-Hamrawein Harbour are presented in Table 5. According to Hakanson [16], the sediments are low contaminated with Fe (0.07), Mn (0.15), Zn (0.22), Cu (0.14), Pb (0.39), Ni (0.32), Hg (0.19) and moderately contaminated with Cd (1.02) (Fig. 6). The average contamination factor (CF) values for the metals examined at El-Hamrawein Harbour exhibit a decreasing order of Cd > Pb > Ni > Zn > Hg > Mn > Cu > Fe. This trend may be linked to the activities associated with phosphate shipments, as well as the discharge of oily waste from vessels operating in the area.

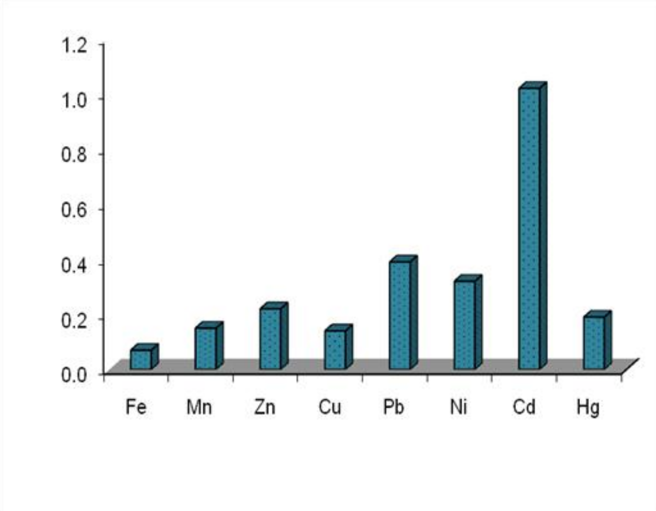

Fig. 6: Average values of contamination factor of sediments at El-Hamrawein Harbour.

3.6.2- Contamination degree (Cd)

This index represents the entirety of all contamination factors for all elements in surface layers of a certain sampling location [16]. Cd equation was used as follows:

$$C_d = \sum_{i=1}^{n} C_f^i$$

Where n represents the total number of pollutant elements analyzed, while i denotes a specific pollutant element, with C_f^i indicating the corresponding contamination factor. The degree of contamination observed in this research varies between 0.95 and 8.6, with an average value of 2.49, suggesting a low level of contamination (Table 5; Fig. 7).

3.6.3- Pollution load index (PLI)

The index has been determined and expressed by Tomlinson et al. [17]. It used to estimate the integrated contamination status of combined pollutants at sampling sites by computing the nth root of the n CF's product of the measured metals.

$$PLI = \sqrt[n]{(C_{f1}^i \times C_{f2}^i \times C_{f3}^i \times \ldots \times C_{fn}^i)}$$

Where C_f^i is the contamination factor, n is the number of investigated metals. PLI results in the studied locations within El-Hamrawein Harbour are represented in table 5. It is raging from 0.06 to 0.45, averaging 0.21. PLI values are < 1 at the area (Fig. 8), which indicates no significant pollution (baseline levels).

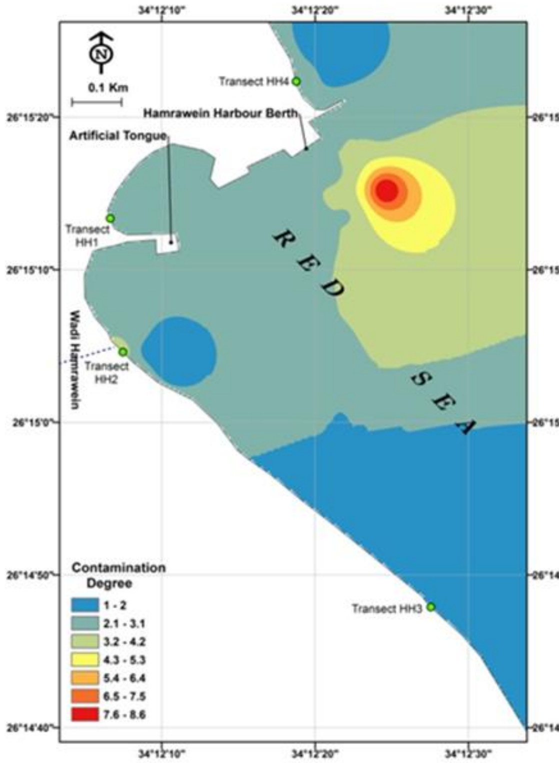

Fig. 7: Spatial representation of contamination degree at El-Hamrawein Harbour.

