Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 28(3): 1253 – 1269 (2024)
www.ejabf.journals.ekb.eg

Evaluating Sediments and Water Pollution of Manzala Wetland, Egypt

Sayed A. Sayed[1], Hesham I. El Kassas[2], Ahmed A. ElKhouly[1]
[1]Plant Ecology and Range Management Department, Desert Research Center, Cairo, Egypt
[2]Department of Environmental Agricultural science, Faculty of Graduate Studies and Environmental Research, Ain Shams University

***Corresponding author: sayed_abdallah2009@yahoo.com**

ARTICLE INFO

Article History:
Received: Dec. 24, 2023
Accepted: April 11, 2024
Online: June 28, 2024

Keywords:
Manzala Wetland,
Heavy metals,
Pollution indicators,
Water,
Hydro-soil contamination

ABSTRACT

One of the highly significant issues in aquatic habitats is the heavy metals contamination, and Manzala Wetland in Egypt is subject to this kind of pollution. Thus, this paper aimed to analyze the geographical distribution of heavy metals pollution in this wetland. To accomplish this target, randomly selected geo-referenced water and hydro-soil samples were collected from the wetland under study. The heavy metals analyzed were Fe, Pb, Cu, Cd, Cr, Zn, and Co. According to the results, the northeastern and southern portions of the wetland's drains have the highest quantities of these heavy metals. This may be caused by urban, industrial, and agricultural wastes flowing down the drains, particularly the industrial waste from Port Said drains and the drains of Bahr El-Baqar. According to the geo-accumulation index, Manzala Wetland is more heavily contaminated with Cd and Pb, as evidenced in the hydro-soil samples. Except for cadmium, all other metals in water are below the permissible levels. Consequently, geo-statistics offer efficient ways to measure contaminated streams and sediments to inform decisions about potential redevelopment projects or elimination strategies.

INTRODUCTION

Due to their toxicity, endurance, and biological accumulation, heavy metals pollution in the aquatic habitats has received special attention. Due to their low solubility, heavy metals are primarily absorbed and accumulated at the bottom of hydrosoil, which serves as both a sink and a carrier of pollutants in the aquatic environment. Hydrosoil in wetlands is a sensitive indicator for monitoring pollutants. The primary anthropogenic sources of heavy metals include industrial processes, petroleum contamination, and sewage disposal **(Abd El-Wahaab & Badawy, 2004; Zahran & Willis, 2009; Farag & El-Gammal, 2012)**.

Manzala Wetland is the largest among Egypt's Mediterranean wetlands and serves as a fisheries center. However, it is being overrun by water hyacinth due to land reclamation, industrial pollution, and nutrient pollution. Over the past 60 years, Manzala Wetland has faced numerous challenges, including drainage from farms, sewage from cities, and wastewater. These contaminants have caused Manzala Wetland to become an unclean and polluted ecosystem, impacting fish production and the distribution of aquatic habitats within the wetland **(Aliaume *et al.*, 2007)**. Nine main drains and canals contribute to the annual flow entering Manzala Wetland of fresh water, primarily from agricultural runoff. It enters and transports most of the wastewater into the wetland through a region of the eastern Delta that is quite heavily inhabited, traveling through Qalubyia, Sharkia, Ismailia, and Port Said, and significantly affecting the wetland's declining water quality. Since heavy metals are toxic, precise data on their levels in aquatic ecosystems are required. Consequently, the goal of the study was to identify, quantify, and link sources of the heavy metal accumulation in Manzala Wetland using heavy metals indicators in water and hydro soils.

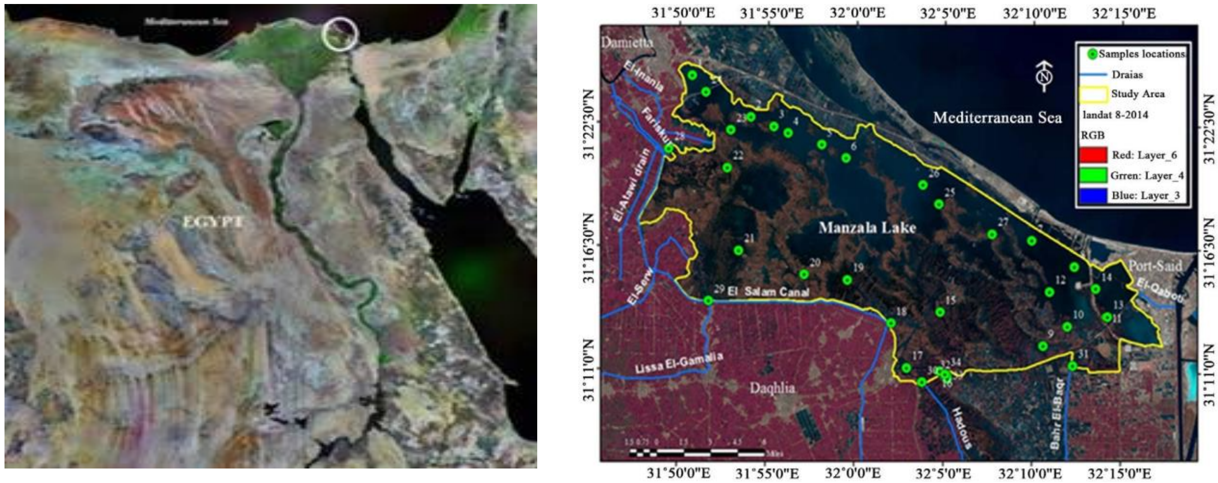
MATERIALS AND METHODS

1. Study area

The largest and most productive wetland for fishing in Egypt's northern region is Manzala Wetland (Fig. 1). It has a surface area of approximately 52,611 hectares. Moreover, it is bounded by the Mediterranean Sea in the north, the Nile-Damietta branch in the west, and the Suez Canal in the east. It is a shallow lagoon with a depth range between 0.5 and 1.0m in around 50% of the wetland surface. Several drains, including Bahr El-Baqar, Hadous, El-Matria, Ramsis Faraskur, Lissa El- Gamalia, and El-Serw discharge polluted water into the wetland **(Khedr, 1996; Shaltout, *et al*., 2010; Elbehiry *et al*., 2018; El-Alfy *et al*., 2020)**.

Climate

It is characterized by dry arid climate as a part of the Mediterranean coastline of Egypt. The research area is in the warm coastal deserts **(Meig, 1973)**, where winter is the coldest season and summer is the warmest with mean temperatures exceeding 10°C. At Manzala Wetland, the average annual temperature is approximately 15.4°C, and the average minimum air temperature varies from 8.4°C in winter to 21.4°C in summer. The mean maximum air temperature ranges from 18.3°C in January to 31°C in August, with an average annual temperature of 24.9°C. The humidity ranges between 68% in May to 76% in August with a mean value of 68%. The yearly average rainfall is 106.7mm, while the evaporation rate ranges from 5.4mm/ day in June to 2.8mm/ day in December and July. In January and February, the predominant wind is from the south. In spring, summer, and autumn, it is from the north and northwest. In October and November, it is from the northeast, and in December, it is from the south **(Ministry of civil aviation, 1979)**. Climatological normal for the Arab Republic of Egypt up to 1975.



