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Determination of available heavy metal concentrations in River Nile sediments, Damietta, Egypt

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Abstract

The present study investigates the distribution and available concentrations of As, Co, Cu, Fe, Sb, Zn, Cd, Se, Ni, Pb in the bottom sediment of the Damietta Nile branch. Available concentrations were determined using the DTPA extraction method. The mean available concentrations were arranged as follows As > Fe > Cu > Zn > Co > Se > Ni > Pb > Sb > Cd. Clustering analysis represents a clear difference between two groups of heavy metal concentrations before and after Damietta Dam. Textural classifications and Total organic matter have been studies. The matrix correlation coefficient, comparison between other studies has been evaluated.

Keywords: Heavy metals, River Nile, sediments, DTPA, Damietta, pollution.

Introduction

Nile River is the main source of freshwater in Egypt. Damietta branch is the main drinking and agricultural water source in Damietta, neighboring region, and connecting to North of Sinai through the Al-Salam canal.
Due to the construction of Aswan High Dam, major changes in the chemical, physical, and biological properties of Nile water were recorded (e.g., Abd El-Hady, 2014). As a result of the continuous population increase along the Nile River, many activities affect negatively on the environment, such as agricultural wastes discharge loaded with impurities of fertilizers and the industrial waste that may contain harmful elements. Fish farms that were located in parts of the study area are a major source of pollution. The above makes it necessary to study the possible pollutants in the area as heavy metal contamination in the bottom sediments.
Understanding heavy metals interaction in the sediment is essential to evaluate and predict their behavior in the sediment-water system. Sediments reflect the current quality of the water system and the chemical parameters history, they are considering as a carrier and probable source of contaminants (Haiyan et al., 2013). Heavy metals contamination in the Nile River and its tributaries can have destructive effects on the ecological system of the river resources and food diversity. The amount of heavy metals in water and even some regions of the Nile is well known to be higher than the limit set by the Egyptian General Authority for Standards and Quality (Anwar et al., 2001).
Most heavy metals in the aquatic environment can be indifferently deposited in the bottom sediments (Salomons et al., 1995). The

sediments are composed of different components, which include carbonates, quartz, clay minerals, feldspar, and organic matter (Tsirambides, 1992). In the river sediments; heavy metals have divided into three groups of components: Erosional and weathering of rocks and solid origin (Detrital solids), water column processes origin (Endogenic fractions), and sediments process (Diagenetic fractions) (Förstner et al., 1976; Jones and Bowser, 1978). The availability of heavy metals is depending on pH, Eh, salinity, organic matter concentrations, and inorganic complexation agents (Calmano and Förstner, 1983).

Two main sources that heavy metals may be derived from, it can be natural (lithogenic source) from the parent material and various anthropogenic (contamination) sources (Alloway, 2012; Ramos-Miras et al., 2011). The main cause of heavy metal contamination in the aquatic ecosystem are anthropogenic activities, such as mining, industrial waste, agricultural production, vehicle emission, and air precipitation (Keshavarzi et al., 2015; Liu et al., 2018). In the study area, fish farms also can be included as a possible source of pollution.

The study area is located between latitudes 31°22'24.45"N, 31°31'12.89"N and longitudes 31°42'46.07"E, 31°50'33.13"E (Figure. 1). It's about 32 Km long starting from Fareskour city and northward to the river mouth near to Ras El-Bar City. It passes through Kafr Albatikh, El-Horany, El-Bostan, Al-Adleiia, Damietta, and Ezbet El-Borg in front of Ras El-Bar city.

This study aims to investigate the presence and distribution of ten heavy metals in the bottom sediments of the study area.

