Journal of Radiation and Nuclear Applications
An International Journal

http://dx.doi.org/10.18576/jrna/070309

Assessment of Heavy Metals Contamination of the Beach Sands along the Coastline between Damietta and Port-Said, Mediterranean Sea, Egypt

R.A. Seif[1], *A. M. Osman*[1], *R.M. Attia*[2], *A. El-Azab*[2] and *I. H. Khalifa*[1]

[1]Geology Department, Faculty of Sciences, Suez Canal University, Egypt.
[2]Nuclear Materials Authority, Al-Katamyia, Egypt.

Received: 9 Jun. 2022, Revised: 19 Jul. 2022, Accepted: 25 Aug. 2022.
Published online: 1 Sep 2022.

Abstract: The aim of this study was to investigate the variation in heavy metal contents and their natural and artificial sources in beach sands along the coastal area between the cities of Port-Said and Damietta, Mediterranean Sea, Egypt. The pollution load indexes and possible ecological impacts with respect to sediment quality guidelines were discussed. Twenty samples were collected from the beach and sabkha sediments and analyzed by XRF technique for 13 heavy metals. Uranium was analyzed by the oxidimetric titration method. The heavy metals; Cr, Ni, Cu, Zn, Pb, Ga, Sr, Y, Rb, V and Ba have lower concentration than their corresponding standard levels except Zr and U. According to multivariate statistical analysis, four factors were determined. The first factor consists of Cr, Ni, V and Ba could be considered as a natural process factor and related to the presence of ferromagnesium and plagioclase feldspar minerals. The second factor include Zr, Sr and Nb represents the presence of heavy minerals such as zircon, monazite and garnet., The third factor includes Cu, Zn and Pb and could be considered as anthropogenic factor. The fourth factor involves U and and could be connected to uranium mobilization as radioactive factor. The analyzed heavy metals have negative values of geoaccumulation factor ($I_{geo)}$, low values of contamination factors (C_f), except few samples considered as uncontaminated to moderately contaminated with Cr, Zr, Ga, Cu, Pb and Zn. The C_d values are lower than 6.0 in nine sediment samples randomly distributed in the study area and indicate low degree of contamination. The calculated C_d values in the rest of samples (>.0.6) are of moderate degree of contamination, most of them are located at Port-Said area. The values of PLI recorded for all samples ranged from 0.07 to 0.5 (< 1.0) indicate a good quality of the beach and sabkha sediment of the study area.

Keywords: Port-Said, Damietta, Mediterranean, heavy minerals, heavy metals pollution.

1 Introduction

Coastal environments are complex and dynamic in their characteristics and nature, it shows sandy beaches as a geographic space of interaction between terrestrial and marine ecosystems [1]. One of the most pollutants agents in coastal environments is the presence of abnormal concentration of heavy metals in beach sediments which results from complex natural processes and anthropogenic activities. The natural processes include accumulation of heavy metals through complex physical and chemical adsorption mechanisms depending on the properties of the adsorbed compounds and the nature of the sediment matrices [1]. Anthropogenic activities such as mining, smelting, electro plating and incineration of solid waste, untreated sewage, and by nonpoint surface runoff are the major source for enrichment of the metals in beach sediments [2].
Under certain conditions, the heavy metals can cause ecological damage when they accumulate to toxic concentration levels [3]. The unplanned evolution activities and development projects affected in serious way on the coastal territory and coastal water resources, it polluted them with unexpected pollution resulted from the domestic sewage, agricultural drains and industrial discharge. Those pollutants reached the coastal water resources through the rivers and drainage system [4]. The accumulation and toxicity of the heavy metals are dependent on many factors such as: level of metal in sediment, grain size, salinity, temperature, pH and organic matter [5-8].

All metals are toxic at higher concentrations [9]. Although, Fe, Zn, Cu and Mg are essential metals as they have important roles in the biological system, the higher concentration of them makes them toxic [10]. Although, heavy metals that have a relatively high density are highly poisonous even at low concentrations [11]. Some heavy metals such as Fe, Co, Ni, Cr, Cd, Pb, Zn, Mn and Cu are

*Corresponding author e-mail:

regarded as serious pollutants metals in aquatic ecosystems due to their environmental perseverance, toxicity and ability to incorporate into food chains [12].

In the present study, heavy metal contents of both beach and sabkha sediments in the coastal area between Port-Said and Damietta were investigated. Choosing this area is due to the commercial importance of the two cities and the presence of Damietta, Port-Said and east of Port-Said ports. The economic activities of the two cities include fishing activities, agriculture, industry activities which made this area attract attention of many researchers and that's why, they are worthy to be studied. This work aims to provide a geochemical framework for evaluating the possible source and mechanism of metals input, their spatial distribution and enrichment. To identify the geochemical signature of the anthropogenic influences in this coastal environment, pollution load index and possible ecological impacts with respect to sediment quality guidelines were discussed.

2 The study area

The study area constitutes the Eastern flank of the Nile Delta and located on the coast of the Mediterranean Sea**,** it constitutes the coast between Port-Said and Damietta cities between longitudes, 31° 39' 9.2–32° 20'9.6 E and latitudes 31° 37'13-31° 0' 54N (Fig.1). Port-Said located in the north-eastern part of Egypt. It surrounded in the east by Suez navigation Canal, in the north by the Mediterranean Sea and in the west by the eastern part of Manzala Lake. Damietta promontory area is located on the north-eastern Nile Delta coast and extends 11.0 km east, 11.0 km west, 5.0 km north and 12.0 km south referenced to the tip of the promontory [13].

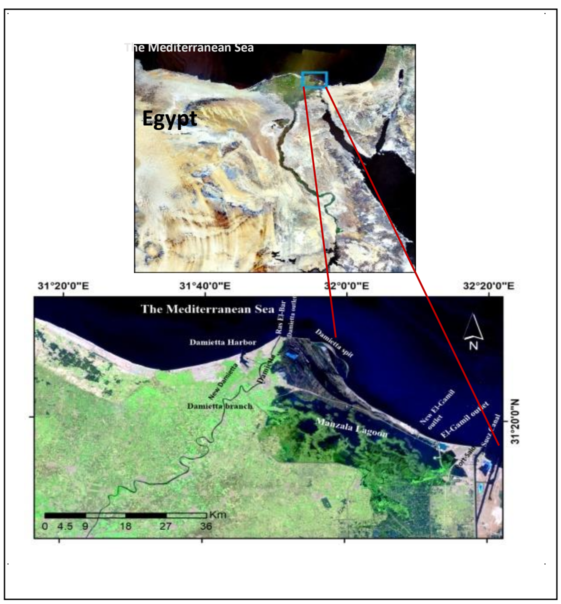


Fig.1: Location map of the area under investigation**.**

3 Experimental

Twenty samples were collected from two different environments from the shoreline and sabkha sediments between Port-Said and Damietta (Fig. 2). The samples were collected manually by rotating a spiral bar to a depth of one meter. The trace elements (Cr, Cu, Ni, Zn, Zr, Ga, Sr, Y, Rb, V, Nb, Pb and Ba) were determined for 20 selected samples using X-ray Fluorescence (XRF) Spectrometry technique on fused beads. X-ray Fluorescence at the laboratories of the Nuclear Materials Authority of Egypt. The trace elements were measured through Philips e PW 1480 X e ray spectrometer X unique II with an automatic sample changer (PW e 1510). Uranium is chemically analyzed using the oxidimetric titration method against ammonium meta vanadate that was used after its reduction [14].

Descriptive statistical analyses (mean, maximum and minimum) were carried out to present results, compare sample characteristics and evaluate the possible concealed relationship between the obtained results. Data management and descriptive statistics were performed using SPSS computer program. Pearson's correlation coefficient test was carried out to support the results obtained by multivariate analysis. It allows investigating the associations among the analyzed elements concerning their origin and geochemical affinity. The cluster analysis is usually used in combination with PCA. It was employed to provide intuitive similarity relationship in order to find the association between heavy metals contents and identify different geochemical groups, using the dendrogram [15].

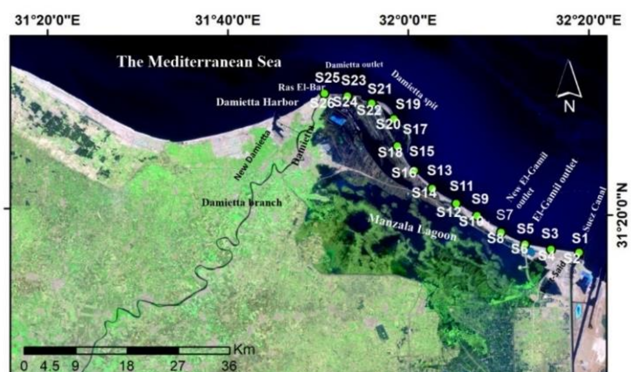


Fig.2: Location map of collected samples in the study area.