A B

Fig. 1. (A) Map of Egypt showing Manzala Wetland

(B) Sample collection sites of water supplies Landsat 8 image for the study area (Manzala Wetland) **(Earth Explorer, USGS 2020)**

Three outlets, El-Gamil, El-Boughdady, and the new El-Gamil connect the wetland under study to the Mediterranean Sea, allowing the exchange of the water and biota between the two bodies of water. Between the wetland and Suez Canal, there is a tiny canal called the El-Qaboty Canal **(Ahmed *et al.*, 2006; Elewa *et al.*, 2007; Zahran & Willis, 2009)**. Numerous significant canals and drains discharge into Manzala Wetland, where 20,000 feddans are served by the agricultural drain. They are:

Faraskur drain, which covers an area of around 44.48km^2 (4% of total inflow).

- El-Serw: Agriculture drain, 13% of total inflow, serves 68,700 feddans (152.8km^2).
- Matariya: It provides service to 50,000 acres of agriculturally reclaimed land (2%).
- Ramsis: It drains a negligibly small volume of water into the 24-km^2 Manzala Wetland.
- The largest drain in the eastern delta, Hadous, serves some agricultural land of about 1756.96km^2 (49 %).
- Bahr El-Baqar: It serves an agricultural area of about 119.2km^2 and receives about 300 million m^3/ year of treated and untreated sewage from Cairo (25% of total inflow).

2.1. Collection of samples

As shown in Fig. (1), 31 water samples and 34 hydro-soil samples were collected seasonally during 2019 randomly from different locations in the wetland. These samples geographic locations were determined using a GPS (Garmin, etrex type) device. In this study, heavy metal analyses were carried out to estimate seven essential heavy metals including: Fe, Pb, Cu, Cd, Zn, Cr, and Co.

2.2. Analytical methods

2.2.1. Analysis of water samples containing dissolved heavy metals

To store surface water samples for analysis, plastic bottles were acid-washed. Following that, 0.45um membrane filters were used to filter these samples. When collecting and handling samples, every precaution was taken to reduce the possibility of sample contamination. To remove solvents from the water samples, methyl isobutyl ketone (MIBK) and thiocarbamate (APDC) were pre-concentrated using the recommended methods for the APDC-MIBK extraction **(APHA, 1999)**. The flame atomic absorption spectrophotometer (AAS: Perkin Elmer Analyst 100) was used to measure the concerned heavy metals in the resulting solution.

2.2.2. Analysis of heavy metals in hydro-soil samples

Soil samples were collected at depths (25cm) using a polyethylene-coated Van-Veen holder **(Amini Ranjbar, 1998)**. Subsamples were taken from the middle part of the grab to avoid contamination. Samples were kept in sealed plastic bags, pre-cleaned with acid, and rinsed with demineralized water. Samples were deep frozen until analysis, dried in an oven at −70°C, sieved using a 0.75mm plastic sieve, and digested for approximately 2h in a mixture with a ratio of 3:2:1 nitric acid (HNO3) to perchloric acid (HClO4) to hydrofluoric acid (HF), respectively **(Origione & Aston, 1984)**. Seven heavy metals (copper, lead, cadmium, chromium, zinc, iron, and cobalt) were measured using atomic absorption spectrometry, with values expressed in μg/ g.

Note:

During the period of 2020, the wetland was developed and dredged, and the depths were increased in all areas, along with the removal of the cover of the natural plants present in the wetland. This explains the lower concentration of all elements than previously.

2.3. Indicators of heavy metals in hydro-soil samples

2.3.1. Enrichment factor

The Enrichment factor (EF) is regarded as useful criterion for determining the extent of environmental pollutants. The regulating element was determined to be iron (Fe) **(Seshan *et al.*, 2010)**. While EF values > 2 suggest that the sources are more likely to be anthropogenic, the metal is entirely derived from crustal sources or natural processes.

$$\textbf{Enrichment factor} = (M/Fe)_{sample} / (M/Fe)_{background} \quad (1)$$

Where, M is the metal level. Shale average is used as the background value. There are six recognized categories: background concentration (< 1), depletion to minimal enrichment (1– 2), moderate enrichment (2– 5), major enrichment (5– 20), very high enrichment (20–40), and extremely high enrichment (> 40).

2.3.2. Contamination factor

Contamination factor (CF) is the ratio created by subtracting the baseline or background value from the total concentration of each element in the sediment **(Tomlinson *et al.*, 1980)**.

$$\textbf{Contamination factor (CF)} = C_{metal} / C_{background} \quad (2)$$

The contamination factor (CF) is categorized as follows: CF < 1 indicates a low contamination factor, CF 1-3 indicates a moderate contamination factor, CF 3-6 indicates a significant contamination factor, and CF > 6 stands for an extremely high contamination factor.

2.3.3. Index of pollution load

The pollution load index (PLI) of a particular site takes into consideration the CF beside the number of concerned metals causing pollution (n). Therefore, the root of n multiplied by the CF values is the PLI of a particular site.

$$\mathbf{PLI = [CF_1\ X\ CF_2\ X\ CF_3\ X \ldots\ CF_n]^{1/n}} \quad \mathbf{(3)}$$

Where, CF is the contamination factor, and n is the number of metals (seven in the current study). PLI values range from zero to one, with one denoting the limit of contamination greater than one denoting the gradual degradation of the location's quality **(Tomlinson *et al*., 1980; Seshan *et al*., 2010)**.

2.3.4. Degree of contamination

Total amount of pollution variables at a particular place is the degree of contamination:

$$\mathbf{DC = \Sigma\ CF / n} \quad \mathbf{(4)}$$

Where, n is the number of elements present (seven in the current study), and CF is the only contamination factor. If the DC value is less than n, the degree of contamination is modest; if it is between n and 2n and the DC value is between 2n and 4n, then the degree of contamination **(Hökanson, 1980)** is significant; and if it is greater than 4n, the degree of contamination is extremely high.

2.3.5. Geo-acumulation index

Muller (1969) first established an index of geo-accumulation (I_{geo}) to identify and quantify the element pollution of hydro-soil samples by comparing the present levels with the manufacturing values using the following equation:

$$\mathbf{I_{geo} = \log2\left(\frac{Cn}{1.5\ X\ Bn}\right)} \quad \mathbf{(5)}$$

Where, 1.5 is the background matrix correction for anthropogenic influences; Bn is the geochemical background value for element n in typical shale, and Cn is the observed concentration of heavy metals in sediments. **Buccolieri *et al.* (2006)** divided the geo-accumulation index (Igeo) into seven divisions.

