Progressive improvement of the water quality criteria of Lake Manzala, Egypt

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ABSTRACT

Lake Manzala is considered the largest natural lake in the Nile delta region, north of Egypt. It is very important from the environmental, economical, and sociological aspects. An ambitious development enterprise was carried out during the 2017-2022 period to recover its original size, quality, and role in the environment. The current work was conducted to report the physicochemical, petroleum hydrocarbon, and elemental level status of the lake ecosystem in 2019 during the development activities. The pollution status was evaluated using the pollution risk indices. Pollutants were swept out of the lake due to the development activities, forming promising results.

INTRODUCTION

Lake Manzala is considered the largest lake (about 1000km^2) of the northern coastal lagoons in Egypt. It is an important and valuable resource area for fish and wildlife. Low sandy bar (1-2m) separates Lake Manzala from the Mediterranean Sea and is bordered by swamps along three other borders. It is located in the east coastal region of the Delta of the River Nile shared by five governorates; namely, Dakahlia, Sharkia, Port Said, Ismailia and Damietta. The lake is about 50km long with a maximum width of 30km. The lake is shallow (<2m); salinity varies from brackish to brackish (**Elmorsi *et al.*, 2017**).

Lake Manzala receives two types of water from two main sources. (1) Al-Sufra (North), Al-Jamil (old and new), Bughaz Al-Raswa, and Al-Qubouti (East) canals are water exchange canals that release seawater flowing into the fresh lake water and vice versa. (2) Fresh water -rich sources from many drains and pumping stations. The western and southern sectors are supplied with waste water from seven main sources. This sub-basin was heavily contaminated with heavy metals and high nutrients discharged from the Farskoor, Al-Anani, Al-Serw, Jamaliah, Matariya, Hados and Ramses drains (**Hamed *et al.*, 2013).** The Bahr El Baqar drain is one of the largest and most polluted drains, providing the largest flow rates and pollution loads that contribute significantly to the deterioration of the lake water quality (**Rasmussen *et al.*, 2009**).

Sewage effluents were also responsible for the high concentrations of heavy metals **(Siegel *et al*., 1994; Badawi & Wahab, 1997)**, organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs) **(Badawi & Wahab, 1997; Yamashita *et al*., 2000; Abbassy *et al.* , 2003)** identified in water, sediment and biota. Overall, this sub-basin receives a discharge of municipal sewage, industrial effluent and agricultural runoff of 12 MCM/day. Untreated wastewater constituted about 98% of Lake Manzala's annual flow, causing an increase in the area of floating vegetation and a decrease in the surface area of the watershed **(Hossen *et al.*, 2018)**.

In aggregate, all contamination indicators (enrichment factor, contamination factor, GI) suggested high contamination by cadmium and lead and moderate contamination with zinc. The lake could be classified into three main categories: 1) the highly polluted southeast, 2) the moderately polluted northeast corner, where the newly widened and deep-sea outlet occurs, 3) the unpolluted northwest part located far from the drains **(Abdelhady *et al.*, 2019)**. Recently in 2021, a large and ambitious wastewater treatment project was inaugurated in Bahr al-Baqar under an ongoing project to develop the lake from 2012 to 2022. In the present work, the researchers continued the previous water quality surveillance associated with the ongoing lake development.

MATERIALS AND METHODS

1. Description of study area

Lake Manzala is located northeastern to the Nile Delta. It is situated between latitudes 31°07`N and 31°30`N and longitudes 31°48`E and 32°17`E. During winter, seawater is motivated into the lake via the El-Gamil outlet and across the ridges, principally by southwest-directed storms. The eastern lake receives saline water from the Suez Canal via the El-Qabouti canal, situated a few kilometers south of Port Said. Until the seventh century, the lake was receiving freshwater from the now-defunct Pelusiac, Tanitic, and Mendesian branches of the Nile; afterwards, freshwater was mostly derived from the Damietta branch **(Nasr *et al.*, 2020)**. Currently, freshwater from the Damietta branch (between Faraskour Dam and Damietta) flows eastward to the lake through El-Ratama, El-Inaniya and other canals (Fig. 1).

