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Distribution of benthic foraminiferal assemblage and heavy metals as a characterization of the environment in Lake Edku, Egypt.

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ABSTRACT

Lake Edku receives considerable amounts of domestic, agricultural, and industrial waste water. Accordingly, the response of benthic foraminifera to heavy metal pollution has been assessed. Surficial sediment samples were collected at 11 stations throughout the lake during June and December 2013. At each station, pH, dissolved oxygen, temperature, salinity, transparency, water depth, concentrations of Pb, Cu and Cd were measured. Benthic foraminiferal distribution and its relationship with environmental parameters and heavy metal concentrations have been investigated using redundancy analysis (RDA) and cluster analysis. The resulted data show that the foraminiferal distribution was significantly affected by these heavy metals pollution. The distribution pattern shows great dominance of *Ammonia tepida* which confirms its tolerance to heavy metals pollution especially Cu and Cd. *Porosononion* spp. correlates positively with Cu, while *Saccorhiza ramosa* correlates positively with Pb and Cd. The most sensitive species to higher concentrations of heavy metals is *Ammonia Parkinsoniana*. It has negative correlation with Pb, Cu and Cd. Limited number of living foraminiferal specimens, low foraminiferal density and diversity have been recorded in Lake Edku. Relatively high percentage of deformed foraminiferal tests (~ 21%) has been observed in the lake.

INTRODUCTION

Coastal ecosystems, including coastal lakes, have been impacted by several human activities such as urban sewage, industrial and agricultural activities or fisheries, and results in environmental problems, such as eutrophication, oxygen deficiency, chemical pollution or physical disturbance (Barras *et al.*, 2014). Heavy metals are dispersed throughout the modern environment mainly as a result of pollution from a variety of industrial sources and continuously enter the aquatic ecosystem where they pose a serious threat because of their toxicity, long persistence and bioaccumulation in the food chain (Papagiannis *et al.*, 2004; Abdallah, 2012). Heavy metals, unlike other pollutants, are not biodegradable and can accumulate in sediments overtime (Tang *et al.*, 2008). Sediments act as a major repository for many natural and anthropogenic contaminants entering the coastal marine systems and can preserve a record of the pollution sources and pathways (Campbell and Tessier, 1989; Degetto *et al.*, 1997).

Among all the benthic microfauna, Foraminifera (class Foraminifera, phylum Granuloreticulata) are the more abundant and most conspicuous protozoa in most marine and brackish water habitats (Murray, 1991; Armynot du Châtelet *et al.*, 2004). The utilization of benthic foraminifera as pollution indicators has many advantages, as they are easy to collect. They have short reproductive cycle (the majority between a few months and a year), which increase their ability to reflect relatively short- to long-term variations. They are small and are often found in high biodiversity and density populations, providing an adequate statistical base. Their mineralized tests readily preserved in the sediments providing an evidence of environmental stress through time. Benthic foraminifera are very sensitive to rapid physicochemical variation in the environment (Alve, 1991; Coccioni, 2000; Yanko *et al.*, 2003; Armynot du Châtelet *et al.*, 2004; Frontalini and Coccioni, 2008; Frontalini *et al.*, 2010). The application of foraminifers for pollution assessment is based on the variation in population assemblages, total foraminiferal number, species diversity, and abnormalities of the foraminiferal tests in the areas affected by pollution (Jayaraju *et al.*, 2008; Elshanawany *et al.*, 2011; Foster *et al.*, 2012; Cosentino *et al.*, 2013; Martins *et al.*, 2013; Barras *et al.*, 2014). The responses of foraminifera can include local extinctions, resulting in a barren zone where polluted levels are high, as well as assemblage modifications with increased density and low diversity (Yanko *et al.*, 1994; Alve, 1995; Cearreta *et al.*, 2002; McGann *et al.*, 2003; Frontalini and Coccioni, 2008). Moreover, other studies investigating the response of foraminifera to pollution have shown that a lower density and diversity occurs in the most polluted areas (Alve, 1991; Armynot du Châtelet *et al.*, 2004; Ferraro *et al.*, 2006; Romano *et al.*, 2008; Armynot du Châtelet and Debenay, 2010; Frontalini and Coccioni, 2011; Cosentino *et al.*, 2013; Martins *et al.*, 2013). Several studies have been focused on benthic foraminiferal response to trace element pollution all over the world (in western Norway e.g., Alve, 1991; in Italy e.g., Coccioni, 2000; Ferraro *et al.*, 2006; Frontalini and Coccioni, 2008; Coccioni *et al.*, 2009; Frontalini *et al.*, 2009; 2010; Frontalini and Coccioni, 2011, in France, e.g., Armynot du Châtelet *et al.*, 2004; Foster *et al.*, 2012, in Portugal, e.g., Martins *et al.*, 2010; 2013; in the Central Mediterranean Sea e.g., Cosentino *et al.*, 2013; in China, e.g., Li *et al.*, 2014; 2015, in the Murter Sea e.g., Vidovic *et al.*, 2014). Along the Egyptian Coast, some related studies have been done (e.g., Samir, 2000 in Edku and Manzalah Lakes; Samir and El-Din, 2001 in El-Max and Miami Bays; Elshanawany *et al.*, 2011 in Abu Qir Bay; Orabi *et al.*, 2017 in Burullus lagoon). The previous studies in Lake Edku were dealing with physical and chemical characteristics (Shakweer, 2006; Badr and Hussein, 2010; Abdel Halim *et al.*, 2013; Khalil and Rifaat, 2013). Persistent organochlorine pollutants, metals residues in sediment, water, freshwater fish species and aquatic macrophytes were also investigated (Badr and Fawzy, 2008; Barakat *et al.*, 2011; Shreadah *et al.*, 2012; Abdallah and Morsy, 2013). Unfortunately, foraminiferal data in Lake Edku was very few (e.g., Samir, 2000). In this previous study, the data was limited to few station numbers (five stations) and the seasonal aspect has not been covered.

