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REGULAR ARTICLE

Assessment of heavy metal contamination in surface water of Burullus Lagoon, Egypt

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Abstract

Burullus Lagoon is one of the five Mediterranean Lagoons of Egypt which used for many purposes including fishing, recreation and contains many organisms. This investigation was aimed to assess the variation pattern in trace metals contamination in different sectors of Burullus Lagoon. Number of 34 representative water samples were collected and analyzed for 7 trace elements according to the standard method. Spatial distribution maps for these metals were created using ordinary Kriging method in ArcGIS. The obtained results indicated that the dissolved heavy metals in Burullus Lagoon were in the range of; Fe (10.55-48.6 µg/l), Pb (2.62-10.76 µg/l), Cu (0.80-48.21 µg/l), Zn (1.65-29.9 µg/l), Co (2.26-7.74 µg/l), Cr (nd-0.82 µg/l) and Cd (nd-9.91 µg/l). The Lagoon is receiving huge amounts of drainage water at the southern parts in comparison to the northern parts. It was also showed that, the highest mean concentrations of most dissolved trace metals take the following sequence: Western > Middle > Eastern. It is highly recommended to control the destructive human activities around the lagoon and to treat resultant wastewater before discharge into the lagoon.

Key words: Burullus Lagoon, GIS, water, pollutants, heavy metals

Introduction

Burullus Lagoon is one of the five Mediterranean Lagoons of Egypt and is important because of the favourable site for the migrating birds and the same time a significant fish resource (Khairy et al., 2015). Apart from its significance, it is one of the most severely affected water resource in the Nile Delta (El-Asmar et al., 2013).

Among the many kinds of pollutions, heavy metal contamination is of more significance due to its wide presence. The progress of industries and intensification of agricultural activities are the main reason of contamination and pollution in ecosystem and water bodies (Zaghloul, 2001; Shafei, 2015). Usually, these heavy metals will pass to the human through the food chain and will cause various problems (Moore et al., 2009). If the heavy metals are present in water bodies it will create undesirable effects in the aqatic life forms and ultimately it will reach human through food web (Lavoie, 2013).

The regular observation of water pollution is an inevitable part of pollution research, as it is the critical factor in human health related issues (Abdullah, 2013). The aim of this work is to determine the concentrations and define distributions of heavy metals in surface waters of Burullus Lagoon to spot the areas most vulnerable to metal pollutants.

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Materials and Methods

Study area

Burullus lagoon is located along the Mediterranean coast bordered from the north by the sea and from the south by the agricultural lands. It lies in the north central position of Kafr El-Sheikh Governorate (31° 36´ N and 31° 07´ Et 31° 22¯N, 30° 33´ E to 31° 22´ N, 31° 07´ E) (Figure 1). Its area is about 460 km^2. Lagoon Burullus is connected to the Mediterranean Sea through the El-Burullus outlet (Boughaz El-Burullus) which is about 250 m wide and 5 m deep. The depth of the Lagoon ranges between 40 cm in its middle sector and near the shores and 200 cm near the outlet to the sea (Shaltout & Khalil, 2005; Zahran & Willis, 2009). Descriptions of sampling locations were as shown in Table (1).

Environmental impact of lagoon

Lagoon area reduction

One of the most hazards that the Lagoon suffers from is area reduction as a result of anthropogenic activities. According to figure (2), it's obvious that the area of Lagoon decreased from the year 1984 (700 km^2) to the year 2014 (460 km^2) while land use changed especially the southern part of the Lagoon as large area changed into fish farms and agricultural lands.

Table 1. Sites description in Burullus lagoon.

Location	N	E	Description
1	31.0083	31.5347	Near Baltim City
2	31.0169	31.5503	El-Burullus area
3	30.9986	31.5456	Elbellaq
4	30.9558	31.5221	Elmahgra
5	30.9885	31.5239	Nearby Elboughaz
6	31.0826	31.5529	East El-Burullus drain
7	31.0292	31.5727	Area before El Boughaz
8	30.9789	31.5771	Elboughaz
9	31.0846	31.5289	Houis Elkashaa
10	31.0765	31.5206	Tirra drain
11	30.961	31.452	Drain (7)
12	30.9168	31.5258	Megatta
13	30.8953	31.5249	N/W El-Burullus
14	30.8539	31.515	Elbiaqo
15	30.8047	31.4982	El-Zanqa
16	30.8129	31.4514	S/W Elkom Elakdr
17	30.8725	31.4627	Bashroush
18	30.925	31.4723	Nearby drain 7
19	30.8454	31.5378	Bar Bahry
20	30.7844	31.5048	Maksba
21	30.7976	31.4154	Damrou drain (8)
22	30.7519	31.4784	El-Maqsaba
23	30.7134	31.4583	Mastrou
24	30.6806	31.4281	Abou Amer
25	30.6568	31.4227	West Abu Amer
26	30.6325	31.416	Elberka El-Gharbia
27	30.6542	31.4099	Open Water
28	30.7067	31.4262	Open Water
29	30.7564	31.4154	Near Elshakhlouba
30	30.6119	31.4311	Zaghloul station
31	30.5681	31.4263	West El-Burullus drain
32	30.5854	31.4009	Brinbal Canal
33	30.6065	31.3831	Elhoks
34	30.7575	31.4028	El Shakhlouba drain (9)