4 Results

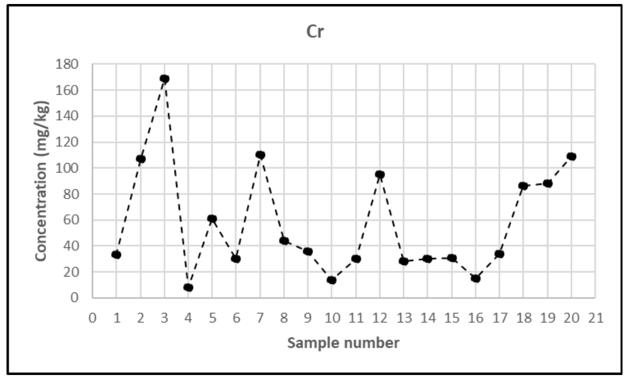
4.1 Heavy metal distribution

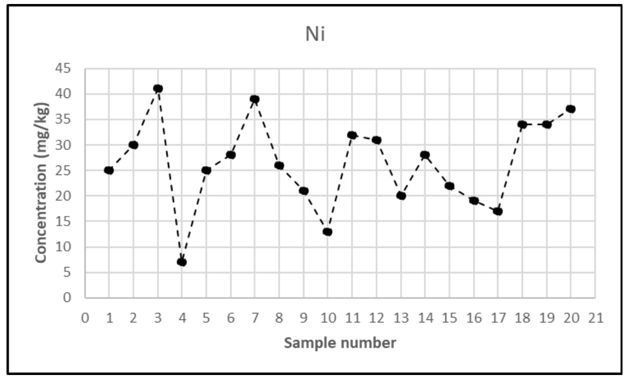
The concentration of the heavy metals Cr, Cu, Ni, Zn, Zr, Ga, Sr, Y, Rb, V, Nb, Pb and Ba are presented in (Table 1). In general, the distribution patterns of heavy metals in the sediment samples were on the following order Zr >Ba> Zn > Sr > Cr > V > Cu > Pb> Ni >Nb > Ga> Y > Rb. Regarding the heavy metal contents of the earth crust [16], the concentrations of the heavy metals of the beach sediments were considered normal except that of Zr and U (Table 1). The concentration of Cr ranged between 8.0 to 169 mg/kg with an average concentration of 57.90 mg/kg less than the average concentration of Cr in shale (Table 1 and Fig. 3). Only five samples have relatively high concentration of Cr (>90 mg/kg) located at both Port-Said city (Eastern zone) and Damietta (western zone). Ni concentration ranged from 7-41 mg/kg with an average concentration of 26.5 mg/kg less than its average concentration in shale [17]. Vanadium concentration ranged from 2.0 to 128 mg/kg with an average concentration 37.5 mg/kg. The spatial distribution of Cr, Ni and V are similar to each other in both the beach and sabkha sediments (Fig. 4). They are high in Port-Said and sabkha and Damietta shoreline and low in the concentrations in the central zone. The high concentrations of these metals are corresponding to the areas of urban areas and fish farm activities (Figs. 5 & 6).

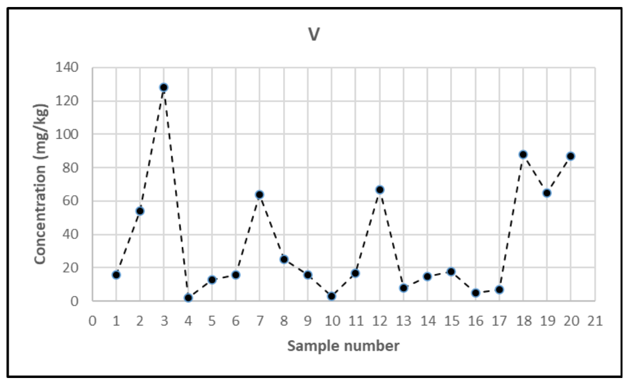
The minimum and maximum concentrations (mg/kg) of Cu, Zn and Pb varied from 14–50, 4-419, 3-49 with an average concentration of 21.7, 31.2 and 3.5 respectively. Only one sabkha sediment sample has a high concentration of these elements (Fig. 3) relative to their average in shale [17]. The spatial distribution of Cu, Zn and Pb are similar to each other in both type of sediments in the study area (Fig. 4). The highest concentrations of these metals are related to urban activities and fish farms (Figs. 7, 8 & 9).

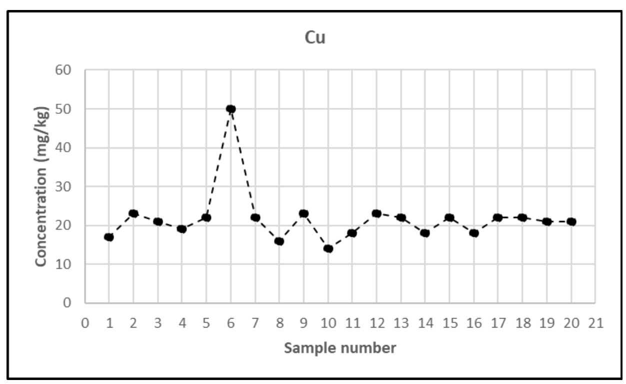
The Zr contents of sediment samples range from 57 to 850 mg/kg with an average of 280 mg/kg. Twelve samples of both types of studied sediments are above the average concentration of Zr in shale [17]. The highest concentrations of Zr are located at Port-Said and Damietta zone. Sr and Ba concentrations varied between 14 to 213 mg/kg and 14 to 563 mg/kg with an average concentration of 73 and 157.9 mg/kg respectively. Both element concentrations are below their average contents in shale. The spatial distributions of Zr, Sr and Ba in beach and sabkha sediments are more or less similar to each other (Fig. 4). They exhibit high concentrations in shoreline and sabkha sediments at Port-Said and Damietta but show low concentrations in the central zone (Fig. 10).

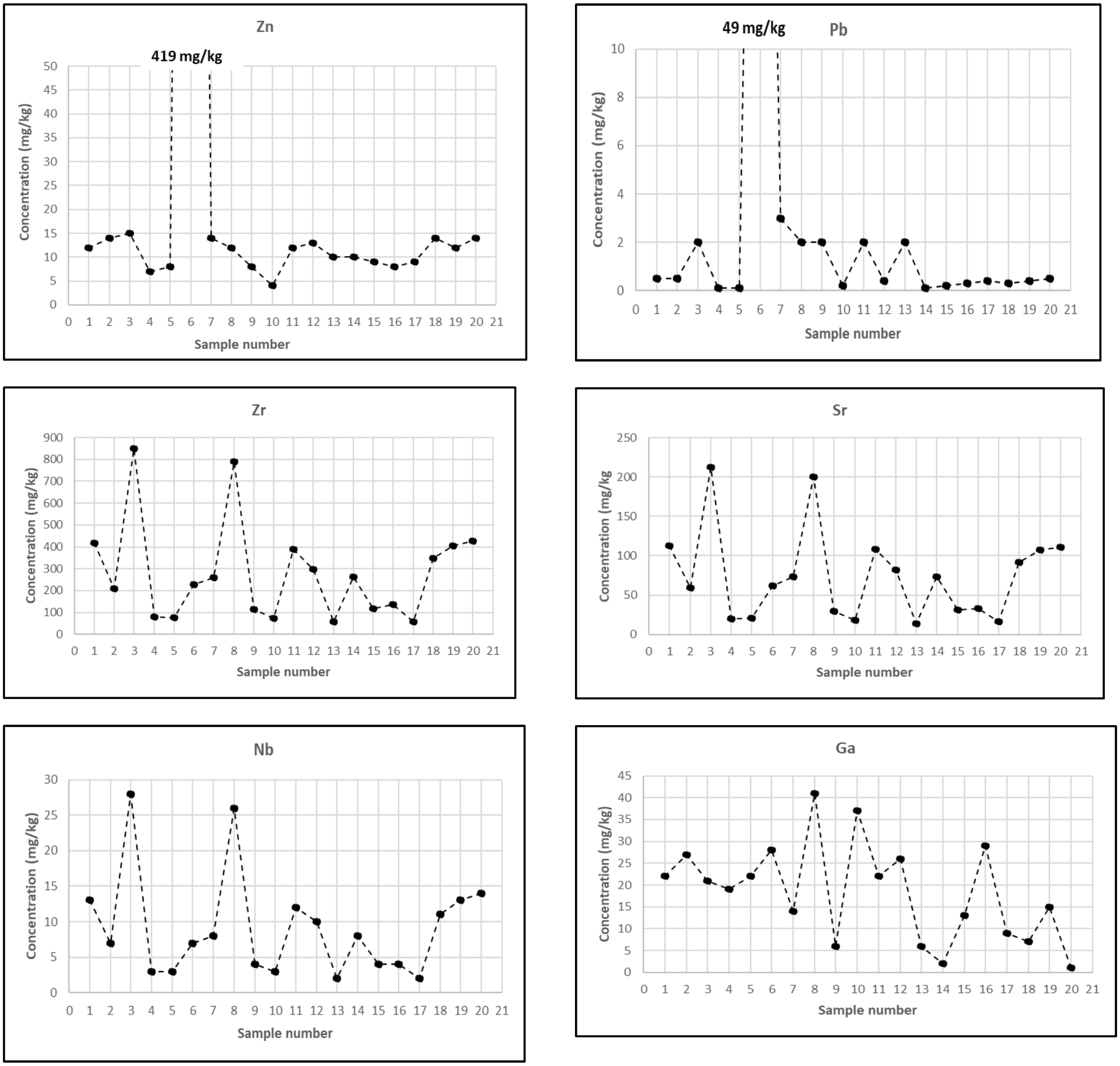
Ga contents ranged between 1.0 to 41 mg/kg with an average concentration of 18.3 mg/kg. Nine samples have slightly higher concentration above the standard limit (19 mg/kg) located at Port-Said and the central zone of the studied area. Nb concentration ranged between 2-28 mg/kg with an average concentration of 9 mg/kg less than its average concentration in shale [17]. Few samples have concentration above the standard limits (9 mg/kg). The samples which have a high concentration of Ga have also the concentration of Zr and Nb (Table 1). Uranium concentration fluctuated between 38 to 41 mg/kg. Both Y and Rb contents are very low below their average contents in shale.