The aim of this research is to test the suitability and applicability of using benthic foraminifera as bioindicator of heavy metal pollution and pollution monitoring in the studied lake, investigate the distribution and abundance of benthic foraminifera in relation with different environmental parameters and heavy metal concentrations in the sediments. Moreover, foraminiferal seasonal changes will be assessed in this study.

Study area

Lake Edku is a shallow brackish coastal basin situated on the western margin of the Nile Delta, 30 km to the east of Alexandria. It lies between longitude 30°8' and 30°22'E and latitude 31°10'" and 31°18'N. Its area has decreased from 28.5 × 10^3 to about 12 × 10^3 Feddans as a result of agricultural reclamation (Abdel Halim *et al*., 2013). The bottom sediments of Lake Edku are rich in silt and clay in the eastern part, and sand near the Lake-Sea connection. A transition zone of shelly mud is found in the central part of the Lake (Ibrahim, 1994). It receives its water from two drains namely: El-Khairy and Barsik. El-Khairy and Barsik Drains discharge huge amounts of drainage waters to the lake. The water sources of El-Khairy Drain are from three drainage waters transporting domestic, agricultural and industrial wastes, as well as the drainage water of more than 300 fish farms. Barsik Drain transports mainly agricultural drainage water to the lake. (Badr and Fawzy, 2008; Badr and Hussein, 2010). The lake receives seawater at its northwestern part through Boughaz El-Meadia from Abu Qir Bay. In recent years, waste waters from industrial and domestic activities have been directly released into Lake Edku in increasing quantities through the drains network, without any pre-treatment. A rapid rise in petro-refineries and fertilizer manufacturing industries is the major source of pollution in the region. Relatively low depth and slow water exchange make contaminants available at higher concentrations (Abdallah and Morsy, 2013) (Fig. 1).

