Melegy et al. Bulletin of the National Research Centre (2019) 43:143
https://doi.org/10.1186/s42269-019-0182-y

Bulletin of the National Research Centre

RESEARCH Open Access

Monitoring of the changes in potential environmental risk of some heavy metals in water and sediments of Burullus Lake, Egypt

Ahmed A. Melegy*, Mohamed S. El-Bady and Husein I. Metwally

Abstract

Background: Burullus Lake has received a great attention because of its environmental and economic importance for connecting with the Mediterranean Sea through El Boughaz opening. Some of the chemical analyses were performed to study the potential environmental risk of Burullus Lake. The present study explores the potentiality of environmental risk of Fe, Mn, Co, Ni, Cr, Cd, Pb, Zn, and Cu for detecting most vulnerable areas to water and sediment pollution at Burullus Lake during different three periods: 2010, 2012, and 2015. The concentrations of DO, BOD, COD, and TDS during three periods 2010, 2012, and 2015 were higher than the WHO limits for the protection of fish and other aquatic life in Burullus lakes.

Results: The mean concentrations of heavy metals in Burullus bottom sediments in 2010 were arranged in descending order as follows: Fe > Mn > Cr > Zn > Ni > Cu > Pb > Cd, while the descending order in 2012 is Fe > Mn > Zn > Cr > Cu > Ni > Pb > Cd, as well as the descending order in 2015 is Fe > Mn > Zn > Cr > Ni > Pb > Cu > Cd. The Fe is the highest concentration in all years.

Conclusions: The potential ecological risk index (RI) 2010 is S4 > S11 > S7 > S6 > S9 > S5 > S1 > S10 > S8 > S2 > S12 > S3, where RI 2012, S4 > S9 > S6 > S10 > S5 > S8 > S2 > S12 > S3 > S11 > S7 > S1 as well as RI 2015, S4 > S11 > S7 > S6 > S9 > S1 > S2 > S10 > S12 > S8 > S3 > S5.

Keywords: Burullus Lake, Environmental risk, Water, Sediment, RI

Background

Burullus Lake has received a great attention because of its environmental and economic importance for connecting with the Mediterranean Sea through El Boughaz opening. The investigation of distribution and pollution degree of heavy metals in Burullus Lake has attracted more public concerns recently because of their potential toxic effects and ability to bioaccumulation in aquatic ecosystems (Christophoridis et al. 2009; Yang et al. 2012; El-Moselhy et al., 2016; Darwish et al. 2018).

Heavy metal refers to any metallic chemical elements that has a relatively high density and is highly poisonous at low concentrations (Harris and Santos 2002). All metals are toxic at higher concentrations (Chronopoulos et al. 1997), and excessive levels can be damaging to the living organism (Fergusson 1990). Their multiple industrial, agricultural, domestic, and new technological applications have led to their wide distribution in the lakes, raising concerns over their potential effects on marine organisms and human health. Metal ions have been distributed to interact with cell components causing DNA damage and conformational changes that may lead to cell cycle modulation and carcinogenesis (Chang et al., 1996; Wang and Shi 2001; Beyersmann and Hartwig 2008).

Heavy metals from incoming drains, tidal, fresh water sources, and weathering of rock substrates are rapidly deposited onto the sediments of lakes. However, metals of anthropogenic origin are more loosely bound in

* Correspondence: amelegy@yahoo.com
Department of Geological Sciences, National Research Centre, Dokki, Cairo, Egypt

sediments and thus are more readily available to organisms (Schropp and Windrom 1988).

Heavy metals such as Fe, Co, Ni, Cr, Cd, Pb, Zn, Mn, and Cu are regarded as serious pollutants of aquatic ecosystems because of their environmental persistence, toxicity, and ability to be incorporated into food chains (Forstner and Wittman, 1993).

The long axis of Burullus Lake, about 65 km long, runs parallel to the adjacent Mediterranean shore; its width is between 6 and 16 km, with the average being 11 km (Radwan and Lotfy 2002). The deepest part lies in the western sector, which also has the lowest salinity, while the eastern sector, which contains its outlet as a 250 m long canal connecting the lake to the sea (Bughaz), is shallow and saline (Doumont and El-Shabrawy 2007). Lake Burullus attracts attention of many authors because of its economic and scientifically importance. Industrial, agricultural and domestic wastes discharges have increased the levels of heavy metals in Lake Burullus. In facts, the studies dealing with the accumulation of heavy metals through different years are still scarce expect few studies.

The present study explores the potentiality of environmental risk of some heavy metals (i.e., Fe, Mn, Co, Ni, Cr, Cd, Pb, Zn, and Cu) for detecting most vulnerable areas to water and sediment pollution at Burullus Lake during different three periods: 2010, 2012, and 2015.

Study area

Burullus Lake is considered as one of the four coastal shallow lakes at Egypt Nile Delta, namely, Edku, Maryout, Burullus, and Manzala Lakes. Burullus is a coastal lagoon situated along the Mediterranean Sea, between the western Rosetta and the eastern Damietta branches of the River Nile with an average depth ranging from 0.5 to 2.1 m. It is the second northern lake in size (Fig. 1). El-Burullus lagoon brackish water (31° 22′ – 31° 26′ N and 30° 33′ – 31° 07′ E), on the northern Egyptian coast, is one of the most important Egyptian northern lakes from an economical point of view. The Lake serves as a reservoir for drainage waters, discharged from agricultural areas in addition to freshwater from Brimbal Canal, situated in the western part of the lake (Samaan et al. 1989).