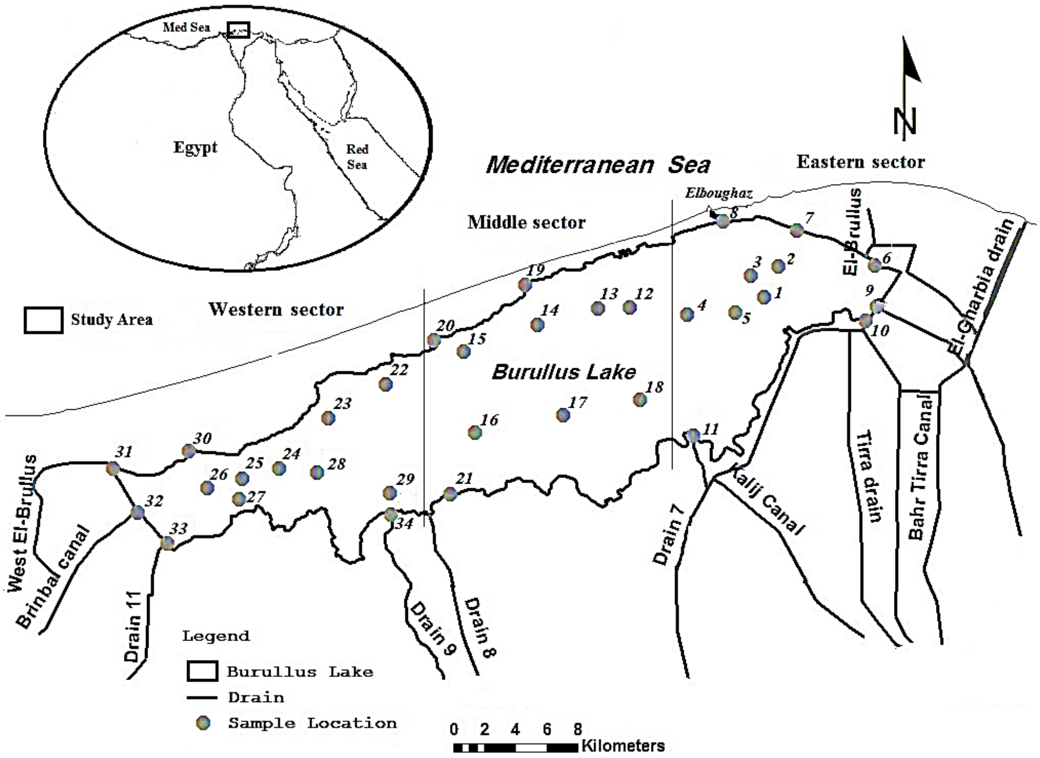

Fig. 1. Sampling locations within Burullus lagoon.

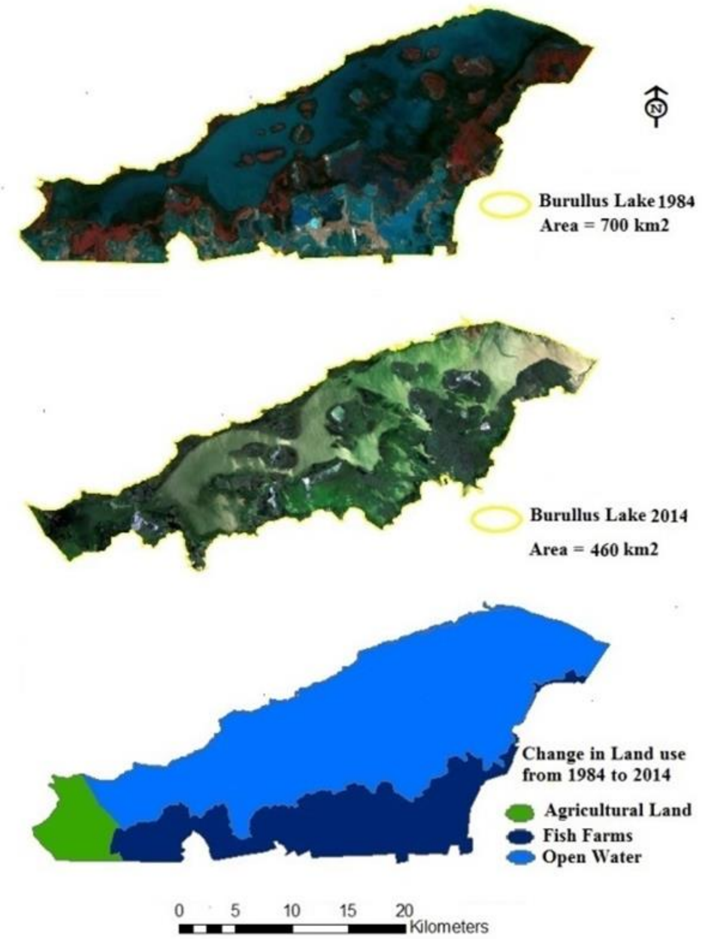

Fig. 2. Change in Lagoon Burullus area within time (1984-2014).