Igeo ≤ 0, class 0, unpolluted; 0 < I*geo* ≤ 1, class 1, from unpolluted to moderately polluted; 1 < I*geo* ≤ 2, class 2, moderately polluted; 2 < I*geo* ≤ 3, class 3, from moderately to strongly polluted; 3 < Igeo ≤ 4, class 4, strongly polluted; 4 < I*geo* ≤ 5, class 5, from strongly to extremely polluted; and Igeo > 5, class 6, extremely polluted.

2.6 Statistical analysis

Pearson's moment correlation (r) and principal component analysis (PCA) were utilized using the statistiXL software (www.statistixl.com/) **(Ma *et al*., 2015)** to ascertain the sources of the HMs. PCA was utilized to define the data in a simple understandable form and to classify the different processes affecting the composition of the sediments. Data normalization and standardization were applied to let the variables have the same weight during analyses. Before PCA analysis, the Kaiser–Meyer–Olkin test and Bartlett's test were executed to assess the adequacy of the metals data for factor analysis and the structure of variability between the metals and suitability for PCA **(Sharma, 1996)**. Principal components with eigenvalues > 1 were retained for interpretation. A level of probability of 0.05 or less was considered significant.

Factor loading was used to compute the propinquity degree between each variable and factor **(Hair *et al*., 1998)**. Variables with the largest absolute values indicated a stronger correlation or relationship among specific factors and variables **(Armstrong *et al*., 2013)**.

RESULTS AND DISCUSSION

Heavy metals typically find their way into the water through geological matrix erosion or anthropogenic activity brought on by industrial effluents, home sewage, and mining wastes. While some metals, such as Zn and Cu, are essential and naturally occurring components of water and sediment, they can become toxic at high levels. Lead and cadmium, on the other hand, are toxic to living organisms, even at very low concentrations.

3.1. Heavy metals in Manzala Wetland water

The levels and distribution of heavy metals in various ecosystems of Manzala Wetland are demonstrated by analyzing the water samples taken from different locations. The measured elements' average concentrations in water were in the order of Fe > Zn > Pb > Co > Cu > Cd > Cr.

Iron concentrations vary from 4.78µg/ l near El-Gamalia city to 183.3µg/ l at Faraskur drain in Manzala Wetland. These concentrations are lower than those reported by **Saeed and Shaker (2008)** and **El-Alfy (2011)**, which were 1420µg/ l and 696µg/ l, respectively. At Faraskur drain, the concentration of copper ranged from 0.51 to 4.87µg/ l. Iron levels in oxygen-consuming waters were notably higher compared to the oxidized northern waters of Manzala Wetland or the nearby El-Boughaz area, as noted by **Saad *et al.* (1981)** and **Ali and Abdel-Satar (2005)** for copper concentrations in the Manzala's water.

One of the most prevalent hazardous heavy metals is zinc, however, most zinc compounds have very low oral toxicity for humans. Due to industrial electroplating and the creation of synthetic fibers, there may be high zinc concentrations in the marine environment. It varied from 1.12 to 11.91µg/ l. It is noteworthy that the highest zinc concentrations were found in industrial sites and drains as a result of industrial waste in these areas but, the middle of the wetland, far from any drains, has the lowest concentration of zinc. However, these values are less than those stated by **Bahnasawy *et al.* (2009)**.

Lead concentrations in water have a range of 1.59 to 8.23µg/ l. The largest levels of lead were found on the northeastern side, close to the industrial compound, whereas the lowest concentration was found far from drainage regions. These sites receive massive amounts of wastewater residues in addition to spills of lead-containing fuel from fishing vessels and lead-rich dirt. The current lead in water result is acceptable according to the **Environmental Protection Agency (USEPA) (1986)**. Lead has been identified by the United States Environmental Protection Agency as possibly dangerous and poisonous to most of the life forms **(EPA, 2002)**.

Cobalt concentrations range from 0.68 to 7.15µg/ l. The central and northern parts of the wetland under investigstion have the lowest cobalt concentrations. Due to agricultural waste from the Bahr El-Baqar drain, the lower regions of the country have the highest concentration of cobalt. This outcome matches those of a previous study **(Nagpal, 2004)**.

Paint and chemical manufacturing facilities, as well as oil drilling and recovery rigs, are the sources of chromium entering the aquatic environment. Chromium may be discharged in large amounts from petrochemical factories, cement, fertilizer, and chemical industry. The range was between 0.09- 22.10µg/ l. In Ashtoum El-Gamil preserved region, near tourist towns, the Petrojet Company has the highest concentration of chromium (Cr). In addition, operations in the coastal area released untreated residential waste into the ocean **(El-Serehy *et al.*, 2012)**. Near Hadous drain, Cr is found in the lowest concentration. The highest quantity of a substance in Manzala Wetland is below the EPA limits but exceeds the threshold level set by Environment Canada, which is 1.5µg/ l **(Environment Canada, 1997)**.

One of the metals on the "blacklist" and one of the most hazardous to both humans and marine life is cadmium. The range of dissolved cadmium in Manzala Wetland's water is 0.22 to 9.15µg/ l. The highest concentration was found close to El-Qaboty regions south of Port Said City because of the overpopulation and agricultural waste, especially the high use of phosphatic fertilizers, as reported in the studies of **Bahnasawy *et al.* (2011)**, **El-Serehy *et al*. (2012)** and **Hamed *et al*. (2013)**. The lowest concentration was found in the Manzala Wetland water away from drains. EPA restrictions are exceeded by the predicted Cd value in this study. It is one of the most poisonous metals and causes widespread human cancers. If its quantity in irrigation water and drinking water surpasses 0.01mg/ L, it is regarded as hazardous.

3.2. Heavy metals in Manzala Wetland sediments

In aquatic systems, hydro-soil contamination is one of the most serious environmental issues, which serves as both a source and sink for toxins in aquatic systems. Analyses of hydro-soil are crucial for determining how polluted the environment is. Fig. (1) shows their regional distribution, and the heavy metals concentrations in the hydro-soils of Manzala Wetland. Except for Fe, which is different from those in the wetland's water, the concentrations of heavy metals in Manzala Wetland's hydro-soils follows the order of: Fe > Cr > Zn > Pb > Cu > Co > Cd.

The range of iron concentration in the sediments of Manzala Wetland was 250 to 666.37µg/ g, while copper concentrations range from 1.25 to 52.68µg/ g. Bahr El-Baqar outflow had the greatest iron value. While, the Bahr Hadous drain had the highest concentration of copper. Domestic, industrial, and agricultural wastes are all disposed in these sewers. These findings concur with those of **Saeed and Shaker (2008)** and **El-Alfy (2011)**. Those drains were discovered to be abundant in total carbon, and some researchers discovered a link between the amount of organic matter and the concentration of heavy metals in sediment. While, the northern regions of the wetland, the El-Boughaz area nearby, and places far from drains showed the lowest iron levels. Whereas, the lowest copper value was found in the El-Temsah area, which is remote from drains. Copper values are higher than those found by **Hamed *et al.* (2013)**. The concentrations of iron and copper in sediments are higher in the current study than the permitted levels outlined by **EPA (2002)**, recording values of 15 and 25mg/ g, respectively.