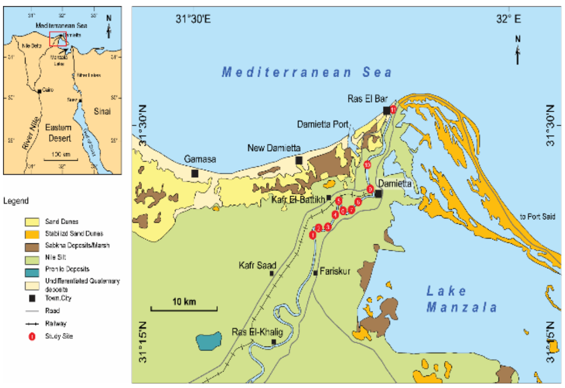

Figure. 1 Study area and sampling stations

Materials and methods

Using a stainless-steel bottom sampling dredge, thirty-three bottom sediment samples were collected from the main-stream of the Nile from eleven sites along the study area (Figure. 1). The depth of collected samples varies from 4 to 13 m with a mean of 7.3m (Table 1). Collection sites were determined using Geographic Position System (GPS), the study area map was drawn using adobe illustrator. At each site, three samples were collected to carry out the grain size analysis, measure the trace metals concentrations, and Collected samples that were preserved in polyethylene bags and carried to the laboratory. Storage and manipulation of sediments for chemical analysis were carried out according to the United States Environmental Protection Agency (USEPA, 2001). Sediment samples were air-dried, homogenized using an agate mortar.

Using a pH meter, pH values were measured in wet sediments at the faculty of science laboratories, Damietta university (Model: Walklab -TI9000). The determination of total organic matter (TOM) content was carried out on the oven, samples dried at 105°C and sieved (<2mm).

Five grams of samples were weighed and placed in an ignition oven at 550°C for 4 hours. After ignition, the samples were left for an hour. Total organic matter is the final loss of weight (Mucha et al., 2003; 2004). Sand-Silt-Clay content was determined according to Folk (1980) at the faculty of agricultural laboratory, Mansoura university (Table 1).

Heavy metal was extracted using a buffered diethylene triamine penta acetic acid (DTPA) solution method (Lindsay and Norvell 1978). This method is specified by the International Organization for Standardization (ISO 14870:2001) and provides a rapid procedure to assess metal solubilities and contamination in sediments. Heavy metals (As, Co, Cu, Fe, Se, Zn, Cd, Sb, Ni, Pb) were determined using a flame atomic absorption spectrometer (Model: PinAAcle 500) at faculty of science, Damietta University laboratories.

The statistical analyses were carried out using the Statistical Package for the Social Sciences (SPSS) version 26, calculating the range (MIN.-MAX.), average, Standard deviation (SDV), and the correlation coefficient was performed to evaluate potential relationships between available heavy metals concentration and sediment properties.

Table. 1 Samples location, sediment type, depth, pH. Total organic matter in the bottom sediment samples along the study area.

Site	Sample	Coordinates	Sediment type	Depth (m)	pH	TOM (%)
Site-1	D1	31°22'24.45"N – 31°42'46.07"E	Sandy siltstone	6.50	6.83	07.11
	D2					07.65
	D3					07.67
Site-2	D4	31°22'48.41"N – 31°43'2.56"E	Sandy siltstone	8.00	6.91	23.68
	D5					23.13
	D6					20.01
Site-3	D7	31°22'49.69"N – 31°44'9.51"E	Muddy sandstone	6.10	6.71	11.44
	D8					11.35
	D9					10.95
Site-4	D10	31°23'39.36"N – 31°45'0.48"E	Silty sandstone	7.50	6.88	07.56
	D11					07.27
	D12					08.68
Site-5	D13	31°24'26.67"N – 31°45'27.31"E	Sandy siltstone	10.00	6.64	07.98
	D14					08.26
	D15					08.67
Site-6	D16	31°23'49.78"N – 31°45'47.77"E	Sandy siltstone	11.50	6.59	09.35
	D17					09.88
	D18					10.28
Site-7	D19	31°23'52.33"N – 31°46'18.58"E	Silty sandstone	13.00	6.65	04.56
	D20					04.13
	D21					03.85
Site-8	D22	31°24'31.40"N – 31°47'5.94"E	Silty sandstone	4.00	6.44	12.65
	D23					12.74
	D24					11.93
Site-9	D25	31°25'26.32"N – 31°48'15.48"E	Sandy mudstone	7.50	6.53	06.75
	D26					06.85
	D27					05.80
Site-10	D28	31°27'32.38"N – 31°48'9.23"E	Sandy mudstone	6.10	6.71	14.23
	D29					14.69
	D30					13.08
Site-11	D31	31°31'12.98"N – 31°50'33.13"E	Muddy sandstone	4.00	6.78	13.87
	D32					13.23
	D33					13.53
Min.					6.44	3.85
Max.					6.91	23.68
Average					6.70	10.69
SDV					0.15	4.80

