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Health risk assessment of heavy metals contamination in sediments of the River Nile, Damietta Branch using Mathematical Models

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ABSTRACT

This study was conducted to evaluate heavy metals pollution in sediments of the Nile River- Damietta Branch using mathematical models of heavy metal indices (enrichment factor (EF), contamination factor (CF), pollution load index (PLI), degree of contamination (DC) and geo-accumulation index (I_{geo})). The results showed that the concentrations of heavy metals in sediment samples, followed the order of Fe> Zn> Pb> Co> Ni> Cu> Mg. The EF for each heavy metal element was calculated relative to the background values after normalization with the Fe element. According to the mean values of EFs, the descending order of heavy metals enrichment in the sediments was: Cd >Fe> Pb > Co > Zn > Ni > Cu (greater to lower). Cd was considered to poses significant to very high enrichment along with the different stations along the study area. In addition, it recorded very high contamination (7.41±0.71) and I_{geo} mean value (6.50 ± 1.32) along the study area. PLI values varied between 0.813 and 2.331 along the study area with a mean value of 1.338 ± 0.477. This result showed a considerable degree of contamination (mean value =16.442 ± 7.136) along the branch. However, stations 3, 5, 9 and 10 recorded a very high degree of contamination with values (30.901, 33.867, 56.932 and 48.536), respectively. HI values of heavy metal order was: Cd (239.63) > Pb (72.65) > Co (34.732) > Ni (14.457) > Zn (5.952) > Cu (4.719) > Fe (2.896). With respect to human health, Ni, Pb, Cd, Fe, Zn, Cu, and Co were identified as potential contaminants. whereas, Pb, Cd and Cu are classified as non-carcinogenic by Agency for Toxic Substances and Disease Registry.

INTRODUCTION

Many environmental stressors impact river and stream environments, with human activity accounting for the bulk of these stressors. Chemical and organic waste, exacerbated by runoff from agricultural pesticides, improperly controlled industrial processes, and the lack of suitable disposal of sewage have plagued streams in developed countries including Egypt, **(*Dorgham et al*., 2019)**.

Heavy metals contamination has become a more serious environmental problem in Egypt as a result of the rapid social, industrial, and economic growth, especially in industrial and agricultural regions, **(Ali *et al*., 2019)**. They are a major source of water pollution and have long been considered critical contaminants in aquatic ecosystems because of their toxicity, persistence, non-degradability and bioaccumulation characteristics. Heavy metals can be found in nature or as a result of human activities. Its contamination is mainly caused by anthropogenic practices such as natural resource growth, metal refining and smelting, chemical manufacturing, industrial emissions, and sewage irrigation. Moreover, acute and persistent exposure can cause problems with the cardiovascular and other systems, and also could lead to cancer, (**Ahmadov *et al*., 2020**).

Previous studies on heavy metal contamination in the Nile River relied on analyzing heavy metals in sediments on a qualitative and quantitative basis. Those studies mostly compare sampling evidence to water quality requirements, and evaluate emission sources and elucidate safety strategies by evaluating the findings **(Yang *et al*., 2018)**. However, they do not have sufficient risk assessment of heavy metals to which humans are easily exposed. The single factor index approach and the systematic index method are the most common approaches for analyzing aquatic heavy metal contamination. The first is a straightforward approach for comparing testing results to water quality requirements. The latter reflects a number of variables, including the grey correlation analysis method, Nemerow index, fuzzy systematic assessment method, and principal feature analysis method, **(Zhang *et al*., 2017).** Most practiced indices for heavy metal contamination assessment are EF, CF, PLI DC and HI which gives a composite influence of several metals on overall sediment and water quality. It summarizes the combined effects of several heavy metals considered harmful to conclude the overall contamination in an easier manner, **(Yang *et al*., 2021)**. The health risk of heavy metals can be divided into non-carcinogenic risk and carcinogenic risk, but due to the undefined toxicity value for carcinogenic risk, only the non-carcinogenic risk was discussed in previous studies. The HI is non-carcinogenic risk caused by consumption of heavy metals containing sediment, calculated separately for infants, children and adult. Several researchers have used the heavy metal pollution indices in their respective region to assess the source and severity of metal contamination **(Ma *et al*., 2018)**

Denaturation of water, which no longer maintains stable habitats for aquatic life, may be one of the consequences. From the viewpoints of ecological monitoring and human health, the assessment of the nature, distribution, and concentrations of toxins in samples from various matrices such as water, sediments, and edible aquatic biota offers valuable knowledge for environmental risk assessment. This will be crucial in identifying the causes and nature of contamination in this area, as well as highlighting guidelines to keep the whole ecosystem in the area save and clean, **(Taher *et al*., 2021)**

Therefore, this study was processed to assess the pollution levels and the associated potential health and ecological risks posed by heavy metals-contamination in the Nile River - Damietta Branch, Egypt. It focused on the assessment and evaluation of the present status of heavy metals contamination of the Nile River-Damietta Branch, depending on the analysis of seven different metals of the branch water and sediments in the 12 selected sites (Ellesan / Ras Elbr, Ras Elbr / Elgerby, The intersection of the navigation channel with the Nile, Damietta Dam Region, Eladlia, Shrbas / Faraskoor, Elsero/Elzarqa, Bosat Kareem Eldein / Sherbein, Talkha, Smnood, Meit Ghmr, Kafr Shokr) along the branch.

MATERIALS AND METHODS

1. Sediments Sampling

Sediment samples were collected seasonally for a whole year from the River Nile-Damietta Branch, Egypt. Twelve sampling stations were selected along Damietta Branch**,** from its beginning at Cairo governorate to its estuaries in the Mediterranean Sea (Fig. 1). The global positioning system (GPS) was used to record those geographical locations (Table 1). Sediment samples (up to 3 cm depth) were collected using a stainless steel grab sampler washed with de-ionized water at each sampling stations to prevent pollution. The collected sediment samples were placed in clean plastic bags for further analyses to identify heavy metals, which were measured following the methods of **Hasaballah *et al*. (2019a)** and **Hasaballah *et al*. (2019b)** using AA-7000 atomic absorption spectrophotometer (AAS: Perkin Elmer Analyst 100).

Table 1. The ecological sites of the study area along Damietta Branch.

Station Number	GPS Location		Station
1	*N 31 31 35.7*	*E 31 50 38.2*	*Ellesan / Ras Elbr*
2	*N 31 29 09.9*	*E 3149 27.2*	*Ras Elbr / Elgerby*
3	*N 31 27 30.6*	*E 31 48 01.2*	*The intersection of the navigation channel with the Nile*
4	*N 31 24 30.3*	*E 31 47 13.6*	*Damietta Dam Region*
5	*N 31 23 42.5*	*E 31 46 07.1*	*Eladlia*
6	*N 31 17 19.2*	*E 31 40 20.6*	*Shrbas / Faraskoor*
7	*N 31 14 30.7*	*E 31 39 00.9*	*Elsero/Elzarqa*
8	*N 31 10 53.6*	*E 31 33 58.2*	*Bosat Kareem Eldein / Sherbein*
9	*N 31 02 58.2*	*E 31 22 49.8*	*Talkha*
10	*N 30 57 32.9*	*E 31 14 48.2*	*Smnood*
11	*N 30 43 21.2*	*E 31 15 07.2*	*Meit Ghmr*
12	*N 30 30 45.0*	*E 31 13 22.5*	*Kafr Shokr*

