Assessment the Seasonal Variability and Enrichment of Toxic Trace Metals Pollution in Sediments of Damietta Branch, Nile River, Egypt

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Abstract: This work appraises the extent of toxic trace metals and seasonal pollution degree in Damietta branch sediments of the River Nile of Egypt. The toxic trace metals Fe, Mn, Cd, Co, Cu, Ni, Pb, and Zn were analysed in sediments from six sites during the summer and winter seasons. The metal concentrations and organic matter were determined using inductively-coupled-plasma mass spectrometry and loss-on-ignition, respectively. Multivariate statistical methods were used in order to allocate the possible metals sources and their relationships in sediments. The seasonal mean sequence of toxic trace metals was: Fe > Mn > Zn > Pb > Cu > Ni > Co > Cd. The mean Cd, Pb, and Zn values exceeded the sediment quality guidelines and average shale and they represent severe potential toxicity for aquatic organisms. Cu and Co were enriched during winter. The geo-accumulation index stipulated that metal pollution degree in the sequence of: Pb > Zn > Cd > Co > Cu > Mn > Ni > Fe. The highest metal pollution index reported in winter in sites S4/S5 and during summer in sites S4–S6. Different agricultural, wastewater discharge, fisheries, and industrial activities, as well as the effect of dilution/concentration during summer/winter seasons, are the main factors that contributed to metal accumulations in Damietta branch sediments. Continuous monitoring and evaluation of toxic trace metal concentrations of the Damietta sediments and similar localities worldwide can help to protect the ecosystem from harmful metal contaminations.

Keywords: pollution load index; geo-accumulation index; toxic trace metals; Nile River sediments; Damietta branch; Egypt

1. Introduction

Pollution of the aquatic system by toxic trace metals is a worldwide problem, because of their toxicity, persistence, and bio-accumulation [1]. Toxic trace metals that are added to the river bottom sediments are affected by various chemical changes. In the bottom sediments, precipitation, sorption, and organism activities can affect toxic trace metals distribution [2]. Less soluble metals in water adsorbed to the bottom sediments [3]. Bedrocks and bank leaching are the main lithogenic sources of toxic trace metals. Wastewater discharge, mining operations, fossil fuel combustion, manufacturing industries, etc., are the principal anthropogenic toxic trace metal pollution sources [4–6]. Some toxic trace metals and metalloids in high doses can be detrimental to the body while others, such as cadmium, lead, chromium, and arsenic, in little quantities, can cause acute and chronic toxicities in humans [7].

As a result of the fast-growing population of Egypt, the fixed amount of freshwater that comes from the Nile and groundwater, and the building of the Grand Ethiopian renaissance dam, the country will face increasing freshwater needs. The longest Nile River in the world (>6500 km), near its end at the Delta, it branches into the western Rosetta and the eastern Damietta. The Damietta branch...
of Nile River (mean width of 200 m and depth from 12 to 20 m) runs downriver to the North-East (242 km). Faraskour dam located between Faraskour and Damietta city (about 20 km south of the Mediterranean Sea) was built in order to protect Damietta city from the Nile flood and it separates the freshwater environment that lies in front of the dam and the marine water environment that lies behind the dam toward the sea. This branch acts as a source of water for agricultural, industrial, drinking, and fisheries. Several pollution sources, including municipal (from El-Serw City and many villages without sanitation facilities), industrial (Talkha fertilizer factory and thermal pollution from cooling the condensers of Kafr Saad Electrical station), and agricultural (agricultural drains), impacted the Damietta [8–11]. Faraskour is the heavily polluted area, as it receives high pollutant load from Delta Milk, Edfina Factories, the sewage, and domestic wastes that discharge from Damietta and Ras El-Bar cities [12] and the aquaculture of Nile Tilapia fish species cages and the resultant fish remnants [13].

Silt sediment loads in the Nile have recently been reduced from $1.16 \times 10^8$ m$^3$ yr$^{-1}$ to almost none, due to the building of the Aswan High Dam in the year 1964 [14]. Only the finest suspended load is transported downstream [15]. Therefore, less than 12% of the river margins rubbed away due to waves from motion of boats, bank erosion, seeping drainage water, and degradation [16]. This decrease has led to the use of chemical fertilizers, which, accordingly, increased contaminants’ load in the Nile drains. The elevated levels of toxic trace metals in this aquatic environment has become a serious concern for human health. Environmental pollution by toxic trace metals is one of the largest challenges that face a human being in Egypt.