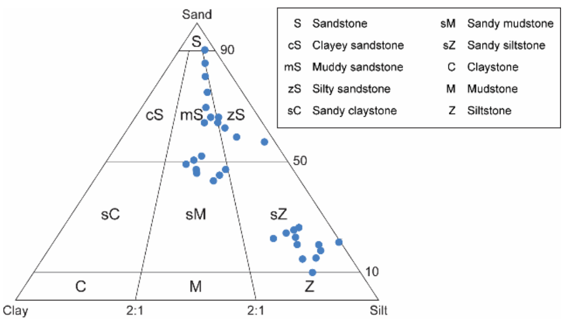

Figure. 2 Ternary plot displays the abundances of sand-silt-clay in collected sediments from the Damietta Nile river (Folk, 1980).

Results

Textural classification

The distributions of Sand-Silt-Clay along the Damietta branch are listed in (Table 1) and illustrated in the triangular diagram after Folk (1980) (Figure 2). The textural classification of the Damietta Nile branch is described as sandy siltstone, silty sandstone, sandy mudstone, and muddy sandstone arranged in descending order of abundance. pH data ranges from 6.44 to 6.91 with an average of 6.70. The highest pH value is recorded at Damietta Power Plant (site-2), while the lowest was observed at Damietta Dam (site-8). Total organic matter (TOM) percentage varied between 3.85% to 23.68% with an average of 10.69%. Hight TOM was recorded at Damietta Power Plant (site-2) while the lowest percentage was after Al-Salam Canal (site-7) (Table 1).

Available heavy metals Distributions

Table 2 presents the concentrations of 33 available heavy metals in 11 sampling sites along the study area. Heavy metals concentration can afford important information for the bottom sediment pollution levels and environmental risk assessment (Palma et al., 2015). Heavy metal levels average are in the following order As > Fe > Cu > Zn > Co > Se > Ni > Pb > Sb > Cd. The matrix correlation coefficient is illustrated in Table 3. The following is a brief description of each studied heavy metals.

Arsenic (As)

Concentrations of As varied from 80.19 µg/g at Damietta to 126.24 µg/g with averaging 99.9 µg/g. Distributions of As in the bottom sediments exhibit a general increase at sites Al-Adliia-1 and Al-Adliia-2 and lower concentrations at Damietta City site. As has a highly significant positive correlation coefficient with Cu (r= +0.628) and there is a significant negative correlation coefficient with Pb (r = -0.667), Cd (r = -0.600) Zn (r = -0.548) and Sb (r = -0.542).

Cobalt (Co)

Cobalt concentrations range from 02.42 µg/g to 8.95 µg/g with averaging 5.37 µg/g. The maximum content of cobalt was at Al-Adliia-1 station and the lowest content at the Kafr Albatikh Water Station site. Co has a highly significant positive correlation coefficient with Fe (r = 0.781) and Ni (r = 0.916).

Copper (Cu)

Cupper ranges from 2.68 µg/g to 16.96 µg/g with an average of 10.71 µg/g. Cu has a maximum content at the Al-Adliia-2 site and the lowest at the Damietta City site. Cu has a highly significant positive correlation coefficient with Fe (r = 0.701) and Ni (r = 0.650) and a highly significant negative correlation coefficient with Pb (r = -0.741)

Table. 2 Available heavy metal concentrations in the bottom sediment samples along the study area.