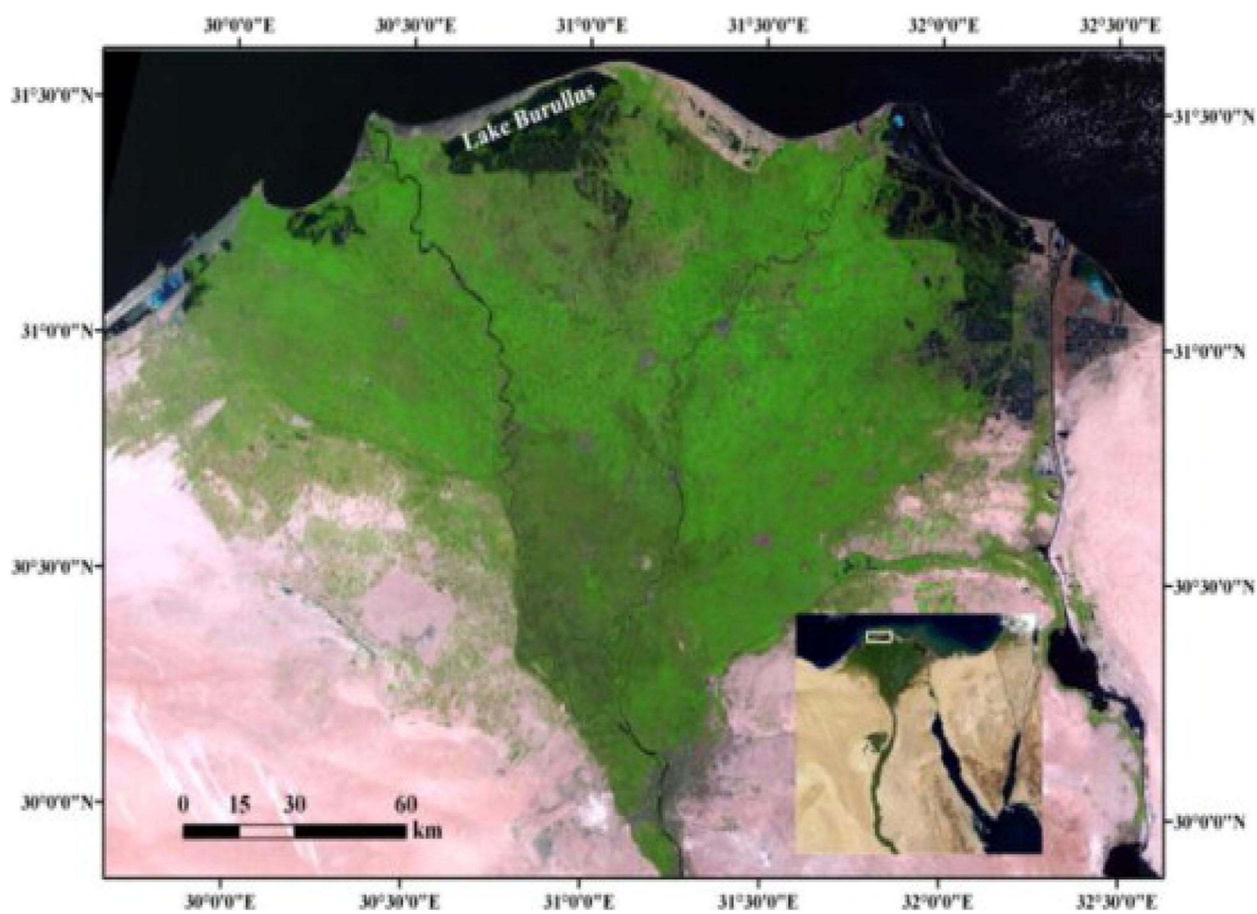

Fig. 1 A Landsat image of the Nile Delta showing the location of Lake Burullus. **a** By using free satellite imagery data sources. **b** The study area of El-Burullus lagoon brackish water (31° 22′ – 31° 26′ N and 30° 33′ – 31° 07′ E)

Table 1 Description of the collected sediments from lagoon Burullus

Samples	Site	Depths (m)
1	In the front of eastern EL-Burullus drain	1.2
2	Buoghaz EL-Burullus	1.9
3	Between samples 1 and 2 (AL-Boulak)	1.6
4	In the front of Drain 7 outlet	1
5	Middle of EL-Burullus Lagoon (EL-Zanka)	1.9
6	Middle of lagoon north of drain 8 and 9 outlet (El-Tawela)	1.9
7	Middle of outlets of drains 8 and 9 (EL-Shakhlawea	1.1
8	North of the lagoon near the coastal road (Mastrow)	1.2
9	North west the lagoon (Abu Amer)	1.4
10	Middle of the western sector (AL-Baraka)	1.3
11	In the front of outlet of drain (Al-Hoksa)	1.3
12	In the front of Brinbal canal outlet (Nile outlet)	1.5

Methods

Water and sediment samples were collected from 12 sites along Lake Burullus during the periods (2010, 2012, and 2015). The location of the sampling sites along Lake Burullus is shown in Table 1 and Fig. 2.

Water samples were collected using NASEN bottles at 1–2 m depth. The collected water samples were filtered using pre-acid-cleaned Millipore membrane filters (0.45 mm pore size; 47 mm diameter). The filtrates were acidified to pH 2, with HNO_3 of supra pure grade; they were stored, in acid-cleaned high-density polyethylene bottles, in plastic bags. Then, these samples were filtered using 0.45-um membrane filters. All the standard precautions recommended by Kremling (1983) to reduce risks of

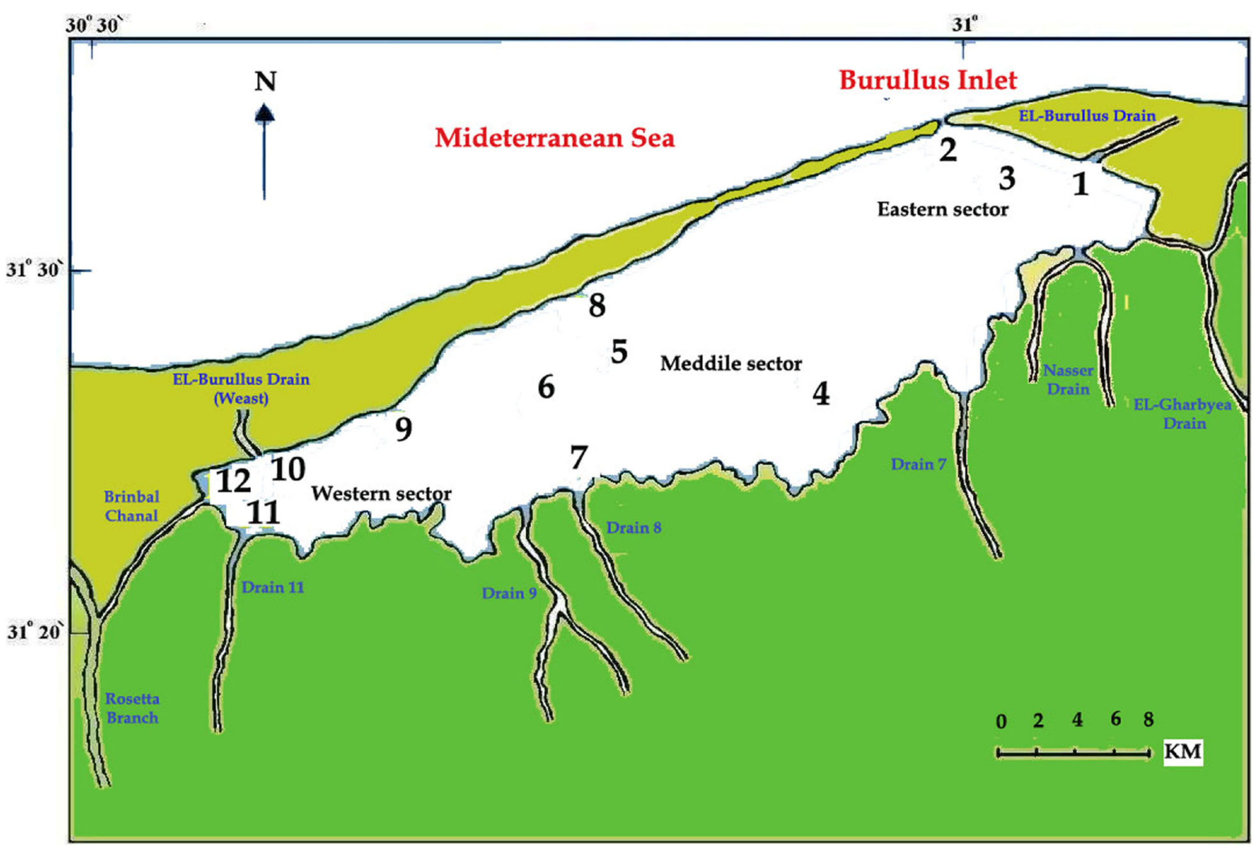

Fig. 2 Lake Burullus and position of 12 sites. **a** Water and sediments samples were collected from 12 sites along Lake Burullus. **b** Location of the sampling sites along Lake Burullus

Table 2 Geoaccumulation index (I_{geo}) classification [EU 1998]

*I*geo	*I*geo class	Designation of sediment quality
> 5	6	Extremely contaminated
4–5	5	Strongly to extremely contaminated
3–4	4	Strongly contaminated
2–3	3	Moderately to strongly contaminated
1–2	2	Moderately contaminated
0–1	1	Uncontaminated to moderately contaminated
< 0	0	Uncontaminated

sample contamination were followed during collection and treatment of samples. Solvent extraction was utilized using ammonium pyrrolidinedi-thiocarbamate (APDC) and methyl isobutyl ketone (MIBK). Water samples were pre-concentrated with APDC-MIBK extraction procedure according to the standard methods (APHA 1989). Heavy metals in the obtained solution were measured using the Flame Atomic Absorption Spectrophotometer (AAS; Perkin Elmer Analyst 100).

Sediment samples were collected using a Van-Veen grab coated with polyethylene. The samples were kept in self-sealed acid pre-cleaned plastic bags, rinsed with metal-free water. The samples were deep-frozen until analysis. The samples were dried in the oven at 70 °C and sieved using 0.75-mm plastic sieve and digested for about 2 h in a mixture of 3:2:1 HNO_3, $HClO_4$, and HF acids, respectively, as described by Oregioni and Aston (1984).