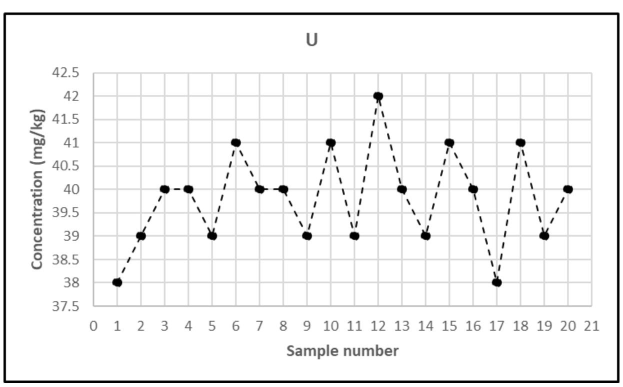


Fig.3: Distribution of trace elements in the beach and sabkha sediments.

4.2 Statistical analysis

The interelement correlation analysis of the variables Cr, Cu, Ni, Zn, Zr, Ga, Sr, V, Nb, Pb, Ba and U in studied beach and sabkha sediments along the coast between Port-Said and Damietta are listed in the (Table 2). The correlation matrix showed a significant correlation between a number of elements that may reflect the mineral composition and the effects of any pollution hazards. The first group of element association includes Cr, Ni, V and Ba has a strong positive correlation with each other. Cr has positive correlation coefficients with Ni (r= 0.826), V (r= 0.948), and Ba (r=0.948). Ni has a positive correlation

Table 1. Concentrations of heavy metal (mg/Kg) in sediments of the study area as well as U (in ppm) compared to the average concentration of heavy metals in sea sediments [17] and Earth crust [16].

Sample no.	Cr	Cu	Ni	Zn	Zr	Ga	Sr	Y	Rb	V	Nb	Pb	Ba	U
1*	33	17	25	12	417	22	113	0.4	1	16	13	1	71	38
3*	169	21	41	15	850	21	213	3	1.8	128	28	2	563	40
5*	61	22	25	8	77	22	21	1	1	13	3	1	56	39
7*	110	22	39	14	260	14	73	2	0.5	64	8	3	276	40
9*	36	23	21	8	114	6	29	1.5	1	16	4	2	71	39
11*	30	18	32	12	390	22	108	0.4	1.3	17	12	2	75	39
13*	28	22	20	10	57	6	14	0.5	0.7	8	2	2	34	40
14*	30	18	28	10	262	2	73	1	0.4	15	8	0.5	68	39
16*	15	18	19	8	138	29	33	0.4	0.5	5	4	0.3	22	40
19*	88	21	34	12	406	15	107	0.4	1	65	13	0.4	285	39
2**	107	23	30	14	210	27	59	1	1.5	54	7	0.4	251	39
4**	8	19	7	7	81	19	20	0.5	0.5	2	3	0.4	15	40
6**	30	50	28	419	229	28	62	5	1.7	16	7	49	70	41
8**	44	16	26	12	789	41	200	2	0.4	25	26	2	108	40
10**	14	14	13	4	75	37	18	1	0.7	3	3	0.5	14	41
12**	95	23	31	13	299	26	82	1.2	1	67	10	0.4	298	42
15**	31	22	22	9	118	13	31	1.5	1	18	4	1	80	41
17**	34	22	17	9	57	9	16	1	1.1	7	2	0.7	28	38
18**	86	22	34	14	348	7	92	1.8	0.2	88	11	1	387	41
20**	109	21	37	14	428	1	111	2	0.4	87	14	0.5	387	40
Min.	8	14	7	4	57	1	14	0.4	0.2	2	2	0.3	14	38
Max.	169	50	41	419	850	41	213	5	1.8	128	28	49	563	41
Ave.	57.90	21.70	26.45	31.20	280.25	18.35	73.75	1.38	0.885	35.70	9.10	3.505	157.95	38.1
Ave. shale	**90**	**45**	**68**	**95**	**160**	**19**	**300**	**26**	**140**	**130**	**11**	**20**	**580**	
Ave. Earth crust	**100**	**50**	**75**	**70**	**165**	**19**	**370**	**33**	**90**	**120**	**20**	**12.5**	**425**	**2.7**

*** Beach sediment sample**
**** Sabkha sediment sample**

coefficient with Ba (r= 0.818) and V (r= 0.820). V has a positive correlation with Ba (r= 1.000). This element association could be related to the presence of ferromagnesium minerals as well as plagioclase minerals in the composition of beach and sabkha sediments. The second group of element association which have strong positive correlation coefficient include Zr, Nb, Sr and relatively Ba. Zr has positive correlation coefficient with Sr (r=0.998) and Nb (r=0.999). At the same time, Sr has strong a positive with Nb (r= 0.995). This element association could be connected to the presence of garnet, feldspars and zircon minerals. The first group of elements (Cr, Ni and V, Ba) has moderate positive correlation coefficient with the second group of elements (Zr, Nb, Sr) suggesting mixed sources of these sediment (mafic to acidic rocks). The third group of element association includes Cu, Pb and Zn which have strong positive correlation coefficients among themselves and weak to negative correlation with the first and the second group of element association indicating different sources. Cu has very strong positive correlation with Zn (r=0.936) and Pb (r=0.930) and Zn has strong positive correlation with Pb (r= 0.996). The concentrations of these groups of elements in general are low and below their average concentration in shale except one sabkha sediment sample located at Port-Said zone. These elements could be due to anthropogenic activity in the study area.

Factor analysis of all measured variables in the sediment of Sabkha and shoreline of the study area was undertaken to classify the different factors that control the distribution of elements in the beach sediments and identify the composition and the nature of the sediments and their sources. The four-factor model account for 94.403% of the data variability, the communalities show that all elements are well accounted by this model (Table 3). The first factor (Factor 1) explains 34.543% of the total variance with a high eigenvalue of 4.145. It is the most prevalent among the obtained factors. It is highly correlated with Cr, Ni, V and Ba and could be considered as a natural process factor. This metals association of this coupled with the strong positive correlation coefficient among themselves related this factor to the presence of ferromagnesium and plagioclase feldspar minerals. The second factor (Factor 2) represents 24.691% of the data variability with an eigenvalue of 3.034. It is

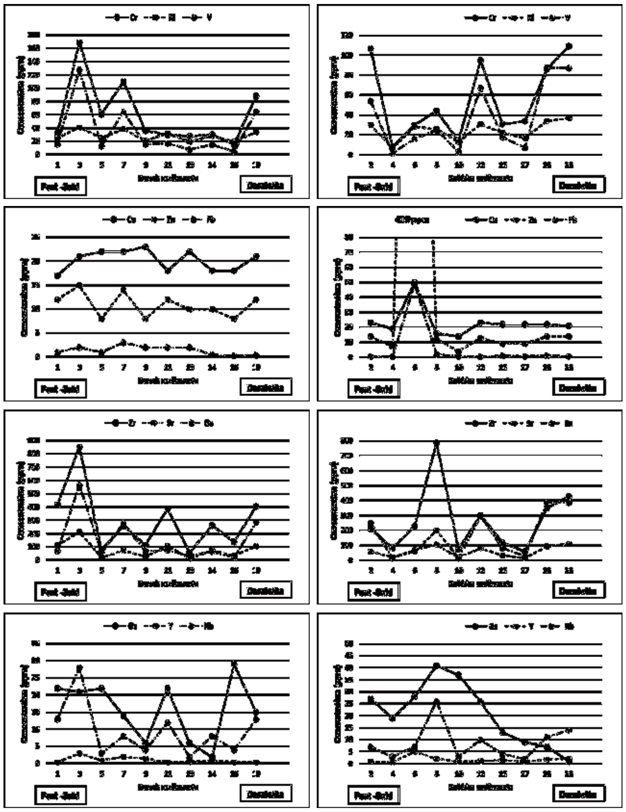


Figure 4. Comparison between trace elements concentration in beach and sabkha sediments

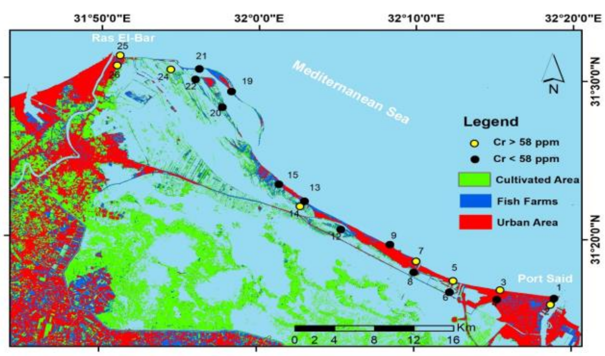


Figure 5. Distribution of Cr in beach and Sabkha sediments between Port-Said and Damietta

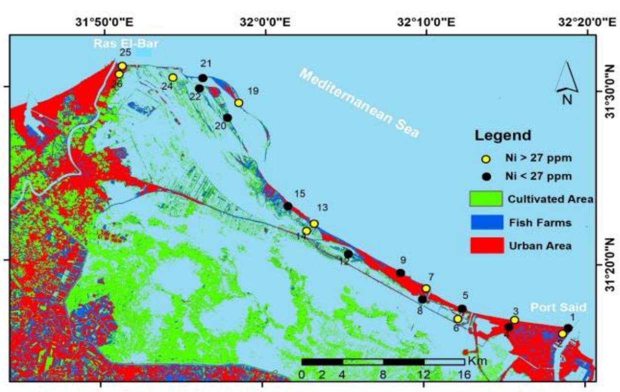


Figure 6. Distribution of Ni in beach and Sabkha sediments between Port-Said and Damietta