2. Sampling

Surface water samples were collected from 5 locations along Lake Manzala using Nansen bottles at a 50cm depth during the study period. Sampling sites were covering different criteria of the lake as possibly heavily (1 and 3), intermediate (2) and low (4 and 5) influenced with wastewater effluents as detailed in Table (1) and Fig. (1). The water samples were filtrated through a Whatman filter paper in order to remove debris and particulates. The filtrated water samples were then kept at -15°C until further analysis. The tilapia fish (*Oreochromis niloticus*) were caught from El Materia- Genka (1), Legan (2) and new El Gamil outlet (5). The plants were water hyacinths (*Eichhornia carssipes*) from El Materia- Genka (1) and Legan (2) and watercress (*Pistia stratiotes*) from Legan (2).
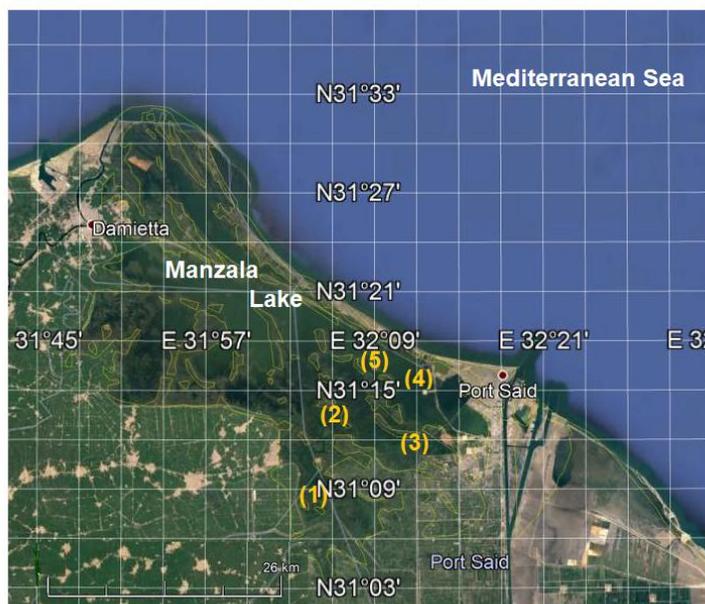
Fig. 1. Sampling sites in Manzala Lake - EGYPT

Table 1. Sampling sites and influencing water effluents

Site	Name	Nearest effluent	Type of effluent
1	Genka-El-Mataria	Ramsis – Hadus	Agricultural waste
2	Legan	Matariya drain	Agricultural waste
3	Bahr El-Baqur	New Bahr Elbaqur	Mixed wastes
4	Old sea outlet	El-Rasoah - El- Qabuty - El- Gamil	Seawater
		Alhuria	Domestic waste
5	New sea outlet	El-Gamil	Seawater

3. Petroleum hydrocarbons analysis

For the determination of total petroleum hydrocarbon (TPHC) in water, one liter of water samples was extracted three times with a 60ml of dichloromethane in a separating funnel. Sample extracts were combined and concentrated by rotary evaporation to 5ml. Finally, samples were concentrated under a gentle stream of pure nitrogen to a final volume of 2ml, followed by the cleanup of samples. Then the samples were analyzed by a digital spectrofluorometer model 450 from Sequoi-turner corporation, USA, with NB 360 for excitation filter and SC 415 for emission filter (**Strickland & Parsons, 1972**).

The procedure used for determining the petroleum hydrocarbons contaminating the sediments was carried out by taking 10-20 g of the freeze – dried sediment sample and extracting it in a Soxhlet-extractor with methylene chloride. The siphon cycle was around 20-30min, repeating at least 10 times. As the extraction was completed, the methylene chloride was evaporated over the rotary evaporator to a volume of less than 20

mL. The extract was then transferred to a 25mL volumetric flask. The Soxhlet extraction flask was rinsed with methylene chloride, and the rinsing solution was used to make the volume reach up to 25mL.