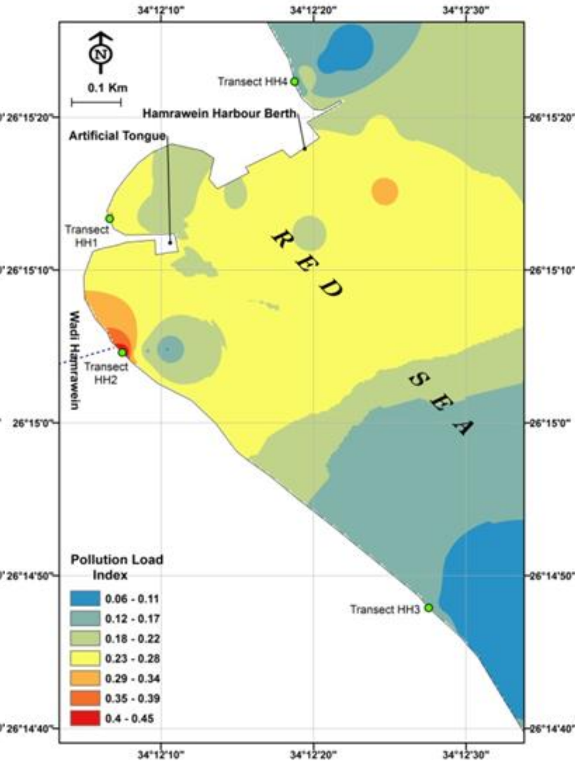

Fig. 8: Spatial representation of pollution load index at El-Hamrawein Harbour.

3.6.4- Modified degree of contamination (mCd)

The general level of contamination at a specific sampling site is estimated using mCd [18] according to the formula:

$$\mathbf{mC_d} = \frac{\sum_{i=1}^{n} C_f^i}{n}$$

Where n is the number of investigated pollutant elements, i is the pollutant element and C_f^i is the contamination factor. The heavy metals show mCd values ranging from 0.14 to 1.23, averaging 0.36 in the present study's sediments, suggesting nil to extremely low level of contamination (Table 5).

3.6.5- Enrichment factor (EF)

The enrichment factor is an excellent technique to estimate the proportion of pollutant elements in sediments. It is determined according to the formula:

$$EF = \frac{(C_s^i / C_S^{Fe})\ sample}{(C_b^i / C_b^{Fe})\ shale}$$

Where (C_s/C_{Fe}) is the metal concentration divided by iron concentration in the same sample, and (C_b/C_{Fe}) is the background concentration of metal in shale divided by Fe concentration in shale. According to Sutherland [19] classification, the sediment of El-Hamrawein Harbour has extremely high enrichment with Cd (42.76), and Pb (41.68), very high enrichment with Ni (21.27), significant enrichment with Zn, Cu and Mn (8.43, 8.34, and 6.65, respectively), and moderately enrichment with Hg (4.4) (Table 5; Fig. 9). According to these findings, every investigated metal under study at El-Hamrawein Harbour has an enrichment factor (EF) in the high categories, with the exception of mercury, which falls in class 2 (moderate enrichment).

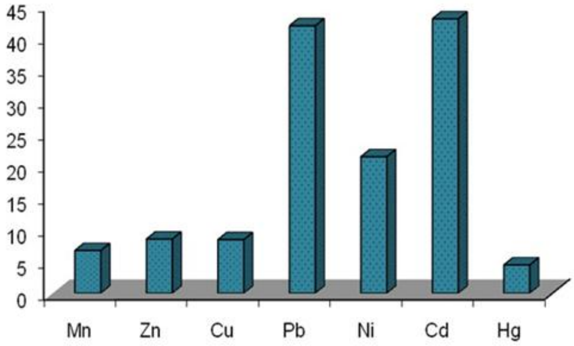

Fig. 9: Average values of enrichment factor of sediments at El-Hamrawein Harbour.