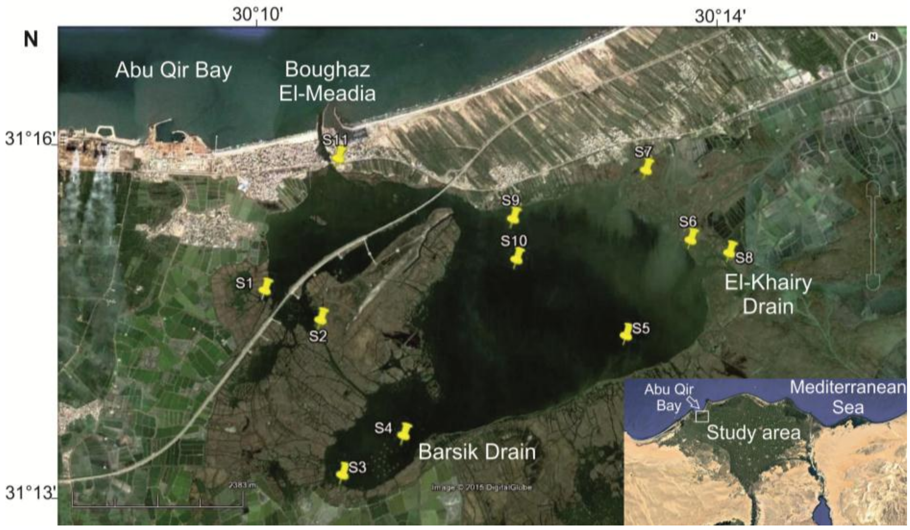

Fig. 1: A Satellite image of Lake Edku showing location of sampling stations.

MATERIALS AND METHODS

Sampling and sediment preparation

Surface sediment samples were collected seasonally from 11 stations (S) in June (J) and December (D) 2013 with a stainless steel grab. Sampling locations were determined with Global Position System. Two aliquots from each sample were taken at each station. The first was stained with Rose Bengal and used through the study of foraminiferal assemblages and the second to measure trace element contents in the sediment. At each station, pH, DO, temperature, salinity, transparency and water depth were measured.

Heavy Metals analysis

Metal content in the collected samples were determined using acid digestion adopted by Wade *et al*. (1993); 0.1 g dried sediment samples were digested with 3 ml

HNO_3 and 2 ml HF for 24 h at 130ºC in a closed Teflon vessels, then 17 ml of boric acid 5% was added to the mixture and diluted up to 25 ml with distilled water then the mixture was stored for analysis. Concentrations of Pb, Cu and Cd were determined using SHIMADZU Atomic Absorption Spectrophotometer AA – 6800. For quality control (QC) and quality assurance (QA), a standard reference material was also digested and analysed similarly to ensure the accuracy of the heavy metals analysis.

Foraminiferal analysis

A constant volume of 50 cm^3 of sediment was taken from the upper 2 cm of each sample and saturated with a solution of Rose Bengal following Walton's technique (1952) to distinguish between living and dead foraminifera. In the laboratory, samples were gently washed through a 63 µm sieve with tap water to remove clay, silt and any excess dye. The residual fractions obtained were oven-dried at 60°C overnight. Whenever possible, at least 300 well-preserved benthic foraminifera from each sample were picked, counted and classified under a binocular microscope. Species were identified by comparison with Cimerman and Langer (1991), Sgarrella and Moncharmont-Zei (1993), and supraspecific classification was based on Loeblich and Tappan (1987). All deformed tests, whenever present, were picked from each sample and morphologically examined.

Statistical analysis

All statistical analyses were performed on foraminiferal relative abundance data; only species showing relative abundance greater than 2% in at least one sample was used. Cluster analysis was performed using version 1.88 of PAST software package (Hammer *et al*., 2008). A Q-mode analysis (sample by sample) was used to produce a dendrogram classification of studied samples, while R-mode analysis was used to produce a dendrogram classification of species to group samples, according to their similarities or differences, in multidimensional space (Murray, 2006). In Q and R mode analyses, the correlation using Spearman's Rho was applied.

Diversity of the foraminiferal assemblage was determined using version 1.88 of PAST software package. Four diversity modes were used. The dominance (D), Simpson index, the Shannon diversity (H), and Fisher’s alpha (S) were calculated as defined by (Hammer *et al*. 2008), applying the equations $D = \Sigma\ (ni\ /\ n)^2$, *Simpson index* = 1 − *dominance*, $H = -\ \Sigma\ (ni\ /\ n)\ ln\ (ni\ /\ n)$, and $S = \alpha\ ln\ (1 + n\ /\ \alpha)$ where ni = number of individuals of taxon i, n = total number of individuals, S is number of taxa, and α is the Fisher’s alpha.

A Detrended Correspondence Analysis (DCA) was performed to test, whether species exhibit a unimodal or linear response to an environmental gradient (Leps and Smilauer, 2005; Leyer and Wesche, 2007). Redundancy Analyses (RDA) were carried out to quantify the relationship between the distribution of benthic foraminifera and ecological parameters such as heavy metal concentrations, water depth, DO, pH, temperature and salinity, using the software package Canoco, version 4.5 (Ter Braak and Smilauer, 2002; Leps and Smilauer, 2005).