Clean-up was made to remove non-petroleum materials, which may fluoresce under certain conditions. Furthermore, materials that may cause quenching were removed simultaneously. An appropriate size of chromatographic column (Pasteur pipette) fitted with a glass wool was plugged to about 5cm (1.15 g) with aluminum oxide. The column was rinsed three times with 2mL n-hexane. One to 2mL of the extract prepared as described before was placed in aliquots (0.2-0.3mL each). The solvent was evaporated and eluted with 5mL n-hexane. That quantity was discarded since it came of the column. An elution was achieved with a mixture of n- hexane as follows: methylene chloride (7:3 v/v) was performed and collected to 10mL in a graduated vial. The vial was covered, and then the extract was used for analysis.

4. Water analysis

The values of water salinity, total dissolved salts (TDS) and the pH were measured in the field using a portable multimeter. For the measurement of nitrate, nitrite, and phosphate at selected water sites, the concentrations of these variables were measured in the lab via the standard methods, using Beckman Du-6-UV-Visible single beam spectrophotometer **(Strickland & Parsons, 1972)**. Total suspended solids (TSS) were determined according to the standard methods **(Strickland & Parsons, 1972)**.

5. Elemental analysis

Sediment (dried), fish (wet muscle) and plant (dried) samples were digested in a microwave oven from MILESTONE CONNECT model ETHOS EASY, using 0.5g of each sample in 8mL concentrated HNO_3 and 2mL concentrated H_2O_2 for the fish and plant samples. For the sediment, 0.1 g of each sample was inserted in 9mL concentrated HCl and 3mL concentrated HNO_3. A thermo scientific iCAP 7400 ICP-OES Duo, Germany was used to analyze the following elements: Li, K, Mg, Ca, Sr, Ba, B, Al, Ga, In, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Se, Ag, As, Cd, and Pb in water and digested samples. Single element stock standards (Fisher Scientific) were used to prepare multielement standard solutions with the necessary element concentrations. The standard solutions were used for calibration curve generation.

6. Pollution risk indices

Bioaccumulation factor

The bioaccumulation factor (BAF) of each metal in plants was calculated by dividing the total content in the plant (X_p^i, µg g^{-1}) by the total content in water (X_w^i, µg mL^{-1}) using the succeeding equation of **Arnot and Gobas (2006)**:

$$BAF = \frac{X_p^i}{X_w^i}$$

Present daily nutrition value (PNV) was calculated in mg per serving meal using the equation of **Elmorsi et al. (2019)** as follows:

$$PNV \ (mg) = \frac{metal \ concentration \ in \ muscle \ (\mu g \ g^{-1}) * mass \ of \ a \ meal \ (201 \ g)}{1000}$$

7. Enrichment factor

Enrichment factor (EF) was calculated according to the methods of **Duce *et al.* (1975)** and **Herron *et al.* (1977)** as follows:

$$EF = \frac{(X_s^i / X_s^{Fe})}{(X_{EC}^i / X_{EC}^{Fe})}$$

Where, X_s^i is the present concentration of a metal in sediment sample (mg kg^{-1}); X_s^{Fe} is the present concentration of iron as an immobile metal in sample (mg kg^{-1}), and (X_{EC}^i / X_{EC}^{Fe}) is the natural abundance ratio of the metal ion (i) in earth crust (EC) in respect to the immobile reference metal Fe.

RESULTS

1. Physicochemical properties

Table (2) shows the physicochemical properties of the water samples in Lake Manzala . The mean values of the phosphate, nitrate, nitrite, ammonia, N/P, TPHC, pH, salinity, TDS and TSS were 0.222, 0.171, 0.072, 0.944µmol L^{-1}, 5.53, 35.13µg L^{-1}, 7.00, 1.54g L^{-1}, 1463, 66.7mg L, respectively. The highest pH and TSS values (7.78 and 110 mg L^{-1}) were obtained at site (4) and (5) at Bahr Elbaqar effluents and the old seawater inlet, respectively, whereas their lowest values (6.51 and 10 mg L^{-1}) were obtained at sites (5) and (1) at Genka, respectively. The highest phosphate, nitrite, ammonia, and salinity (0.286, 0.073, 1.144µmol L^{-1} and 2.90g L^{-1}, respectively) were obtained at site (5) at the old seawater inlet); whereas, the highest nitrate value was obtained at site (1). The lowest salinity, phosphate and ammonia values (0.64g L^{-1}, 0.150 and 0.625µmol L^{-1}) were obtained at site (1), whereas the lowest values of nitrate and nitrite (0.123 and 0.071 µmol L^{-1}) were recorded at the sites (5) and (3) at the old inlet of seawater and Genka, respectively. N/P values were within 4.69 at the site (5) and 6.58 at the site (1).