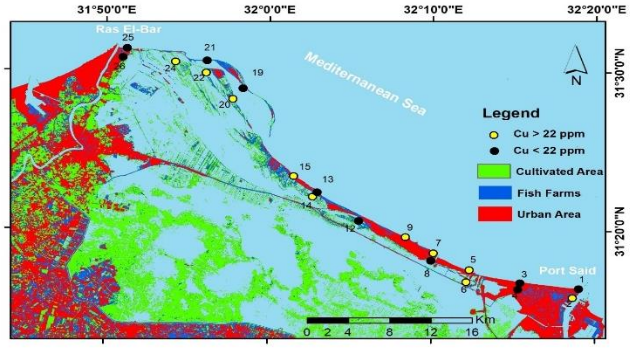


Figure 7. Distribution of Cu in beach and Sabkha sediments between Port-Said and Damietta

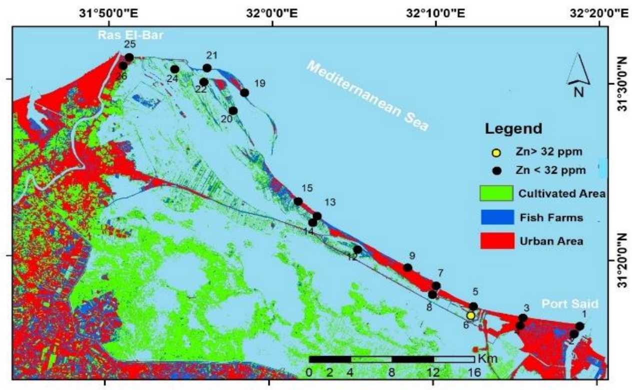


Figure 8. Distribution of Zn in beach and Sabkha sediments between Port-Said and Damietta

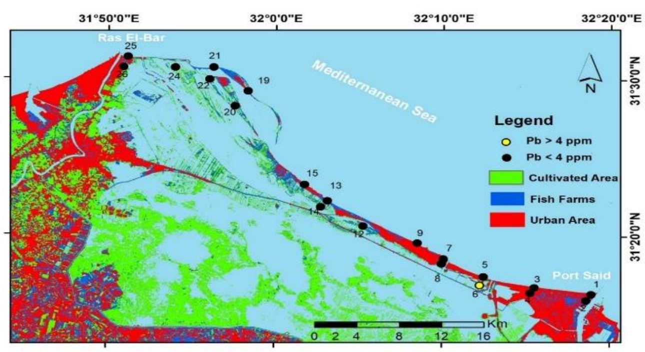


Figure 9. Distribution of Pb in beach and Sabkha sediments between Port-Said and Damietta

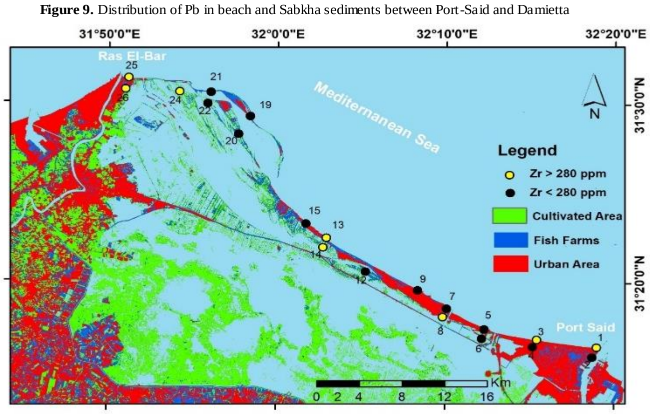


Figure 10. Distribution of Zr in beach and Sabkha sediments between Port-Said and Damietta

Table 2. Pearson correlation coefficient of elements in beach and sabkha sediments (20 samples) between Port-Said and Damietta**.**

Element	Cr	Cu	Ni	Zn	Zr	Ga	Sr	V	Nb	Pb	Ba	U
Cr	1											
Cu	.033	1										
Ni	**.826****	.160	1									
Zn	-.127	**.936****	.070	1								
Zr	**.573****	-.124	**.643****	-.032	1							
Ga	-.124	-.003	-.181	.197	.232	1						
Sr	**.578****	-.117	**.668****	-.026	**.998****	.223	1					
V	**.948****	.023	**.823****	-.104	**.642****	-.181	**.644****	1				
Nb	**.582****	-.135	**.626****	-.047	**.999****	.244	**.995****	**.645****	1			
Pb	-.132	**.930****	.071	**.996****	-.021	.202	-.016	-.115	-.035	1		
Ba	**.948****	.022	**.818****	-.105	**.638****	-.179	**.640****	**1.000****	**.641****	-.117	1	
U	.112	.264	.061	.268	.018	.241	.006	.244	.030	.264	.244	1

highly correlated with Zr, Sr and Nb and could represent the presence of some heavy minerals such as zircon, monazite and garnet. The third factor (Factor 3) accounts for 25.284% of the data variability of this model with eigenvalue of 2.963. It is highly correlated with Cu, Zn and Pb and could be considered as anthropogenic factor. The fourth factor (Factor 4) explains a further 10.744 % of the variance with eigenvalue of 1.186. It is highly correlated with U with some contribution of Ga. The weak correlation coefficient between U and Ga indicate that there is no relationship between them, therefore we can consider this factor as a single element factor and may be considered related to uranium mobilization as the radioactive factor. The negative loading of Zr in this factor as well as the weak correlation with U indicates zircon mineral metamictization and mobilization of uranium from its structure incorporating monazite, as the main sources of radioactivity in the black sand in the studied area [18, 19].

Cluster analysis was conducted to determine the correlation between the analyzed chemical elements (R-mode cluster analysis). The applied analysis is depended on the Euclidean average linkage method (within groups), which is adequate as its clusters are distinct and decisive revealing the nature of the sediment of the study area (Fig. 11). Although R-mode cluster analysis is not notably different from factor analysis, it is an alternative to confirm the results [20]. The dendrogram of R-mode cluster analysis (Fig. 10) shows four distinct groups of elements association The first group of elements included V, Ba and Cr, the second group comprised Zr, Nb and Sr, the third group included Cu, U and Ni; the fourth group encompassed Zn and Pb. The elements first and the second groups of element association were found to be consistent with and confirm the results obtained from both factor analysis and other statistical data. The third (Cu, U and Ni) and the fourth group (Zn and Pb) of element association appear to be related to the radioactive minerals in the black sands with anthropogenic sources.

Table 3. R-mode varimax rotated factor matrix of elements in beach and sabkha sediments (20 samples)

Element	Factor 1	Factor 2	Factor 3	Factor 4
Cr	**.911**	.245	-.064	.047
Cu	.118	-.155	**.967**	.060
Ni	**.837**	.342	.147	-.124
Zn	-.080	.041	**.987**	.105
Zr	.435	**.886**	-.033	-.029
Ga	-.441	.573	.089	**.533**
Sr	.444	**.883**	-.024	-.047
V	**.943**	.270	-.059	.122
Nb	.434	**.885**	-.049	-.008
Pb	-.090	.057	**.986**	.099
Ba	**.942**	.266	-.062	.125
U	.205	-.089	.195	**.909**
Eigenvalue	4.145	3.034	2.963	1.186
Variance (%)	34.543	25.284	24.691	9.885

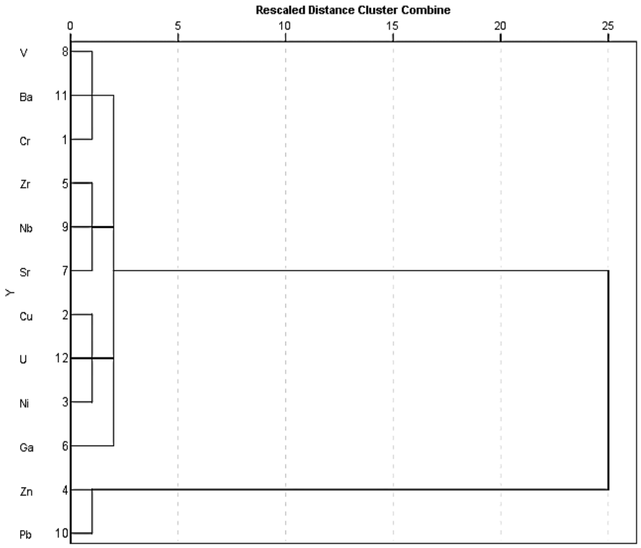


Figure 11. R-mode cluster analysis of trace elements in beach and sabkha sediments between Port-Said and Damietta

5 Sediment Quality Guidelines (SQGs)

The obtained data of heavy metal concentrations in the sediments samples in the study area was compared with the average concentration of heavy metals in sea sediments defined by [17]. This comparison provides a reliable basis for evaluating the quality of sediment conditions in the studied area. In this concern, the trace element contents of Ni, Sr, Y, Rb, V and Ba in all the analyzed sediments samples in the study area are lower than standard levels, however, some samples have high concentrations of Zr, Ga, Nb, Cu, Zn and Pb.