Determination of physical parameters (pH, Eh, DO, TDS, conductivity, and temperature) in water samples was carried out according to UNEPA/APHA. pH, Eh, and temperature (°C) were measured using pH electrode meter while dissolved oxygen was measured with Jenway Model 9070 waterproof DO meter.

Determination of chemical oxygen (COD) demand was carried out according to the method described by the Standing Committee of Analysts (1986).

Dissolved oxygen (DO) meter was also calibrated prior to measurement with the appropriate traceable calibration solution of 5% HCl. The BOD_5 was computed by subtracting the DO after 5 days of incubation from the DO measured on collection of samples at point in milligram per liter.

Geostatistical analysis

- Geoaccumulation index (Igeo) is calculated by the following equation:

$$\mathrm{Igeo} = \mathrm{Log}_2\left[\mathrm{C_n}/(1.5)\ \mathrm{B_n}\right]$$

which was introduced by Müller (1979) and the numerical factor (1.5) artificially introduced by Covelli and Fontolan (1997).

where C_n is the measured concentration of the studied metal "*n*" in the sediment and B_n is the geochemical background concentration of the metal "*n*" values in argillaceous sediment. The factor 1.5 is used because of possible variations of the background values for a given metal in the environment, as well as very small anthropogenic influences. Müller (1979) presented seven classes of geoaccumulation index (Table 2).

- The degree of contamination (Dc) is defined as the sum of all contamination factors for a given site (Hökanson 1980):

$$\mathrm{Dc} = \sum_{1}^{n} CF$$

where *CF* is the single contamination factor and *n* is the count of the elements present. Dc values less than *n* would indicate low degree of contamination; $n \leq$ Dc < 2n, moderate degree of contamination; 2n ≤ Dc < 4n, considerable degree of contamination; and Dc > 4n, very high degree of contamination (Caeiro et al. 2005; Pekey et al. 2004).

For the description of the degree of contamination in the study area, the terminologies used are as follows: Dc < 8 denotes low degree of contamination, 8 < Dc < 16 moderate degree of contamination, 16 ≤ Dc < 32 considerable degree of contamination, and Dc > 32 very high

Table 3 Grading of modified degree of contaminations

Modified degree of contamination (mDc)	According to [Kremling 1983]
mDC < 1.5	Nil to very low degree of contamination
1.5 < mDC < 2	Low degree of contamination
2 < mDC < 4	Moderate degree of contamination
4 < mDC < 8	High degree of contamination
8 < mdC < 16	Very high degree of contamination
mdC **>** 32	Ultra high degree of contamination
16 < mDC < 32	Extremely high degree of contamination

Table 4 Physicochemical parameters in surface water (during 2010)

No.	Ec mS/cm	PH	TDS g/l	DO mg/l	BOD mg/l	COD mg/l
1	24.3	8.21	15.5	8.6	15.5	146.3
2	51.3	8.12	32.8	12.3	10.5	122.3
3	19.9	8.13	12.8	8.5	5.36	88.3
4	55.3	8.92	36.5	9.6	29.5	212.3
5	3.9	8.14	2.6	13.6	9.6	69.3
6	5.6	8.56	3.6	9.8	21.3	188.3
7	25.3	9.21	16.3	9.7	29.5	178.3
8	27.3	8.22	17.6	12.3	12.3	96.3
9	16.2	8.21	10.6	10.5	12.4	99.6
10	18.3	11.2	3.5	8.9	11.9	89.3
11	2.1	9.15	1.3	8.4	20.3	220.3
12	22.2	8.31	14.2	13.2	16.3	77.2

degree of contamination, where n = 8 = the count of the studied heavy metals.

- Modified degree of contamination (mDc)

Abrahim, 2005, Abrahim and Parker, 2008) presented a modified and generalized form of the Hakanson (1980) equation for the calculation of the overall degree of contamination at a given sampling site. The modified equation for a generalized approach to calculating the degree of contamination is given below:

$$\mathrm{mDc} = \left(\sum_{i=1}^{i=n} Dc\right)/n$$

where n is the number of analyzed elements, i is the i_{th} element (or pollutant), and CF is the contamination factor. Using this generalized formula to calculate the mDc allows the incorporation of many metals as the study may analyze with no upper limit. For the classification and description of the modified degree of contamination (mDc), the following gradations have been given below (Table 3).

- An ecological risk factor ($\mathrm{Er_i}$) to quantitatively express the potential ecological risk of a given contaminant is also suggested by Hakanson (1980)

$$\mathrm{Er} = \mathrm{Tr} \times \mathrm{CF}$$

where Tr is the toxic-response factor for a given substance, and CF is the contamination factor. The Tr values of heavy metals suggested by Hakanson (1980). The Tr values of Pb, Cu, Co, Cd, Cr, Ni, and Zn are 5, 5, 5, 30, 2, 3, and 1, respectively. The terminologies used to describe the risk factor are as follows: Er < 40, low potential ecological risk; 40 ≤ Er < 80, moderate potential ecological risk; 80 ≤ Er < 160, considerable potential ecological risk; 160 ≤ Er < 320, high potential ecological risk; and Er ≥ 320, very high ecological risk.

- The potential ecological risk (RI) of the heavy metals is quantitatively evaluated by the potential ecological risk index (Er) (Håkanson 1980; Zhu et al. 2008), which takes into account both contamination factor (CF) and the "toxic-response" factor.

The potential ecological risk values obtained were compared with categories grade of Er and RI of metal pollution risk on the environment suggested by Hakanson (1980) and Shi et al. (2010). The potential ecological

Table 5 Physicochemical parameters in surface water (During 2012)

No.	Ec mS/cm	PH	TDS g/l	DO mg/l	BOD mg/l	COD mg/l
1	9.2	8.2	5.8	7.2	15.3	42.2
2	14.4	8.1	9.2	12.2	30.5	31.2
3	9.9	8.2	6.3	8.6	22.2	44.4
4	16.8	8.3	10.8	9.2	5.3	62.3
5	1.6	8.9	1.02	13.5	8.5	44.2
6	7.7	8.1	4.9	5.2	12.2	45.5
7	8.7	7.9	5.5	8.7	25.5	55.6
8	9.9	8.1	6.4	12.1	13.3	42.2
9	9.8	8.0	6.2	10.5	12.2	43.3
10	8.8	8.1	5.6	9.2	11.2	62.3
11	1.3	8.2	0.6	0.8	20.3	66.6
12	8.8	8.2	5.5	10.2	5.3	30.3

Table 6 Physicochemical parameters in surface water (during 2015)

No.	Ec mS/cm	PH	TDS g/l	DO mg/l	BOD mg/l	COD mg/l
1	4.53	8.2	2.9	5.6	10.3	46.5
2	15.9	8.11	10.2	10.3	0.65	22.3
3	3.9	8.3	2.5	6.5	5.2	44.6
4	3.9	8.9	2.5	5.6	11.3	102.3
5	2.9	8.11	1.9	11.6	5.3	32.2
6	3.6	8.55	2.3	5.8	10.6	88.3
7	5.01	9.11	3.2	5.7	11.5	87.3
8	7.03	8.12	4.5	12.3	2.3	25.5
9	4.06	8.01	2.6	9.5	2.4	29.5
10	3.43	8.02	2.2	8.9	1.9	35.3
11	5.01	9.02	3.2	6.7	10.3	100.3
12	2.34	8.01	1.5	12.9	6.6	36.6

Table 7 Distribution of Fe, Mn, Zn, Cu, Ni, Cr, Pb, and Cd (μg/L) in water samples during 2012–2015