The intents of this study are to (1) investigate the spatial distribution toxic trace metals over time in the bottom sediments of Damietta branch, Nile River and (2) identify the variability of metal origins with assessing the risk of toxic trace metals enrichment in order to protect the environment and the aquatic ecosystem.

2. Materials and Methods

2.1. Study Area and Sample Collection

The examined area stretches about 237.0 km from the delta barrage until the Damietta outlet. The Damietta branch pass through five governorates: El-Qalubia, El-Menofia, El-Gharbyia, El-Dakahlyia, and Damietta. The water temperature ranged from 17 °C in winter to 31 °C in summer with rare rainfall [12]. The very fine-grained recently precipitated bottom sediment samples were collected along the middle of the river’s active channel. Six sediment sampling sites were chosen on the Damietta branch, starting from the north of Cairo (north delta barrage (Elqanater)) to the north of the Damietta branch. The following six sampling sites were chosen for the study (Figure 1):

- North of delta barrage (S1): this site is located 26.0 km downstream from delta barrage (Elqanater).
- Near Benha (S2): this site is located 58.0 km from delta barrage.
- Near Kafr Shukr (S3): this site is located 70.0 km downstream of delta barrage.
- Between Mit Ghamr and Mansoura (S4): this site is located 111.0 km downstream delta barrage.
- Near Sherbeen (S5): this site is located 169.0 km downstream delta barrage.
- Damietta outlet (S6): this site is located 237.0 km downstream delta barrage

The first site (S1) was chosen as control station, the sites (S2 to S5) have three sources of pollution (agricultural, industrial, and domestic discharges) and the last site (S6) was near the sea. The samples were gathered while using an Ekman dredge sampler during summer and winter seasons in the year 2019, from the uppermost 2–5 cm of the river bottom sediments. The sediment samples are characterized by sandy clay texture. The investigated area showed irregular width and height topography. The depth of water fluctuates between 12 to 20 m. The sediment samples were air-dried, and then grind and sieved in order to attain the required sediment fraction (<63 µm).
Figure 1. Map of Nile delta and different sampling sites along Damietta Nile River branch.

2.2. Sample Preparation

2.2.1. Organic Matter Analysis

The samples (0.5 g from each sample) were oven-dried at 105 °C. Afterwards, they were heated to about 700 °C for 30 min. Then, the samples were cooled in the desiccator and weighed. The organic matter was quantified by weight difference while using the loss on ignition methodology [17–19].

2.2.2. Toxic Trace Metals Analysis

The samples were digested according to the method of [20]. The eight toxic trace metals (Fe, Mn, Cd, Co, Cu, Ni, Pb, and Zn) were measured after digestion by HNO₃: HF: ClO₄. 0.5 g of grinded sample was weighed and placed in a Teflon beaker for digestion. Concentrated HNO₃ (4.0 mL), HClO₄ (4.0 mL), and HF (15.0 mL) were added. A cover was then put on the beaker and simmered during the night on a heatable plate at 80–90 °C. The beaker contents evaporated slowly until dryness. 2.0 mL of the HClO₄ was put on with continues evaporation till dryness. Subsequently, conc. HCl (2.0 mL) and distilled water (10.0 mL) were added to the residue. 0.5 mL of conc. HNO₃ was then put on and completed by distilled water. Inductive Coupled Plasma Mass Spectrometry (ICP-MS, Model: Elan 9000, Perkin Elmer, Waltham, MA, USA) was used in order to estimate the toxic trace metal content. Reagent blank samples were evaluated in duplicate. Standard reference materials (CANMET SRSD-1 and 3) [21] were used for laboratory quality assurance (QA) and quality control (QC).
2.3. Contamination Indices

2.3.1. Contamination Factor (CF) and Pollution Load Index (PLI)

Contamination factor (CF) is the metal content in the sediment and background value in shale ratio [22]. It is a practical method for monitoring the pollution changes within time and it is calculated, as follows:

$$\text{CF} = \frac{C_{\text{metal}}}{C_{\text{background}}}$$

(1)

The Pollution load index (PLI) defines how many times the toxic trace metal values in the sediment overpassed the background value. The PLI in the studied sediments of the Damietta branch of the Nile River was calculated while using by applying the equation [23,24]:

$$\text{PLI} = \left( \text{CF}_1 \times \text{CF}_2 \times \text{CF}_3 \times \ldots \times \text{CF}_n \right)^{1/n}$$

(2)

where \(n\) is the number of metals studied and CF is the contamination factor. The PLI can give an easy and comparative way of metal contamination levels in sediments. PLI < 1 indicates perfection; PLI = 1 just baseline pollutant degrees are existing and PLI > 1 denote debilitation of quality [23].