5.1 The geo-accumulation index (I_{geo})

The geo-accumulation index (I_{geo}) is a numerical measure of the degree of pollution of heavy metal in sediments. It is calculated by comparing the concentrations of heavy metal in the present study with pre-industrial levels [21]. It builds on the background level of natural fluctuations including very low anthropogenic input. I_{geo} is calculated by the following equation (1):

$$I_{geo} = \log_2\left(\frac{C_n}{K \times B_n}\right) \rightarrow \qquad \textbf{(1)}$$

where, C_n is the measured concentration of metal in sediment, B_n is the corresponding geochemical background of element in average shale proposed by [17] and K is the background matrix correction factor (K = 1.5). The respective background content (B_n) is multiplied by the constant factor 1.5 to achieve the following: 1) get the upper limit of the lowest load class 0, 2) minimize the effect of possible variations in the background values which might due to lithologic variations in the sediments, 3) analyze natural fluctuation between the content of a given substance in environment and very small anthropogenic influences [22-25], generally [26].

In these regards, the world average concentration of Cr (90 mg/kg), Cu (45 mg/kg), Ni (68 mg/kg), Zn (95 mg/kg), Zr (160mg/kg), Ga (19 mg/kg), Sr (300 mg/kg), Y (26 mg/kg), Rb (140mg/kg), Nb (11 mg/kg), Pb (20 mg/kg) and Ba (580 mg/kg) reported for world shale were considered as the background values of sediments [17, 27, 28, 29].The results of geo-accumulation index of the 13 heavy metals in each sediment sample were calculated and listed in (Table 4) and depicted in (Figs 12, 13 & 14). Negative I_{geo} values were detected in all samples for Cr Ni, V, Cu, Pb, Zn, Sr, Rb, Y, which revealed that the beach and sabkha sediments are uncontaminated with these metals except few samples (e.g., sample no. 6 is contaminated with Pb and Zn). However, the I_{geo} values for Zr were the highest as compared to all the other metals in which eight samples are belonged to uncontaminated to moderately uncontaminated and two samples are moderately contaminated. The moderately contaminated samples with Zr are located mostly at Port-Said beach. The moderately contaminated samples with Zr are related to the presence of zircon minerals in the beach and sediments. Ga and Nb are practically uncontaminated in all samples except three samples which are uncontaminated to moderately contaminate along the shoreline of Port-Said and Damietta.

5.2 Contamination Factor and Contamination Degree (C_f)

The contamination factor is the ratio between the sediment metal concentration at a given site and its normal content level [30]. In the current study, the contamination factor (C_f) and degree of contamination (C_d) are used to describe the pollution grade of beach and sabkha sediments. C_f was calculated using the following equation (2):

$$C_f = C_i / C_n \rightarrow \textbf{(2)}$$

where C_i is the mean content of a substance in sediments" and C_n is the standard level (background) for that metal. The criteria used to display the values of the contamination factor [31] are presented in (Table 5).

The contamination factor **(C_f)** of Ni, Sr, Y, Rb, V and Ba of all studied samples show low degree of contamination (Table 6 and Figs. 14, 15 & 16). The C_f values of Cr and Nb are slightly different where, some samples exhibit moderate degree of contamination. The contaminated samples with Cr and Nb are randomly distributed along the study area. Only one sabkha sediment sample (no.6) has C_f values for Cu, Pb and Zn > 1.0 however, the rest of samples are considered uncontaminated. Zr C_f values have a different distribution rather than the other heavy metals,

Table 4. I_{geo} of (Cr, Cu, Ni, Zn, Zr, Ga, Sr, Y, Rb, V, Nb, Pb and Ba) in sediment samples and PLI. I_{geo}: Geo-Accumulation index and PLI: pollution load index.

Serial no.	Sample no	Cr	Cu	Ni	Zn	Zr	Ga	Sr	Y	Rb	V	Nb	Pb	Ba	PLI
1	1*	-2.03	-1.99	-2.03	-3.57	0.80	-0.37	-1.99	-6.61	-7.71	-3.61	-0.34	-4.91	-3.62	0.20
2	2**	-0.34	-1.55	-1.77	-3.35	-0.19	-0.08	-2.93	-5.29	-7.13	-1.85	-1.24	-6.23	-1.79	0.25
3	3*	0.32	-1.68	-1.31	-3.25	1.82	-0.44	-1.08	-3.70	-6.87	-0.61	0.76	-3.91	-0.63	0.50
4	4**	-4.08	-1.83	-3.87	-4.35	-1.57	-0.58	-4.49	-6.29	-8.71	-6.61	-2.46	-6.23	-5.86	0.07
5	5*	-1.15	-1.62	-2.03	-4.15	-1.64	-0.37	-4.42	-5.29	-7.71	-3.91	-2.46	-4.91	-3.96	0.15
6	6**	-2.17	-0.43	-1.87	1.56	-0.07	-0.03	-2.86	-2.96	-6.95	-3.61	-1.24	0.71	-3.64	0.43
7	7*	-0.30	-1.62	-1.39	-3.35	0.12	-1.03	-2.62	-4.29	-8.71	-1.61	-1.04	-3.32	-1.66	0.29
8	8**	-1.62	-2.08	-1.97	-3.57	1.72	0.52	-1.17	-4.29	-9.04	-2.96	0.66	-3.91	-3.01	0.29
9	9*	-1.91	-1.55	-2.28	-4.15	-1.07	-2.25	-3.96	-4.70	-7.71	-3.61	-2.04	-3.91	-3.62	0.15
10	10**	-3.27	-2.27	-2.97	-5.15	-1.68	0.38	-4.64	-5.29	-8.23	-6.02	-2.46	-5.91	-5.96	0.09
11	11*	-2.17	-1.91	-1.67	-3.57	0.70	-0.37	-2.06	-6.61	-7.34	-3.52	-0.46	-3.91	-3.54	0.22
12	12**	-0.51	-1.55	-1.72	-3.45	0.32	-0.13	-2.46	-5.02	-7.71	-1.54	-0.72	-6.23	-1.55	0.27
13	13*	-2.27	-1.62	-2.35	-3.83	-2.07	-2.25	-5.01	-6.29	-8.23	-4.61	-3.04	-3.91	-4.68	0.10
14	14*	-2.17	-1.91	-1.87	-3.83	0.13	-3.83	-2.62	-5.29	-9.04	-3.70	-1.04	-5.91	-3.68	0.14
15	15**	-2.12	-1.62	-2.21	-3.98	-1.02	-1.13	-3.86	-4.70	-7.71	-3.44	-2.04	-4.91	-3.44	0.16
16	16*	-3.17	-1.91	-2.42	-4.15	-0.80	0.03	-3.77	-6.61	-8.71	-5.29	-2.04	-6.64	-5.31	0.10
17	17**	-1.99	-1.62	-2.58	-3.98	-2.07	-1.66	-4.81	-5.29	-7.58	-4.80	-3.04	-5.42	-4.96	0.11
18	18**	-0.65	-1.62	-1.58	-3.35	0.54	-2.03	-2.29	-4.44	-10.04	-1.15	-0.58	-4.91	-1.17	0.25
19	19*	-0.62	-1.68	-1.58	-3.57	0.76	-0.93	-2.07	-6.61	-7.71	-1.58	-0.34	-6.23	-1.61	0.25
20	20**	-0.31	-1.68	-1.46	-3.35	0.83	-4.83	-2.02	-4.29	-9.04	-1.16	-0.24	-5.91	-1.17	0.24

*** Beach sediment sample**
**** Sabkha sediment sample**

it has 8 samples show low degree of contamination ($C_f < 1$) and ten samples exhibit moderate degree of contamination ($1 < C_f < 3$) and the rest two samples display considerable degree of contamination ($3 < C_f < 6$). The moderately contaminated to considerably contaminated samples with Zr are distributed randomly in the study area due to the presence of zircon minerals in the black sand in both beach and sabkha sediments. The C_d values are lower than 6.0 in nine sediment samples randomly distributed in the study area and indicate low degree of contamination. The C_d values in the rest of samples are of moderate degree of contamination and have a considerable degree of contamination in Port-Said area (Table 6).

Table 5. Terminologies used to describe the contamination factor (C_f) and contamination degree (C_d).

C_f	C_d	Description
$C_f < 1$	$C_d < 6$	Low degree of contamination
$1 < C_f < 3$	$6 \leq C_d < 12$	Moderate degree of contamination
$3 < C_f < 6$	$12 \leq C_d < 24$	Considerable degree of contamination
$C_f > 6$	$C_d \geq 24$	Very high degree of contamination

Table 6. The contamination factor (C_f) of Cr, Cu, Ni, Zn, Zr, Ga, Sr, Y, Rb, V, Nb, Pb and Ba in sediment samples, C_d is the contamination degree