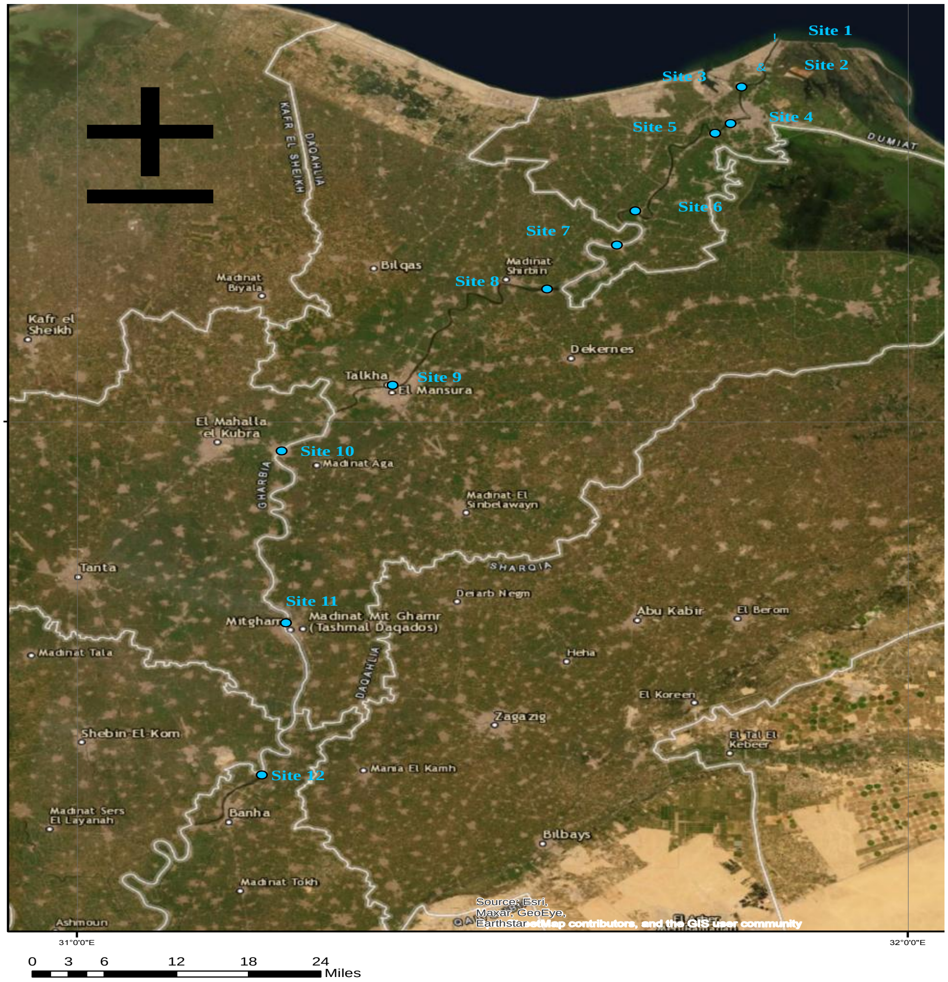

Fig. 1. Geographic Map of the study area (Damietta Branch) and the ecological sites, **(ArcGIS, Arc map10.7).**

2. Mathematical Models using Heavy Metals Indices

2.1. Enrichment Factor (EF)

Tto evaluate the contaminants magnitude in the environment, the effective tool of EF was used in assessing the contamination degree and understanding the elements distribution originated from anthropogenic activities **(Looi, 2019)**. Since heavy metals geochemical normalization to Iron (Fe) was employed, Fe was the chosen controlling element to identify unusual concentration metals **(Yang *et al*., 2021)**. In case that the EF values were lower than 2, an indication of a natural source of the metal generated entirely from natural processes or crustal materials would be proposed; whereas if EF values were more than 2 , a suggestion of anthropogenic sources of the metal would occure **(Darwish *et al*., 2018)**. To calculate the value of EF, the successive equation was processed:

$$EFm = \frac{Cm\ (sediment)/CFe\ (sediment)}{Cm\ (earth\ crust)/CFe\ (earth\ crust)}$$

Where: Cm (sediment) is the metal concentration in the sediment sample; CFe (sediment) is the concentration of the reference metal (Fe) in the sediment sample; Cm (earth crust) is the metal concentration in the earth crust; and CFe (earth crust) is the concentration of the referenced metal (Fe) in the earth crust, **(Barbieri, 2016).**

The EF values are also classified into six categories, ≤ 1background concentration, 1- 2 depletion to minimal enrichment, 2 – 5 moderate enrichment, 5–20 significant enrichment, 20 – 40 very high enrichment and > 40 extremely high enrichments, **(Al-Shami *et al*., 2019)**.

2.2. Contamination Factor (CF)

The contamination factor (CF) expressed contamination level, the ratioof which is calculated by using the following equation:

Contamination Factor = C metal / C background

The background value corresponds to the baseline concentrations reported by **Turekian and Wedepohl** (**1961**), which is based on the abundance of element in the sedimentary rocks. Its value is described as follows: CF < 1 (low contamination factor); 1 ≤ CF < 3 (moderate contamination factors); 3 ≤ CF < 6 (considerable contamination factors) and CF ≥ 6 (very high contamination factor) **(Ahmadov *et al*., 2020)**

2.3. Pollution Load Index (PLI)

The PLI provides information about the quantity of a component in a specific area to better understand the environment. It is the root of number (n) of multiplied contamination factor (CF) values for a single site as follows:

$$PLI = (CF1 \times CF2 \times CF3 \times \cdots \times CFn)^{1/n}$$

Where, n is the number of metals (eleven in the present study) and CF is the contamination factor **(Sallet *et al*., 2019)**.

When the PLI value was more than 1, pollution would be recorded, whereas if PLI value was lower than 1, no pollution would be indicated. One the other hand, value of zero points out perfection; a value of one points out only pollutants baseline levels, and values greater than one would suggest declining in the quality of site**.**

2.4. Degree of contamination (DC)

Degree of contamination (DC) is another index derived from the CF values. **Hökanson (1980)** defined DC as the sum of all contamination factors for a given site.

$$DC = \sum_{i=1}^{N} CFi$$

Where CF is the single contamination factor, and n is the count of the elements present. DC values less than n would indicate low degree of contamination; n≤ DC < 2n, would sustain a moderate degree of contamination; 2n ≤ DC < 4n would state a considerable degree of contamination, whereas DC > 4n would represent a very high degree of contamination. To describe the degree of contamination in the studied river, the following division was used:

DC < 11= low degree of contamination; 11 < DC < 22= moderate degree of contamination; 22 > DC < 44= considerable degree of contamination and DC > 28= very high degree of contamination. Where, n=11= the count of the studied heavy metals, **(Antoniadis *et al*., 2019).**

2.5. Geo-accumulation Index

An index of geo-accumulation (I_{geo}) was originally defined by **Muller (1969)** to determine and define the metal contamination in sediments by comparing current concentrations with pre-industrial levels following the equation below:

$$I_{geo} = Log_2\,(C_n/1.5B_n)$$

Where, C_n is the measured concentration of heavy metals in sediments, B_n is the geochemical background value in average shale of element n, and 1.5 is the background matrix correction due to terrigenous effects. Factor 1.5 is used because of possible variations in background values for a given metal in the environment as well as very small anthropogenic influences.

The geo-accumulation index (I_{geo}) was distinguished into seven classes by **Buccolieri *et al*. (2006)**: $I_{geo} \le 0$, class 0, unpolluted; $0 < I_{geo} \le 1$, class 1, from unpolluted to moderately polluted; $1 < I_{geo} \le 2$, class 2, moderately polluted; $2 < I_{geo} \le 3$, class 3, from moderately to strongly polluted; $3 < I_{geo} \le 4$, class 4, strongly polluted; $4 < I_{geo} \le 5$, class 5, from strongly to extremely polluted; and $I_{geo} > 5$, class 6, extremely polluted.