RESULTS

Environmental parameters

In the present study, the recorded depth of the investigated stations ranges from 0.43 m at S2 to 2.5 m at S11(Boughaz El-Meadia) in June and ranges from 0.26 m at S8 (El-Khairy Drain) to 3.32 m at S11 in December (Boughaz El-Meadia). Boughaz El-Meadia station (S11) is the deepest station in both seasons. S8 and S2 have the lowest depth in December. Generally the water depth is low in both seasons especially in December, but it increases towards Lake-Sea connection (Table 1).

Water temperature undergoes huge seasonal variations but it has narrow spatial variations in both seasons. It has a range of 15.3°C at S5 and 17.9°C at S11 in December. It ranges from 26.7°C at S1 to 29.2°C at S7 in June. Temperature is higher in June than in December (Table 1).

Water salinity of Lake Edku has a general spatial increasing trend towards Boughaz El-Meadia and S1and a seasonal increasing trend in June. It ranges from 0.8‰ at S7 to 5.5‰ at S1 in June and from 0.1‰ at S8 (El-Khairy Drain) to 0.9‰ at S11 (Boughaz El-Meadia) and S1 in December. Station 1 and S11 have the highest salinity values in both seasons. On the other hand S7 and S8 (El-Khairy Drain) have the lowest salinity value in June and in December respectively (Table 1).

The pH values in the investigated stations have small spatial and seasonal variations. It ranges from 7.7 at S4 to 8.82 at S11 in June and from 7.33 at S8 to 8.49 at S4 in December (Table 1). The data show that the water of Lake Edku is slightly alkaline.

Lake Edku is oxygenated with a range of 2.51 mg/l at S8 and12.51 mg/l at S3 (Table 1).

The Water transparency of Lake Edku increases toward the Mediterranean Sea at S9, S10 and S11 as the depth increases. It has a range of 16.5 cm at S6 and 86.5 cm at S9 (Table 1).

Table 1: Environmental parameters in the investigated stations of Lake Edku during June and December 2013.

Stations	Latitude (N)	Longitude (E)	Depth (m)	Temperature (°C)	pH	DO (mg/l)	Transparency (Cm)	Salinity (‰)	Pb (µg/g)	Cu (µg/g)	Cd (µg/g)
S1J	31° 15´ 00.4	30° 10´ 09.2	0.93	26.7	8.28	-	-	5.5	89.35	30.96	0.000
S1D	31° 15´ 00.4	30° 10´ 09.2	0.41	16.0	8.09	8.51	20.5	0.9	76.58	24.10	0.000
S2J	31° 14´ 46.8	30° 10´ 39.2	0.43	27.6	8.46	-	-	1.8	116.15	48.46	0.000
S2D	31° 14´ 46.8	30° 10´ 39.2	0.38	16.5	8.33	9.38	17.0	0.3	72.75	25.45	0.700
S3J	31° 13´ 36.7	30° 10´ 51.9	1.00	28.5	8.46	-	-	1.5	84.25	36.89	0.425
S3D	31° 13´ 36.7	30° 10´ 51.9	0.65	16.3	8.18	12.51	16.8	0.3	98.29	49.54	0.338
S4J	31° 13´ 54.4	30° 11´ 24.3	1.00	26.8	7.70	-	-	1.7	141.69	30.43	0.738
S4D	31° 13´ 54.4	30° 11´ 24.3	0.78	15.9	8.49	10.16	32.0	0.2	91.90	19.79	1.175
S5J	31° 14´ 39.6	30° 13´ 23.3	1.48	27.7	8.47	-	-	1.2	131.46	37.43	0.000
S5D	31° 14´ 39.6	30° 13´ 23.3	0.63	15.3	7.92	9.95	18.5	0.2	76.58	53.73	0.700
S6J	31° 15´ 23.5	30° 13´ 58.7	1.15	27.3	8.04	-	-	0.9	80.41	96.79	0.000
S6D	31° 15´ 23.5	30° 13´ 58.7	0.54	17.1	7.52	4.22	16.5	0.2	97.00	71.61	0.125
S7J	31° 15´ 56.1	30° 13´ 35.1	0.95	29.2	7.74	-	-	0.8	85.53	44.83	0.000
S7D	31° 15´ 56.1	30° 13´ 35.1	0.72	17.3	7.90	7.78	56.5	0.2	82.96	46.59	0.038
S8J	31° 15´ 17.5	30° 14´ 19.5	1.50	28.7	7.96	-	-	1.1	109.78	49.26	0.000
S8D	31° 15´ 17.5	30° 14´ 19.5	0.26	16.5	7.33	2.51	15.5	0.1	91.90	68.25	0.000
S9J	31° 15´ 33.4	30° 12´ 22.9	1.23	27.3	8.77	-	-	0.9	76.59	29.35	0.000
S9D	31° 15´ 33.4	30° 12´ 22.9	1.97	16.3	8.29	8.11	86.5	0.2	61.28	8.75	0.000
S10J	31° 15´ 14.6	30° 12´ 24.7	1.30	26.8	8.76	-	-	1.1	88.08	46.31	0.000
S10D	31° 15´ 14.6	30° 12´ 24.7	1.17	16.5	8.14	6.96	72.5	0.2	91.90	0.00	0.213
S11J	31° 16´ 01.7	30° 10´ 47.9	2.50	28.8	8.82	-	-	4.5	99.55	3.24	0.000
S11D	31° 16´ 01.7	30° 10´ 47.9	3.32	17.9	8.03	6.06	71.5	0.9	84.25	16.29	0.125