Serial no.	Sample no	Cr	Cu	Ni	Zn	Zr	Ga	Sr	Y	Rb	V	Nb	Pb	Ba	C_d
1	1*	0.37	0.38	0.37	0.13	2.61	1.16	0.38	0.02	0.01	0.12	1.18	0.05	0.12	6.90
2	2**	1.19	0.51	0.44	0.15	1.31	1.42	0.20	0.04	0.01	0.42	0.64	0.02	0.43	6.80
3	3*	1.88	0.47	0.60	0.16	5.31	1.11	0.71	0.12	0.01	0.98	2.55	0.1	0.97	14.96
4	4**	0.09	0.42	0.10	0.07	0.51	1.00	0.07	0.02	0.00	0.02	0.27	0.02	0.03	2.67
5	5*	0.68	0.49	0.37	0.08	0.48	1.16	0.07	0.04	0.01	0.10	0.27	0.05	0.10	3.89
6	6**	0.33	1.11	0.41	4.41	1.43	1.47	0.21	0.19	0.01	0.12	0.64	2.45	0.12	12.91
7	7*	1.22	0.49	0.57	0.15	1.63	0.74	0.24	0.08	0.00	0.49	0.73	0.15	0.48	6.97
8	8**	0.49	0.36	0.38	0.13	4.93	2.16	0.67	0.08	0.00	0.19	2.36	0.1	0.19	12.04
9	9*	0.40	0.51	0.31	0.08	0.71	0.32	0.10	0.06	0.01	0.12	0.36	0.1	0.12	3.18
10	12**	0.16	0.31	0.19	0.04	0.47	1.95	0.06	0.04	0.01	0.02	0.27	0.025	0.02	3.59
11	13*	0.33	0.40	0.47	0.13	2.44	1.16	0.36	0.02	0.01	0.13	1.09	0.1	0.13	6.78
12	14**	1.06	0.51	0.46	0.14	1.87	1.37	0.27	0.05	0.01	0.52	0.91	0.02	0.51	7.70
13	15*	0.31	0.49	0.29	0.11	0.36	0.32	0.05	0.02	0.01	0.06	0.18	0.1	0.06	2.37
14	19*	0.33	0.40	0.41	0.11	1.64	0.11	0.24	0.04	0.00	0.12	0.73	0.025	0.12	4.29
15	20**	0.34	0.49	0.32	0.09	0.74	0.68	0.10	0.06	0.01	0.14	0.36	0.05	0.14	3.51
16	21*	0.17	0.40	0.28	0.08	0.86	1.53	0.11	0.02	0.00	0.04	0.36	0.015	0.04	3.96
17	22**	0.38	0.49	0.25	0.09	0.36	0.47	0.05	0.04	0.01	0.05	0.18	0.035	0.05	2.47
18	24**	0.96	0.49	0.50	0.15	2.18	0.37	0.31	0.07	0.00	0.68	1.00	0.05	0.67	7.38
19	25*	0.98	0.47	0.50	0.13	2.54	0.79	0.36	0.02	0.01	0.50	1.18	0.02	0.49	8.02
20	26**	1.21	0.47	0.54	0.15	2.68	0.05	0.37	0.08	0.00	0.67	1.27	0.025	0.67	8.21

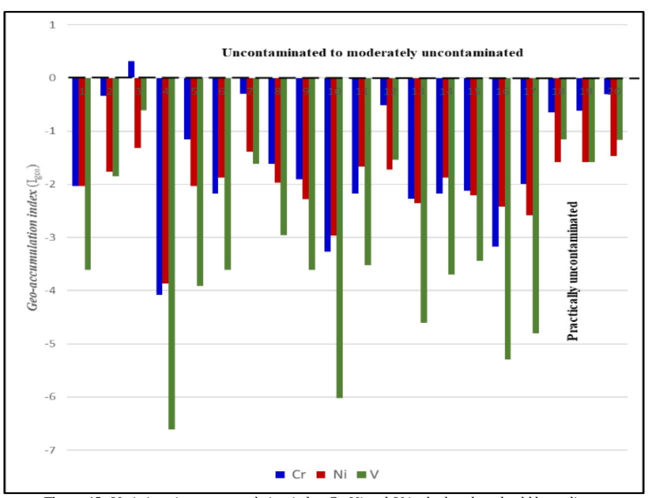


Figure 12. Variations in geoaccumulation index Cr, Ni and V in the beach and sabkha sediment of the study area

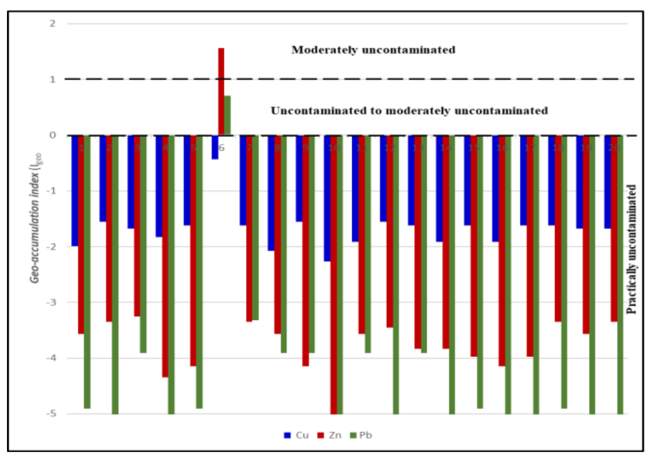


Figure 13. Variations in geoaccumulation index Cu, Zn and Pb in the beach and sabkha sediment of the study area

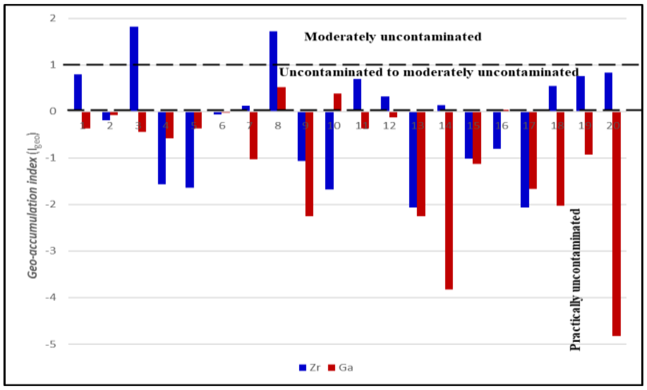


Figure 14. Variations in geoaccumulation index Zr and Ga in the beach and sabkha sediment of the study area

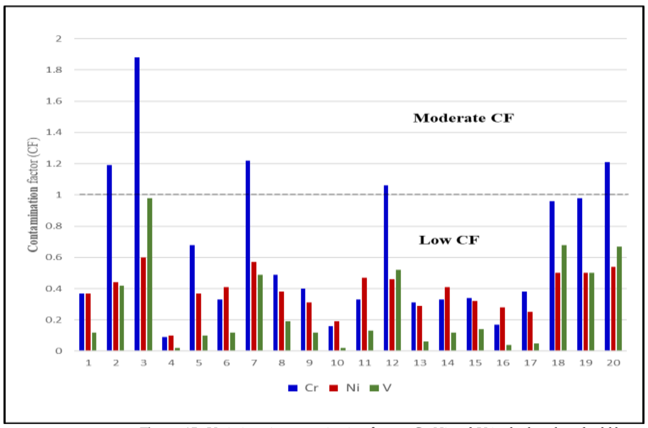


Figure 15. Variations in contamination factors Cr, Ni and V in the beach and sabkha sedin the study area

5. 3 Pollution Load Index (PLI)

The overall pollution level of each sample was calculated using pollution load index (PLI) according to Tomlinson et al. [30]. Each sampling cites has been evaluated for the extent of the pollution load of sediments by using the method based on pollution load index (PLI). The PLI is expressed as concentration factors (C_f) which provides a simple and comparative means for measuring the level of heavy metal pollution according to equation (3):.

$$\mathrm{PLI} = \sqrt[n]{C^i_{f1} \times C^i_{f2} \times C^i_{f3} \times \cdots \times C^i_{fn}} \quad \rightarrow \quad \textbf{(3)}$$

Where, C^i_f = contamination factor of each metal, n = number of metals. The PLI value are classified into two classes such as PLI > 1.0 indicating pollution and PLI > 1.0 is not polluted and close to background concentration [32]. The values of PLI recorded for all samples ranged from 0.07 to 0.5 (less than 1) indicating a good quality in all sediment samples of the study area (Table 4 & Fig. 18).

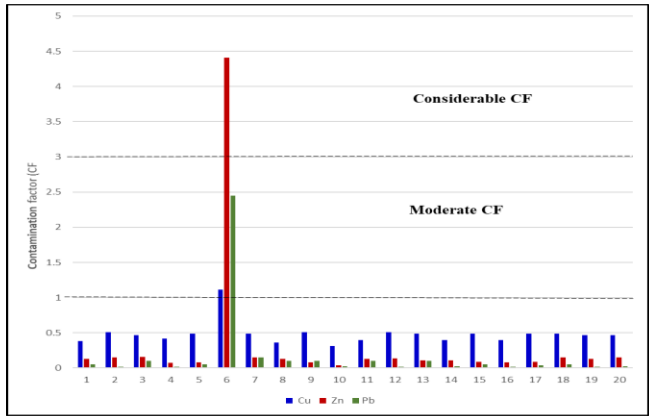


Figure 16. Variations in contamination factors Cu, Zn and Pb in the beach and sabkha sediment of the study area

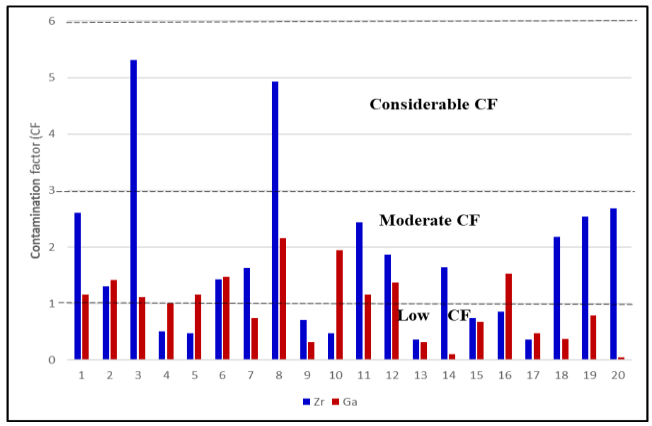


Figure 17. Variations in contamination factors Zr, Ga and Pb in the beach and sabkha sediment of the study area