Table 2. Different drains that drain into Burullus Lagoon.

Drain	Description	Inflow (%)
1) Tirra	Sewage, Agricultural and industrial	17
2) Burullus	Agricultural	2
3) Drain (7)	Agricultural and industrial	13
4) Drain (11)	Sewage, Agricultural and industrial	17
5) Drain (8)	Agricultural and fish farms drainage water	12
6) Bur/West	Agricultural	3
7) Drain (9)	Sewage, Agricultural and industrial	19.98
8) Gharbia	Sewage, Agricultural and industrial	12
9) Brinbal	Fresh water from Rosetta Branch (River Nile)	5.09

Drainage system within Burullus lagoon

Agricultural drainage water from about 950 thousand feddan is collected in the catchment area (EMI, 2012). The Lagoon is attached to the Mediterranean Sea via Boughaz El-Burullus at the northeastern part of the Lagoon. Table 2 indicates drains and its uses.

Field measurements

The pH value of surface water was measured in situ by using Electrical-pH meter (Model Lutron YK-2001pH meter) digital analyzer with glass electrode previously adjusted with a standard buffered solution at pH 7. While Conductivity was measured directly using conductivity meter (Model Corning, NY 14831 USA) and the results were expressed as ds.m^{-1}.

Analysis of the dissolved heavy metals

Analysis of the dissolved heavy metals was done by following the standard methods (APHA, 1989). Heavy metals in the obtained solution were measured using the Flame Atomic Absorption Spectrophotometer (AAS: Perkin Elmer Analyst 100).

Statistical analyses

Statistic and correlation analyses were carried out using the statistical analyses were carried out by using the SPSS software package (SPSS. ver.16) program. Cluster analyses based on Bray–Curtis similarity index were calculated using the PAST program (multivariate statistical package, ver. 1.72).

Geostatistics

The Geostatistical analyst in ArcGIS (ver. 10.1) software package was used to develop the ordinary Kriging method and the semivariogram between each pairs of points versus their separation distances (ESRI, 2012). This semivariogram was used in predicting the studied heavy metals in waters of Burullus Lagoon. Table (3) showed RMSE of the Kriging method while creating maps for calculated metals.

Results and discussion

The pH values along three sectors ranged between 7.9 to 8.3 indicated that water is slightly alkaline especially at northern parts. Values of pH are within the permissible limits (6.5 – 9) (Mishra et al., 2008). EC varied from 4.5 ms/cm at the western sector may due to the impact of drained water from Brinbal canal (fresh water source) to 16.7 ms/cm at the eastern part as a result of sea water intrusion in this area from Boughaz El-Burullus in the northeastern part of Lagoon (Table 4 and Fig. 3).

Table 3. Description of Kriging method and fitted parameter of variogram model for dissolved metals in water.

Metal	Type	Mean	RMS	MS	RMSS	AS
Fe	spherical	-0.54	8.06	-0.05	1.04	7.27
Co	spherical	-0.12	1.19	-0.04	0.79	1.53
Zn	spherical	-0.37	5.13	-0.05	0.93	5.13
Cu	spherical	0.27	8.28	0.033	1.04	7.9
Cr	spherical	0.003	0.24	0.01	1.058	0.23
Pb	spherical	0.11	2.03	0.026	0.81	2.47
Cd	spherical	-0.014	4.03	-0.004	1.06	3.75

RMS: root mean square, MS: mean standardized, RMSS: root mean square standardized, AS: average standardized.

Table 4. Concentrations of dissolved heavy metals in Burullus Lagoon.