Heavy metal content in surface sediment

Lead (Pb) has the highest values of the studied metals at all stations. Station 4 (Barsik Drain) has the highest Pb concentrations especially in June. It ranges from 61.28 µg/g in the central part at S9D to 141.69 µg/g at S4J (Barsik Drain) in the western part. Station 9, S10, followed by S11 have lower Pb values in both seasons compared to the other stations. Pb has higher concentration values in June at most of the stations (Table 1).

Copper (Cu) has the highest value at S6 in both seasons (96.79 µg/g in June and 71.61 µg/g in December), followed by S8 (El-Khairy Drain) especially in December (68.25 µg/g). Station11 has the lowest detectable value (3.24 µg/g in June and 16.29 µg/g in December) followed by S9 especially in December (8.75 µg/g). It has undetectable limit at S10 in December. It has higher values in June compared to December at the most of stations (Table 1).

Cadmium (Cd) exhibits the lowest level of the studied metals in Lake Edku sediments; it reaches to nearly zero value at some stations, while it shows a maximum of 1.175 µg/g at S4 (Barsik Drain) in December and 0.738 µg/g in June. Cadmium (Cd) has more recognizable values in December compared to June (Table 1).

According to U.S. Environmental Protection Agency (U.S. EPA, 1999) and Environmental Canadian Standards (2002), Lake Edku sediments exceed the permissible limits of Pb, Cu and Cd in several stations (Table 2).

Table 2. Permissible limits of Heavy metals (µg/g). Abbreviations: U.S. EPA: U.S. Environmental Protection Agency; C-EQG: Canadian Environmental Quality Guidelines; PEL: Probable Effect Level; ISQG: Interim Sediment Quality Guideline

Metal	U.S. EPA	C-EQG		Present study
		PEL	ISQG	
Pb	31	91.3	33	61.28–141.69
Cu	16	197	35.7	0–96.79
Cd	0.6	3.5	0.6	0–1.175

Benthic Foraminiferal Assemblage

Rotaliina is the most dominant suborder; representing 89.9% of the total foraminiferal assemblage. Textulariina is the second most dominant suborder; representing 7.1% of the total foraminiferal assemblage. Miliolina, representing 2.92% of the total foraminiferal assemblage, is in the third order and about 0.08% representing different other suborders, unknown species and/or fragments. Rotaliina has the highest abundance values in almost all stations except at S4J. It decreases significantly at Boughaz El-Meadia. Textulariina was observed only at S4J (96%), S7D (39%) and S8j (2.4%). Miliolina abundance was low at almost all stations and it increases towards Lake-Sea connection especially at S11 (Boughaz El-Meadia) (Fig. 2). Among 38 recorded species belonging to 20 genera; 15 species showing relative abundance greater than 2% in at least one sample. *Ammonia tepida* is the most dominant taxon representing 51.5% of the total foraminiferal assemblage. It is followed by *Ammonia Parkinsoniana* representing (32.1%), *Saccorhiza ramosa* (7.14%), and *Porosononion* spp. (2.5%).