Lead concentrations in the hydro-soils of Manzala Wetland ranged from 3.44 to 65.53µg/ g. The highest concentration of lead was found close to the drains because they receive a lot of sewage, industrial waste, and agricultural drainage water via the Bahr El-Baqar drain. This may be ascribed to the decay of the plankton and the precipitation of organic matter that contains Pb and Cd into the sediment **(Bahnasawy *et al.*, 2011; Mostafa & Elhaddad, 2022)**. At El-Temsah (in the northern wetland regions, far from the drainage water), the lowest lead concentration was observed. The maximum level of lead is higher than the standard provided by **EPA (2002)**; however, it is within the limits provided by **EU (2002)**. Zinc concentrations ranged from 2.43 to 157.70µg/ g; the greatest concentration may have been caused by industrial waste spilling into the wetland either directly or indirectly. The area surrounding the industrial compound to the north of Manzala Wetland yielded the highest zinc concentration in hydro-soils. This outcome surpasses that of **El-Alfy (2011)** and **Hamed *et al.* (2013)**. The western portion of the wetland, far from industrial trash, was projected to have the lowest Zn value. High levels of zinc are found in sediments, especially in areas near the sea where seawater is clearly present. It is evident that cadmium (Cd) and lead (Pb) accumulate in lower concentrations in seawater compared to zinc (Zn), which accumulates more prominently **(Saeed & Mohammed, 2012)**. EPA limit is exceeded by the zinc maximum levels.

Cobalt was present in Manzala Wetland's hydro-soils in concentrations of 2.79- 20.24µg/ g. Its highest levels are found close to Damietta City, which may be related to the presence of agricultural activity and irrigation. High levels of Co were seen as well close to Bahr El-Baqar drain. The northwest corner wetland, far from any drains, was where the lowest values were found. These values were less than the range reported by **El-Bady (2014)** at Bahr El-Baqar drain, with 54.29 to 80.30µg/ g. However, cobalt levels of Manzala Wetland's sediments exceeded the EU limit **(EU, 2002)**.

Chromium levels ranged between 2.64- 101.50µg/ g. The chromium content was found to be low far from the drains. While, Port Said industrial areas showed the highest concentration, particularly around the Bahr El-Baqar and Bahr Hadous drains, as demonstrated by **Nagpal (2004)**. Additionally, the Ashtoum El-Gamil preserved region, nearby the tourist towns, and Petrojet Projects Company (Zohr natural gas field) were found to have high Cr concentrations. Chromium is within the EU's limit **(EU, 2002)**, but its maximum value exceeds the EPA limit **(EPA , 2002)**.

The hydro-soils had varying amounts of cadmium ranging from 0.56 to 2.82µg/ g. At Faraskur drain, the concentration was the lowest. However, the areas with the highest concentrations were those close to the industrial activities. The earlier findings coincide with those of **Bahnasawy *et al.* (2011)** and **Hamed *et al.* (2013)**. They related the high quantities in this location to the paint factory's untreated waste dumping into the wetland. Cadmium measured levels are higher than the standards for sediment quality and concur with the results of **Saeed and Shaker (2008)**. Cadmium levels in sediment are under the **EPA (2002)** recommended value of 6µg/ g. Uncontaminated soils cannot contain more cadmium than 0.7ppm.

3.3 Indicators of heavy metals in the sediments of Manzala Wetland

3.3.1. Enrichment factor

Fig. (2) shows the heavy metal enrichment factors (EF) in the sediments of Manzala Wetland. The EF values are as follows: Cd at 5.24, Pb at 112.79, Zn at 3.95, Co at 253.32, Cr at 4.59, Cu at 115.53, and for unknown elements, values were 32.51 for Zn, 22 for Co, 160 for Cr, and 1435.26 for Cu.

3.3.2. Contamination factor

The values of the contamination factor (CF) for Fe in Fig. (3) indicate a low level of contamination. All sites had low copper, whereas Bahr Hadous and Bahr El-Baqar drains had moderate level copper (CF more than 1). For Cr, CF is less than 1 CF, and it is greater than 1 in the part near the sea wetland. Lead's CF ranged from 0.17 to 3.28, with significant CF. Cobalt has CF 1 in all locations (low CF) and only >1 near Bahr El-Baqar drain (middle CF). Cadmium's CF displayed middle, significant, and high CF value.

3.3.3. Pollution load index and degree of contamination

Fig. (4) shows the degree of pollution (PLI) and degree of contamination (DC), with the PLI in Manzala Wetland study region ranging from 0.11 to 0.57, respectively. This demonstrated that there isn't much metal pollution in Manzala Wetland. According to the results of the contamination degree, the level of contamination was between low and moderate. Fig. (5) shows the spatial distribution of dc in the Wetland

3.3.4. Index of geo-accumulation

Fig. (6) presents the index of geo-accumulation (I_{geo}) results. According to Muller's classification **(Müller, 1981)**, the negative Fe, Cr, Co, Cu, and Zn levels in the wetland is not contaminated with those metals. According to the results of the geo-accumulation index, the lead Igeo values at the sewage treatment plant, east of Port Said City, close to the sea end of the wetland's surrounding drains, ranges from not polluted to moderately polluted. Cadmium Igeo findings also indicate moderate pollution levels across the board.

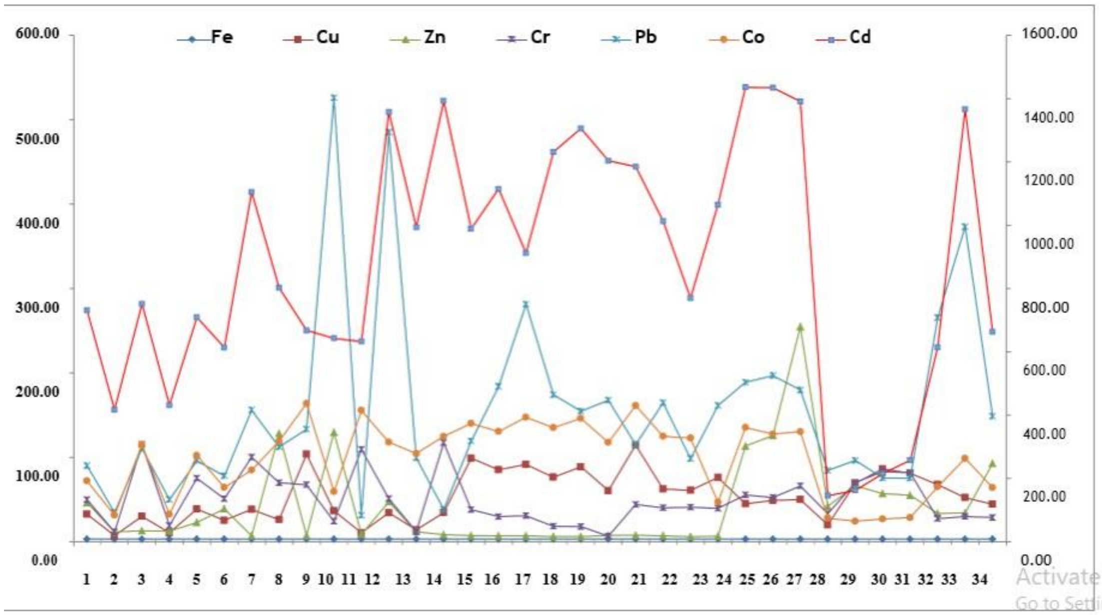


Fig. 2. The enrichment factors of heavy metals in the hydro-soil samples of Manzala Wetland