Tables (2, 3) present the total petroleum hydrocarbon (TPHC) concentration in water, sediment, plant and fish at the selected sites of Lake Manzala. The highest TPHC value in water (71.80µg L^{-1}) was obtained at the site (1), while the lowest value (14.10µg L^{-1}) was observed at the site (5). The obtained TPHC values in sediments and fish parts at site (1) were higher than those at site (5). However, the studied plants at site (2) showed much higher TPHC value in the water cress than in water hyacinth (almost five times) and even the sediments and fish parts at sites (1) and (5).

2. Elemental analysis

Table (4) displays the ICP-OES results of multiple elements in water, sediment, fish and plants for the selected sites in Lake Manzala . Water sample at site (5) contained more amounts of most metal ions than site (1), whereas those of the sediments were variable. Additionally, the metal contents in the plant of site (1), where $\sum=30200$µg g^{-1} were generally higher than those at the site (2), where $\sum=21664$ µg g^{-1}. Whereas, fish samples at both sites showed variable trends although the summation of them at site1 (5678µg g^{-1}) was slightly higher than that at site2 (5390µg g^{-1}).

Table 2. Physicochemical parameters of water at selected sites

Site	Phosphate (μmol L^{-1})	Nitrate (μmol L^{-1})	Nitrite (μmol L^{-1})	Ammonia (μmol L^{-1})	N/P	TPHC (μg L^{-1})	pH	Salinity (g L^{-1})	TDS (mg L^{-1})	TSS (mg L^{-1})
1	0.150	0.264	0.072	0.651	6.58	71.80	6.76	0.64	674	10
2	-	-	-	-		-	6.87	-	-	-
3	0.231	0.126	0.071	1.036	5.34	19.49	7.10	0.99	1016	80
4	-	-	-	-		-	7.78	-	-	-
5	0.286	0.123	0.073	1.144	4.69	14.10	6.51	2.90	2700	110
Mean	0.222	0.171	0.072	0.944	5.53	35.13	7.00	1.54	1463	66.7

TPHC, total petroleum hydrocarbon; TDS, total dissolved salts; TSS, total suspended solids.

Table 3. Total petroleum hydrocarbon (TPHC) concentration in sediment, plant and fish at selected sites in Manzala Lake

Site	Total petroleum hydrocarbon (μg/g)				
	Sediment	Fish part		Plant	
		Gills	Muscles	Water cress	Water hyacinth
1	386	154	155.8	-	-
2	-	-	-	527	108.5
5	238	86.5	43.5	-	-

Concentration in μg g^{-1} dry wt.

Table 4. ICP-OES results for multiple elements in water, sediment, fish and plants for selected sites in Manzala Lake