Site	Sample	As	Co	Cu	Fe	Sb	Zn	Cd	Se	Ni	Pb
Site-1	D1	88.10	02.42	08.36	11.81	00.49	05.76	00.04	00.00	00.91	01.26
	D2	84.71	03.67	07.66	13.32	00.41	05.15	00.05	00.00	01.12	01.07
	D3	86.10	02.86	10.59	14.49	00.48	05.12	00.04	00.00	00.84	00.99
Site-2	D4	93.43	04.14	11.18	85.69	00.35	06.08	00.04	04.31	01.44	00.83
	D5	96.76	04.56	11.16	81.76	00.38	06.16	00.03	04.39	01.56	00.77
	D6	95.47	04.67	10.83	86.77	00.41	05.91	00.05	04.28	01.62	00.80
Site-3	D7	103.41	06.03	14.47	123.35	00.53	06.15	00.04	02.57	02.35	00.89
	D8	104.61	06.33	14.39	121.74	00.52	06.44	00.04	02.77	02.39	00.95
	D9	102.54	06.51	14.49	119.65	00.46	06.27	00.04	03.11	02.57	00.73
Site-4	D10	99.34	05.31	12.10	128.62	00.23	05.43	00.04	01.09	02.14	00.59
	D11	99.93	05.24	12.05	129.46	00.19	06.23	00.04	01.00	02.36	00.54
	D12	99.59	05.32	11.98	131.56	00.21	06.18	00.04	00.92	01.90	00.53
Site-5	D13	104.96	08.69	14.43	237.90	00.48	06.66	00.04	03.79	02.69	00.45
	D14	104.95	08.95	14.85	238.40	00.48	06.78	00.04	03.56	02.71	00.45
	D15	106.65	08.91	14.47	242.50	00.51	07.17	00.05	03.76	02.76	00.46
Site-6	D16	125.93	07.46	16.96	138.91	00.60	06.54	00.04	04.49	02.48	00.45
	D17	126.24	07.42	16.12	140.15	00.56	06.67	00.04	04.42	02.46	00.44
	D18	125.77	07.48	16.19	140.88	00.61	06.49	00.04	04.47	02.50	00.34
Site-7	D19	115.91	05.60	13.56	38.01	00.63	06.79	00.05	05.09	02.24	00.82
	D20	116.56	05.62	12.99	37.96	00.61	06.60	00.04	05.11	02.53	00.86
	D21	116.67	05.82	13.07	38.21	00.67	06.95	00.05	04.97	02.06	00.78
Site-8	D22	118.96	02.50	07.10	04.85	00.57	04.87	00.04	02.45	00.65	00.77
	D23	118.53	02.55	07.15	04.52	00.50	04.71	00.03	02.59	00.56	00.80
	D24	118.79	02.57	07.06	05.13	00.61	04.62	00.03	02.44	00.73	00.87
Site-9	D25	80.19	06.94	02.68	35.33	03.52	08.76	00.23	13.09	01.92	03.51
	D26	81.12	07.23	03.24	34.98	03.19	09.24	00.20	13.02	02.14	03.75
	D27	80.31	06.83	03.05	36.19	03.99	08.80	00.20	13.10	01.93	03.47
Site-10	D28	84.16	05.61	10.84	76.50	02.12	08.82	00.13	03.66	01.59	02.02
	D29	84.40	05.21	10.95	76.22	02.34	08.80	00.13	03.71	01.56	02.01
	D30	84.94	05.06	10.94	76.48	01.96	09.28	00.15	03.91	01.83	02.02
Site-11	D31	82.91	03.26	06.23	38.11	01.02	08.19	00.06	04.22	01.05	01.33
	D32	82.54	03.29	06.22	38.09	01.07	08.11	00.07	04.14	01.08	01.40
	D33	82.23	03.09	06.21	38.16	00.95	08.12	00.07	04.30	01.09	01.27
Min.		80.19	02.42	02.68	04.52	00.19	04.62	00.03	00.00	00.56	00.34
Max.		126.24	08.95	16.96	242.50	03.99	09.28	00.23	13.10	02.76	03.75
Average		99.90	05.37	10.71	83.81	00.96	06.78	00.07	04.08	01.81	01.16
SDV		15.24	01.93	03.97	67.63	00.98	01.35	00.05	03.25	00.68	00.89