H.M	Date	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Fe (μg/l)	2010	415	202	255	419	95	222	252	212	215	224	430	218
	2012	270	97	122	100	99	96	102	105	112	272	202	166
	2015	214	112	154	219	100	122	152	112	115	124	230	118
Mn (μg/l)	2010	62	35	44	99	42	89	45	43	49	82	99	78
	2012	55.6	13.5	42.3	71.5	40.2	35.2	42.2	39.9	39.8	40.2	66.6	52.2
	2015	22	14	14	33	22	24	15	13	19	32	39	18
Zn (μg/l)	2010	512	196	95	544	186	195	84	166	162	178	552	158
	2012	190.9	27.7	28.5	180.8	88.5	55.4	29.9	33.5	34.5	45.6	188.9	55.9
	2015	212	69	56	244	86	56	54	68	64	78	246	58
Cu (μg/l)	2010	33	8	22	30	8	9	28	27	25	26	33	25
	2012	70.6	7.2	10.5	77.8	22.2	7.5	7.7	33.3	34.5	45.6	188.9	55.9
	2015	124	22	56	112	18	19	89	75	56	68	124	54
Ni (μg/l)	2010	9	4	6	10	2	2	1	3	1	2	5	2
	2012	9.5	7.5	9.2	10.2	7.8	8.1	14.5	10.2	8.8	9.8	8.7	6.6
	2015	9	3	5	10	1	1	2	4	1	2	8	3
Cr (μg/l)	2010	12	3	6	13	3	2	2	2	1	4	11	6
	2012	7.2	5.2	5.5	7.4	3.3	4.6	3.5	5.8	4.3	4.3	8.6	4.2
	2015	11	2	5	12	2	1	1	2	1	3	10	4
Pb (μg/l)	2010	35	65	12	55	35	45	45	68	44	46	48	42
	2012	31.2	52.2	32.2	34.3	32.3	42.3	42.3	91.5	33.3	36.2	35.2	31.2
	2015	30	75	22	56	30	35	40	78	74	36	43	32
Cd (μg/l)	2010	2.6	4.7	1.9	8.5	1.6	5.3	4.3	2.6	3.2	2.9	4.3	2.6
	2012	2.1	7.7	1.5	6.6	1.6	3.5	4.2	2.1	3.3	3.2	3.9	0.3
	2015	1.2	2.1	1.3	2.5	1.1	2.1	2.2	1.6	1.6	1.5	2.1	1.1

risk index (RI) was in the same manner as the degree of contamination defined as the sum of the risk factors.

$$\mathrm{RI} = \sum\nolimits_{1}^{n} \mathrm{Er}$$

where Er is the single index of ecological risk factor, and n is the count of the heavy metal species. The terminology used for the potential ecological risk index was as follows: RI < 150, low ecological risk; 150 ≤ RI < 300, moderate ecological risk; 300 ≤ RI < 600, considerable ecological risk; and RI > 600, very high ecological risk (Håkanson 1980; Shi et al. 2010). Er and RI denote the potential ecological risk factor of individual and multiple metals, respectively.

Results

The hydrogen ion concentration is a reflection of many biological and chemical processes occurring in the aquatic environment, photosynthetic activity of the aquatic plants, respiration of aquatic organisms, and decomposition matter. The pH of the Lake Burullus in the representative area is slightly alkaline (8.12–9.21) and varies within narrow.

During 2010 (Table 4), the concentrations of COD for the 12 sampling sites ranged between 69.3 and 220.3 mg/l. BOD ranged between 5.36 and 29.5 mg/l; DO ranged from 8.4 to 13.6 mg/l. The percentage of TDS in the water samples ranged from 1.3 to 36.5 g/l. During

Table 8 Statistical analysis of heavy metals during 2010, 2012, and 2015

Year	Statistical analysis	Fe	Mn	Zn	Cu	Ni	Cr	Pb	Cd
2010	Min	95	35	48	8	1	1	12	1.6
	Max	430	99	552	33	10	13	68	8.5
	Average	263	64	252	23	4	5	45	4
	St. dv	234	94	174	41	18	22	58	19
2012	Min	96	13.5	27.7	7.2	6.6	3.3	31.2	0.3
	Max	272	71.5	190.9	199.8	14.5	8.6	91.5	7.7
	Average	145	45	80	47	9	5	41	3
	St. dv	182	68	72	72	23	20	47	16
2015	Min	100	13	54	18	1	1	22	1.1
	Max	230	39	246	124	10	12	78	2.5
	Average	148	22	108	68	4	5	46	2
	St. dv	134	34	74	70	19	20	48	17

2012 (Table 5), the concentrations of COD ranged from 30.3 to 66.6 mg/l and BOD ranged from 5.3 to 30.5 mg/l; DO ranged from 0.8 to 13.5 mg/l. TDS ranged from 0.6 to 10.8 g/l. During 2015 (Table 6), COD ranged from 22.3 to 102.3 mg/l, BOD ranged from 5.60 to 11.5 mg/l, and DO from 5.6 to 12.9 mg/l. TDS ranged from 1.5 to 10.2 g/l. Reduced DO levels in water during 2015 may be attributed that Burullus lake was warm due to high contamination pushes the oxygen molecules out of the spaces between the moving water molecules. COD values in all studied periods, 2010–2015 are always higher than the BOD values because COD includes both biodegradable and non-biodegradable substances whereas BOD contains only biodegradable. The concentrations of DO, BOD, COD, and TDS were higher than the WHO limits for the protection of fish and other aquatic life in Burullus lakes. The distribution of heavy metal concentrations for the 12 sites of the investigated area were reported in Table 7. Metal concentrations in Burullus water were found in Table 8, and distribution of heavy metals in Burullus lagoon are given in Table 10 while modified degree of contaminations (mDc) were listed in Tables 11, 12, and 13 and Fig. 4, and in addition, the potential ecological risk index (RI) were given in Tables 14, 15, and 16 and Fig. 5.

Discussion

The dissolved cadmium concentration in water ranged between 1.6 and 8.5 μg/l during 2010, 0.3 and 7.7 μg/l during 2012, and 1.1 and 2.5 μg/l during 2015 (Table 7). The average concentration of Cd in the 12 stations under investigation was decreased in the order of 2010 > 2012 > 2015, with the total annual average of 1 μg/l which exceed the natural concentration of seawater (0.1 μg/l) according to Fifield and Haines (2000).

The concentration of dissolved lead in the investigated area ranged from 12 μg/l at S3 to 68 μg/l at S8 during 2010, from 31.2 μg/l at S1 to 91.5 μg/l at S8 during 2012, and from 22 μg/l at S3 to 78 μg/l at S8 during 2015.The average concentration of dissolved lead ranges from 41 μg/l to 46 μg/l recorded during 2012 and 2015, respectively. Based on the annual average concentration of lead, it is higher than that of natural sea water concentration (0.03 μg/l) according to Fifield and Haines (2000) but is still lower than acceptable limits (100 μg/l) according to the WHO guideline value of heavy metals.

Iron is one of the essential elements in human nutrition, and high concentration of iron in humans has been found to bring about vomiting and cardiovascular collapse, while iron deficiency may lead to failure of blood clotting. The highest concentration value of Fe (430 μg/l) in the water samples was detected at S11 (Tables 7 and 8), while the least value of 96 μg/l was observed at point S6 during 2012, according to the WHO guideline value and maximum contaminant levels of 300 μg/l (water).

Copper compounds can be added to fertilizers and animal feeds as a nutrient to support plant and animal growth. The levels of Cu in the water samples fluctuate between 7.2 and 188 μg/l. S11 during 2012 shows the highest value, while the least values was observed at S2 during 2012. The copper concentrations in the water samples in sites (S1, S4, S11, and S12) of Lake Burullus during 2012 were found to be higher than the permissible limit of 50 μg/l set by WHO (2004).