2.3.2. Geo-Accumulation Index (Igeo)

The Geo-accumulation index (Igeo) was offered by [25] to calculate the sediment pollution with metals when compared to the background natural levels in shale by applying the following formula:

$$I_{\text{geo}} = \log_2 \left( \frac{C_n}{1.5B_n} \right)$$

(3)

where \(C_n\) and \(B_n\) are the concentrations of the element ‘n’ in the sediment and in average shale, respectively, and 1.5 is the correction factor due to lithological variability [26]. The Igeo divided sediment quality into seven classes (Table 1).

| Igeo Value | Class | Quality of Sediment       |
|------------|-------|---------------------------|
| Igeo ≤ 0   | 0     | Unpolluted                |
| 0 < Igeo ≤ 1 | 1   | Unpolluted - moderately polluted |
| 1 < Igeo ≤ 2 | 2   | Moderately polluted       |
| 2 < Igeo ≤ 3 | 3   | Moderately - highly polluted |
| 3 < Igeo ≤ 4 | 4   | Highly polluted           |
| 4 < Igeo ≤ 5 | 5   | Highly - very highly polluted |
| Igeo > 5   | 6     | Very highly polluted      |

2.4. Multivariate Statistical Analysis

Principal component analysis (PCA) and hierarchical cluster analysis (HACA), were accomplished using the statistiXL software in order to determine the relationships between toxic trace metals in the Damietta sediments and their viable sources (www.statistixl.com). PCA is used to extract a fewer number of independent factors (principal components) from a big set of inter-correlated variables [4,27]. Thereto, natural and anthropogenic contributions of toxic trace metals in the Damietta sediments can be identified.

3. Results and Discussions

3.1. Environmental Assessment and Variations in Toxic Trace Metal Pollution

The bottom Nile sediments from sites of the Damietta branch have medium to fine-texture. The maximum value of organic matter is recognized at sites S6 (17.5%) and S5 (10.7%), which may
refer to the direct discharge of wastewater and/or the spreading of fisheries (Nile Tilapia fish species) at these locations [28,29] and very low at sites S1–S2, which are away from direct contaminations (Table 2). The organic matter being higher during the summer season may be due to the enrichment of calcareous algae [30]. Toxic trace metals, like Cu, Fe, Mn, Ni, and Zn. are important nutrients for the life in living organisms, some other non-degradable metals, like Cd, Cr, Pb, and Co, can agglomerate in the human body, causing nervous system, kidneys, and bones damage [31,32]. The periodic mean sequence of toxic trace metals concentration in the Damietta branch sediments was: Fe > Mn > Zn > Pb > Cu > Ni > Co > Cd. The toxic trace metal values are higher in the winter season (Table 2, Figure 2). The average discharge of water from Aswan High Dam during the summer season (5823 million m$^3$) is almost double of winter (2666 million m$^3$) as a result of discontinuation of irrigation systems during winter [33]. Therefore, water declination during the winter season principally influences the distribution of toxic trace metals [34].

In this study, the quality guidelines for sediment, like the effect range low (ERL) and the probable effect level (PEL), are used to identify the environmental pollution and the ecotoxicology induced by toxic trace metals [26,27,35] in bottom sediments of the Damietta branch, and these results are presented in Table 2. Concentrations that are lower than the ERL represent that the influence on living organisms would rarely happen, whereas values that are higher than the PEL denotes that potential effects can repeatedly occur. Iron is not considered to be a hazardous metal pollutant. In the study area, the Fe values were greater than other metals, indicating a natural high occurrence in the sediments. The mean values of Cd, Pb, and Zn in the summer and winter seasons were greater than the average shale, ERL, and PEL. Cu and Co showed enrichment during the winter season. This increase in toxic trace metal concentrations suggests adverse potential toxicity to aquatic organisms. Mn, Co, Cu, Ni, and Pb are enriched during summer and winter seasons at sites S5 and S6 due to different agricultural, wastewater discharge, and industrial activities [26,36]. Agricultural and industrial wastes affect the values of Cu and Ni [26,35,37] and Pb corroborated sewage effluents and industrial wastes [38,39]. Nickel is a common metal in the environment. Transportation activities, industrial discharges, and the application of sewage wastes increase Co concentration [26]. Cd and Zn being enriched at sites S3 to S4 may be due to the agricultural activities contributing to the use of pesticides and chemical fertilizers [6,40,41]. Additionally, pesticides can increase the Cd values in the sediments of aquatic organisms [42]. Cd is principally related to the application of phosphate fertilizers [42]. Additionally, wastewater discharge and/or the spreading of fisheries (Nile Tilapia fish species) at these sites increase the organic matter, which can adsorb the toxic trace metals [43]. The toxic trace metal dispensation in the sediment in summer and winter seasons is not completely homogeneous along the Damietta (Figure 2). The toxic trace metals enrichment in the Damietta branch bottom sediments is due to point source contaminant discharge, Nile water level, and the distribution of fisheries. Mn, Cu, Zn, and Cd exhibited higher enrichment during the summer season in the Rosetta branch [19], while the Mn, Pb, and Zn showed greater enrichment during the summer season and Fe during both seasons in the Damietta branch. In a similar study by [44], the smaller concentrations of Fe, Mn, Pb, Cu, Ni, and Zn were reported at the northern part of Damietta aside from drainage water, while the greater concentrations of those metals were registered in localities that were distributed from Banha and Faraskur cites.
Table 2. Concentration of toxic trace metals and organic matter (%) in Damietta branch sediments during summer and winter seasons (mg/g).