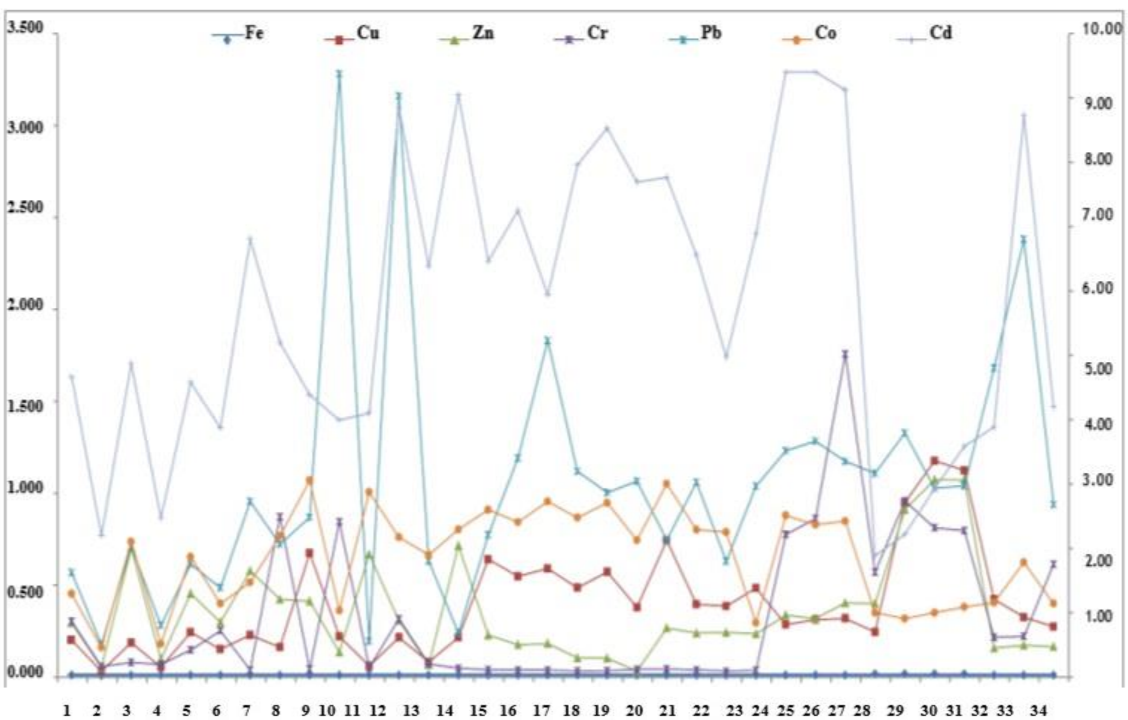


Fig. 3. The contamination factors of heavy metals in the hydro-soil samples of Manzala Wetland

3.3.5. The relationship between heavy metals in both hydro-soils and water

From Table (1), Fe in hydro-soil samples correlates significantly and positively with Cu and Cr in sediments, where r = 0.7, $P < 0.01$; Fe, Zn, and Co in water were measured, recording (r = 0.7, $P < 0.01$), (r = 0.5, $P < 0.05$), and (r = 0.9, $P < 0.01$); but negatively correlates with Co and Cd in hydro-soil (r = - 0.4, $P < 0.05$) for each. When compared to Cr in hydro-soil and Co in water, copper in hydro-soil displayed a significant positive correlation (r = 0.5, $P < 0.05$) for each. In sediments, zinc correlates with Cr, Fe, Co, and Zn in the water (r = 0.4, $P < 0.05$), as well as with Cu in the water (r = 0.6, $P < 0.05$). Iron (Fe) in water shows a significant positive correlation with chromium (Cr) in hydro-soil (r = 0.37, $P < 0.01$). Copper (Cu) in water correlates positively with Cr in hydro-soil (r = 0.49, $P < 0.05$). Zinc (Zn) in water exhibits a positive correlation with Cr in hydro-soil (r = 0.54, $P < 0.05$). Cobalt (Co) in water demonstrates a strong positive correlation with Cr in hydro-soil (r = 0.7, $P < 0.01$). Cobalt in hydro-soil shows significant negative correlations with Fe, Cu, Zn, and Co in water. Cadmium (Cd) in water is positively correlated with Fe (r = 0.44, $P < 0.05$), Cu (r = 0.53, $P < 0.05$), Zn (r = 0.54, $P < 0.05$), and Co (r = 0.6, $P < 0.05$) in hydro-soil. Cadmium in hydro-soil exhibits significant negative correlations with Fe, Cu, Zn, and Co in water. Copper (Cu), zinc (Zn), and cobalt (Co) in water show significant positive correlations with iron (Fe) in water, with (r = 0.8, $P < 0.01$), (r = 0.6, $P < 0.05$), and (r = 0.7, $P < 0.01$), respectively. Zinc (Zn), lead (Pb), and cobalt (Co) are positively correlated with each other in water, with (r = 0.7, $P < 0.01$), (r = 0.4, $P < 0.05$), and (r = 0.8, $P < 0.05$), respectively. Chromium (Cr) in water shows positive correlations with cadmium (Cd) (r = 0.6, $P < 0.05$) and zinc (Zn) (r = 0.36, $P < 0.05$) in water. Other relationships between the components either lacked significance or did not exist. **Dan *et al.* (2014)** identified similar sources for the heavy metals with positive correlations.