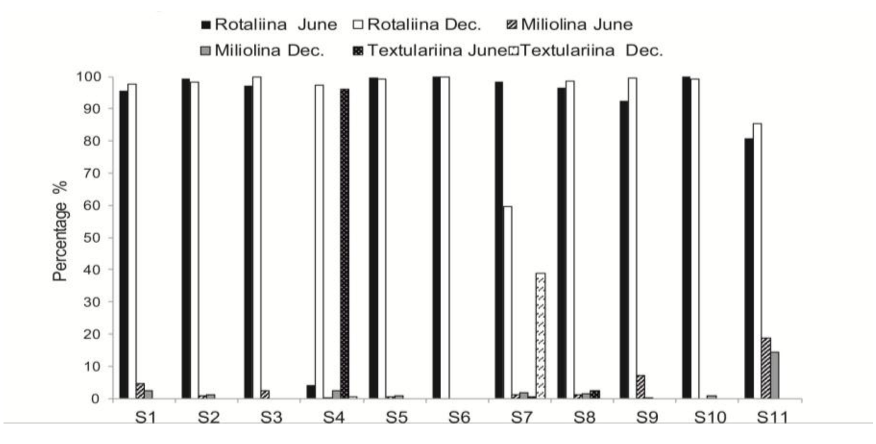

Fig. 2: Distribution pattern of the major foraminiferal suborders in Lake Edku.

Ammonia tepida, the most dominant taxon, decreases towards Boughaz El-Meadia which connects Lake Edku with the Mediterranean Sea. It has lower values at S9, S10 and S11 in both seasons and at S4J. Concerning the seasonal distribution, *A.*

tepida has high relative abundances in winter season (Fig. 3a). *Ammonia parkinsoniana*, the second most dominant species, has its highest values at S10 (74.6% in June and 54.2% in December) and S9 (60.7% in June and 42.8% in December). Its distribution is higher in June than December (Fig. 3b). *Saccorhiza ramose*, the third dominant species, has its maximal distribution (96%) at S4J (Barsik Drain). It was recorded sporadically in two other stations S7D and S8J (El-Khairy Drain) with lower percentage 39% and 2.4% respectively. It has very low percentage (0.4%) at S4D (Fig. 3c). *Porosononion* spp., the fourth dominant species, has its highest abundance at S2D (7.9%) and S1D (7.6%) (Fig. 3d). *Quinqueloculina lata*, the fifth dominant species, has its highest values at S11J (8.9%) and S9J (4.7%). Its distribution is higher in June than in December with some exceptions (Fig. 3e).

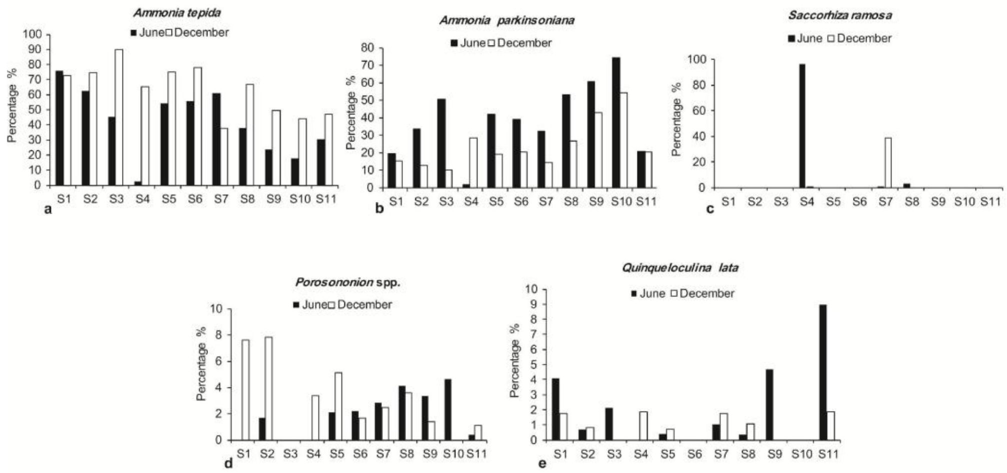

Fig. 3: Distribution pattern of the five most-dominant foraminiferal species expressed as relative abundance.