Mn concentration in water samples was observed to be higher at S4 and S11 (99 μg/L), while S8 shows the least value of 13 μg/l. Manganese compounds are used

Table 9 Bottom sediments with P, N, H2S, and OM in EL-Burullus Lagoon 2010–2015

Samples	P Total μg/g			N Total %			H2S μg/g			OM %		
	2010	2012	2015	2010	2012	2015	2010	2012	2015	2010	2012	2015
1	1492	1080	1112	8.5	2.5	3.5	182	182	152	9.7	6.3	7.3
2	895	890	795	8.5	2.5	3.5	65	65	45	1.5	1.5	1.6
3	1088	1010	1000	6.3	1.3	2.3	68	68	48	8.2	6.2	5.2
4	1432	1000	1132	8.2	2.2	3.2	185	185	185	8.9	5.9	5.9
5	999	828	889	2.5	1.1	1.5	132	132	122	9.6	6.6	6.6
6	985	928	985	2.2	3.2	2.2	55	55	35	6.8	5.6	6.8
7	1521	1040	1321	3.1	3.1	3.1	290	290	250	9.6	4.6	9.6
8	1060	940	960	3.1	3.1	2.1	96	96	56	8.6	5.6	5.6
9	969	760	966	2.1	3.1	2.1	65	65	65	9.6	4.7	9.6
10	1052	1002	1002	3.1	3.1	2.1	75	75	75	5.6	6.5	4.6
11	1221	1003	1121	5.2	3.2	3.2	274	274	202	9.6	6.6	8.6
12	1010	980	990	3.5	5.2	2.5	95	95	85	7.3	7.9	6.3

Table 10 The concentration of heavy metals of EL-Burullus Lagoon during periods of 2010, 2012, and 2015

H.M	Date	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	Means μg/g
Fe μg/g	2010	29264	9595	15232	32023	10500	22921	25256	16249	18265	16656	28245	19258	20289
	2012	25252	9658	18562	27562	8541	18652	28560	14235	12423	122	225623	156254	45454
	2015	25264	8695	10232	29023	7500	18921	20256	16245	15265	16656	26245	16258	17547
Mn μg/g	2010	3580	665	864	2545	755	752	1902	1860	1056	986	2352	1260	1548
	2012	1124	659	898	1012	852	1312	1021	869	302	569	1002	969	882
	2015	1580	365	564	1645	355	752	1002	960	856	986	1352	960	948
Zn μg/g	2010	88	56	49	108	55	59	56	45	99	52	104	59	69
	2012	105	54	44	68	190	66	101	58	99	51	77	88	83
	2015	58	36	42	78	35	55	56	45	49	52	47	39	49
Cu μg/g	2010	80	25	22	80	25	35	42	41	24	26	71	29	42
	2012	45	35	25	51	26	25	26	30	27	20	65	24	33
	2015	52	19	18	59	15	25	32	25	24	26	45	21	30
Ni μg/g	2010	65	39	33	78	40	55	65	39	39	36	71	45	50
	2012	42	35	24	45	24	24	25	31	26	27	61	26	33
	2015	44	29	33	52	22	35	45	29	30	25	49	35	36
Cr μg/g	2010	142	40	36	144	35	75	85	56	46	49	90	45	70
	2012	54	42	23	32	35	36	38	41	36	26	95	32	41
	2015	75	35	36	77	25	55	56	35	38	40	66	35	48
Pb μg/g	2010	9	11	9	10	10	8	5	9	8	8	10	5	9
	2012	12.3	14.3	9.6	18.9	15.3	11.2	5.6	10.3	9.9	3.5	20.2	16.5	12
	2015	22	42	26	42	19	25	33	35	26	34	41	32	31
Cd μg/g	2010	1.6	1.3	1.2	4.3	1.7	2.2	3.2	1.5	1.8	1.6	3.3	1.2	2
	2012	0.01	0.1	0.11	0.51	0.2	0.3	0.1	0.2	0.56	0.3	0.001	0.1	0.21
	2015	0.12	0.1	0.11	0.5	0.1	0.2	0.3	0.1	0.2	0.11	0.3	0.11	0.19

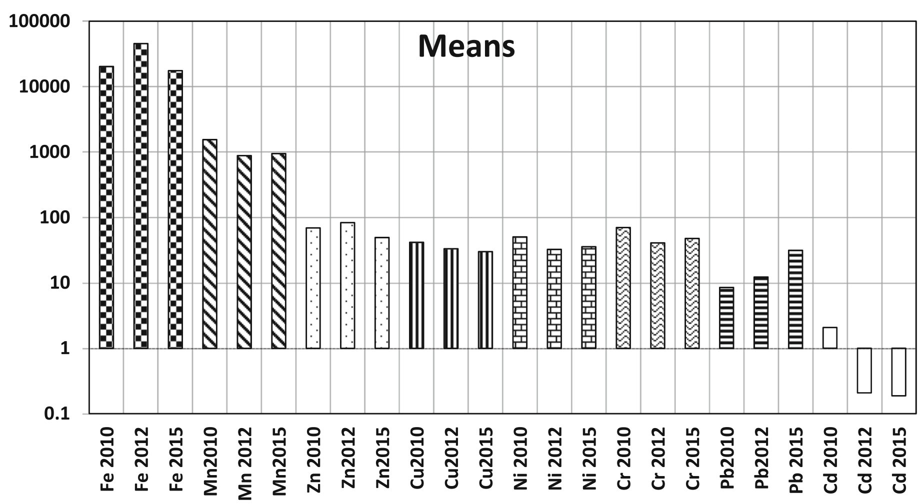

Fig. 3 Means of heavy metals in different stations. **a** Means of heavy metals of EL-Burullus Lagoon during periods of 2010, 2012 and 2015. **b** Results show the comparison between the mean concentrations of each heavy metal in bottom sediments through different 3 years

Table 11 Contamination factor 2010

SITE	Fe μg/g	Mn μg/g	Zn μg/g	Cu μg/g	Ni μg/g	Cr μg/g	Pb μg/g	Cd μg/g	Dc	mDc
S1	0.62	4.21	0.93	1.78	0.96	1.58	0.45	5.33	15.85	1.98
S2	0.20	0.78	0.59	0.56	0.57	0.44	0.55	4.33	8.03	1.00
S3	0.32	1.02	0.52	0.49	0.49	0.40	0.45	4.00	7.68	0.96
S4	0.68	2.99	1.14	1.78	1.15	1.60	0.50	14.33	24.17	3.02
S5	0.22	0.91	0.58	0.56	0.59	0.39	0.50	5.67	9.41	1.18
S6	0.49	0.88	0.62	0.78	0.81	0.83	0.40	7.33	12.14	1.52
S7	0.54	2.24	0.59	0.93	0.96	0.94	0.25	10.67	17.11	2.14
S8	0.34	2.19	0.47	0.91	0.57	0.62	0.45	5.00	10.56	1.32
S9	0.39	1.24	1.04	0.53	0.57	0.51	0.40	6.00	10.69	1.34
S10	0.35	1.16	0.55	0.58	0.53	0.54	0.40	5.33	9.45	1.18
S11	0.60	2.77	1.09	1.58	1.04	1.00	0.50	11.00	19.58	2.45
S12	0.41	1.48	0.62	0.64	0.66	0.50	0.25	4.00	8.57	1.07

in fertilizers and as livestock feeding supplements. Manganese can be bioaccumulated in lower organisms (e.g., phytoplankton, algae, mollusks, and some fish) but not in higher organisms; biomagnifications in food chains are not expected to be very significant (Abbasi et al. 1998). The concentrations of Mn during 2010 within the sites (S1, S4, S6, S10, S11, and S12) from this portion of the lake exceeded the permissible limit of 50 μg/l (water) by WHO (2004).

Metal concentrations in Burullus water were found in Table 8 in the following order: Fe > Zn > Mn > Cu > Pb > Cr > Ni > Cd.

Nickel concentrations in the water samples ranged between 1 and 14.5 μg/l. The concentration of Ni in the water Lake S4 (10.2 μg/l), S7 (14.5 μg/l), and S8 (10.2 μg/l) exceeded the permissible limit of 10 μg/l set by WHO (2004). The high concentration of Ni in the water samples from this portion of the lake could be from agricultural runoff, which may carry higher concentrations of this metal, which arise from anthropogenic activities such as use of chemical fertilizers and pesticides in agriculture land. The concentrations of Cr in water samples from this portion of the lake were lower than the permissible limits of 100 μg/l set by WHO (2004).