	Water			Sediment		Earth crust abundance (Yaroshevsky, 2006)	Plant			Fish		-Permissible level (Nauen, 1983)
Site	1	5	Permissible level (Ezzat et al., 1999)	1	5		1	2	Recorded level (Elmorsi et al., 2019)	1	2	
Metal		mg L^{-1}						μg g^{-1}				
Alkali metals												
Li	0.44	0.62	-	105.41	87.65	32	11.59	14.17	-	6.41	7.04	
K	57.60	76.34	=	4344	5241	25000	33872	14811	-	2195	2643	
Alkaline earth elements												
Mg	184.10	255.05	-	10246	1219	18700	6828	4452	-	353.5	461.46	
Ca	43.66	90.59	-	N/A	N/A	29600	15744	14779	-	3786	3849	
Sr	1.00	3.57	-	267.81	472.16	340	139.51	123.67	-	7.04	9.24	
Ba	N.D.	N.D.	-	127.47	48.37	650	12.22	11.64	-	2.13	1.62	
B	0.37	0.80	-	504.77	492.25	12	7.02	12.58	-	N.D.	N.D.	
Al	0.73	N.D.	-	24295	28602	80500	6565	1548	-	1218.8	832.67	
Ga	3.73	N.D.	-	N.D.	N.D.	19	N.D.	N.D.	-	22.11	N.D.	
In	N.D.	2.58	-	N.D.	N.D.	0.25				N.D.	N.D.	
Essential heavy metals												
V	0.63	N.D.	-	116.97	115.39	90	5.55	N.D.	16.65	6.02	0.88	
Cr	N.D.	0.04	0.05	370.86	309.48	83	43.83	39.42	17.80	23.19	31.58	10
Mn	0.21	0.67	0.5	818.76	629.55	1000	385.63	312.58	1663	4.83	3.59	
Fe	0.35	0.52	1.0	43758	39749	46500	325.62	252.57	1472	145.43	96.78	180
Co	0.06	N.D.	-	29.02	25.57	18	N.D.	0.36	2.20	N.D.	N.D.	0.5
Ni	0.07	N.D.	0.1	20.20	N.D.	58	5.86	5.24	13.70	10.99	10.55	10

Cu	0.57	0.32	1.0	14.57	N.D.	47	18.46	10.52	21.40	12.03	9.84	10-30
Zn	0.13	0.09	1.0	192.58	174.26	83	95.91	98.50	25.90	70.46	62.89	40-1000
Se	0.46	0.50	0.01	N.D.	N.D.	0.05	1.80	3.80	-	1.02	3.57	0.3-2.0
Toxic metals												
Ag	0.15	0.13	0.05	1.33	3.71	0.07	0.16	2.11	-	5.55	5.57	
As	N.D.	0.06	0.05	0.40	1.69	1.7	2.38	N.D.	-	N.D.	1.08	1.0
Cd	0.01	N.D.	0.01	3.77	3.55	0.13	N.D.	N.D.	-	0.08	0.10	0.05-0.2-1.0
Pb	0.73	0.66	0.05	53.20	39.19	16	13.70	11.64	-	9.36	9.58	2.0-5.0
Sum	240	356		80821.52	82855.89		30199.72	21663.68		5678.33	5390.05	

Concentration in $\mu g\ g^{-1}$ dry wt.; N.D., not detected; N/A, not analyzed

According to the average concentration of the studied metal ions in water and sediments samples from sites (1) and (5), the relative metal abundance follows the order of Mg > Ca > K > Sr > Ga > In > Pb > B > Li > Se > Cu > Mn > Fe > Al > V > Ag > Zn > Ni > Co > As > Cr > Cd > Ba and Fe > Al > Mg > K > Mn > B > Sr > Cr > Zn > V > Li > Ba > Pb > Co > Ni > Cu > Cd > Ag > As > Ga = In = Se, respectively. The relative metal abundance order in the fish and plant were Ca > K > Al > Mg > Fe > Zn > Cr > Ga > Cu > Ni > Pb > Sr > Li > Ag > Mn > V > Se > Ba > As > Cd > B = Co = In and K > Ca > Mg > Al > Mn > Fe > Sr > Zn > Cr > Cu > Li > Pb > Ba > B > Ni > Se > V > In > As > Ag > Co > Cd = Ga, respectively.

3. Pollution evaluation

The average BAF value at site (1) was 125.8 mL/g, whereas the highest BAF values (8993, 1836, 930 and 737 mL g^{-1}) were recorded for the metal ions of Al, Mn, Fe and Zn, respectively. On the other hand, the lowest values were recorded for the metal ions of Cd, Co and Ga. The highest EF of the average metal contents in sediments were from B, Ag and Cd. PNV values for sites (1) and (2) were within 0 to 1.93mg per meal in case of the toxic metals and within 0 for Co to 29.2mg per meal for Fe in case of the essential heavy metals. The highest daily PNV exceeding the allowed UL was observed for the elements of Al, Cr and Pb. BASF, BAF, EF, PNV and daily UL details are shown in Table (5).