2.6. Potential Ecological Risk Index (RI).

To screen sediment contamination degree caused by heavy metals, potential ecological risk index (RI), which was developed based on sedimentary theory, was introduced to assess the ecological risk degree of heavy metals in the present sediments. Potential ecological risk index was originally proposed by **Hakanson (1980)**, and has been widely used in sediment heavy metal pollution assessment. The value of RI can be calculated by the following formulas:

$$\mathbf{E^i_r = T^i_r \times C^i_f}$$
$$\mathbf{RI = \sum E^i_r}$$

E^i_r is to quantitatively express the potential ecological risk of a given contaminant, where T^i_r is the toxic response factor for a given substance viz: Pb = Cu = 5, Cd = 30, Cr = 2, Zn = 1, Ni = 5, Mn=1 and C^i_f is the contamination factor (**Khan *et al*., 2020**).

3. Health Risk Assessment

a- Non cancer effect evaluation

There are three paths by which humans may be subjected to heavy metals: ingestion, inhalation, and dermal contact. The average daily intake (ADI) of metals in soil is calculated according to the successive equations:

$$\mathbf{ADD_{ing} = C*IR_{ing}*EF*ED*SAF / BW*AT}$$

$$\mathbf{ADD_{dermal} = C*SA*ABS*EF*ED*SAF/ BW*AT}$$

$$\mathbf{ADD_{inhalation} = C*IR_{inh}*EF*ED*CF /PEF*BW*AT}$$

where C is the concentration of a specific metal in soil (mg/kg, obtained in this study); IR_{ing} is the ingestion rate (mg/day), which is 100 mg/day for adults; EF is the exposure frequency, i.e., 180 days/year; ED is the exposure duration, i.e., 24 years for adults; IR_{inh} is the inhalation rate (m^3 /day), i.e., 14.7 m^3 /day for adults; PEF is the dust emission factor (m^3 /kg), i.e., 1.36 * 109 m^3 /kg; SA is the exposed area through dermal contact, i.e., 5700 cm^2 for adults; SAF is the adherence factor, i.e., 0.2 mg/cm^2 ; ABS is the dermal absorption factor, i.e., 0.001 for all considered elements. BW: is body weight, i.e., 57 kg for adults; AT is the average exposure time per year, for non-carcinogens: ED *365 days and for the carcinogens (As, Cr, and Cd): 70 (lifetime) *365 days **(Praveena, *et al*., 2015)**.

Non-carcinogenic Risk Assessment

A method proposed by the US Environmental Protection Agency was used to assess the potential health risk related to the non-carcinogenic impacts of metals on soils. The hazard quotient (HQ) was calculated as the ratio of the ADI and the reference dose (RFD) for a given metal,

$$HQ = ADI/RfD$$

Where RfD is the reference dose of the metal (mg/kg day-1): for Cd = 0.001, Cu = 0.04, Ni = 0.02, Pb = 0.0035, Fe = 0.7, Co = 0.02 and Zn = 0.3 That dose is the maximum acceptable level of a metal with no risky effects on human health. The sum of the HQ values of all metals in the soil, HI was used to evaluate the overall non carcinogenic effects posed by multiple metals **(Kusin *et al*., 2018)**.

$$HI = HQ1 + HQ2 \ldots\ldots + HQn$$

If the HI value was 1, there could be a risk of non-carcinogenic effects and if it was more than 1, the HI value would indicate high probability of the occurrence of adverse health effects.

b- Cancer Effect Evaluation

For carcinogens, the risks are estimated as the incremental possibility of each person developing cancer over a lifetime as a result of exposure to the potential carcinogen. The equation for calculating the excess lifetime cancer risk is:

$$\text{Cancer risk} = \sum ADI * CSF$$

Where risk determines that of an individual developing cancer over a lifetime. ADI (mg/kg/day) and CSF $(mg/kg/day)^{-1}$ are the average daily intake and the cancer slope factor, respectively for number of heavy metals **(Thongyuan *et al*., 2020).** The cancer slope factor (CSF) values for Cd, Co, Pb and Ni are 6.3, 9.8, 0.0085 and 9E-5 mg/kg/day **(USEPA, 2012).** The acceptable threshold value of the cancer risk is 1.0E-04, whilst the tolerable LCR for regulatory purposes is in the range of 1.0E-06–1.0E **(Kusin *et al*., 2018)**.

RESULTS AND DISCUSSION

1. Heavy Metals Indices

Pollution assessment models are indicators used to assess the presence and intensity of anthropogenic contaminant deposition on soils **(Nwankwoala** & **Ememu, 2018).**

1.1 Enrichment Factor (EF)

The enrichment factor has been widely used to assess the degree of pollutant enrichment and sources of pollution according to the classification of the enrichment factor **(Kusin *et al*., 2018).**

Table 2. Enrichment factors (EF) of the sediments from the studied area.

Station No.	Enrichment Factor (EF)										
	Fe	**Co**	**Ni**	**Pb**	**Cd**	**Zn**	**Cu**	**Na**	**K**	**Ca**	**Mg**
1	1.31	0.76	0.29	1.68	11.40	0.10	-	1.50	0.38	0.87	--
2	1.03	0.96	0.37	1.62	15.58	0.24	-	1.21	0.36	0.98	--
3	0.42	2.38	0.06	2.03	25.49	1.01	-	0.65	0.17	0.45	--
4	1.63	0.61	0.02	0.80	7.30	0.59	-	0.40	0.07	0.20	--
5	2.84	0.35	0.05	0.45	0.02	0.07	0.001	0.10	0.02	0.08	0.03
6	1.80	1.49	0.04	0.94	24.21	0.37	-	0.32	0.03	0.21	--
7	1.04	0.55	0.10	0.92	18.60	0.24	-	0.24	0.03	0.21	--
8	1.33	0.75	0.07	1.04	4.59	0.21	0.02	0.16	0.02	0.14	0.07
9	1.96	0.51	0.07	0.79	28.39	0.26	0.03	0.09	0.01	0.11	0.10
10	1.55	0.64	0.11	0.46	7.19	0.54	0.13	0.05	0.01	0.06	0.39
11	1.43	0.69	0.47	1.46	61.48	0.55	-	0.12	0.04	0.21	--
12	0.48	1.97	0.07	1.81	39.60	1.91	-	0.12	0.06	0.21	--
mean	1.401	0.971	0.143	1.166	20.320	0.507	0.045	0.413	0.1	0.310	0.147
SD	0.065	0.063	0.014	0.053	1.726	0.051	0.005	0.047	0.013	0.030	0.016

Notably, the enrichment factor (EF) can be used to assess the degree to which the sediment has been contaminated with metals. However, EF is unable to identify its biologic and chemical activity but could recommend the source of metal and metalloids in a particular area. The EF for each heavy metal element was calculated relative to the background values after normalization with Fe element. Generally, there was no enrichment of neither Ni, Zn and Cu in the sediments nor in Ca, Mg, K, and Na, as the EF values were lower than 2 (Table 2).

Simultaneously, the values of Fe, Co, and Pb were classified as deficiency to minimal enrichment except at Eladlia and the interaction of navigation canal with the Nile stations, respectively. These metals were primarily natural in origin and therefore, the sediment was classified as being uncontaminated with respect to these elements. On the other hand, Cd was considered to possess significant to very high enrichment along the different stations along the study area (Fig. 2). According to the mean values of EFs, the descending order of heavy metals enrichment in the sediments was: Cd >Fe> Pb > Co > Zn > Ni > Cu (greater to lower) and also, Na> Ca> Mg >K (greater to lower).