The average concentration of zinc in lake ranged between 48 and 552 μg/l (Table 8). The annual average concentrations were 80, 108, and 252 μg/l which is lower than the European permissible limits (EU 1998) (30–2000 μg/l). The lowest average concentration of Zn was S2 (27.7 μg/l) during 2012 while the highest value was recorded at S11 during 2010 (552 μg/l). The low levels recorded during summer 2012 are probably attributed to high precipitation process of zinc salt from water column to sediment due the high temperature in summer season. The relatively high concentrations of Zn were reported by the low adsorption of Zn in winter with temperature decreasing (Warren and Zimmerman 1994).

Mn concentration in water samples from the 12 sites was observed to be higher at S11 during 2010 (99 μg/l), while S8 during 2015 shows the least value of 13 μg/l (Table 7). The concentrations of Mn within the six sites (S1, S4, S6, S10, S11, and S12) from this portion of Lake Burullus (Tables 7 and 8) exceeded the permissible limit of 50 μg/l (water) and 30 μg/g (USEPA 2002; WHO 2004). It is attributed that the source of manganese compounds as wastes in lake from fertilizers, varnish, and fungicides and as livestock feeding supplements. It can also bioaccumulation in lower organisms (phytoplankton, algae, mollusks, and some fish) but not in higher organisms; biomagnifications in food chains are not expected to be very significant (Abbasi et al. 1998).

The chemical properties are completely different in the 12 sites represented by P, N, H_2S, and OM during the periods 2010–2015 (Table 9). Changing values in all

Table 12 Contamination factor, degree contamination, and modified degree contamination for 2012

SAMPLES 2012	Fe Mg/g	Mn Mg/g	Zn Mg/g	Cu Mg/g	Ni Mg/g	Cr Mg/g	Pb Mg/g	Cd Mg/g	Dc	mDc
1	0.54	1.32	1.11	1.00	0.62	0.60	0.62	0.03	5.83	0.73
2	0.20	0.78	0.57	0.78	0.51	0.47	0.72	0.33	4.36	0.54
3	0.39	1.06	0.46	0.56	0.35	0.26	0.48	0.37	3.92	0.49
4	0.58	1.19	0.72	1.13	0.66	0.36	0.95	1.70	7.29	0.91
5	0.18	1.00	2.00	0.58	0.35	0.39	0.77	0.67	5.93	0.74
6	0.40	1.54	0.69	0.56	0.35	0.40	0.56	1.00	5.50	0.69
7	0.61	1.20	1.06	0.58	0.37	0.42	0.28	0.33	4.85	0.61
8	0.30	1.02	0.61	0.67	0.46	0.46	0.52	0.67	4.69	0.59
9	0.26	0.36	1.04	0.60	0.38	0.40	0.50	1.87	5.40	0.68
10	0.00	0.67	0.54	0.44	0.40	0.29	0.18	1.00	3.51	0.44
11	4.78	1.18	0.81	1.44	0.90	1.06	1.01	0.00	11.18	1.40
12	3.31	1.14	0.93	0.53	0.38	0.36	0.83	0.33	7.81	0.98

Table 13 Contamination factor, degree contamination, and modified degree contamination for 2015 samples

SAMPLES 2015	Fe µg/g	Mn µg/g	Zn µg/g	Cu µg/g	Ni µg/g	Cr µg/g	Pb µg/g	Cd µg/g	Dc	mDc
1	0.54	1.86	0.61	1.16	0.65	0.83	1.10	0.40	7.14	0.89
2	0.18	0.43	0.38	0.42	0.43	0.39	2.10	0.33	4.66	0.58
3	0.22	0.66	0.44	0.40	0.49	0.40	1.30	0.37	4.27	0.53
4	0.61	1.94	0.82	1.31	0.76	0.86	2.10	1.67	10.07	1.26
5	0.16	0.42	0.37	0.33	0.32	0.28	0.95	0.33	3.16	0.40
6	0.40	0.88	0.58	0.56	0.51	0.61	1.25	0.67	5.46	0.68
7	0.43	1.18	0.59	0.71	0.66	0.62	1.65	1.00	6.84	0.86
8	0.34	1.13	0.47	0.56	0.43	0.39	1.75	0.33	5.40	0.68
9	0.32	1.01	0.52	0.53	0.44	0.42	1.30	0.67	5.21	0.65
10	0.35	1.16	0.55	0.58	0.37	0.44	1.70	0.37	5.52	0.69
11	0.56	1.59	0.78	1.00	0.72	0.73	2.05	1.00	8.43	1.05
12	0.34	1.13	0.41	0.47	0.51	0.39	1.60	0.37	5.22	0.65

studied sites are attributed to the difference in the nature and the environmental conditions of the 12 locations.

Phosphorus and nitrogen are the nutrients that ultimately determine productivity in lakes. The highest concentration of phosphorous was observed at sites (S7, S1, S4, and S11, respectively) while site S2 shows the least concentration which ranges from 795 to 895 µg/g. Nitrogen and phosphorus in Burullus Lake support the growth of algae and aquatic plants, which provide food and habitat for fish, shellfish, and smaller organisms that live in water. Phosphorus indicates high concentrations from the periods of 2010 to 2015 which is attributed to the increase of human activity and to be a major cause of excessive algae growth and degraded lake water quality (Table 9). Some algal blooms are harmful to fishes because they produce elevated toxins and bacterial growth. Phosphorus remains in the sediments of the lake as it is generally not available for use by algae; however, various chemical and biological processes can allow sediment phosphorus to be released back into the water.

The concentration of H_2S ranges from 65 to 290 µg/g during 2010, ranges from 55 to 290 µg/g during 2012 and ranges between 12.2 and 250 µg/g. The highest concentrations in three periods were in S7 and S11 indicating that H_2S is an extremely active chemical and biochemical participant in biogeochemical transformations. Its presence and reactions rank with photosynthesis, algal respiration, and the iron in the aquatic environment (Bass Becking et al. 1960). Organic matter (OM) constitutes a minor in Burullus Lake but important in lake sediment which provides information that is important to interpretations of both natural and human-induced changes in ecosystem. The decomposition

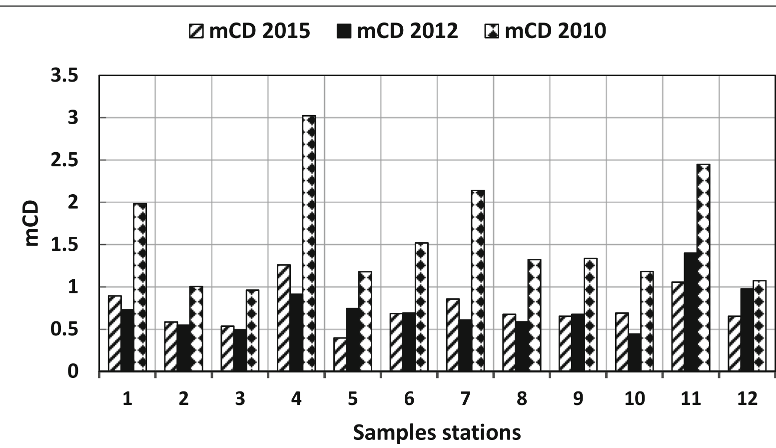

Fig. 4 Modified degree of contaminations (mDc) variations in 3 years. **a** Using this generalized formula to calculate the degree of contamination: mDc = (∑*Dc*)/n. **b** Results show the degree of contamination in bottom sediments through different 3 years

Table 14 Ecological risk factor 2010

Sites	Zn µg/g	Cu µg/g	Ni µg/g	Cr µg/g	Pb µg/g	Cd µg/g	Ri
1	0.93	8.89	2.87	3.16	2.25	160	178.09
2	0.59	2.78	1.72	0.89	2.75	130	138.73
3	0.52	2.44	1.46	0.80	2.25	120	127.47
4	1.14	8.89	3.44	3.20	2.50	430	449.17
5	0.58	2.78	1.76	0.78	2.50	170	178.40
6	0.62	3.89	2.43	1.67	2.00	220	230.60
7	0.59	4.67	2.87	1.89	1.25	320	331.26
8	0.47	4.56	1.72	1.24	2.25	150	160.24
9	1.04	2.67	1.72	1.02	2.00	180	188.45
10	0.55	2.89	1.59	1.09	2.00	160	168.11
11	1.09	7.89	3.13	2.00	2.50	330	346.62
12	0.62	3.22	1.99	1.00	1.25	120	128.08

process of organic matter in sediments occurred in the absence of oxygen (Berner 1963).