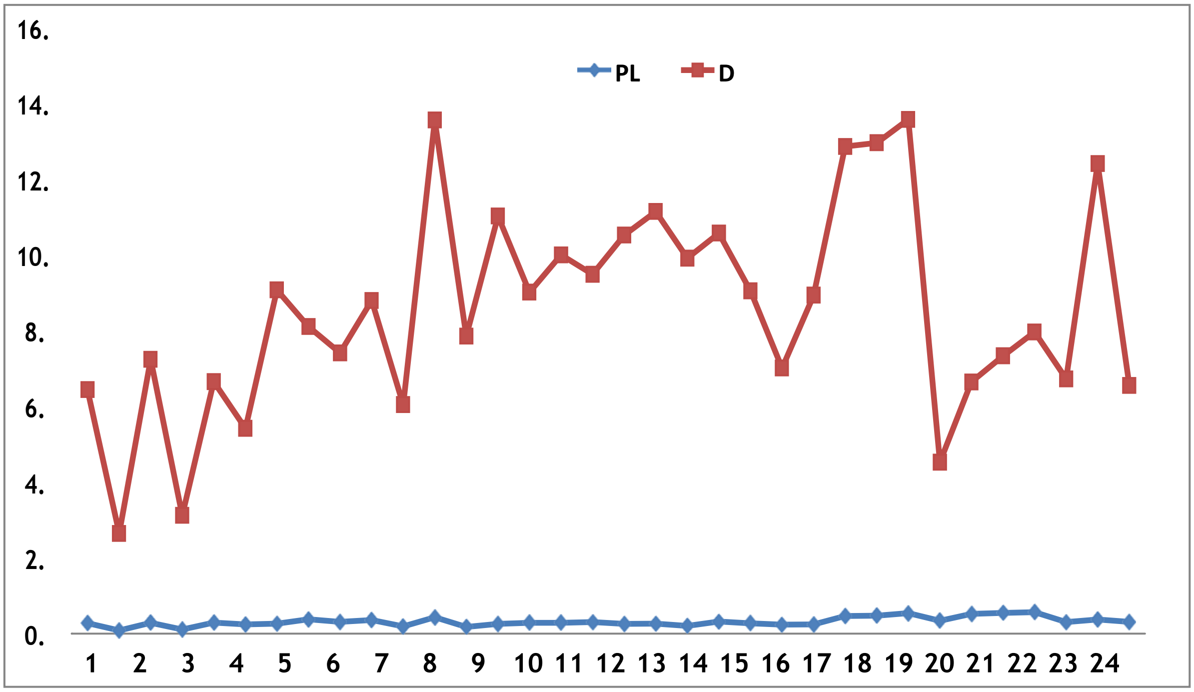


Fig. 4. The pollution load index and degree of contamination of heavy metals in the hydro-soil samples of Manzala Wetland

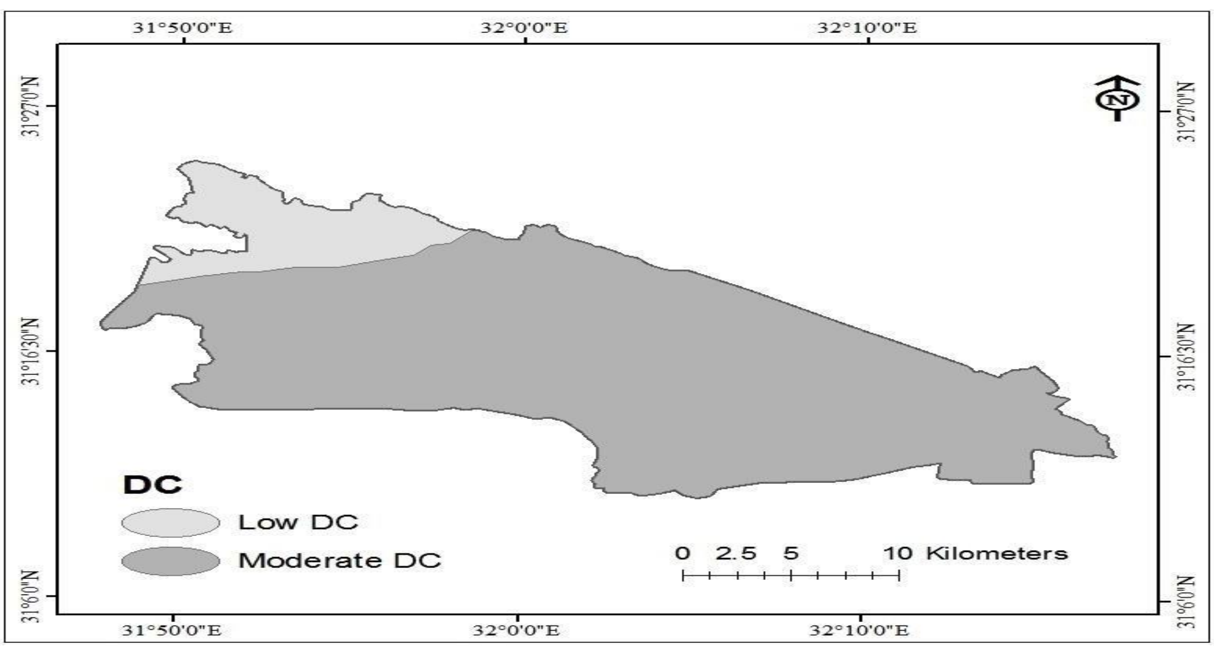


Fig. 5. The spatial distribution of the degree of contamination (DC) of heavy metals in the hydro-soil samples of Manzala Wetland

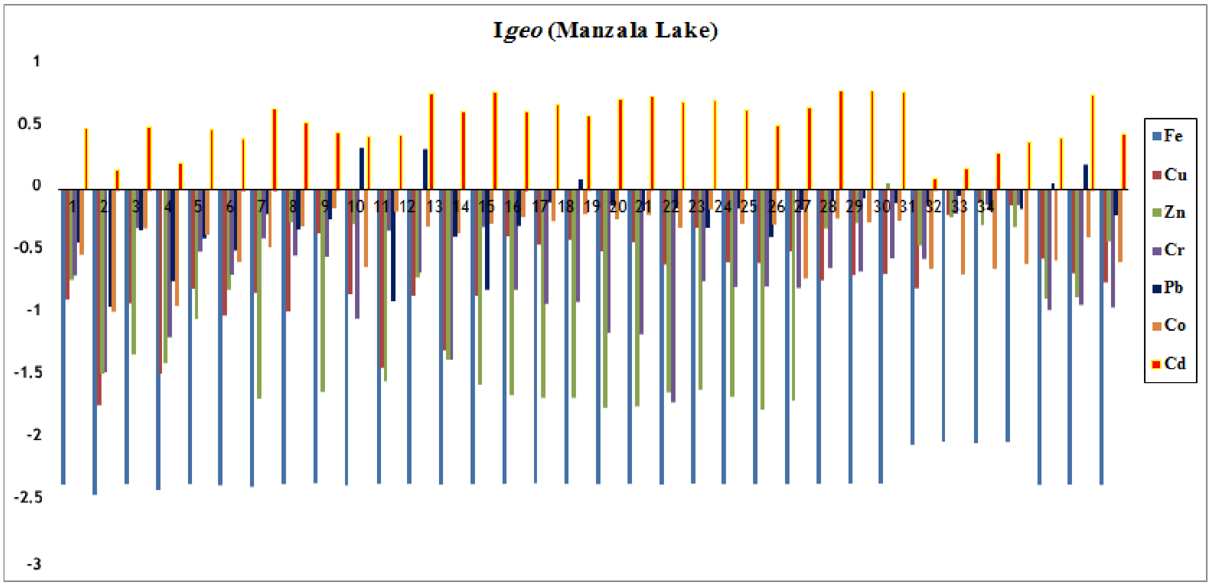


Fig. 6. The Index of geoaccumulation (I_{geo}) of heavy metals concentrations in the hydro-soil samples of Manzala Wetland