Dead benthic foraminifera

The distribution trend of living foraminifera is low in almost all stations of Lake Edku. Living foraminiferal percentage are higher in June than in December. Non-living foraminifera has higher percentage especially in December. The highest percentages of living foraminifera were found at S10J representing 53.76% and S8J representing 42.76%, while the highest percentages of non-living foraminifera were found at S4J (Barsik Drain) representing 100% and S8D (El-Khairy Drain) representing 95.34% (Fig. 4).

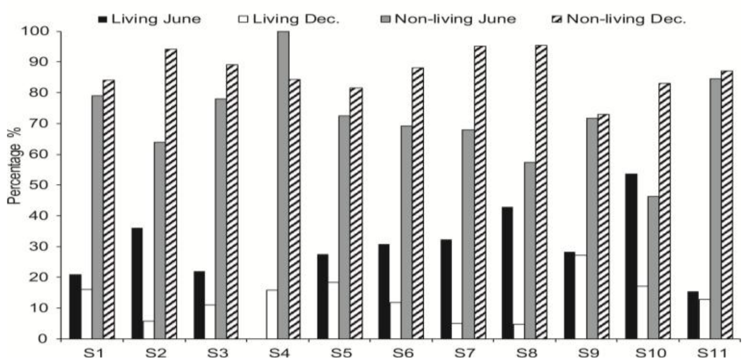

Fig. 4: Distribution pattern of living and non-living foraminifera in the investigated samples.

Foraminiferal density and diversity

Concerning the total foraminiferal assemblage, foraminiferal density (number of individuals per 50 cm^3 of sediment) is highly variable at spatial scale ranging from

64 individuals per 50 cm^3at S6D to 152228.6 individuals per 50 cm^3 at S10D. It has two outstanding peaks at S10D and S9J (152228.6 and 140169.6 individuals per 50 cm^3 respectively) (Table 3).

Table 3: Density, diversity indices and percentage of deformed species in the investigated stations of Lake Edku.

Station	S	Individuals	Dominance	Shannon	Simpson	Fisher's	Density	Deformed
S1J	4	292	0.618	0.678	0.382	0.656	17528.6	9.2
S1D	10	288	0.561	0.917	0.439	2.012	10600.0	15.6
S2J	6	294	0.506	0.829	0.495	1.067	1350.2	12.2
S2D	11	242	0.582	0.910	0.418	2.374	1200.0	19.0
S3J	7	281	0.463	0.881	0.537	1.301	26250.0	16.7
S3D	2	276	0.818	0.328	0.182	0.292	8528.6	10.9
S4J	4	300	0.916	0.217	0.084	0.652	4446.4	3.0
S4D	7	267	0.507	0.888	0.493	1.316	1500.0	17.2
S5J	5	237	0.475	0.840	0.525	0.896	6037.5	8.9
S5D	4	136	0.602	0.721	0.398	0.773	74.5	20.6
S6J	6	136	0.465	0.911	0.535	1.284	71.5	20.6
S6D	3	118	0.650	0.587	0.351	0.560	64.0	17.8
S7J	12	283	0.478	0.974	0.522	2.541	1753.8	10.6
S7D	12	284	0.314	1.415	0.686	2.539	1101.7	7.0
S8J	10	290	0.428	1.058	0.572	2.008	352.2	9.3
S8D	7	279	0.523	0.865	0.477	1.303	1114.3	7.2
S9J	19	298	0.428	1.300	0.572	4.520	140169.6	13.5
S9D	9	292	0.431	1.031	0.569	1.758	24725.7	9.2
S10J	8	279	0.589	0.824	0.411	1.536	26062.5	10.8
S10D	7	295	0.488	0.789	0.512	1.287	152228.6	5.1
S11J	28	245	0.158	2.393	0.842	8.149	35863.6	11.0
S11D	18	273	0.275	1.841	0.726	4.326	18573.5	9.9

Regardless of these two peaks, foraminiferal density increases toward seaward direction at S9, S10, S11 in both seasons and decreases in stations near to the discharge such as S6, S8 (El-Khairy Drain), S4 (Barsik Drain) and S5 in both seasons. S6 is considered as very poor station in both seasons, followed by S5 in December. In addition, Total foraminiferal density shows clear seasonal trend; since foraminiferal density is generally higher in June compared to December (Table 3).