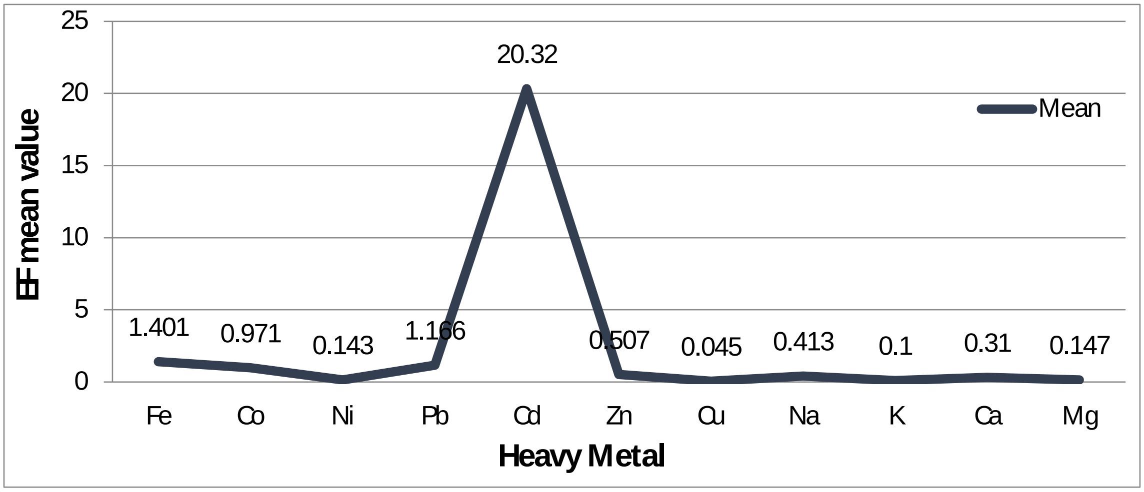

Fig. 2. Enrichment factors (EF) (mean value) of heavy metals in sediments of the study area.

1.2. Contamination Factor (CF)

The contamination factor was used to determine the contamination status in the sediments by evaluating the level of pollution by single substance **(Kusin *et al*., 2018)** according to the classification of the contamination factor. The contamination factors (CF) in the surface sediments are depicted in Table (3). As with the distribution of CF, the sediment possessed generally a considerable contamination ($3 \leq CF < 6$) and that also occurred with Fe, Zn, Cu, Co and Pb. On the other hand, low contamination was found in Ni (0.560±0.03), but very high contamination was found in Cd (7.41±0.71) along the study area. However, some stations recorded low and moderate contamination individually along the branch for different metals (Table 3). The calculated CF values were found in the following sequence: Cd > Fe > Pb > Cu > Co > Zn >Ni.

1.3. Pollution Load Index (PLI)

The pollution load index (PLI) gave an evaluation of the overall toxicity status of the sample as a consequence of the contribution of the seven studied metals. A PLI value of zero indicates perfection, while a value of one indicates the presence of only baseline levels of pollutants, and those above one would indicate progressive deterioration of the site quality. The PLI value > 1 is polluted, whereas PLI value < 1 indicates no pollution. The pollution load index (PLI) values as shown in Fig. (3) varied between 0.813 and 2.331 along the study area with mean a value of 1.338 ± 0.477 (Table 3). The decrease in PLI values indicates the dilution and dispersion of metal content with increasing distance from source areas. PLI could give indication about the trend spatially and temporarily. In addition, it also provides significant data and advice to the policy and decision makers considering the contamination degree of the area **(Nabil *et al*., 2018).**

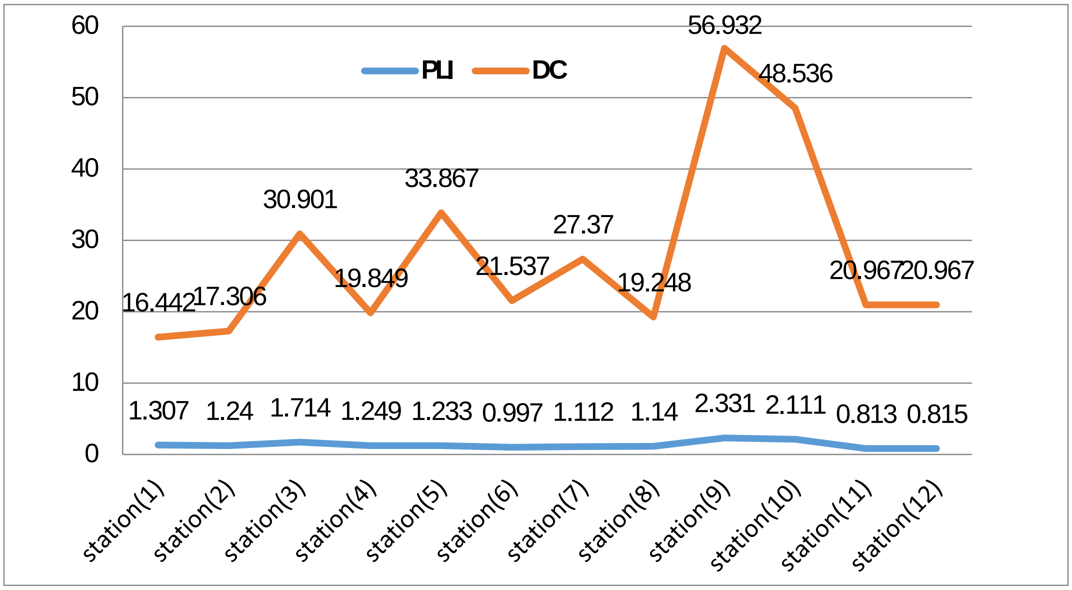

Fig. 3. PLI and DC values in the study area.

Table 3. The contamination factor (CF), pollution load index (PLI) and degree of contamination (DC) of the annual mean values of the total heavy metals in the sediments.

Station No.	**Contamination Factor (CF)**							**PLI**	**DC**
	Fe	**Co**	**Ni**	**Pb**	**Cd**	**Zn**	**Cu**		
1	2.775	2.11	0.827	4.68	3.16	2.89	-	1.307	16.442
2	2.182	2.105	0.814	3.545	3.40	5.26	-	1.240	17.306
3	4.576	10.89	0.308	9.30	1.16	4.663	-	1.714	30.901
4	5.247	3.265	0.147	4.215	3.83	3.145	-	1.249	19.849
5	11.31	3.984	0.658	5.11	4.60	8.07	0.13	1.233	33.867
6	3.427	5.121	0.155	3.245	8.30	1.289	-	0.997	21.537
7	3.976	2.205	0.419	3.66	7.40	9.71	-	1.112	27.37
8	5.074	3.810	0.404	5.315	2.33	1.075	1.24	1.140	19.248
9	9.779	4.982	0.736	7.75	27.76	2.555	3.37	2.331	56.932
10	10.09	6.478	1.144	4.71	7.26	5.549	13.3	2.111	48.536
11	2.027	1.410	0.969	2.98	12.46	1.121	-	0.813	20.967
12	1.851	3.842	0.144	3.345	7.33	3.914	-	0.815	20.426
Mean	5.193	4.183	0.560	4.821	7.41	4.103	4.51	1.338	27.781
SD	0.352	0.279	0.034	0.916	0.713	0.279	0.698	0.477	2.193

1.4. Degree of contamination (DC)

The degree of contamination (DC) is another index that can be derived from the CF values. DC values less than n would indicate a low degree of contamination; $n \leq DC < 2n$, a moderate degree of contamination; $2n \leq DC < 4n$, a considerable degree of contamination; and $DC > 4n$, a very high degree of contamination. For the description of the degree of contamination in the studied river branch, the following terminologies were used:

DC < 7 low= degree of contamination; 7 < DC < 14= moderate degree of contamination; 14 > DC < 28= considerable degree of contamination; and DC > 28= very high degree of contamination. Where, n=7= the count of the studied heavy metals **(Darwish *et al*., 2018)**. The present result showed a considerable degree of contamination (mean value =16.442 ± 7.136) along the branch (Fig. 3). However, stations 3, 5, 9 and 10 showed a very high degree of contamination with values 30.901, 33.867, 56.932 and 48.536, respectively (Table 3).