S. No	pH	EC (ms/cm)	Metal (µg l-1)						
			Fe	Pb	Cu	Zn	Co	Cr	Cd
Eastern sector									
1	8.58	5.1	16.81	9.503	4.825	2.698	2.261	0.185	0.977
2	8.51	10	14.83	10.55	7.16	5.598	2.443	0.426	0.27
3	8.2	41.8	14.31	10.56	2.274	5.057	3.375	ND	0.054
4	8.28	52.8	14.58	4.23	2.665	1.697	7.556	0.268	ND
5	8.29	41.8	13.85	5.07	1.983	2.066	7.735	0.144	0.028
6	7.8	1.61	21.48	4.47	2.774	5.489	7.092	0.111	ND
7	8.11	7.3	13.56	10.6	2.464	2.418	6.645	0.326	0.162
8	8.23	6.26	21.2	5.209	1.727	4.116	6.476	ND	1.246
9	8.26	4.51	21.29	3.25	5.504	4.832	5.005	0.135	9.909
10	8.23	2.47	19.49	2.62	3.768	4.604	5.634	0.102	0.791
11	8.47	10.01	27.67	4.29	1.876	12.31	5.901	0.384	0.323
Middle sector									
12	7.92	9.57	21.09	10.76	3.691	3.926	3.212	0.409	0.323
13	7.93	8.91	13.91	10.69	4.435	3.431	3.195	0.003	0.178
14	7.99	6.5	13.8	10.29	10.61	2.1	4.381	0.824	0.895
15	7.9	4.62	12.16	8.904	4.977	2.109	5.106	0.492	0.262
16	7.9	2.5	12.77	10.51	6.509	3.07	7.489	0.127	1.6555
17	7.78	6.74	11.93	10.62	6.465	3.032	7.535	ND	2.103
18	7.89	7.36	15.24	5.27	4.052	2.071	6.923	0.625	0.06
19	7.79	1.5	15.88	4.74	0.804	2.573	6.476	0.011	0.056
20	7.9	1.5	27.6	5.07	5.463	4.449	6.449	0.235	0.526
21	8.36	5.24	48.6	5.69	1.362	4.619	6	0.011	ND
Western sector									
22	7.75	4.6	18	9.98	7.492	2.43	5.361	0.616	0.72
23	7.84	9.03	11.69	9.35	7.284	1.972	5.319	0.641	0.323
24	7.68	5.69	14.46	8.95	2.501	3.102	4.503	0.285	0.25
25	7.77	3.66	10.55	9.78	3.785	2.433	5.826	ND	0.131
26	7.69	3.93	12.64	10.2	48.21	2.573	5.343	0.376	20.28
27	7.9	2.25	15.61	10.27	5.627	1.646	5.757	0.542	1.005
28	7.93	5.17	17.71	9.24	9.374	5.353	6.039	0.359	3.068
29	7.97	4.51	16.95	2.9	1.664	1.946	6.636	0.285	0.16
30	7.91	1.4	36.76	7.97	7.661	29.9	5.853	0.169	0.486
31	7.81	1.3	18.89	5.2	3.053	10.87	5.478	0.567	0.3
32	8.15	5.2	24.08	4.25	2.267	2.58	6.193	0.252	ND
33	8.05	2.5	22.22	4.59	2.255	2.947	5.514	0.393	ND
34	8.06	10.06	24.3	4.53	2.842	3.968	6.283	ND	ND
EPA, 2002			300	50	50	5000	--	100	2.37