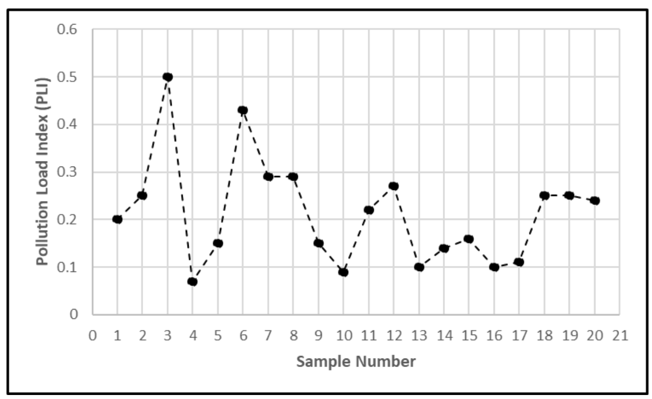


Figure 18. Variations in pollution load index in beach and sabkha sediments in the study area

6 Discussion and conclusion

The main objective of this chapter was to distinguish the contamination processes of coastal environments between the Port-said and Damietta which are subjected to various types of natural and anthropogenic contamination. The spatial distribution of heavy metals supported by a statistical study was done to connect the relationship between various elements and lead to the identification of potential sources of contamination. The observation of the spatial distribution of trace elements indicated that Ni, Sr, Y, Rb, V and Ba have a lower concentration than their corresponding standard levels and exhibit negative values of geoaccumulation factor (I_{geo}), low values of contamination factors (C_f), indicating that the beach and sabkha sediments are uncontaminated. On the other hand, most samples are uncontaminated with Cr, Zr, Ga, Cu, Pb and Zn except a few samples are considered as uncontaminated to moderately contaminate. (Table 8) shows a comparison between the average concentrations of some heavy metal from the study area with those from other beach sediment along the Mediterranean Sea coast.

The pollution effects of heavy metals on the beach sand along the Mediterranean Sea were discussed by many authors. Dorgham et al. mentioned that the Damietta coast is negatively suffered from environmental pollution in the last few decades resulted from the anthropogenic activities of agriculture, industry, fishing and untreated domestic sewage [33].

These activities have dramatically changed the environment represented by a decrease in the salinity, frequent anoxic conditions, high nutrient levels and intensive phytoplankton growth.

El-Sorogy and Attiah concluded that beach samples along Rosetta Coast have higher concentrations of certain heavy metals like Pb, Zn and Ni [34]. Geoaccumulation index and contamination factor indicated an enrichment of Pb and Ni as a result of anthropogenic inputs. The natural sources of heavy metals in the study area are attributed to weathering and decomposition of mountain ranges of the Sudan and Ethiopia, while the anthropogenic ones are the metals produced from industrial, sewage, irrigation and urban runoff.

According to El-Baz and Khalil, Cu highest levels were found in Ras El-Bar, New Damietta, Eastern Harbor and El Gamil East, Zn highest levels were found in Ras El-Bar and Port-Said, Fe and Mn highest intensity were found at Ras El-Bar Rashid East and El-Gamil East [35]. Ali et al. concluded that the beach sediments at Rosetta are uncontaminated to moderately contaminate with Ba, however, it is moderately contaminated with Zn and moderately to heavily contaminated with Cr [36].

The average concentrations of some analyzed heavy metals in beach sediments of the study area and that of similar deposits in some worldwide regions are listed in the (Table 9). The present study area has lower contents Ni, Cu, Zn and Pb than the beach sediments in the Arabian Gulf and Caspian Sea (Azerbaijan) and Gokcekaya Dam Lake (Turkey). On the other hand, the beach sediments in the present study, have higher concentrations of Ni, Cu, Zn and Pb than the beach sediments at Salaam Coast on the Indian Ocean (Tanzania), Caspian Sea (Tanzania), Red Sea Coast (Saudi Arabia). The contents of heavy metals in beach and sabkha sediments are below the average concentration of these elements in the continental crust [37] which indicated that the area under study can be considered as unpolluted and safe for the living organisms.

Table 8. Comparison between average heavy metal concentrations along Port-Said-Damietta Coast with other Mediterranean Sea coast (in mg/kg)

Area	Cr	Ni	Zn	Pb	Cu	Zr	Reference
This study	**57.9**	**26.45**	**31.2**	**3.505**	**21.7**	**280**	
Industrial area of Port-Said	-	22-26	40-42	16-17	11-12	-	[38]
Mediterranean Coast (Between Damietta and Port-Said	-	-	7.99-400.3	1.16-19.07	1.62-14.69	-	[39]
Eastern of Manzala lake	-	-	13.5	15.0	110.0	-	[40]
Manzala lagoon	-	-	48.8-12.15	9.6-146.8	7.84-380		[41]
The Mediterranean coast	82.74	25.93	22.19	13.17	8.46		[42]
The Mediterranean coast	-	-	12.3-59	5.3-57	6.4-18.5		[35]
North of Nile Delta, Egypt	1814		671			6225	[36]
Edku Lagoon	-	-	40-352	4-37.14	18-60		[41]
Rosetta coast	0.26	803	340.23	405.71	-	0.29	[34]
Abu-Qir Bay	-	-	50.98	8.20	13.64		[43]

Table 9. Comparison between average heavy metal concentrations along Port-Said-Damietta Coast with other worldwide areas (in mg/kg)

Area	Ni	Zn	Cu	Sr	Pb	Reference
The present study	**26.45**	**31.20**	**21.7**	**73.75**	**3.505**	
Al Khobar, Arabian Gulf	75.10	52.68	182.97	-	5.3	[44]
Red Sea Coast, Saudi Arabia	13.66	16.75	18.67	-	3.54	[45]
Arabian Gulf, Saudi Arabia	77.07	48.26	297.29	480 1.71	5.25	[46]
Gokcekaya Dam Lake, Turkey	125.7	265.8	108.99	-	74.47	[47]
Mediterranean Sea, Libya	22.65	26.36	17.30	-	11.69	[48]
Caspian Sea, Russia	14	17.1	8.3	-	4.19	[49]
Azerabaijan, Caspian Sea	50.1	83.2	31.9	-	19.6	[50]
Indian Ocean, Salaam Coast Tazania	1.1	5.7	0.8	-	1.2	[51]
Background continental crust	75	70	55	375	12.5	[37]

References

[1] S. N. Bramha, A. K. Mohanty, K. K. Satpathy, K. V. Kanagasabapathy, S. Panigrahi, M. K. Samantara, and M. V. R. Prasad. Heavy metal content in the beach sediment with respect to contamination levels and sediment quality guidelines: a study at Kalpakkam coast, southeast coast of India. Environmental earth sciences, 72(11), 4463-4472, 2014. doi:10.1007/s12665-014-3346-y.

[2] N. Milenkovic, M. Damjanovic and M. Ristic. Study of Heavy Metal Pollution in Sediments from the Iron Gate Danube River), Serbia and Montenegro. Polish Journal of Environmental Studies, 14(6), 2005.

[3] R Ravisankar, M Tholkappian, A Chandrasekaran, P Eswaran, A El-Taher Effects of physicochemical properties on heavy metal, magnetic susceptibility and natural radionuclides with statistical approach in the Chennai coastal sediment of east coast. Applied water science 9 (7) 1-12. 2019

[4] A. El-Zeiny. Monitoring and Evaluation of some Pollutants at New Damietta – Damietta – Egypt (M.Sc. thesis). Damietta, Fac. Of Sci. Mans. Univ. 2010.

[5] W. X. Wang, Q. L. Yan, W. Fan and Y. Xu. Bioavailability of sedimentary metals from a contaminated bay. Marine Ecology Progress Series, 240, 27-38, 2002.

[6] S. Galanopoulou, A. Vgenopoulos and N. Conispoliatis. Anthropogenic heavy metal pollution in the surficial sediments of the Keratsini harbor, saronikos Gulf, Greece. Water Air Soil Pollut. 202 (1-4), 121-130, 2009.

[7] E.S. Kim, S.R. Cho, J.K. Park, T. Rack and J.M. Lee. Distribution of heavy metals in the environmental samples of the saemangeum coastal area, Korea. In: Ishimatsu, A., Lie, H.-J. (Eds.), Coastal Environmental and Ecosystem Issues of the East China Sea, pp. 71-90, 2011.

[8] D. Mallick, I.M. Shafiqul, A. Talukder, S. Mandol, M. Al Imran and S. Biswas. Seasonal variability in water chemistry and sediment characteristics of intertidal zone at Karnafully estuary, Bangladesh. Pollution 2 (4), pp. 411-423, 2016.

[9] J. Chronopoulos, C. Haidouti, A. Chronopoulou-Sereli and I. Massas. Variations in plant and soil lead and cadmium content in urban parks in Athens, Greece. Science of the Total Environment, 196(1), 91-98, 1997.

[10] C. Hogstand and C. Haux. Binding and detoxification of heavy metals in lower vertebrates with reference to metallothionein. Comp Biochem Physiol C. (100)137–214, 2011.

[11] R.R. Harris and M. C. F. Santos. Heavy metal contamination and physiological variability in the Brazilian mangrove crabs Ucides cordatus and Callinectes danae (Crustacea: Decapoda). Mar. Biol. (137) 691-703, 2000.

[12] U. Forstner and G.T.W. Wittmann. Metal Pollution in Aquatic Environment, 2nd ed. Springer-Verlag, Berlin, Heidelberg, New York, pp.481, 1983.