1.5. Geo-accumulation index (I_{geo})

The geo-accumulation index (I_{geo}) is used to determine and define the metal contamination in sediments by comparing current concentrations with pre-industrial levels. Geo-accumulation index (I_{geo}) determines the enrichment of metal concentration above background or baseline concentration. The I_{geo} was calculated to estimate metal accumulation in sediment when the concentration of toxic heavy metal is 1.5 or greater than their lithogenic background values **(Kutty & Al-Mahaqeri, 2016).** The geo-accumulation index (I_{geo}) was distinguished into seven classes by **Buccolieri *et al*. (2006)**; $I_{geo} \leq 0$, class 0, unpolluted; $0 < I_{geo} \leq 1$, class 1, from unpolluted to moderately polluted; $1 < I_{geo} \leq 2$, class 2, moderately polluted; $2 < I_{geo} \leq 3$, class 3, from moderately to strongly polluted; $3 < I_{geo} \leq 4$, class 4, strongly polluted; $4 < I_{geo} \leq 5$, class 5, from strongly to extremely polluted; and $I_{geo} > 5$, class 6, extremely polluted. The results of I_{geo} are shown in Table (4). There were positive and negative values. The negative values of Ni and Cu depending on the classification of **Muller (1969)**, indicated that Damietta branch of the Nile River is not polluted with those metals, although Cu appeared moderately to heavy pollution of this metal at *Smnood* and *Talkha* stations. I_{geo} of Pb, Co and Zn indicate moderately to heavy pollution of these metals along the branch. Generally, those moderately polluted values of zinc, lead, and cobalt may be attributed to their release from the anti-fouling paints of ships, as well as other anthropogenic sources such as: sewage outfall and industrial effluents **(Neta *et al*., 2019).** Fe and Cd indicate extremely pollution according to their I_{geo} mean value (5.99 ± 0.49 and 6.50 ± 1.32), respectively along the branch. The calculated I_{geo} values were found in the following sequences: Cd > Fe > Pb > Zn > Co > Cu >Ni.

Table 4. Geo-accumulation index (I_{geo}) of the annual mean values of the total heavy metals in sediment.

Station No.	Geo-accumulation Index (I_{geo})						
	Fe	**Co**	**Ni**	**Pb**	**Cd**	**Zn**	**Cu**
1	5.36	2.34	-5.71	4.76	4.12	3.64	-
2	5.01	2.34	-5.61	4.65	4.98	3.24	-
3	6.08	4.7	-3.83	3.25	8.13	4.6	-
4	6.28	2.94	-5.44	2.1	7.56	3.49	-
5	7.39	3.26	-5.17	4.34	5.60	3.76	-2.47
6	5.66	3.62	-4.32	2.26	6.27	3.11	-
7	5.88	2.41	-4.49	3.69	5.86	3.28	-
8	6.23	3.19	-6.15	3.64	6.01	3.82	0.74
9	7.18	3.58	-2.58	4.4	7.26	4.36	2.18
10	7.22	3.96	-4.51	5.14	8.38	3.65	4.16
11	4.91	1.7	-3.74	4.90	6.07	2.99	-
12	4.78	3.21	-4.50	2.15	7.87	3.15	-
Mean	5.998	3.104	-4.670	3.773	6.509	3.590	1.152
SD	0.496	0.112	0.106	0.528	1.329	0.118	2.792

1.6. Potential Ecological Risk Index (RI).

The potential ecological risk index method was proposed by **Hakanson (1980)** and **Hakanson (1988**) from a sediment logical perspective to assess the characteristics and environmental behavior of heavy metal contaminants in coastal sediments. The main function of this index is T^r_i to indicate the contaminant agents, where contamination studies should be prioritized. The potential ecological risk index (RI) was introduced to assess the degree of heavy metal pollution in sediments (Table 5). According to the toxicity of heavy metals and the response of the environment, RI is calculated as the sum of all risk factors for heavy metals in sediments, E^r_i is the monomial potential ecological risk factor, Cf is the contamination factor, and is the toxic response factor, representing the potential hazard of heavy metal contamination by indicating the toxicity of particular heavy metals and the environmental sensitivity to contamination, **(Devanesan *et al*., 2017).**

Table 5. Relationship among RI, E^i_r and pollution levels (Devanesan *et al*., 2017)

General level of potential ecological risk	**Scope of potential toxicity index (RI)**	**Ecological risk level of single-factor pollution**	**Scope of potential ecological risk index (E^i_r)**
Low-grade	RI < 150	Low	$E^i_r < 40$
Moderate	150 ≤ RI < 300	Moderate	$40 \leq E^i_r < 80$
Severe	300 ≤ RI < 600	Higher	$80 \leq E^i_r < 160$
Serious	600 ≤ RI	High	$160 \leq E^i_r < 320$
–	–	Serious	$320 \leq E^i_r$

As shown in Table (6), according to the standardized toxic response factor proposed by **Hakanson (1980),** the E^r_i values of Ni, Zn and Cu were less than 40 which indicate that sediments are low potential ecological risk (Fig. 4). On the other hand, potential ecological risk index of Cd, Co and Pb were more than 160 and less than 320 which indicate high potential ecological risk. In the same way Ni, Zn and Cu have moderate level of potential ecological risk index where values were 259.04,299.25 and 90.2, respectively (Fig. 5). While potential ecological risk index of Cd, Pb and Co were more than 600 which indicate serious potential ecological risk along Damietta Branch. This index was applied for each station individually along the study area for the all seven metals in the study. The values ranged from 430.46 to 1548.78 which indicate severe to serious level of potential ecological risk along Damietta Branch (Table 7).