Iron (Fe)

Fe ranges from 04.52 µg/g to 242.5 µg/g with an average of 83.81 µg/g. The high content of Fe was recorded at the Al-Adliia-1 site, and the lowest values were at the Damietta Dam site. Fe has a highly significant positive correlation coefficient with Ni (r = 0.764) and a significant negative correlation coefficient with Pb (r = -0.428).

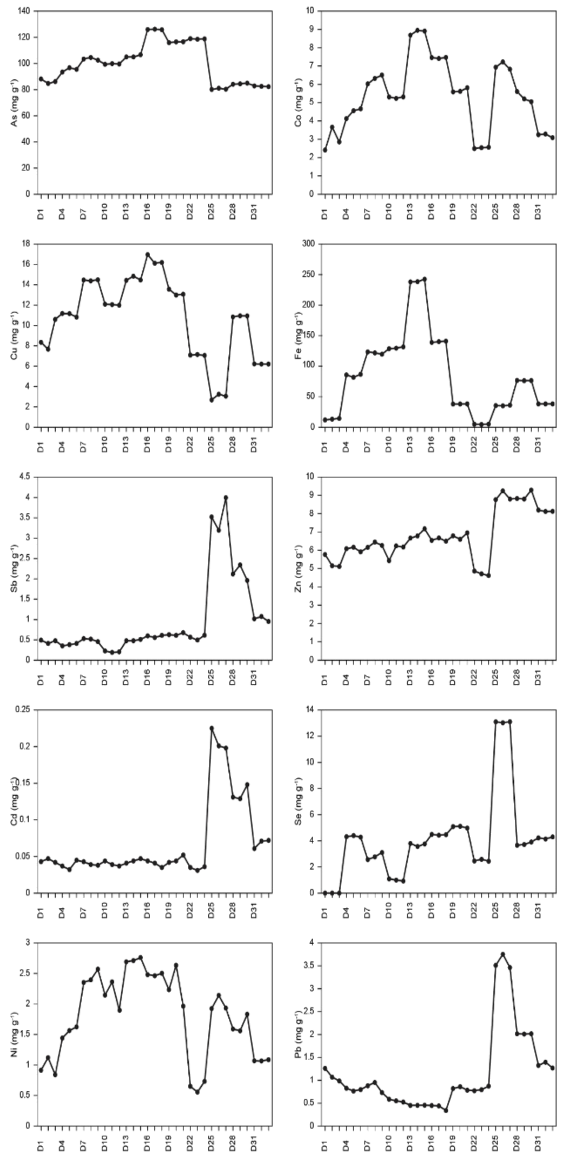

Figure. 3 Heavy metal concentrations in the bottom sediment samples along the study area.

Antimony (Sb)

Sb ranges from 0.19 µg/g to 3.99 µg/g with an average 0.96 µg/g. The maximum concentration was at Damietta City site and the lowest at El-Bostan site. Sb has a highly significant positive correlation coefficient with Zn (r = 0.779), Cd (r = 0.976), Se (r = 0.827) and Pb (r = 0.956).

Zinc (Zn)

Zn ranges from 4.62 µg/g to 9.28 µg/g with an average of 6.78 µg/g. The higher value was recorded at Damietta harbor canal station and the lowest was at Damietta Dam station. Zn has a highly significant positive correlation coefficient with Cd (r = 0.789), Se (r = 0.659) and Pb (r = 0.711).

Cadmium (Cd)

Cd ranges from 0.03 µg/g to 0.23 µg/g and averaging 0.067 µg/g. Cd distribution has high content at Damietta Dam and low content at the Damietta Plant site. Cd has a highly significant positive correlation coefficient with Se (r = 0.796) and Pb (r = 0.959).