Table 1. The Pearson-moment correlation (r) between the heavy metals' concentrations in Manzala Wetland's hydro soils and water

	Variable	Hydro-soil (µg/g)							Wetland water (µg/l)						
		Fe	Cu	Zn	Cr	Pb	Co	Cd	Fe	Cu	Zn	Cr	Pb	Co	Cd
Hydro soil (µg/g)	Fe	1													
	Cu	0.669**	1												
	Zn	0.426*	0.180	1											
	Cr	0.714**	0.495**	0.362*	1										
	Pb	0.046	0.119	0.268	−0.154	1									
	Co	−0.352*	0.057	−0.185	−0.109	−0.014	1								
	Cd	−0.445**	−0.080	−0.022	−0.269	0.239	0.641**	1							
Wetland Water (µg/l)	Fe	0.755**	0.202	0.367*	0.372*	0.116	−0.449*	−0.549**	1						
	Cu	0.721**	0.193	0.614**	0.498**	−0.073	−0.539**	−0.479**	0.800**	1					
	Zn	0.510.9**	−0.079	0.395*	0.546**	−0.181	−0.541**	−0.589**	0.606**	0.709**	1				
	Cr	−0.084	−0.240	−0.108	−0.156	−0.089	0.035	0.081	−0.063	−0.085	0.036	1			
	Pb	0.108	−0.211	0.272	0.309	−0.151	−0.125	−0.152	0.285	0.432*	0.336	−0.048	1		
	Co	0.934**	0.480**	0.481**	0.703**	−0.010	−0.536**	−0.510**	0.723**	0.805**	0.660**	−0.044	0.216	1	
	Cd	−0.149	−0.222	−0.214	0.113	−0.018	0.285	0.254	−0.100	−0.206	−0.170	0.368*	0.077	−0.120	1

A significance level of 0.01, a correlation is present.At the 0.05 level, correlation is significant.

CONCLUSION

The geographical distribution of heavy metals in the water and hydro-soil samples of the Egypt's Manzala Wetland might be evaluated and studied with the aid of geospatial technologies, such as simple Kriging. The obtained data unequivocally show that almost all the wetland under study is seriously polluted by Pb, Fe, Cr, and Cd because of the ongoing flow of various contaminants into it. The drains which include Bahr El-Baqar, Bahr Hadous, El-Matria, Ramsis Faraskur, Lissa El- Gamalia, and El-Serw are a significant contributor to the serious pollution in Manzala Wetland. This is particularly true in the wetland's southeast area, which receives large amounts of effluent from the Bahr El-Baqar, Bahr Hadous, and Ramsis drains. Cadmium is more prevalent than other metals, according to the order of enrichment factor of heavy metals in the sediment of Manzala Wetland, while Cu displays the lowest appearance. Only the moderately contaminated Bahr El-Baqar drain in the area and the contamination factor of cadmium exhibits moderate, significant, and extremely high contamination factor there. According to the pollution load index and degree of contamination, Manzala Wetland is not significantly polluted. Results of the geo-accumulation index (I_{geo}) for lead and cadmium indicate that all areas are moderately contaminated. To safeguard the wetland under study from pollution and lower the risk to the ecosystem, significant efforts and collaboration between various authorities are required. Treatment of sewage, industrial, and agricultural discharges can help achieve this target. It is also crucial to regularly assess the wetland's pollution levels.

Acknowledgement

The authors wish to extend deep thanks and gratitude to Prof. Dr. Kamal H. Shaltout, professor of plant ecology, faculty of Science, Tanta University for his help in preparing and revising this study.

REFERENCES

Abd El-Wahaab, R. A. and Badawy, M. I. (2004). Water Quality Assessment of the River Nile System: An Overview. Biomedical and environmental sciences, 17: 87-100.

Ali, M. and Abdel-Satar, A. (2005). Studies of Some Heavy metals in Water, Sediment, Fish and Fish Diets in Some Fish Farms in EL-Fayoum Province. Egyptian Journal of Aquatic Research, 31: 261-273.

Aliaume, C .; Do Chi, T.; Viaroli, P. and Zaldívar, J. M. (2007). Coastal lagoons of Southern Europe: recent changes and future scenarios. TWM, Transit. Waters Monogr., 1: 1-12.

Amini Ranjbar, G. H. (1998). Heavy metal concentration in surficial sediments from Anzali Wetland, Iran. Water Air Soil Pollut., 104: 305–312.

Anonymous (1979). Climatological Normals for the Arab Republic of Egypt up to

1975. Ministr of Civil Aviation, Cairo.

APHA (1999). Standard Methods for the Examination of Water and Wastewater, Part 3, Determination of Metals. 17th, American Public Health Association, Washington DC, 164.

Arain, M.B. ; Kazi, T.G. ; Jamali, M.K. ; Afridi, H.I. ; Baig, J.A. ; Jalbani, N. and Shah, A. (2008). Evaluation of Physico- Chemical Parameters of Manchar Wetland Water and Their Comparison with Other Global Published Values. Pakistan Journal of Analytical & Environmental Chemistry, 9, 101-109.

Armstrong, C. S. ; Banerjee, S. and Corona, C. (2013). Factor-loading uncertainty and expected returns. Review of Financial Studies, 26(1): 158–207. https://doi.org/10.1093/Rfs/Hhs102

Bahnasawy, M. ; Khidr, A. and Dheina, N. (2011). Assessment of Heavy metals Concentrations in Water, Plankton, and Fish of Manzala Wetland, Egypt. Turkish Journal of Zoology, 35: 271-280.

Bahnasawy, M.H. ; Khidr, A.A. and Dheina, N.A. (2009). Assessment of Heavy metals Concentrations in Water, Plankton and Fish of Manzala Wetland, Egypt. Egyptian Journal of Aquatic Biology and Fisheries, 13: 117-133.

Buccolieri, A. ; Buccolieri, G. and Cardellicchio, N. (2006). Heavy metals in Marine Sediments of Taranto Gulf (Ionian Sea, Southern Italy). Marine Chemistry, 99:227-235. http://dx.doi.org/10.1016/j.marchem.2005.09.009.