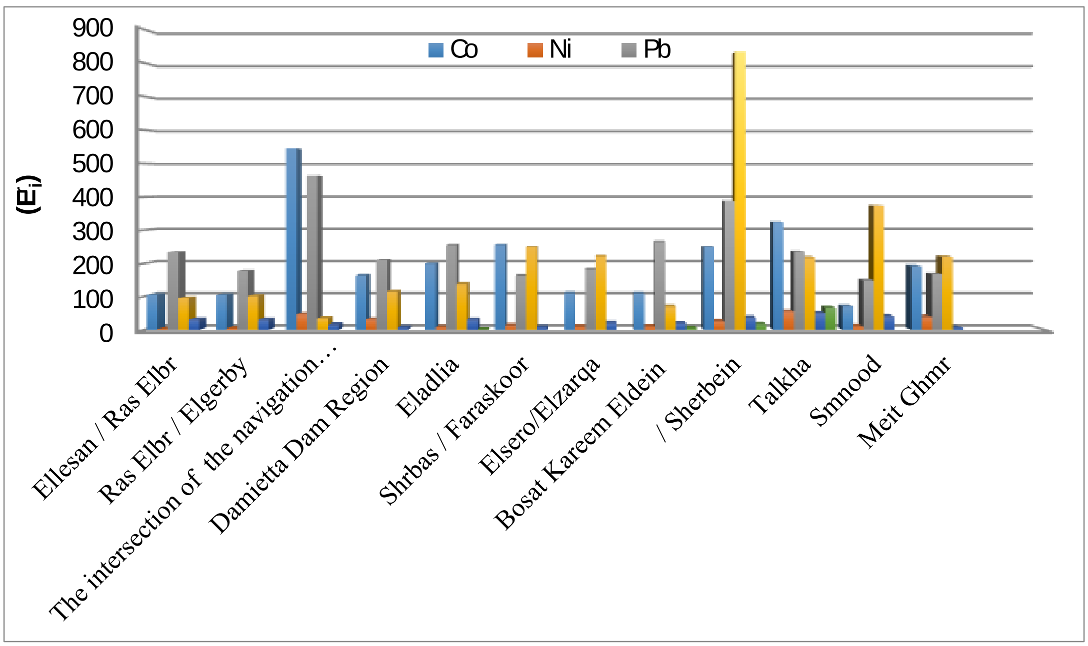

Fig. 4. Monomial potential ecological risk (E^r_i) factor of heavy metals in the study area.

2. Health Risk Assessment

Human health risk assessment HRA is the process of estimating the nature and probability of adverse health effects in humans who may be exposed to chemicals in contaminated environmental media due to behavioral and physiological differences. This study divided the people who live in close proximity to the examined mining areas into three groups: children, adult males and adult females. The health risks posed to those three groups were estimated and analyzed **(Khandare *et al*., 2020)**.

Table 6. Monomial potential ecological risk (Eri) factor and potential ecological risk index (RI) of heavy metals.

Station No.	Potential Ecological Risk factor (E^i_r) Co	Ni	Pb	Cd	Zn	Cu	RI
1	105.50	2.89	234	94.99	31.35	-	478.73
2	105.25	5.26	177.25	102	30.7	-	430.46
3	544.7	46.63	465	34.99	15.40	-	1106.72
4	163.25	31.45	210.75	114.99	7.35	-	527.79
5	199.2	8.07	255.5	138	30.9	0.65	634.32
6	256.05	12.89	162.25	249	7.75	-	687.94
7	110.25	9.71	183	222	20.95	-	545.91
8	109.5	10.75	265.75	69.99	20.2	6.2	482.39
9	249.1	25.55	387.5	832.98	36.8	16.85	1548.78
10	323.9	55.49	235.5	217.99	50.2	66.5	956.58
11	70.5	11.21	149	373.99	40.45	-	653.15
12	192.1	39.14	167.25	219.99	7.2	-	625.68
RI	2429.3	259.04	2892.75	2670.91	299.25	90.2	
Mean	202.44	21.586	241.06	222.57	28.020	22.55	723.20
SD	13.211	7.189	9.581	21.410	7.679	3.061	32.749

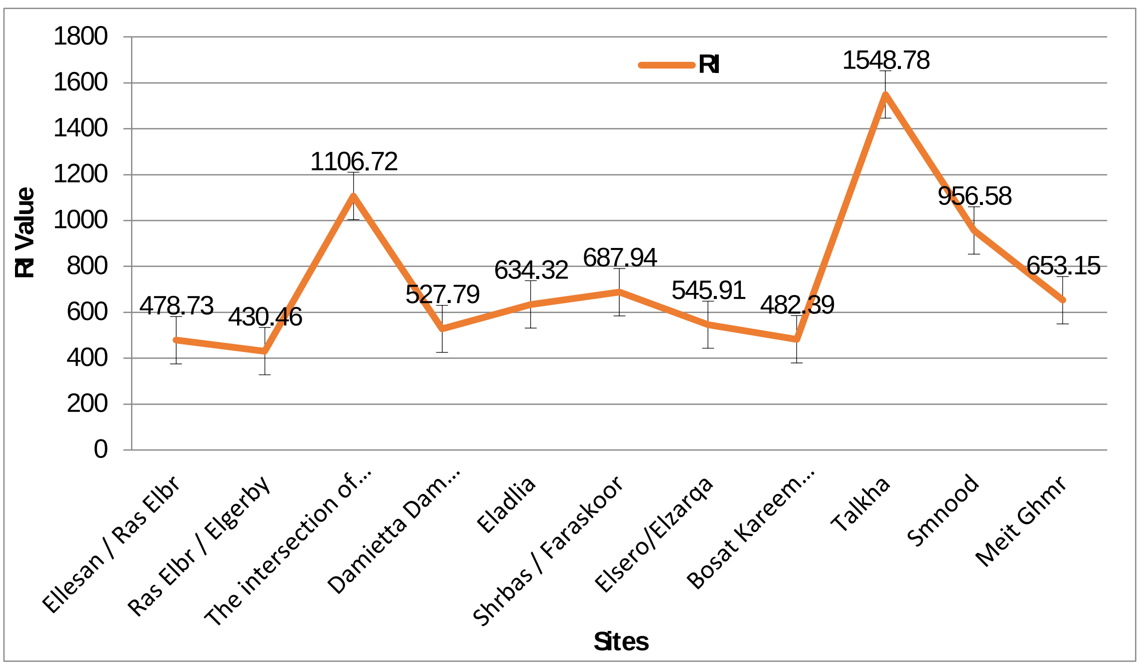

Fig. 5. Potential ecological risk index (RI) of heavy metals in the study area.

a- Exposure assessment

The general exposure equations used in this study were based on recommendations provided by several American and Canadian publications **(Ghany *et al*., 2020)**

b- Non-carcinogenic risk assessment

Non-carcinogenic hazards are typically characterized by the hazard quotient (HQ). The hazard quotient is defined as the quotient of the chronic daily intake, or the dose divided by the toxicity threshold value, which is referred to as the reference dose (RfD) of a specific chemical **(Kormoker *et al*., 2019).** To assess the overall potential for non-carcinogenic effects posed by more than one chemical, a hazard index (HI) approach was applied. If the HI value was less than one, the exposed population would unlikely experience obvious adverse health effects. Whereas, if the HI value exceeded one, then adverse health effects might occur. Because no reference doses are presently available for directly evaluating dermal absorption exposure to contaminants, the USEPA has developed a method to extrapolate oral toxicity values to be used in dermal risk assessment.

c- Carcinogenic risk assessment

Carcinogenic risks are estimated by calculating the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen. The slope factor (SF) converts the estimated daily intake of a toxin averaged over a lifetime of exposure directly to the incremental risk of an individual developing cancer, **(Fernández-Caliani *et al*., 2019).** Health risk assessment is developed to estimate potential health risk posed to human caused by contaminants. It contains four main components which are hazard identification, exposure assessment, dose-response assessment and risk characterization. In this study Ni, Pb, Cd, Fe, Zn, Cu and Co were identified as potential contaminants with respect to human health. Pb, Cd and Cu are classified as non-carcinogenic by Agency for Toxic Substances and Disease Registry **(ATSDR, 2005)**. In order to evaluate HRA different pathways, an average daily dose value (ADD) (mg/ kg/day) of a contaminant was applied. The Exposure Factors Handbook **USEPA (2012)** was used as a main guide in order to obtain the IngR, EF, ED and AT values in ADD calculation for soil. The input parameters and data source as reference involved in this study are shown in Table (7).