Selenium (Se)

Se concentration ranges from zero to 13.10 µg/g an average of 4.1 µg/g. The maximum concentration was at the Damietta City site and the lowest at Kafe Albatikh site. Se has a highly significant positive correlation coefficient with Pb (r = 0.775).

Nickel (Ni)

Ni ranges from 0.56 µg/g to 2.76 µg/g at and averaging 1.81 µg/g. Al-salam canal site was recorded the highest value of Ni and, the lowest value was at Damietta Dam. Ni has a significant negative correlation coefficient with TOM (r = -0.356).

Lead (Pb)

Pb ranges from 0.34 µg/g at Al-Adliia to 3.75 µg/g at Damietta city site and averaging 1.16 µg/g. Pb recorded the maximum values at Damietta City site and the lowest at Al-Adliia-2.

Table. 3 Correlation coefficient in the study area.

Correlations											
	As	Co	Cu	Fe	Sb	Zn	Cd	Se	Ni	Pb	TOM
As	1.000										
Co	0.231	1.000									
Cu	**0.628**[a]	0.497[a]	1.000								
Fe	0.274	**0.781**[a]	**0.701**[a]	1.000							
Sb	-0.542[a]	0.196	-0.611[a]	-0.284	1.000						
Zn	-0.548[a]	0.348[b]	-0.288	0.026	**0.779**[a]	1.000					
Cd	-0.600[a]	0.204	-0.609[a]	-0.249	**0.976**[a]	**0.789**[a]	1.000				
Se	-0.240	0.407[b]	-0.454[a]	-0.127	**0.827**[a]	**0.659**[a]	**0.796**[a]	1.000			
Ni	0.315	**0.916**[a]	**0.650**[a]	**0.764**[a]	-0.012	0.229	0.009	0.234	1.000		
Pb	-0.667[a]	0.030	-0.737[a]	-0.428[b]	**0.956**[a]	**0.711**[a]	**0.959**[a]	**0.775**[a]	-0.144	1.000	
TOM	-0.183	-0.330	-0.052	-0.041	-0.128	-0.039	-0.117	-0.118	-0.356[b]	-0.098	1.000

Bold is a significant positive correlation between metal pairs

[a] Correlation is significant at the 0.01 level (2-tailed).

[b] Correlation is significant at the 0.05 level (2-tailed).

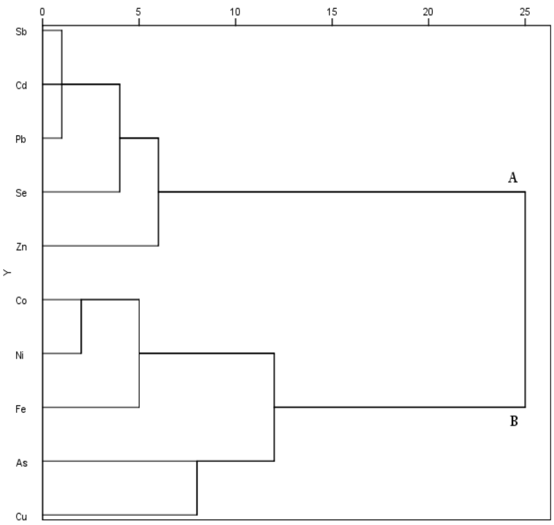

Figure. 4 Hierarchical clustering, based on the correlation coefficient of similarity using between-group linkage method

Discussion

The study area can be separated into two regions; the first starts about 16 Km before Damietta Dam, the second after to the end of the river mouth in front of Ras El-Bar city. In comparison between concentrations of heavy elements before and after Damietta Dam shows that there are abnormally high levels of (Co, As, Cu, Fe, Ni) than the average values in Al-Adliia 1 and Al-Adliia 2 area (sites-5 & site-6), this increase may be due to the random fish farms and agricultural discharge in the mainstream. The second abnormal increases of (Co, Cd, Sb, Zn, Cd, Se, Pb) concentrations than average, observed in Damietta City (site-9), It may be related to anthropogenic activities and domestic waste discharge.