Distribution of heavy metals in Burullus lagoon are given in Tables 10. The highest concentration of Fe (28560 µg/g) in the sediment samples was detected at site S7 during 2012, while the least value was observed at site S10 during 2012.

The mean concentrations of heavy metals in Burullus bottom sediments of 2010 were arranged in a descending order as follows: Fe > Mn > Cr > Zn > Ni > Cu > Pb > Cd. The descending order of 2012 is Fe > Mn > Zn > Cr > Cu > Ni > Pb > Cd and in the descending order is Fe > Mn > Zn > Cr > Ni > Pb > Cu > Cd in 2015.

Comparison between the mean concentrations of each heavy metal in bottom sediments of Burullus lagoon in 3 years (2010, 2012, 2015) as Fe, 2010 < 2012 >2015; Mn, 2010 > 2012 < 2015; Zn, 2010 < 2012 > 2015; Cu, 2010 > 2012 > 2015; Ni, 2010 > 2012 < 2015; Cr, 2010 > 2012 < 2015; Pb, 2010 < 2012 < 2015; Cd, 2010 < 2012 < 2015 (Table 10 and Fig. 3).

The contamination factor (CF) for sediments are listed in Tables 11, 12, and 13 during the periods 2010, 2012, and 2015, respectively. The degree of contamination (Dc) and modified degree of contamination (mDc) were calculated and listed in these tables.

Modified degree of contaminations (mDc) were studied for 3 years (2010, 2012, and 2015) (Tables 11, 12, and 13 and Fig. 4), where the mDc vary in the stations as well as in different years as follows:

mDc in 2010 are in the following descending order in different stations S4 > S11 > S7 > S1 > S6 > S9 > S8 > S5 > S10 > S12 > S2 > S3 where mDc in 2012 S11 > S12 > S4> S5 > S1 > S6 > S9 > S7 >S8>S2 > S3 > S10, as well as mDc in 2015 S4 > S11> S7 > S1 > S6 > S9 > S8 > S10 > S5 > S12 > S2 > S3 (Fig. 4).

Ecological risk factor (EC) and potential ecological risk index (RI) were listed in Tables 14, 15, and 16 and Fig. 5.

The potential ecological risk index (RI) was studied for each station in the study area (Tables 14, 15, and 16 and Fig. 5), where they showing the following:

During 2010, 2012, and 2015, the highest value of RI was found for S4 in the middle sector, and the lowest degree of contamination were found for S3 during 2010, for S1 in the eastern sector during 2012, and in middle sector for S5 during 2015 of the Lake Burullus. They were arranged in a descending order as follows: S4 > S11 > S7 > S6 > S9 > S5 > S1 > S10 > S8 > S2 > S12 > S3. During 2012, RI 2012 is S4 > S9 > S6 > S10 > S5 > S8 > S2 > S12 > S3 > S11 > S7 > S1 as well as RI 2015; S4 > S11 > S7 > S6 > S9 > S1 > S2 > S10 > S12 > S8 > S3 > S5 (Fig. 5). This study has explored the potential ecological risk index of some selected heavy metals for

Table 15 Ecological risk factor 2012

Site	Zn µg/g	Cu µg/g	Ni µg/g	Cr µg/g	Pb µg/g	Cd µg/g	RI
1	1.11	5.00	1.85	1.20	3.08	1.00	13.23
2	0.57	3.89	1.54	0.93	3.58	10.00	20.51
3	0.46	2.78	1.06	0.51	2.40	11.00	18.21
4	0.72	5.67	1.99	0.71	4.73	51.00	64.80
5	2.00	2.89	1.06	0.78	3.83	20.00	30.55
6	0.69	2.78	1.06	0.80	2.80	30.00	38.13
7	1.06	2.89	1.10	0.84	1.40	10.00	17.30
8	0.61	3.33	1.37	0.91	2.58	20.00	28.80
9	1.04	3.00	1.15	0.80	2.48	56.00	64.46
10	0.54	2.22	1.19	0.58	0.88	30.00	35.40
11	0.81	7.22	2.69	2.11	5.05	0.10	17.99
12	0.93	2.67	1.15	0.71	4.13	10.00	19.58

Table 16 Ecological risk factor (2015)

SITE	Zn Mg/g	Cu Mg/g	Ni Mg/g	Cr Mg/g	Pb Mg/g	Cd Mg/g	Ri
1	0.61	5.78	1.94	1.67	5.50	12	27.50
2	0.38	2.11	1.28	0.78	10.50	10	25.05
3	0.44	2.00	1.46	0.80	6.50	11	22.20
4	0.82	6.56	2.29	1.71	10.50	50	71.88
5	0.37	1.67	0.97	0.56	4.75	10	18.31
6	0.58	2.78	1.54	1.22	6.25	20	32.37
7	0.59	3.56	1.99	1.24	8.25	30	45.62
8	0.47	2.78	1.28	0.78	8.75	10	24.06
9	0.52	2.67	1.32	0.84	6.50	20	31.85
10	0.55	2.89	1.10	0.89	8.50	11	24.93
11	0.78	5.00	2.16	1.47	10.25	30	49.66
12	0.41	2.33	1.54	0.78	8	11	24.07

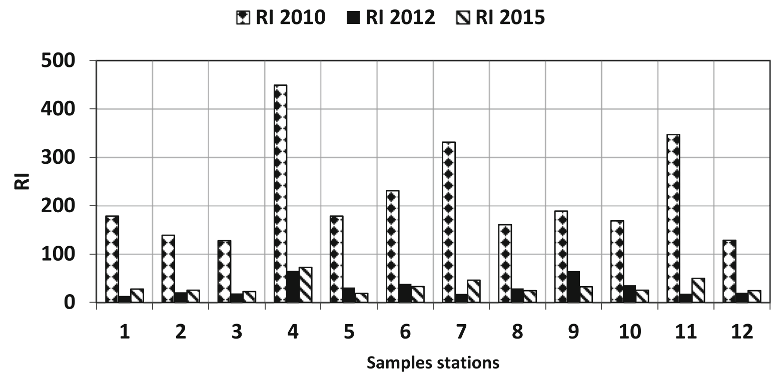

Fig. 5 RI variation in 3 years. **a** The potential ecological risk index (RI) was defined as the sum of the risk actors: RI = ∑Er. B. **b** The results through different 3 years the degree of contamination in bottom sediments

detecting most vulnerable areas to water and sediment pollution at Burullus Lake in all studied sectors during different three periods: 2010, 2012, and 2015.

Conclusions

This study explores the potentiality of environmental risk of some heavy metals (i.e., Fe, Mn, Co, Ni, Cr, Cd, Pb, Zn, and Cu) for detecting most vulnerable areas to water and sediment pollution at Burullus Lake during different three periods: 2010, 2012, and 2015. Comparison between the mean concentrations of each heavy metal in bottom sediments through different 3 years were in the following order Fe, 2010 < 2012 > 2015; Mn, 2010 > 2012 < 2015; Zn, 2010 < 2012 > 2015; Cu, 2010 > 2012 > 2015; Ni, 2010 > 2012 < 2015; Cr, 2010 > 2012 < 2015; Pb, 2010 < 2012 < 2015; Cd, 2010 < 2012 < 2015.

The concentrations of DO, BOD, COD, and TDS during three periods 2010, 2012, and 2015 were higher than the WHO limits.