[13] M. Esmail, A.L.I. Masria and A. Negm. Monitoring land use/land cover changes around damietta promontory, Egypt, using RS/GIS, Procedia Eng. 154, pp.936–942. world rivers. Marine chemistry, 7(3) 173-206, 2016.

[14] K. Mathew, S. Bürger, S. Vogt, P.M.E.M. Mason, M. Morales-Arteaga and U. Narayanan. Uranium assay determination using Davies and Gray titration: an overview and implementation of GUM for uncertainty evaluation. Journal of radioanalytical and nuclear chemistry, 282(3), 939-944, 2009.

[15] S. Maslennikova, N. Larina and S. Larin. The effect of sediment grain size on heavy metal content. Lakes reservoirs and ponds, 6(1), 43-54, 2012.

[16] K.B. Krauskopf and D.K. Bird. Introduction to Geochemistry McGraw-Hill. New York, p.617, 1979.

[17] K. K. Turekian and K. H. Wedepohl. Distribution of the elements in some major units of the earth's crust. Geological society of America bulletin, 72(2), 175-192, 1961.

[18] Y. H. Dawood and H. H. Abdel-Naby. Mineral chemistry of monazite from the black sand deposits, northern Sinai, Egypt: A provenance perspective. Mineralogical Magazine, 71(4), 389–406, 2007. doi:10.1180/minmag.2007.071.4.389.

[19] M.I. Moustafa and N.A. Abdelfattah. Physical and chemical beneficiation of the Egyptian beach monazite. Resour. Geol. 60, 288–299, 2010. https://doi.org/10.1111/j.1751-3928.2010.00131.x.

[20] A. Facchinelli, E. Sacchi and L. Mallen. Multivariate statistical and GIS– based approach to identify heavy metal sources in soils. Environmental Pollution 114, 313–324, 2001.

[21] K. M. Banat, F. M. Howari and A. A. Al-Hamad. Heavy metals in urban soils of central Jordan: should we worry about their environmental risks?. Environmental research, 97(3), 258-273, 2005. doi:10.1016/j.envres.2004.07.002

[22] G. Müller. Schadstoffe in Sedimenten-Sedimente als Schadstoffe. Mitteilungen der Osterreichischen Mineral-ogischen Gesellschaft, 79,107–126, 1986.

[23] G. M. S. Abrahim and R. J. Parker. Assessment of heavy metal enrichment factors and the degree of contamination in marine sediments from Tamaki Estuary,

Auckland, New Zealand. Environmental monitoring and assessment, 136(1), 227-238, **2008.** doi:10.1007/s10661-007-9678-2

[24] G. Qingjie and D. Jun. Calculating pollution indices by heavy metals in ecological geochemistry assessment and a case study in parks of Beijing. J. Chin. Univ. Geosci., 19 (3), 230–241, 2008.

[25] M. Chakravarty and A. D. Patgiri. Metal pollution assessment in sediments of the Dikrong River, NE India. Journal of Human Ecology, 27(1), 63-67, 2009.

[26] G. Müller. The heavy metal pollution of the sediments of Neckarsand its tributary: a stocktaking. Chemical Zeitung, 105:157–164, 1981.

[27] J. M. Martin and M. Meybeck. Elemental mass-balance of material carried by major world rivers. Marine chemistry, 7(3), 173-206, 1979.

[28] M.J. Onyari, A.W. Muohi, G. Omondi and K.M. Mavuti. Heavy metals in sediments from Makupa and Port-Reitz Cree systems. Kenyan Coast Environ. Int., 28(7): 639-647, 2003.

[29] H. Bradl, (Ed.). Heavy metals in the environment: origin, interaction and remediation. Elsevier, 2005.

[30] D. L. Tomlinson, J. G. Wilson, C. R. Harris and D. W. Jeffrey. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. Helgoländer meeresuntersuchungen, 33(1), 566-575,1980.

[31] J.A.L. Ramos, L.E.R. Barrón and I.M. Sandoval. Combined use of aquifer contamination risk mapsand contamination indexes in the design of water quality monitoring networks in Mexico. J. Geofísica Int., 43, 641–650, 2004.

[32] P.S. Harikumar, U.P. Nasir and M.P. MujeebuRahma. Distribution of heavy metals in the core sediments of a tropical wetland system; International Journal of Environmental Science and Technology, 6: 225-232, 2009.

[33] M. M. Dorgham, W. S. El-Tohamy, N. E. A. Aziz, A. El-Ghobashi and J. G. Qin. Protozoa in a stressed area of the Egyptian Mediterranean coast of Damietta, Egypt. OCEANOLOGIA, 55 (3), 733–750, 2013. doi:10.5697/oc.55-3.733.

[34] A.S. El-Sorogy and A. Attiah. Assessment of metal contamination in coastal sediments, seawaters and bivalves of the Mediterranean Sea coast, Egypt. Marine Pollution Bulletin, 101(2), 867-871, 2015.

[35] S.M. El Baz and M.M. Khalil. Assessment of trace metals contamination in the coastal sediments of the Egyptian Mediterranean coast. Journal of African Earth Sciences 143,195-200, 2018. doi:10.1016/j.jafrearsci.2018.03.029

[36] A. Ali, M. Fayez-Hassan, N. A. Mansour, F. Mubarak, T. S. Ahmed and W. F. Hassanin. Elemental analysis and radionuclides monitoring of beach black sand at north of Nile delta, Egypt. Pure and Applied Geophysics, 175(6), 2269-2278, 2018. doi:10.1007/s00024-017-1757-x

[37] S.R. Taylor. Abundance of chemical elements in the continental crust: a new table. Geochimica et cosmochimica acta, 28(8), 1273-1285, 1964.

[38] T. E. Attia, E. H. Shendi and M. A. Shehata. Assessment of natural and artificial radioactivity levels and radiation hazards and their relation to heavy metals in the industrial area of Port Said city, Egypt. Environmental Science and Pollution Research, 22(4), 3082-3097, 2015. doi:10.1007/s11356-014-3453-z

[39] H. T. Abd El-Hamid, T. A. Hegazy, M. S. Ibrahim and K. M. El-Moselhy. Assessment of heavy metals pollution in marine sediments along the mediterranean sea, Egypt. J Geogr Env Earth Sci Int, 7, 1-11, 2016. doi:10.9734/JGEESI/2016/26887.

[40] M.O. Arnous and M.A. Hassan. Heavy metals risk assessment in water and bottom sediments of the eastern part of Lake Manzala, Egypt, based on remote sensing and GIS. Arabian Journal of Geosciences, 8(10), 7899-7918, 2015. doi:10.1007/s12517-014-1763-6

[41] B.N. Shalaby, Y.M. Samy, A.O. Mashaly and M.A. El Hefnawi. Comparative geochemical assessment of heavy metal pollutants among the Mediterranean deltaic lakes sediments (Edku, Burullus and Manzala), Egypt. Egypt. J. Chem. 60 (3), 361-378, 2017.

[42] N.F. Soliman, S.M. Nasr and M.A. Okbah. Potential ecological risk of trace metals in sediments from the Mediterranean coast, Egypt. J. Environ. Health Sci. Eng. 13-70, 2015.

[43] S. A. Ghani, G. El Zokm, A. Shobier, T. Othman and M. Shreadah. Metal pollution in surface sediments of Abu-Qir bay and Eastern harbour of Alexandria, Egypt. The Egyptian Journal of Aquatic Research, 39(1), 1-12, 2013. doi:10.1016/j.ejar.2013.03.001.

[44] T. Alharbi and A. El-Sorogy. Assessment of metal contamination in coastal sediments of Al-Khobar area, Arabian Gulf, Saudi Arabia. Journal of African Earth Sciences, 129, 458-468, 2017. doi:10.1016/j.jafrearsci.2017.02.007

[45] A. Kahal, A.S. El-Sorogy, H. Alfaifi, S. Almadani and

H.A. Ghrefat. Spatial distribution and ecological risk assessment of the coastal surface sediments from the Red Sea, northwest Saudi Arabia. Mar. Pollut. Bull. 137, 198–208, 2018.

[46] Hashem A Madkour, Mohamed Anwar K Abdelhalim, Kwasi A Obirikorang, Ahmed W Mohamed, Abu El-Hagag N Ahmed, A El-Taher Environmental implications of surface sediments from coastal lagoons in the Red Sea coast Journal of Environmental Biology 36, 6, 2015.

[47] WM Badawy, OG Duliu, H El Samman, A El-Taher, MV Frontasyeva A review of major and trace elements in Nile River and Western Red Sea sediments: An approach of geochemistry, pollution, and associated hazards. Applied Radiation and Isotopes 170, 109595. 2021.

[48] H. Nour and A.S. El-Sorogy. Distribution and enrichment of heavy metals in Sabratha coastal sediments, Mediterranean Sea, Libya. J. Afr. Earth Sci. 134, 222–229

[49] De Mora, S., Villeneuve, J.P., Sheikholeslami, M.R., Cattini, C. and Tolosa, I., (2004). Organochlorinated compounds in Caspian Sea sediments. Marine Pollution Bulletin, 48(1-2), 30-43, 2017.

[50] S. De Mora, M.R. Sheikholeslami, E. Wyse, S. Azemard and R. Cassi. An assessment of metal contamination in coastal sediments of the Caspian Sea. Mar. Pollut. Bull. 48, 61–77, 2004a.

[51] C. Rumisha, M. Elskens, M. Leermakers and M. Kochzius. Trace metal pollution and its influence on the community structure of soft bottom molluscs in intertidal areas of the Dar es Salaam coast, Tanzania. Mar. Pollut. Bull. 64, 521–531, 2012.