Hierarchical cluster analysis was operated on the analyzed heavy metals to recognize different groups that may represent the sources that controlling their distribution, using between-group linkage (Figure 4) these results are deduced by a person's correlation coefficient (Table 3). Two main groups (A and B) at the level of similarity of 0.94 appeared in figure 4. The first group (A) involved Sb, Cd, Pb, Se, and Zn additional separated into two sub-clusters (Sb, Cd, and Pb/Zn, Se) clustered at the level of (0.82). The second group (B) involved Co, Ni, Fe, Cu, and As further can be parted into two sub-clusters (Co, Ni, and As, Cu, Fe) clustered at the level of (0.65). The intense correlation between available (Sb, Cd) in group A and (Co, Ni) in group B leads to the statement that they are initiated from the same sources (Massas and Ehaliotis, 2010). metals assembled under this cluster can be considered to have an anthropogenic source (Imperato et al. 2003; Moller et al. 2005; Wang et al. 2005). Probable high levels of Pb and As may be related to industrial activity and pesticides used in agriculture activity (Sany et al., 2013). Fertilizers, petroleum, textile, and sewage sludge is the main source of Cd (El Nemr et al., 2007), in this area also observed an active ships industry, domestic and agricultural discharge.

The obtained data of the available heavy metals concentrations in the present study are compared with other studies (Table 4). In the present study; the concentrations of Ni and Fe are more than El-Namla (2019), although low in Cd, Cu, and Co.

Table. 4 The available heavy metal concentrations in Nile River sediment samples from various studies.

Locations	Heavy Metal concentrations (mg g^{-1})										References
	As	Co	Cu	Fe	Sb	Zn	Cd	Se	Ni	Pb	
Nile River (Damietta), Egypt	80.19-126.24	2.42–8.95	2.68–16.96	4.52–242.5	0.19–3.99	4.62–9.28	0.03–0.23	0–13.1	0.56–2.76	0.34-3.75	Present study
Nile River (Mansoura), Egypt	–	0.00-29.18	01.04-21.99	07.69-128.23	--	–	00.31-8.89	-	0.02-1.57	-	El-Namla (2019)

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Conclusion

The collected bottom sediments from form Damietta branch have an average metal levels in the following order As > Fe > Cu > Zn > Co > Se > Ni > Pb > Sb > Cd. Damietta Dam separated the concentrations into two clustering A, B according to their abundance in the same sites. there are abnormally high concentrations levels of (Co, As, Cu, Fe, Ni) than the average values in Al-Adliia-1,2 (sites no. 5 & 6), this increase may be due to the random fish farms and agricultural discharge in the mainstream. And other abnormal increase of (Co, Cd, Sb, Zn, Cd, Se, Pb) concentrations than the average observed in Damietta City (site no.9). It may be related to anthropogenic activities and domestic waste discharge.

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الملخص العربي

عنوان البحث : تعيين تركيزات العناصر الثقيلة في رسوبيات نهر النيل، دمياط، مصر

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هذه الدراسة تدرس توزيع تركيزات عناصر القصدير، الكوبلت، النحاس، الحديد، الأنتيمونيوم، الزنك، الكادميوم، السيلينيوم، النيكل والرصاص وذلك في روسوبيات قاع فرع النيل بدمياط. تم استخدام طريقة حمض داي إيثيلين تراي أمين بنتا أسيتيك لإستخلاص العناصر الثقيلة. ترتيب متوسطات العناصر مرتب كالتالي : قصدير > حديد > نحاس > زنك > كوبلت > سيلينوم > نيكل > رصاص انتيمونيوم > كادميوم. التحليل العنقودي قسم العناصر الي مجموعتين بينهما تباين واضح في تركيزات العناصر قبل وبعد سد دمياط. تم عمل تصنيف لعينات الرسوبيات، حساب نسبة المواد العضوية الكلية، معامل ارتباط المصفوفة بين تركيزات العناصر ومقارنة بين البحث الحالي وأبحاث أخرى.