|      | mg/g | Fe  | Mn  | Cd  | Co  | Cu  | Ni  | Pb  | Zn  | OM(%) |
|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-------|
|      |      |     |     |     |     |     |     |     |     |       |
| Summer |     |     |     |     |     |     |     |     |     |       |
| Mean  | 13.81| 0.79| 0.0004| 0.02| 0.04| 0.04| 0.11| 0.46| 7.77|       |
| Min   | 2.25 | 0.49| 0.0002| 0.01| 0.02| 0.03| 0.04| 0.06| 1.70|       |
| Max   | 21.67| 1.36| 0.0005| 0.03| 0.06| 0.05| 0.18| 1.10| 17.50|       |
| Winter |     |     |     |     |     |     |     |     |     |       |
| Mean  | 26.44| 1.31| 0.0008| 0.04| 0.06| 0.05| 0.20| 0.58| 5.60|       |
| Min   | 17.33| 0.69| 0.0006| 0.02| 0.05| 0.04| 0.07| 0.10| 2.5  |       |
| Max   | 38.14| 2.27| 0.0010| 0.05| 0.08| 0.07| 0.30| 2.41| 9.6  |       |
| Seasonal mean values |  20.12| 1.05| 0.0006| 0.03| 0.05| 0.05| 0.15| 0.52| 6.68|       |
| Average shale |  47.2 | 0.85| 0.0003| 0.02| 0.045| 0.068| 0.02| 0.095| – |       |
| ERL   | –    | –   | 0.0012| –   | 0.03| 0.0209| 0.05| 0.15| – |       |
| PEL   | –    | –   | 0.0042| –   | 0.108| n.a| 0.112| 0.271| – |       |

Figure 2. Total toxic trace metal concentrations in Damietta branch sediments during summer and winter seasons.
3.2. Contamination Indices

3.2.1. Pollution Load Index (PLI)

The maximum PLI of toxic trace metals in the Damietta branch sediments was recorded in the winter season. The PLI values ranged from 0.57 in site S1 and 1.42 in site S4 with a mean value of 1.09 during summer. During winter, the values run from 1.07 in site S1 and 2.51 in site S6, with mean value 1.87. The PLI of toxic trace metals indicated a deterioration of the Nile sediments by toxic trace metals (Table 3, Figure 3). The mean PLI value that was reported in this study was greater than the threshold (<1), which denoted the presence of pollutants or loads higher than the background levels [45]. The highest metal pollution values were marked in winter season in sites S4 and S5 and during summer in sites S4–S6 may be owing to various anthropogenic sources, such as industrial, agricultural, and fishery activities at these sites.