Dan, S.F. ; Umoh, U.U. and Osabor, V.N. (2014). Seasonal Variation of Enrichment and Contamination of Heavy Met- als in the Surface Water of Qua Iboe River Estuary and Adjoining Creeks South-South Nigeria. Journal of Oceano- graphy and Marine Science, 5: 45-54. http://dx.doi.org/10.5897/JOMS2013.0103

El-Alfy , M.A.; El-Amier ,Y.A. and El-Eraky, T.E. (2020). Land use/ cover and eco-toxicity indices for identifying metal contamination in sediments of drains, Manzala Wetland, Egypt. Heliyon 6:(1) 1-9.

El-Alfy, M.A. (2011). An Integrated Approach for Monitoring the Impact of Industrial Activities on the Northeastern Part of Manzala Lagoon, Egypt. Master's Thesis, Environmental Sciences Department, Damietta Faculty of Science, Mansoura University, Mansoura.

El-Bady, M.S.M. (2014). Spatial Distribution of Some Important Heavy metals in the Soils South of Manzala Wetland in Bahr El-Baqar Region, Egypt. Nova Journal of Engineering and Applied Sciences, 2: 1-15.

Elbehiry, F.; Mahmoud, M. A. and Negm, A. M. (2018). Land use in Egypt's coastal Wetlands: opportunities and challenges. Egyptian coastal Wetlands and wetlands: Part I: 21-36. https:// doi. org/ 10. 1007/ 698_ 2018_ 250.

Elewa, A. A.; Saad, E. A.; Shehata, M. B. and Ghallab, M. H.,(2007). Studies on the effect of drain effluents on the water quality of Manzala Wetland, Egypt. J.

Aqu. Biol. & Fish., 11(2): 65-78.

El-Serehy, H.A. ; Aboulela, H. ; Al-Misned, F. ; Kaiser, M. ; Al-Rasheid, K. and Ezz El-Din, H. (2012). Heavy metals Contamination of a Mediterranean Coastal Ecosystem, Eastern Nile Delta, Egypt. Turkish Journal of Fisheries and Aquatic Sciences, 12: 751-760.

Environment Canada (1997). Canadian Water Quality Guidelines for Chromium. Supporting Document, Environment Canada, Science Policy and Environmental Quality Branch, Ottawa.

Environmental Protection Agency (2002). National Recommended Water Quality Criteria. EPA, USA, 822-R-02-047.

EPA (1986). Quality Criteria for Water. EPA 440/5-86-001. Office of Water Regulations and Standards, Washington DC.

European Union (2002). Heavy metals in Wastes, European Commission on Environment.
http://ec.europa.eu/environment/waste/studies/pdf/heavy_metalsrepor .pdf

Hair, J. ; Anderson, R. ; Tatham, R., and Black, W. (1998). *Multivariate data analysis* (5th ed.). Prentice Hall.

Hamed, Y.A. ; Abdelmoneim, T.S. ; ElKiki, M.H. ; Hassan, M.A. and Berndtsson, R. (2013). Assessment of Heavy Met- also Pollution and Microbial Contamination in Water, Sediments and Fish of Manzala Wetland, Egypt. Life Science Journal, 10: 86-99.

Hökanson, L. 1980. An ecological risk index for aquatic pollution control: a sedimentological approach. *Water Research*, 14: 975–1001.

Khedr, A. A. (1996). Aquatic macrophyte distribution in Manzala Wetland, Egypt. Inter. J. of Salt Wetland Res., 5: 221-239.

Ma, Y. Q. ; Qin, Y. W. ; Zheng, B. H. ; Zhang, L. and Zhao, Y. M. (2015). Seasonal variation of enrichment, accumulation, and sources of heavy metals in suspended particulate matter and surface sediments in the Daliao river and Daliao river estuary, Northeast China. *Environmental Earth Sciences*, *73*:5107–5117.

Mostafa, R. and Elhaddad, E. (2022). Heavy metal pollution in Manzala Wetland sediments, Egypt: sources, variability, and assessment. Environmental Monitoring and Assessment (2022) 194:436.

Meig, P. (1973). World Distribution of Coastal Deserts. Coastal Deserts. Their Natural and Human Environment's, ed. David, H.K., Amiran and Andereu W. Wiloon. Univ. of Arizona Press: 3 -13.

Muller, G. (1969). Index of Geo-Accumulation in Sediments of the Rhine River. GeoJournal, 2: 108-118.

Müller, G. (1981). Die Schwermetallbelastung der sedimente des Neckars und seiner Nebenflusse: Eine Bestandsauf- nahme. Chemical Zeitung, 105: 157-164.

Nagpal, N.K. (2004). Technical Report, Water Quality Guidelines for Cobalt. Water Quality—Standards—British Co- lumbia. Ministry of Water, Land and Air

Protection, 6.

Oregioni, B. and Aston, S.R. (1984). The Determination of Selected Trace Metals in Marine Sediments by Flameless/ Flam-Atomic Absorption Spectrophotometry. IAEA Monaco Laboratory Internal Report.

Saad, M.A.H. ; Ezzat, A.A. ; El-Rayis, O.A. and Hafez, H. (1981). Occurrence and distribution of chemical pollutants in Wetland mariut, Egypt. II. Heavy metals. Water, Air, and Soil Pollution, 16:401-407. http:// dx. doi. org/ 10. 1007/ BF01048131

Saeed, S.M. and Mohammed, M.A. (2012). Influence of Physico-Chemical Characteristics of Water on Metals Accu- mulation in Water and Tilapia Zillii Inhabiting Different Habitats in Egypt. Journal of the Arabian Aquaculture Society, 7: 29-50.

Saeed, S.M. and Shaker, I.M. (2008). Assessment of Heavy metals Pollution in Water and Sediments and Their Effect on Oreochromis Niloticus in the Northern Delta Wetlands, Egypt. 8th International Symposium on Tilapia in Aquaculture, 475-490.

Seshan, B.R.R. ; Natesan, U. and Deepthi, K. (2010). Geochemical and Statistical Approach for Evaluation of Heavy metals Pollution in Core Sediments in Southeast Coast of India. International Journal of Environmental Science and Technology, 7: 291-306. http://dx.doi.org/10.1007/BF03326139

Shaltout, K. H.; Sharaf El-Din, A. and Ahmed, D. A. (2010). Plant Life in the Nile Delta. Tanta University Press, Tanta, Egypt, p. 243

Sharma, S. (1996). *Applied Multivariate Techniques* (p. 512). John Wiley and Sons Inc

Tomilson, D.C. ; Wilson, D.J. ; Harris, C.R. and Jeffrey, D.W. (1980). Problem in Assessment of Heavy metals in Estu- aries and the Formation of Pollution Index. HelgoländerMeeresuntersuchungen,33:566-575. http://dx. doi. org/ 10. 1007/ BF02414780

USGS (2020) EarthExplorer. https:// earth explo rer. usgs. gov/. Accessed 27 Dec 2020.

Zahran, M. A. and Willis, A. J. (2009). The Vegetation of Egypt. 2nd ed. Springer. Netherlands.