For cancer risks, ADD is multiplied by corresponding slope factor (SF) to produce a level of cancer risk. Slope factor (SF), inhalation unit risk (IUR), gastrointestinal absorption factor (ABSGI) and dermal absorption factor (ABSd) were estimated according to the integrated risk information system **(USEPA, 2012)**. Cancer slope factor (SF) of Ni=$9x10^{-5}$, Cd=6.3, Pb=0.0085 and Co=9.8. The total lifetime cancer risk (LCR) is expressed as the sum of the cancer risk from each exposure pathway. The acceptable or tolerable LCR for regulatory purposes is 1×10^{-5} (**USEPA, 2012**). For non-cancer risk, each element (Pb, Cd, Co and Ni) and exposure pathway is subsequently divided by the corresponding reference dose (RfD) to yield a hazard quotient (HQ). Cumulative non-cancer risks, expressed as the hazard index (HI), is equal to the sum of HQs (Table 8). If the value of HI was less than 1, it is believed that there would be no significant risk of non-carcinogenic effects. If HI exceeded 1, then there is a chance that non-cancer risks effects might occur, with a probability which tends to increase as the value of HI increases, **(Bahloul, 2019**).

Table 7. Parameters used for estimation of ADD via ingestion, dermal contact and inhalation exposure pathways**.**

parameter	symbol	unite	Value
Heavy metal in soil concentration	–	mg/kg	-
Soil ingestion rate	IngR	mg/day	100 mg/day : adults
Exposure duration	ED	years	24 years : adults
Exposure frequency	EF	Days/year	350
Average body weight	BW	Kg	62.65
Averaging time	AT	days	8760 non-cancer 25,550 for cancer
Conversion factor	CF	kg/mg	1×10^{-6}
Surface area of the skin that contacts the soil	SA	cm^2/event	5700
Skin adherence factor	AF_{soil}	mg/cm^2	0.07
Dermal absorption factor (chemical specific)	ABS	mg/cm^2	0.001 non-cancer 0.03 for cancer
Inhalation rate	InhR	m3/day	Adults 20 mg/cm^2
Particle emission factor	PEF	m^3/kg	1.36×10^9 m^3/kg

The summary of HRA (cancer and non-cancer risks) is presented in Table (8). Although some heavy metal such as Pb and Zn are essential nutrients, contaminated soil can cause serious impacts on human health. Direct risks of heavy metal in playgrounds, residential, traffic and industrial areas are from soil via ingestion, dermal and inhalation pathways **(Famuyiwa *et al*., 2019)**. For HRA interpretation, total cancer risk (cancer hazard) and cumulative HQ for non-cancer risk, hazard index (HI) was combined for studied heavy metals in sediment along Damietta Branch. Ingestion pathway contributed the most to total LCR and HI values followed by dermal contact and ingestion that was the most contributed pathway.

For non-cancer risks as in Table (9), average HI values of heavy metal was ordered as follows: Cd (239.63) > Pb (72.65) > Co (34.732) > Ni (14.457) > Zn (5.952) > Cu (4.719) > Fe (2.896). HI value more than 1 for all the seven elements indicate different pollution sources along the branch influenced by the heavy metal exposure corresponding to human health. Presence of the navigation channel which connected Damietta port to Damietta branch, Kafr Saad power station Talkha fertilizer factory and Omar bank and the other drains are the direct source of the contamination of those elements. HI more than 1 may imply that toxicity could be due to heavy metals.

Table 8. Hazard quotient (HQ) and cumulative hazard index (HI) for non-carcinogenic risk.

Station No.	Pathway	Average Daily Intake (*ADI*) Values of Heavy Metals in mg/kg/day						
		Fe	Co	Ni	Pb	Cd	Zn	Cu
1	ADD ingestion	1.13E-6	3.4E-2	4.8E-3	0.81	2.8E-2	0.23	-
	ADD dermal	1.11E-6	3.96E-3	5.5E-3	9.2E-3	3.2E-4	2.7E-3	-
	ADD inhalation	1.05E-10	3.7E-11	5.2E-11	8.7E-11	3.1E-12	2.5E-11	-
	ADI average	1.13E-6	3.7E-2	1.03E-2	0.81	2.8E-2	0.23	-
	HI	1.6E-6	1.89	0.51	234.05	28.32	0.77	-
2	ADD ingestion	0.89	0.34	0.47	0.613	3.02E-2	0.43	-
	ADD dermal	1.01E-2	3.9E-3	5.4E-3	6.9E-3	3.4E-4	4.9E-3	-
	ADD inhalation	9.6E-11	3.7E-11	2.1E-12	6.6E-11	3.2E-12	4.6E-11	-
	ADI average	0.900	0.34	0.47	0.61	0.03	0.434	-
	HI	1.28	17.19	23.77	177.11	30.54	1.44	-
3	ADD ingestion	1.86	1.79	0.18	1.60	0.10	3.83	-
	ADD dermal	2.1E-2	2.04E-2	2.07E-3	1.8E-2	1.18E-3	4.3E-2	-
	ADD inhalation	2.01E-10	1.9E-10	1.9E-11	1.7E-10	1.1E-11	4.1E-10	-
	ADI average	1.88	1.81	0.18	1.61	0.10	3.87	
	HI	2.68	90.52	9.10	462.28	101.18	12.91	
4	ADD ingestion	2.14	0.52	8.6E-2	0.72	3.4E-2	2.58	-
	ADD dermal	2.4E-2	6E-3	9.8E-4	8.3E-3	1.1E-3	2.9E-2	-
	ADD inhalation	2.3E-10	5.6E-11	9.3E-12	7.8E-11	2E-8	2.7E-10	-
	ADI average	2.16	0.52	8.6E-2	0.72	0.035	2.61	
	HI	3.09	26.3	4.34	208.08	35.10	8.69	
5	ADD ingestion	4.62	1.01	0.38	0.88	4.1E-2	0.66	5.1E-3
	ADD dermal	5.2E-2	7.4E-3	4.4E-3	0.01	4.6E-4	7.5E-3	5.9E-5
	ADD inhalation	4.9E-10	7E-11	4.1E-11	9.5E-11	4.4E-12	7.1E-11	5.6E-13
	ADI average	4.67	1.01	0.38	0.89	0.041	0.66	5.15E-3
	HI	6.67	50.87	19.22	254.28	41.46	2.22	13.9E-2
6	ADD ingestion	1.3	0.84	9.1E-2	0.56	7.3E-2	1.05	-
	ADD dermal	1.5E-2	9.5E^{-3}	1.04E-3	6.4E-3	8.4E-4	1.2E-2	-
	ADD inhalation	1.5E-10	9.1E-11	9.9E-2	6.1E-11	7.9E-12	1.1E-10	-
	ADI average	1.31	0.85	9.2E-2	0.56	7.3E-2	1.06	
	HI	1.87	42.47	4.60	161.82	73.84	3.54	-
7	ADD ingestion	1.62	0.36	0.24	0.63	6.5E-2	0.79	-
	ADD dermal	1.8E-2	4.1E-3	2.8E-3	7.2E-3	7.5E-4	9.1E-3	-
	ADD inhalation	1.7E-10	3.9E-11	2.6E-11	6.8E-11	7.1E-12	8.6E-11	-
	ADI average	1.63	0.36	0.24	0.63	5.6E-2	0.79	-
	HI	2.34	18.20	12.14	182.05	56.75	2.66	-
8	ADD ingestion	2.07	0.62	0.23	0.91	0.02	0.88	4.8E-2
	ADD dermal	2.3E-2	7.1E-3	2.7E-3	9.3E-3	2.3E-4	0.001	5.5E-4
	ADD inhalation	2.2E-10	6.7E-11	2.5E-11	9.9E-11	2.2E-12	9.5E-11	5.2E-12
	ADI average	2.09	0.62	0.23	0.92	2.02E-2	0.89	4.8E-2
	HI	2.99	31.3	11.63	262.65	20.23	2.96	1.30
9	ADD ingestion	3.9	0.81	0.42	1.34	0.24	2.10	0.13
	ADD dermal	4.5E-2	9.3E-3	4.9*E-3	1.5E-2	2.8E-3	2.3E-2	1.4E-3
	ADD inhalation	4.3E-10	8.8E-11	4.6E-11	1.4E-10	2.6E-11	2.2E-10	1.4E-11
	ADI average	3.94	0.81	0.42	1.35	0.24	2.12	0.13
	HI	5.63	40.96	21.24	387.14	242.8	7.07	3.54
10	ADD ingestion	4.12	1.06	0.67	0.81	6.4E-2	4.56	0.51
	ADD dermal	4.6E-2	1.2E-2	7.6E-3	9.2E-3	7.3E-4	5.1E-2	5.9E-3
	ADD inhalation	4.4E-10	1.1E-10	7.2E-11	8.8E-11	6.9E-12	4.9E-10	5.6E-11
	ADI average	4.16	1.07	0.67	0.819	0.06	4.61	0.51
	HI	**5.95**	53.60	33.88	234.05	64.73	15.37	13.90
11	ADD ingestion	0.82	0.23	0.57	0.51	0.11	0.92	-
	ADD dermal	9.4E-3	2.6E-3	6.4E-3	5.8E-3	1.2E-3	0.001	-
	ADD inhalation	8.9E-11	2.5E-11	6.1E-11	5.5E-11	1.1E-11	9.9E-11	-
	ADI average	0.82	0.23	0.57	0.515	0.11	0.93	-
	HI	1.18	11.63	28.82	147.37	111.2	3.10	-
12	ADD ingestion	0.75	0.63	8.4E-2	0.57	6.5E-2	3.21	-
	ADD dermal	8.6E-3	7.2E-3	9.6E-4	6.5E-3	7.4E-4	3.6E-2	-
	ADD inhalation	8.1E-11	6.8E-11	9.1E-12	6.2E-2	7E-12	3.4E-10	-
	ADI average	0.75	0.63	0.084	0.57	0.065	3.21	-
	HI	1.08	31.86	4.24	164.7	65.7	10.7	-