Figure 3. The Geo-accumulation index (Igeo) (a) and the pollution load index (PLI) (b) of toxic trace metals in Damietta branch sediments during summer and winter seasons.
Table 3. Igeo and PLI values for toxic trace metals in Damietta branch sediments during summer and winter seasons.

|        | Igeo | Fe    | Mn    | Cd    | Co    | Cu    | Ni    | Pb    | Zn    | PLI |
|--------|------|-------|-------|-------|-------|-------|-------|-------|-------|-----|
| Summer |      |       |       |       |       |       |       |       |       |     |
| Mean   | −2.67| −0.79 | −0.30 | −0.73 | −1.03 | −1.48 | 1.75  | 0.73  | 1.09  |     |
| Min    | −4.98| −1.38 | −1.17 | −1.52 | −1.72 | −1.77 | 0.44  | −1.36 | 0.57  |     |
| Max    | −1.71| 0.09  | 0.24  | 0.08  | −0.19 | −1.09 | 2.62  | 2.95  | 1.42  |     |
| Winter |      |       |       |       |       |       |       |       |       |     |
| Mean   | −1.48| −0.11 | 0.83  | 0.18  | −0.17 | −0.95 | 2.57  | 0.97  | 1.87  |     |
| Min    | −2.03| −0.89 | 0.44  | −0.41 | −0.51 | −1.36 | 1.27  | −0.58 | 1.07  |     |
| Max    | −0.89| 0.83  | 1.14  | 0.69  | 0.31  | −0.56 | 3.33  | 4.08  | 2.51  |     |
| Seasonal mean concentrations | −2.08| −0.45 | 0.27  | −0.27 | −0.60 | −1.21 | 2.16  | 0.85  | 1.48  |     |

3.2.2. The Geo-Accumulation Index (Igeo)

The Geo-accumulation index (Igeo) values of toxic trace metals in the Damietta branch sediments declared that the sediments were more polluted with all metals, except Fe and Ni (Table 3, Figure 3). The Igeo values for Fe and Ni during summer and winter seasons fell into class 0, Mn, Co, and Cu remain mostly in class 0, but, in winter season, they became in classes 1 at some sites (S3 to S6). The Igeo values for Cd ranged from class 0 during summer (sites S1–S3) to class 2 (sites S3–S4). The Igeo values for Pb during summer and winter seasons ranging from class 1 to class 4 (sites S5–S6), indicating a moderately to strongly pollution with Pb, especially during the winter season. Zn ranges from class 0 (sites S1–S2), class 2 (sites S3–S4) in summer, and strongly to extremely polluted with class 5 during winter at site S4. Extreme pollution was recorded for Pb and Zn that reach class 5, suggesting that the river bed sediments are very highly polluted with Pb and Zn accumulation. The seasonal mean pollution degree in sediments followed the order of: Pb > Zn > Cd > Co > Cu > Mn > Ni > Fe. Industrial, agricultural, domestic pollution sources, and Nile level water during summer and winter seasons along the course of the Damietta seem to be responsible for high sediment pollution [26].

3.3. Multivariate Analysis and Toxic Trace Metals Sources in the Damietta

The PCA was carried out for metals concentrations and the organic matter content in the Damietta branch sediments in the summer and winter seasons, in order to identify the possible contributing factors among the metals. Therefore, varimax rotation with Kaiser normalization was applied (Table 4, Figure 4). The first two components (PCA 1 and 2) with eigenvalues >1 were extracted and they explain 72.8% and 20.9% of the data variation in the summer season, and 73.8% and 17.9% of the data variation in the winter season.

Figure 4. Plot of the first two principal components obtained from the PCA of toxic trace metal concentrations in Damietta branch sediments during the summer (a) and winter (b) seasons.
Table 4. Loadings matrices of the variables extracted while using varimax rotation. Bold-faced values are loadings >0.80.

| Variable | Summer PCA 1 | Summer PCA 2 | Winter PCA 1 | Winter PCA 2 | Summer Communalities | Winter Communalities |
|----------|--------------|--------------|--------------|--------------|----------------------|----------------------|
| OM       | 0.98         | -0.06        | 0.97         | 0.80         | -0.29                | 0.73                 |
| Fe       | -0.14        | 0.88         | 0.79         | 0.95         | 0.30                 | 1.00                 |
| Mn       | 0.97         | -0.21        | 0.99         | 0.99         | 0.06                 | 0.98                 |
| Cd       | 0.84         | 0.53         | 0.99         | 0.42         | 0.87                 | 0.93                 |
| Co       | 0.98         | -0.04        | 0.95         | 0.97         | 0.13                 | 0.95                 |
| Cu       | 1.00         | -0.05        | 0.99         | 0.99         | 0.10                 | 0.99                 |
| Ni       | 0.99         | 0.00         | 0.99         | 0.90         | 0.41                 | 0.98                 |
| Pb       | 0.98         | 0.12         | 0.98         | 0.90         | 0.38                 | 0.96                 |
| Zn       | 0.06         | 0.88         | 0.77         | -0.07        | 0.86                 | 0.74                 |