Table 4: shows total variance and matrix of principal components analysis of El-Hamrawein Harbour's marine sediments.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.633	38.604	38.604	4.633	38.604	38.604	4.081	34.009	34.009
2	2.995	24.957	63.561	2.995	24.957	63.561	3.542	29.516	63.525
3	1.309	10.907	74.468	1.309	10.907	74.468	1.313	10.943	74.468

Component matrix				Rotated component matrix			
Element	PC1	PC2	PC3	Element	PC1	PC2	PC3
Zn	0.865	0.159	0.175	Fe	0.923	-0.085	-0.081
Cu	0.854	-0.285	-0.215	Ni	0.910	0.167	0.217
Ni	0.840	-0.401	0.194	Cu	0.868	0.255	-0.198
Mn	0.787	0.338	-0.002	Carb.	-0.805	0.203	-0.087
Fe	0.703	-0.599	-0.114	TP	-0.003	0.878	-0.072
TP	0.506	0.720	-0.037	Mud	-0.052	0.786	0.197
Mud	0.414	0.660	0.229	Hg	0.010	0.780	-0.072
Carb.	-0.539	0.635	-0.053	Mn	0.446	0.731	-0.016
Hg	0.460	0.633	-0.042	Cd	-0.067	0.677	-0.153
Cd	0.337	0.598	-0.124	Zn	0.607	0.637	0.169
TOM	-0.436	0.208	0.756	Pb	0.418	-0.035	0.748
Pb	0.323	-0.308	0.732	TOM	-0.500	-0.054	0.743

Table 5: shows the contamination factor (CF), contamination degree (Cd), pollution load index (PLI), modified degree of contamination (mCd), and enrichment factor (EF) of heavy metals in the sediment samples of El-Hamrawein Harbour**.**

Index	CF								Cd	PLI	mCd	EF						
	Fe	Mn	Zn	Cu	Pb	Ni	Cd	Hg				Mn	Zn	Cu	Pb	Ni	Cd	Hg
Stdev	0.08	0.06	0.15	0.08	0.27	0.11	1.10	0.17	1.34	0.09	0.19	16.89	20.51	28.12	182.58	73.50	89.72	4.85
Min	0.00	0.04	0.03	0.06	0.04	0.18	0.23	ND	0.95	0.06	0.14	0.43	0.55	1.10	1.20	1.52	0.83	ND
Max	0.46	0.30	0.62	0.53	1.20	0.69	6.96	0.61	8.60	0.45	1.23	101.1	121.7	166.6	1072.9	434.9	525.94	19.19
Avg.	0.07	0.15	0.22	0.14	0.39	0.32	1.02	0.19	2.49	0.21	0.36	6.65	8.43	8.34	41.68	21.27	42.76	4.40

IV. Conclusion

The sand fraction is the dominant component, making up over 84% of the total, while the gravel fraction exhibited elevated levels in samples collected close to coral reefs, primarily due to the abundance of biogenic fragments. The area's deepest parts showed the highest mud values, where mud fraction increased with increasing depth of water. Activities including the shipping of phosphate ore, dredging, and landfilling in the harbour site are all related to the high mud fraction content. The area's high levels of organic matter are caused by the bottom facies of algae, seaweed, and seagrass.

High levels of total phosphorous were identified at the study area, which are more than double the probable effect level regulated by the sediment quality evaluation standard of Environment Ministry of Ontario. Mn, Hg, Zn, and Cd spatial distribution showed that the highest concentrations are located close to the phosphate shipping berth, which diminishes as distance from the berth increased, due to the shipping processes of phosphate ore, whereas the supratidal, beach and intertidal area of transect HH2 showed high concentrations of Fe, Cu, and Ni, attributed to the terrigenous flux from Wadi Hamrawein. In contrast, the sediments analyzed in the present study exhibited lower heavy metal levels compared to those recorded in the same area by Madkour et al. [8] but significantly more than those noted in Hurghada area [9]. From another point of view, the current average levels of heavy metals are considerably less than the level of the threshold effect, except for Ni, which marginally surpasses the threshold effect level.

The analysis of the average levels of heavy metals' modified degree of contamination (mCd), pollution load index (PLI), and contamination factor (CF) indicates that the sediments in the study area are not contaminated. However, the average values of the enrichment factor reveal that the sediments are extremely enriched with cadmium (Cd) and lead (Pb), very highly enriched with nickel (Ni), significantly enriched with zinc (Zn), copper (Cu), and manganese (Mn), and moderately enriched with mercury (Hg). To mitigate dust emissions, it is essential to implement a telescopic shot system for the transportation of phosphate ore from storage facilities to shipping vessels.

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