Table 9. Average HI values of heavy metals along Damietta branch.

Station No.	HI values of heavy metals						
	Fe	**Co**	**Ni**	**Pb**	**Cd**	**Zn**	**Cu**
1	1.6E-6	1.89	0.51	28.32	234.05	0.77	-
2	1.28	17.19	23.77	30.54	177.11	1.44	-
3	2.68	90.52	9.10	101.18	462.28	12.91	
4	3.09	26.3	4.34	35.10	208.08	8.69	
5	6.67	50.87	19.22	41.46	254.28	2.22	13.9E-2
6	1.87	42.47	4.60	73.84	161.82	3.54	-
7	2.34	18.20	12.14	56.75	182.05	2.66	-
8	2.99	31.3	11.63	20.23	262.65	2.96	1.30
9	5.63	40.96	21.24	242.8	387.14	7.07	3.54
10	5.95	53.60	33.88	64.73	234.05	15.37	13.90
11	1.18	11.63	28.82	111.2	147.37	3.10	-
12	1.08	31.86	4.24	65.7	164.7	10.7	-
Sum	34.8	416.79	173.49	871.85	2875.58	71.43	18.879
Mean	2.896	34.732	14.4575	72.65417	239.6317	5.9525	4.71975
SD	0.2126	2.357	0.781	6.667	9.603	0.892	0.680

Table 10. The excess lifetime cancer risk.

Station No.		Co	Ni	Pb	Cd
1	**∑ADI**	0.81	1.03E-2	3.7E-2	2.8E-4
	Cancer Risk	6.885E-3	9.27E-7	0.362	0.176
2	**∑ADI**	0.61	0.47	0.34	0.03
	Cancer Risk	5.185E-3	4.23E-5	3.33	18.1E-4
3	**∑ADI**	1.61	1.8	1.81	0.10
	Cancer Risk	1.3E-2	1.62E-2	17.64	0.630
4	**∑ADI**	0.72	8.6E-2	0.52	0.035
	Cancer Risk	6.12E-3	3.906 E-5	5.09 E-5	22.1 E-5
5	**∑ADI**	0.89	0.38	1.01	0.041
	Cancer Risk	7.565E-3	3.42E-5	9.8 E-5	25.8 E-5
6	**∑ADI**	0.56	9.2E-2	0.85	7.3E-2
	Cancer Risk	4.76E-3	8.28E-6	8.33 E-4	45.9 E-6
7	**∑ADI**	0.63	0.24	0.36	5.6E-2
	Cancer Risk	5.35E-5	2.16E-5	3.528 E-5	3.52 E-5
8	**∑ADI**	0.92	0.23	0.62	2.02E-4
	Cancer Risk	7.82E-4	2.07E-5	6.076 E-5	1.27 E-5
9	**∑ADI**	1.35	0.42	0.81	0.24
	Cancer Risk	1.147E-2	1.91E-3	7.938	1.512
10	**∑ADI**	0.819	0.67	1.07	0.06
	Cancer Risk	6.961E-3	6.03E-5	10.486	37.8 E-5
11	**∑ADI**	0.515	0.57	0.23	0.11
	Cancer Risk	4.377E-6	5.13E-5	2.254 E-4	69.3 E-5
12	**∑ADI**	0.57	0.084	0.63	0.065
	Cancer Risk	4.845E-5	7.56E-6	6.17 E-5	40.9 E-5
Mean value of Cancer Risk		2.14 E-4	6.75 E-6	45.03 E-4	7 E-4
		6.02 E-6	5 E-6	2.7 E-6	3.78 E-6

It was shown that rapid economic development, environmental pollution has been increasingly serious in such studies. The highest HI values were found in station 3 (The navigation channel) and station 9 (Talkha), which also represent residential areas. Air pollution caused by congested traffic and locations near main roads have also raised the deterioration of soil and water pollution in the branch. The carcinogenic risks of heavy metals were within the acceptable level (1×10^{-4}). **El-Alfy *et al*. (2019)** stated that the carcinogenic risk posed by those toxic elements to adults along Damietta branch via ingestion or dermal is accessible when paralleled with inhalation. While for total cancer risk values of the branch sediment, all the locations were not below than tolerable LCR for regulatory purposes. The current findings showed that non-cancer and cancer risk of Pb, Cd and Co through ingestion pathway still need to be extensively studied (Table 10). However, the present results highlighted the importance of exposure pathways, heavy metal bioavailability in assessing realistic human health impacts due to soil and sediment pollution. A framework of health risks due to heavy metal exposure from soil is recommended to take into consideration the land use, type activities, and bioavailability data to be applied in risk management decision and site specific soil guideline.

CONCLUSION

There are many factors affecting the water quality of the Nile River-Damietta branch that cause accumulation of pollutants in its sediments as: climatic conditions, water levels discharges, thermal pollution produced from the two different power stations, Omar-Bek drain, recharge from different industrial compound, the sewage and domestic wastes from El-Serw City. Additionally, the agricultural wastes behind Faraskour Dam as well as the Mediterranean Sea water intrusion into Damietta branch are also considered. A framework of health risks, due to heavy metal exposure from sediment, is recommended to take into consideration the land usage, type activities and bioavailability data to be applied in risk management decision and site specific soil guideline. The current findings showed that non-cancer and cancer risk of Pb, Cd and Co through ingestion pathway still need to be extensively studied.

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Conflicts of Interest:

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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