In summer, the first PCA explaining 72.8% of total variance was prevailed by large positive loading of Mn, Cd, Co, Cu, Ni, Pb, and organic matter, especially at sites S5 and S6. These loadings combinations exhibit a great relation among the factors. Fe and Zn (PCA 2, 20.9% of the total variance) were highly associated at sites S3 and S4, demonstrating loading values of 0.88. In winter, PCA 1 was prevailed by Fe, Mn, Co, Cu, Ni, Pb, and organic matter explaining 73.8% of the total variance, at S5 and S6 sites. Cd and Zn (PCA 2, 17.9% of the total variance) were highly affiliated, showing large positive loading at sites S3, S4, and S5 (Table 4, Figure 4). Co, Cd Cu, Ni, Pb, and Zn are used in many agricultural, municipal sewage sludge, and industrial applications [46,47]. Many toxic trace metals, like Cd, Cr, Zn, As, and Se, are derived from phosphorus fertilizers [46]. The associations of these toxic trace metals are mostly anthropogenic origin [36]. A dendrogram was also used in this study in order to identify the relationship between the six sites based on toxic trace metal concentrations [48,49]. An almost analogous relationship was observed between pollution in the summer and winter seasons. The resulting dendrograms (Figure 5) classified these metals into three main clusters: the first cluster, including sites S1 and S2, a second cluster, including sites S3 and S4, and the third one, including sites S5 and S6. Each cluster shares the same characteristics and sources of metals. The first cluster represents the very low contaminated sites by toxic trace metals, the second cluster represents the moderately contaminated sites by toxic trace metals, and the third cluster shows a positive correlation with most of the toxic trace metals.

The very high enrichments of toxic trace metals at sites S5 and S6 represent the discharge and endpoint locations for industrial sewage effluents, Talkha fertilizer factory, and Kafr Saad Electrical station, and different agricultural drains impacted these areas. Enrichment at sites S3 and S4 with Zn can be related to the high agricultural activities and fluctuations of Fe during summer and Cd during winter may be allied to the application of pesticides [17] and the dilution and concentration-effect during different seasons [33,34]. Additionally, Cd has different sources in the soil, namely transportation activities, industrial discharges, and sewage sludge wastes [26].

The variability of the toxic trace metals concentration is mainly the result from different toxic trace metals sources, dilution and concentration during winter and summer seasons, non-point pollution sources from wastes, such as agricultural (fertilizers and pesticides), industrial (fertilizer and thermal pollution), municipal sewage, Tilapia species fisheries in the northern part of the Damietta branch, and precipitation, adsorption, and redox reactions that can take place in the bottom sediments [2,26,33,42]. The results of PCA, metal pollution (PLI), and Geo-accumulation (Igeo) indices were concordant. Pollution sources from agricultural, industrial, and urban discharges were accountable for the greatest metal enrichment at specific sites along the Damietta branch.
Figure 5. Hierarchical clustering results (dendrogram) of toxic trace metal concentrations in Damietta branch sediments during the summer (a) and winter (b) seasons.

This study has offered a comprehensive toxic trace metal pollution analysis and possible risk inside a vital water source in the Nile delta of Egypt. The results expressed in this study provide toxic trace metal data and risk research in Damietta Branch of the Nile River, which may have definite implications for toxic trace metal pollution regulation. Metal partitioning characteristics and mineralogical analysis of river sediments are required to extrapolate the behaviour of toxic trace metals and contribute to future monitoring studies.

4. Conclusions

Metal variations, enrichment, and distribution in the Damietta branch sediments on the Nile River of Egypt were varied in the summer and winter seasons at different locations. The toxic trace metals concentrations showed the order: Fe > Mn > Zn > Pb > Cu > Ni > Co > Cd. The Cd, Pb, and Zn mean values were higher than the average shale, ERL, and PEL during all seasons. Cu and Co were greater during winter. The distribution of organic matter and toxic trace metals is influenced by water declination during the winter season. The seasonal mean Igeo degree followed the order of Pb > Zn > Cd > Co > Cu > Mn > Ni > Fe. The highest PLI recorded in winter, in sites S4 and S5, and in summer, in sites S4-S6. The PCA results were concordant with the PLI and Igeo data. The main anthropogenic sources that affected the Damietta branch are agricultural, wastewater discharge and industrial activities, and the dilution and concentration-effect during different seasons. This study will aid in delineating toxic trace metal sources, distribution, and accumulation in the bottom sediments in the Damietta branch over time.
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