DISCUSSION

1. Physicochemical properties

The water of the studied regions in Lake Manzala may be categorized as fresh water mostly in the south part that gradually changes to mild brackish water in the north according to the recorded salinity and TDS values. The nutrients salts recorded in the current study were quite lower than those recorded in 2015; 3.47-22.9, 0.64-24.5, 2.61-15.1, and 5.47-249µmol L^{-1} for phosphate, nitrate, nitrite and ammonia, respectively (**Elmorsi *et al.*, 2017**).

In addition, the pH and TSS values were within the acceptable range for estuarine water and lower than the data recorded in 2015 (7.65 to 8.88 and 120-387mg L^{-1}, respectively) (**Ismail & Hettiarachchi, 2017**), which may be mainly due to the large fresh run off of drains and canals. On the contrary to other recorded water parameters, the TPHC in water is slightly higher than that previously reported in Manzala (1.8 and 65.0µg L^{-1}) (**Badawy *et al.*, 1995**), which may be attributed to the contemporary massive mechanical dredging activities carried out then. TPHC values in sediments of 1.533 to 5.253µg g^{-1} were recorded in Lake Manzala in 2007 (**Nemr *et al.*, 2007**). While for tilapia fish, it was 15.7µg g^{-1} (**Badawy & Wahaab, 1997**).

The N/P ratio is necessary to be followed for the control of the undesirable growths of algae and plants occurring with eutrophication. If N/P ratio records within 5

and 10, either nutrient could be limiting and if < 5, nitrogen is the limiting for plant growth **(Downing and McCauley, 1992)**. The N/P ratio at the investigated sites of Lake Manzala was below 5 at the site 4 indicating that nitrogen is the limiting nutrient only there whereas other sites were within 5 and 10 indicating that either elements could be the limiting nutrients at most sites. Since most lake sites are characterized with moderate N/P ratios, the green algal dominance, macrophytes and zooplankton were not favored, which is a positive remark of the efforts of the lake development, compared to the N-limiting eutrophication situation in Lake Manzala in a previous study **(Elmorsi et al., 2017)**.

Table 5. Evaluation of BAF, EF and PNV in Manzala Lake ecosystem

Element	log BAF at site (1)	EF at site (1)	EF at site (5)	Average EF	PNV at site (1), mg	PNV in site (2), mg	UL, mg (WHO, 1996; LANGMAN, 2003; EFSA, 2006)
Li	1.42	3.5	3.2	3.4	1.29	1.42	250
K	2.77	0.2	0.2	0.2	441.14	531.18	7000
Mg	1.57	0.6	0.8	0.7	71.06	92.75	250
Ca	2.56	-	-	-	760.94	773.66	2500
Sr	2.14	0.8	1.6	1.2	1.42	1.86	
Ba	-	0.2	0.1	0.2	0.43	0.33	
B	1.28	44.7	48.0	46.4	0	0	9.6
Al	3.95	0.3	0.4	0.4	244.98	167.37	65
Ga	-	0	0	0	4.44	0	
In	-	0	0	0	0	0	
V	0.95	1.4	1.5	1.5	1.21	0.17688	13.0*
Cr	-	4.7	4.4	4.6	4.66	6.34758	0.25
Mn	3.26	0.9	0.7	0.8	0.97	0.72159	8.7-12.2
Fe	2.97	-	-	-	29.23	19.45278	
Co	-	1.7	1.7	1.7	0	0	1.4
Ni	1.92	0.4	0	0.2	2.21	2.12055	0.49
Cu	1.51	0.3	0	0.2	2.42	1.97784	5
Zn	2.87	2.5	2.5	2.5	14.16	12.64089	25
Se	0.59	0	0	0	0.21	0.71757	0.30
Ag	0.03	20.2	62.0	41.1	1.12	1.11957	
As	-	0.3	1.2	0.7	0	0.21708	0.14*
Cd	-	30.8	31.9	30.9	0.02	0.0201	0.07
Pb	1.27	3.5	2.9	3.4	1.88	1.92558	0.21*

BAF, EF, PNV and UL denote the bioaccumulate factor, enrichment factor based on the average metal contents in the sediment, present nutrition value and adult upper limit, respectively. * Daily UL values for a 65 kg adult were calculated from the weekly dosage per kg weight.