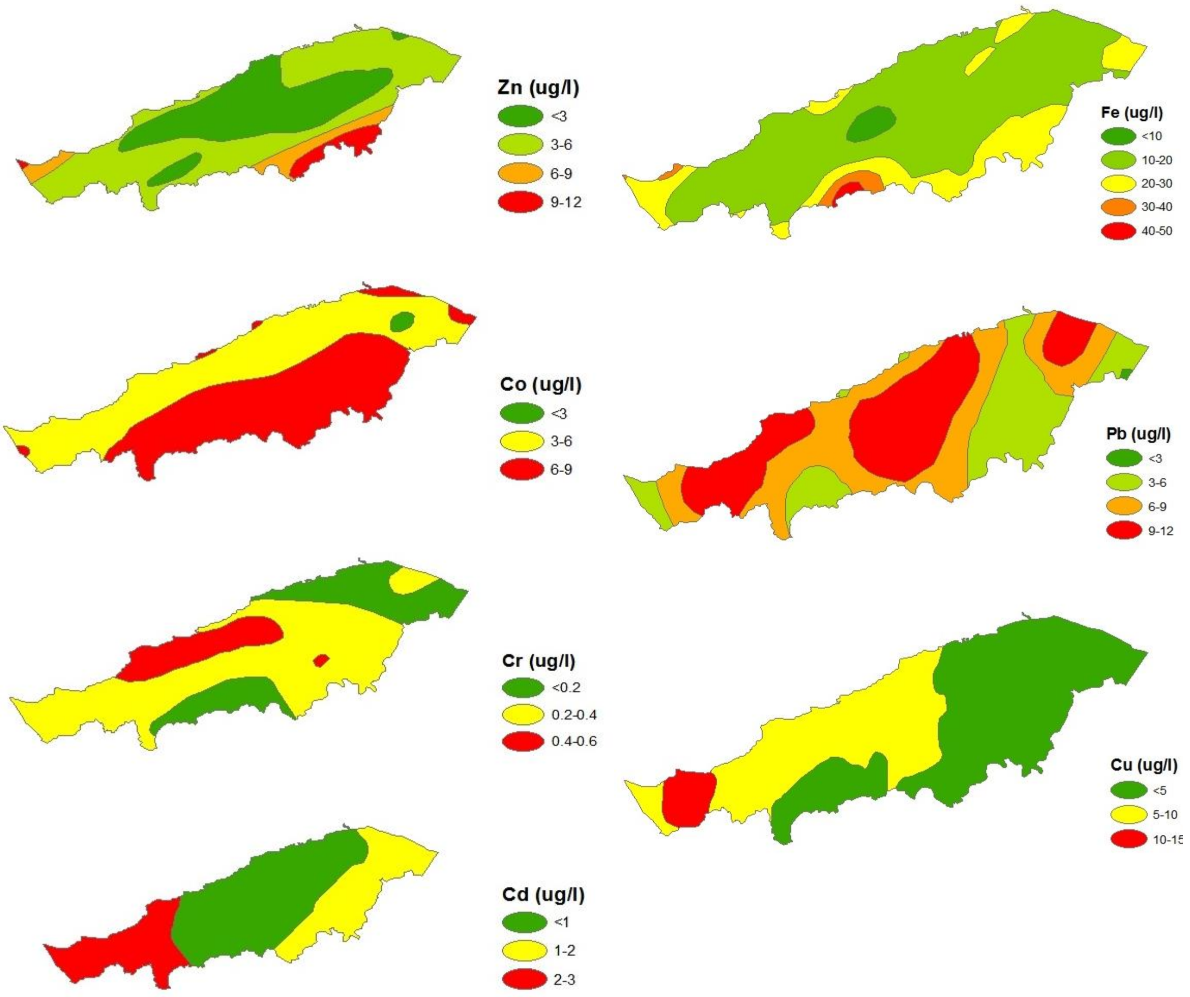

Fig. 3. Spatial distribution of dissolved metals in water samples of Burullus Lagoon using GIS tool.

Dissolved trace element concentrations are generally taken as indicators of the water bodies contamination (Moore et al., 2009). There are many natural sources of metals which will reach to water bodies. Other than this there are industrial and domestic wastes supply metals to aquatic forms (Zarazua et al., 2006). The concentrations of dissolved heavy metals in water samples of Burullus Lagoon within different sectors are as shown in Table 4. Heavy metals in water take the following sequence; Fe > Pb > Co > Cu > Zn > Cd > Cr.

Iron (Fe)

Iron is a trace element in water bodies but its high concentrations harm the aquatic flora and fauna (Ajayan & Parameswara, 2014). It is the most abundant element of the heavy metals in most Lagoons. This is agreed with the findings of Shama et al. (2011). The highest value of iron (48.6 µg/l) was recorded at Damru drain, while the lowest value (10.55 µg/l) was obtained at west of Abou Amer area far from drainage areas. These values are lower than that (1550 µg/l) recorded by Basiony (2014). The high values detected at drains locations. This might be due to the flushing of agricultural drainage and industrial wastes (Abdel-Moati and El-Sammak, 1997). The iron values were within the limit of EPA (2002) (300 µg/l).

Copper (Cu)

Cu is a toxic metal for aquatic life if exceeded a certain limit (Horne & Dunson, 1995) The highest concentrations of copper were observed nearby drains and highly distributed in the western part as a result of shipping activities using antifouling paints including Cu. The estimated Cu values in the water are within the EPA (2002) limit (2.37 µg/l).

Zinc (Zn)

Zinc contributes a degree of toxicity to the aquatic life (Datar & Vashishtha, 1990). It will affect the human health as well if present in an excessive amount (Nriagu, 2007). The highest concentration of dissolved zinc was recorded at north part (29.9 µg/l) as a result to drainage water. These values are within the EPA (2002) limit (5000 µg/l). According to the Egyptian standards for copper and zinc (out of 1000 µg/l) in receiving water bodies are very high (European standards are 50 µg/l for copper and 150 µg/l for zinc).

Lead (Pb)

This element can create undesirable effects in high concentration like hemorrhages and congestion of the gastrointestinal tract and kidneys of fish (Abdelhamid & El-Ayouty, 1991). The highest concentration of lead (10.76 µg/l) was recorded at Megatta area. This may be due to anthropogenic activities. The lowest value was (2.9 µg/l). These results are higher than those (4.13 - 10 µg/l) recorded by Masoud et al. (2011) and Darwish (2008) and lower than those (79.9 -12.07 µg/l) obtained by Basiony (2009 & 2014). The concentrations of lead in the water are within the limit of EPA, 2002.