The highest degree of contamination (mDc) was found for (S4) in middle sector, and the lowest degree of contamination was found for (S3) in eastern sector of the Lake Burullus. mDc during 2010 are in the following descending order in different stations S4 < S11 < S7 < S1 < S6 < S9 < S8 < S5 < S10 < S12 < S2 < S3. During 2012, the highest mDc was found in S11 (south of western sector) and the lowest degree of contamination was in S10 (north of the western sector). They were arranged in a descending order as follows: S11 < S12 < S4 < S5 < S1 < S6 < S9 < S7 > S8 > S2 > S3 > S10. mDc during 2015 were S4 > S11 > S7 > S1 > S6 > S9 > S8 > S10 > S5 > S12 > S2 > S3.

Recommendations

This study tried to introduce some solutions and recommendations for improvement and future management of Burullus Lake like the regular evaluation and monitoring of water and sediment quality. Spatial assessment of water and sediment quality in Burullus Lake are needed to protect the biodiversity in Burullus Lake.

Acknowledgements
The authors acknowledge with thanks the Ministry of Environment for the technical support.

Authors' contributions
All authors contributed equally in this article steps. The author read and approved the final manuscript

Funding
The authors cover the cost in design of the study and collection, analysis, and interpretation of data in the manuscript.

Availability of data and materials
All data generated or analyzed during this study are included in this published article.

Ethics approval and consent to participate
The study was approved by the ethical rules of the National Research Centre.

Consent for publication
Accepted.

Competing interests
The authors declare that they have no competing interests.

Received: 15 October 2018 Accepted: 19 August 2019
Published online: 05 September 2019

References

Abbasi SA, Abbasi N, Soni R (1998) Heavy metals in the environment. Mittal Publications, Delhi, p 314
Abrahim GM (2005) Holocene sediments of Tamaki Estuary: characterization and impact of recent human activity on an urban estuary in Auckland, New Zealand. Ph.D. thesis, University of Auckland, Auckland, p 361
Abrahim GMS, Parker RJ (2008) Assessment of heavy metal enrichment factors and the degree of contamination in marine sediments from Tamaki Estuary, Auckland, New Zealand. Environ Monit Assess.:227–238
APHA (1989) Standard Methods for the Examination of Water and Wastewater, Part 3, Determination of Metals. 17th, American Public Health Association, Washington DC, p 164
Bass Becking LMG, Kaplan IR, Moore D (1960) Limits of the natural environment in terms of pH and oxidation-reduction potentials. J. Geol. 68:243–284
Berner RA (1963) Electrod studies of hydrogen sulphide in marine sediment. Geochimicaet Cosmochimica Acta 27:563–575
Beyersmann D, Hartwig A (2008) Carcinogenic metal compounds: recent insight into molecular and cellular mechanisms. Arch Toxicol. 82(8):493–512

Caeiro S, Costa MH, Ramos TB (2005) Assessing heavy metal contamination in Sado Estuary Sediment: an index analysis approach. Ecological Indicators. 5: 151–169
Chang LW, Magos L, Suzuki T (1996) Toxicology of Metals. CRC Press, Boca Raton
Christophoridis C, Dedepsidis D, Fytianos K (2009) Occurrence and distribution of selected heavy metals in the surface sediments of Thermaikos Gulf, N. Greece. Assessment using pollution indicators. Journal of Hazardous Materials 168(2-3):1082–1091
Chronopoulos J, Haidouti C, Chronopoulou A, Massas I (1997) Variations in plant and soil lead and cadmium content in urban parks in Athens, Greece. Sci Total Environ. 196:91–98
Covelli S, Fontolan G (1997) Application of a normalization procedure in determining regional geochemical baselines. Environ Geol 30:34–45
Darwish DH, El-Gammal M, Mohamedein LI, El-Batrawy O, El-Moselhy K (2018) Evaluation of heavy metals pollution using sediments in Burullus Lake and the nearby Mediterranean Sea, Egypt. International Journal of Environment and water 7(2):p17–p34
Doumont H, El-Shabrawy G (2007) Lake Borullus of the Nile Delta: a short history and uncertain future. Royal Swedish Academy of Science Ambio. 36(8):677–682
El-Moselhy KHM, Saad EM, El-Shaarawy RF, Mohamedein LI, Mohmoud SA (2016) Assessment of heavy metals pollution using sediments and bivalve Brachidontes variabilisas bio indicators in the Gulf of Suez, Egypt. International Journal of MarineScience 6(26):1–13
EU. The quality of drinking water in the European Union, synthesis report on the quality of drinking water in the member states of the European Union in the period 1999-2001 Directive 1998. 80/778/EEC.
Fergusson JE (1990) The heavy elements: chemistry, environmental impact and health effects. Pergamon Press, Oxford
Fifield FW, Haines PJ (2000) Environmental analytical chemistry, 2nd edn. Blackwell Science Ltd, Cambridge
Forstner U, Wittman GTW (1993) Metal pollution in the aquatic environment. Springer-Verlag, Berlin
Håkanson L (1980) An ecological risk index for aquatic pollution control: a sedimentological approach. Water Res. 14:975–1001. https://doi.org/10.1016/0043-1354(80)90143-8
Harris RR, Santos MCF (2002) Heavy metal contamination and physiological variability in the Brazilian mangrove crabs Ucidescordatus and Callinectesdanae (Crustacea: Decapoda). Mar. Biol. 137:691–703
Kremling K (1983) Determination of trace metals. Methods of Seawater Analysis, 2nd edn. Verlag-Chemie, Berlin, pp 189–246
Müller G (1979) Schwermetalle in den sediments des Rheins-Veranderungenseitt 1971. Umschan 79:778–783
Oregioni B, Astone SR (1984) The determination of selected trace metals in marine sediments by flameless/flame-atomic absorption spectrophotometry. IAEA Monaco Laboratory, Internal Report
Pekey H, Karakaş D, Ayberk S (2004) Ecological risk assessment using trace elements from surface sediments of İzmit Bay (Northeastern Marmara Sea) Turkey. Marine Pollution Bulletin 48:946–953
Radwan A, Lotfy I (2002) On the pollution of Burullus Lake water and sediments by heavy metals. Egypt. J. Aquat. Biol. & Fish. 6(4):147–164
Samaan A, Ghobashy AF, AboulEzz M (1989) The benthic fauna of lake Burullus: 1. Community composition and distribution of the total fauna. Bull. Nat. Inst. Oceanogr. Fish Egypt. 15(1):217–224
Schropp SJ, Windom HL (1988) In: Schropp SJ, Windom HL (eds) A guide to the interpretation of metal concentrations in estuarine sediments, Savannah, p 53
Shi G, Chen Z, Bi C, Li Y, Teng J, Wang L, Xu S (2010) Comprehensive assessment of toxic metals in urban and Suburban Street deposited sediments (SDSs) in the biggest metropolitan area of China. Environ. Pollu. 158:694–703
Standing Committee of Analysts. Chemical oxygen demand (Dichromate Value) of polluted and waste waters (second edition) 1986, methods for the examination of waters and associated materials, 1986. ISBN 0117519154.
USEPA. Risk assessment: technical background information. 2002.
Wang S, Shi X (2001) Molecular mechanisms of metal toxicity and carcinogenesis. Mol Cell Biochem. 222:3–9
Warren LA, Zimmerman AP (1994) The influence of temperature and NaCl on cadmium, copper and zinc partitioning among suspended particulate and dissolved phases in an urban river. Water Res. 28(9):1921–1931
WHO (2004) World Health Organization standard for drinking water, Guidelines for Drinking Water Quality, Vol. 1, Recommendation. WHO, France, p 181
Yang Y, Chen F, Zhang L, Liu J, Wu S, Kang M (2012) Comprehensive assessment of heavy metal contamination in sedimentof the Pearl River Estuary and adjacent shelf. Marine Pollution Bulletin 64(9):1947–1955
Zhu W, Bian B, Li L (2008) Heavy metal contamination of road-deposited sediments in a medium size city of China. Environ. Monit.Assess. 147(1–3): 171–181. https://doi.org/10.1007/s10661-007-0108-2

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.