2. Elemental analysis

The major investigated elements in the aquatic ecosystem of Lake Manzala (K, Ca, Mg, Al, Mn and Fe) are similar to the previous results of **Badawy and Wahaab (1997)**, **El-Badry and Khalifa (2017)** and **Elmorsi et al. (2017)**. The site (5) at the north

of the lake showed higher metal contents in water and sediment compared to the site (1) at the south of the lake, which is contradicting with the common trend of concentration of pollutants along Lake Manzala , previously reported in the study of **Elmorsi et al. (2017)**. This may be related to the agitating nature of the dredging procedure occurring in the frame of the development process. Consequently, particulates and sediments loaded with decades-long elemental load memory from the heavily polluted south region may easily spread in the lake with the water stream to the northern exchange canals. The present levels revealed from the elemental analysis (Table 4) of V, Cr, Mn, Fe, Co, Ni, Cu and Zn in the water of Lake Manzala are high compared to those reported in 2015 (21.33–94.79, 3.54–10.04, 1.69–7.96, 135.9–874.1, 0.54–1.39, 17.38–45.22, 21.25–133.8 and 43.33–168.4µg L^{-1}, respectively **(Elmorsi et al., 2017)**. The observed high levels of metal in water may be correlated with the contemporary developing activities mentioned above; nevertheless, they are still lower than the permissible levels, except for Pb as shown in Table (4).

Nonetheless, sediments showed lower amounts of the investigated elements compared to their natural abundance, except for Li, B, V, Cr, Co, Zn, Ag, Cd and Pb (Table 4). Moreover, the As and Se in sediment were remarkably lower than levels recorded in 2017 (12 and 4ppm, respectively) **(El-Badry and Khalifa, 2017)**.

The water hyacinth recorded lower levels of the same investigated elements in 2015, except for Cr and Zn **(Elmorsi et al., 2017)**. The metal and metalloid levels in the tilapia muscles in the present study are mostly lower than values reported in 2017 (28.4, 15.6, 24.40, 45.5, 13.30 and 51.8µg g^{-1} for Cu, Zn, Ni, Cd, Pb and Cr **(Badawy & Wahaab, 1997)**, except for Ni and Cr. Furthermore, the element levels were lower than the permissible levels in fish muscles except for Pb, which were slightly higher as detailed in Table (4).

3. Pollution evaluation

Pollution evaluation is important to evaluate the pollution risk status. The elaborated pollution indices were BAF, EF, PNV and upper limit (UL). The BAF refers to the efficiency of a plant species to absorb a metal into its tissue from the surrounding environment **(Arnot & Gobas, 2006)**. The highest bioaccumulation was recorded for Al, Mn, Fe and Zn, which may be owed to their preferred sorption on the expense of the lowest BAF for Ag and Se, which were showed lowest BAF values. Lake Manzala may have minor enrichment with most of the studied metals (EF=1–3), except for Li, Cr and Pb, which were considered moderately enriched (EF=3–5) and B, Ag and Cd, which were evaluated severely to very severely enriched (EF> 10-50). Additionally, site (5) was relatively more polluted than site (1), which is consistent with the physicochemical properties and the TPHC levels, indicating the presence of common pollution resources and the sweeping of the lake pollutants towards its north exchange canals. The PNV values in the present study was appreciably higher than the values for similar essential metals in the tilapia fish muscles in Lake Manzala (0.31, 0, 0.31, 0.14, 2.6, 0.014, 0.023,

0.053, 0.56mg g^{-1} for V, Cr, Mn, Fe, Co, Ni, Cu and Zn (**Elmorsi *et al.*, 2017**). However, most PNV values of the studied elements were within the international recommended UL values (**WHO, 1996; LANGMAN, 2003; EFSA, 2006**) except for Al, Cr and Pb. The dredging activities taking place meanwhile may be the reason for such high PNV values. The pollution status is expected to be highly improved according to the completeness of the development plan of Lake Manzala in 2022 and the inauguration of the biggest water treatment station for Bahr El Baqar drain in 2021.

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