Cadmium (Cd)

Cadmium is a non-essential element and is highly toxic to marine and freshwater aquatic life (Edokpayi, 2016). There may be natural causes as well, for this metal. the lowest mean value of cadmium was obtained at the Lagoon open water far away from drains, while the highest mean value was recorded at Houis El-Khashaa (9.91 µg/l) as a result of agricultural wastes especially agricultural fertilizers, this is in agreement with Hamed et al. (2013). This value is lower than (14 µg/l) recorded by Saeed & Shaker (2008), but higher than (3.83 and 10 µg/l) recorded by Masoud et al. (2011) and Basiony (2014), respectively. The estimated Cd values in the water are more than the EPA (2002) limit (2.37 µg/l).

Chromium (Cr)

Chromium is mainly coming from sewages and industrial flushes (Pawlisz et al., 1997). The highest concentration of Cr in Burullus Lagoon was (0.567 µg/l) at west El-Burullus drain which may contain untreated sewage. But the lowest concentration was observed at N/W El-Burullus area. The present value is lower than those recorded by Basiony (2014). The maximum value of Cr is within EPA (2002) limit (100 µg/l).

Cobalt (Co)

The highest concentration of cobalt (7.74 µg/l) was observed in the eastern part of the lagoon which may attribute to the anthropogenic activities. Cobalt may be coming from agricultural or industrial activities (Akan et al., 2012). The lower value of cobalt (2.26 µg/l) was recorded nearby Baltim city.

The results showed that the western sector of the lagoon was contaminated with dissolved metals because of drainage water from two serious drains namely Elhoks (industrial drainage water) and Elshakhloba drains, followed by middle sector and finally the eastern sector, it may be attributed to intrusion of sea water that make dilution to water in this side of lagoon. The decreasing of Cu concentration in surface water in the eastern sector is related to the increasing of pH. While, rapid decreasing of Zn concentration in water in acidic conditions, this is agreed with Balintova et al. (2012). Average values of pH, EC and dissolved metals within sectors of Lagoon Burullus are shown in Table 5 and Figs. 4, 5.

Table 5. Average values of pH, EC and dissolved metals within sectors of Lagoon Burullus, ns = not significant at $P < 0.05$. *: Values are significant at $P < 0.05$, **: Values are significant at $P < 0.01$, ***: Values are significant at $P < 0.001$.

Variable		Sector in Lagoon			Mean	F-value	$LSD_{0.05}$	EPA (2002)
		Eastern	Middle	Western				
pH		$8.3^{a} \pm 0.06$	$7.9^{b} \pm 0.05$	$7.9^{b} \pm 0.04$	8.03	0.0001^{***}	0.16	-
EC (ms/cm)		$16.7^{a} \pm 5.69$	$5.4^{b} \pm 0.92$	$4.5^{b} \pm 0.73$	8.87	0.032^{*}	10.64	-
Fe		$18.10^{a} \pm 1.36$	$19.30^{a} \pm 3.60$	$18.76^{a} \pm 1.93$	18.72	0.674^{ns}	6.71	300
Pb		$6.40^{a} \pm 0.96$	$8.25^{a} \pm 0.85$	$7.48^{a} \pm 0.76$	7.38	0.473^{ns}	2.73	50
Cu		$3.37^{a} \pm 0.53$	$4.84^{a} \pm 0.88$	$8.00^{a} \pm 3.43$	5.40	0.413^{ns}	7.96	50
Zn	(µg l^{-1})	$4.63^{a} \pm 0.88$	$3.14^{a} \pm 0.30$	$5.52^{a} \pm 2.14$	4.43	0.656^{ns}	1.72	5000
Co		$5.47^{a} \pm 0.59$	$5.68^{a} \pm 0.51$	$5.70^{a} \pm 0.15$	5.61	0.933^{ns}	1.43	-
Cr		$0.23^{b} \pm 0.04$	$0.30^{ab} \pm 0.09$	$0.41^{a} \pm 0.06$	0.31	0.093^{ns}	0.20	100
Cd		$1.53^{a} \pm 0.88$	$0.67^{a} \pm 0.23$	$2.67^{a} \pm 1.54$	1.62	0.646^{ns}	3.74	2.37

Different superscript letters (a, b) indicate significant differences ($P < 0.05$) between different sector in Burullus Lagoon

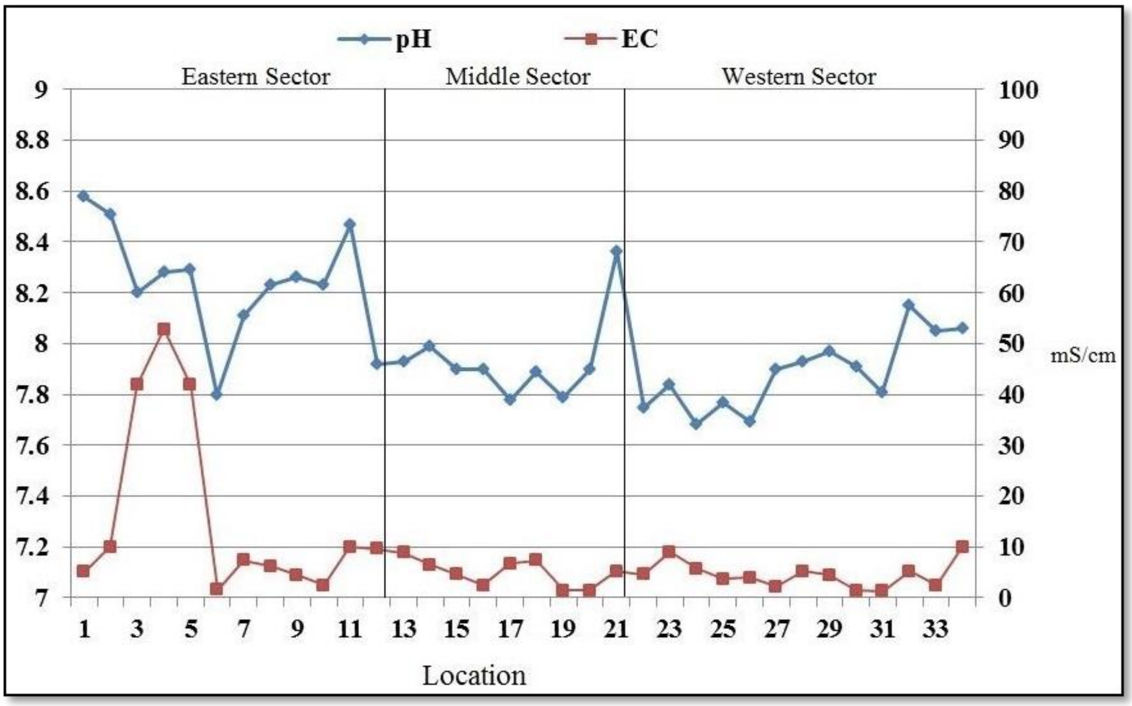

Fig. 4. Distribution of pH and EC within sectors of Burullus Lagoon.

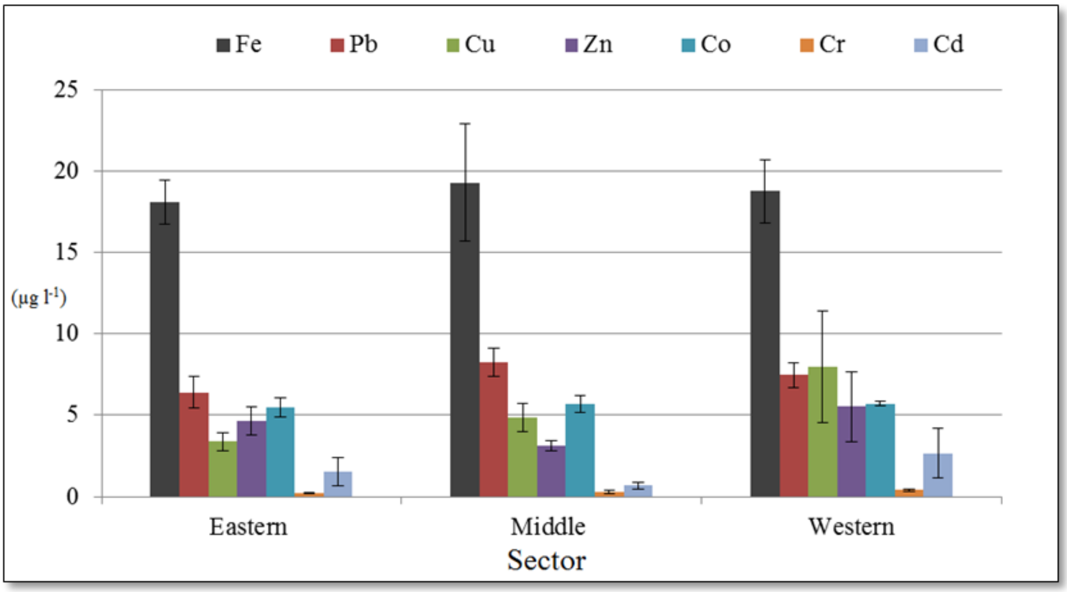

Fig. 5. Means and standard errors of dissolved heavy metals within sectors of Burullus Lagoon.

Table 6. Pearson moment correlation between different variables within sectors of Lagoon Burullus. *: Values are significant at P < 0.05, **: Values are significant at P < 0.01.

Variable	pH	EC	Fe	Pb	Cu	Zn	Co	Cr	Cd
pH	1								
EC	0.348*	1							
Fe	0.146	-0.213	1						
Pb	-0.200	-0.068	-0.361*	1					
Cu	-0.278	-0.132	-0.162	0.309	1				
Zn	0.066	-0.170	0.824**	-0.135	-0.044	1			
Co	-0.295	0.161	0.064	-0.446*	-0.071	0.031	1		
Cr	-0.223	-0.086	-0.217	0.3	0.148	-0.152	-0.089	1	
Cd	-0.154	-0.129	-0.106	0.059	0.887**	-0.079	-0.020	-0.057	1

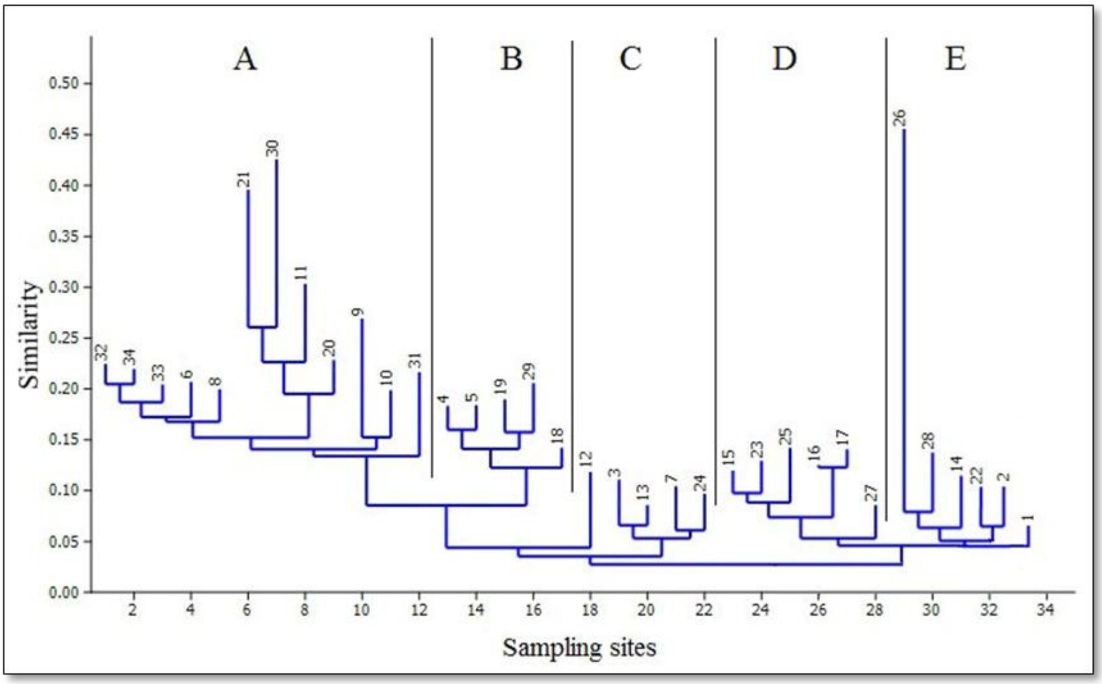

Fig. 6. Similarity dendrogram of sampling sites plotted according to heavy metals analysis of water samples in Burullus lagoon.

From Table (3), mean standardized is close to zero as it varied from -0.05 to 0.033 and the RMSS is close to 1 as it ranged between 0.79 and 1.058. When the average estimated prediction errors were close to the root mean square prediction errors from cross validation, then it could be confident that the root mean square prediction errors were appropriate (Omran et al., 2014; El-Gammal et al., 2015).

The spatial distribution of dissolved metals was mapped using ArcGIS tool to indicate the most areas vulnerable to pollutants (Fig. 3). It's obvious that the highest concentrations of metals were observed at the outlets of drains, and the lowest concentrations were near the northern parts far from drainage areas.

As shown in Table (6) Iron showed significant positive correlation with zinc and copper with cadmium. But there is negative significant correlation between lead with iron and cobalt. It may be interpreted that metals positively correlated are coming from similar sources, but those negatively correlated were from different sources (Dan et al., 2014).

The cluster analysis of sampling sites according to heavy metals maintained fairly similar trends, exhibiting five distinct clusters (A-E), each composed of similar sampling sites distributed within these three sectors of the study area. The clustering pattern indicated that the similarity index of sampling sites in groups as following: A-C, B-D and E (Fig. 6). Groups of A and C representing the sites of northern part of Lagoon, whereas groups B and D occupying the most sites of southern part. Group E representing the sites of drains outlets.

Conclusion

Burullus Lagoon suffers from different pollutants agricultural, industrial or municipal wastes. The quality of water was affected by different pollutants especially trace metals. The western sector of the lagoon was contaminated with dissolved metals, followed by middle sector and finally the eastern sector. The concentrations of dissolved metals were highly distributed nearby drains outlets. So we recommended that; wastewater must be treated before being drained into lagoon, periodical assessment and monitoring of different pollutants in Lagoon Burullus, using new tools in tracking the sources of pollutants and great efforts and cooperation between different authorities are needed to solve pollution problems in the lagoon.

Authors' contributions

Authors contributed equally to the overall design of the study as well as field work, treatment of data and manuscript preparation and approved the final version of the manuscript for publication.

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