Species diversity refers to the number of taxa in an assemblage, while dominance is expressed as a percentage of the population, and lower dominance tends to be found with higher diversity (Armstrong and Brasier, 2005). Concerning the total foraminiferal assemblage, the foraminiferal diversity is low in the investigated stations and increases towards the sea connection near Boughaz El-Meadia. For example, Shannon diversity H has low values with a range of 0.217 to 1.841 with the exception of S11 which reaches to 2.393. Station11 in both seasons, S7D and S9J have the highest different diversity indices values, while S4J, S3D and S6D have the lowest values (Table 3). The opposite trend was recorded for the dominance; since the most seaward station (S11) has the lowest dominance in both seasons (Table 3). No clear seasonal diversity pattern has been recorded. Few species numbers are recorded in the study area. It ranges from 2 to 19 with the exception of S11 at Boughaz El-Meadia; since it reaches to 28 (Table 3).

Test deformation

In this study, the percentage of deformed tests are relatively high (up to ~ 21% of the total foraminiferal assemblage). There are ten modes of deformation including: lose milioline coiling (Fig. 5.1), not rounded periphery (Fig. 5.2–5), protruding in last chamber (Fig. 5.6-8), abnormal additional chamber (s) (Fig. 5.9–10), distortion in coiling (Fig. 5.10), Siamese twins (Fig. 5.11, 12), abnormal growth (Fig. 5.13–17), division in last chamber (Fig. 5.18), spiroconvex shape (Fig. 5.19), and highly deformed specimens (Fig. 5.20). The distribution of deformed specimens was decreasing towards the Lake-Sea connection at S9, S10 and S11. In contrast, higher deformation percentages are present at S1, S2, S3, S4, S5, S6 and S7 with few exceptions. The highest percentages of deformed foraminifera were found at S6J and S5D (20.58%) while the lowest percentage of deformed foraminifera were found at S4J (3%) and S10D (5.08%) (Table 3). The highest deformation percentage was recorded in Rotaliina (11.24%). *Ammonia tepida* is the highest deformed species in Rotaliina suborder (7.5%), followed by *A. parkinsoniana* (3.48%) and *Porosononion* spp. (0.12%). Miliolina showed very low deformation percentage (0.1%). Only *Q. lata* and *Quinqueloculina* spp. were deformed. Textulariina shows no deformation.

Redundancy analysis (RDA)

The length of the first gradient of DCA indicates the linear character of the dataset, that's why RDA has been processed. The first RDA axis represents 34.8% of the total variance, while the second RDA axis represents 24.1% of the variance. From the statistical analysis four groups with comparable distribution patterns can be recognized. Group 1 composes of one species, *S. ramosa*. This species indicates a close positive relation to Pb, Cd concentrations and to a lesser extent with temperature, water depth and salinity, while it indicates a negative correlation with pH and moderate negative correlation with Cu content and DO (Pb-Cd tolerant species). Group 2 is dominated mainly by *A. tepida* followed by *Porosononion* spp. They are ordinated at positive part of the Cu, DO gradient and at the negative part of Pb, temperature, depth and salinity. *Ammonia tepida* shows a similar correlation as *Porosononion* spp., but with different gradient length. Additionally *A. tepida* shows a moderate positive correlation with Cd, while *Porosononion* spp. shows a moderate negative correlation with Cd (Cu and/or Cd tolerant, Pb sensitive species). Group 3 is dominated by *A. parkinsoniana*. This species is related to higher temperature, pH, water depth, while it related to lower Pb, Cd and Cu content and DO (heavy metals sensitive species). Group 4 is dominated by the rest of species which is ordinated in the center of graph (Fig. 6).

Cluster analysis

R-mode cluster analysis groups the species into two main clusters, (A, B). Two distinct sub-clusters (A1 and A2) can be recognized within cluster A. Sub-cluster A1 is composed of *S. ramosa*. Sub-cluster A2 is divided into A2I and A2II. A2I is composed of *A. parkinsoniana* (sensitive species) and it is distinguished from the rest of the species (A2II). Cluster B is composed of the tolerant species such as *A. tepida* and *Porosononion* spp. (Fig. 7). Q-mode cluster analysis is succeeded in separating S11D (Boughaz El-Meadia), the less polluted station, in cluster A. The rest of the stations are grouped in cluster B. Station 4J, which is dominated by *S. ramose*, is distinguished in sub-cluster B1. The rest of stations are located in sub-cluster B2 (Fig. 8).

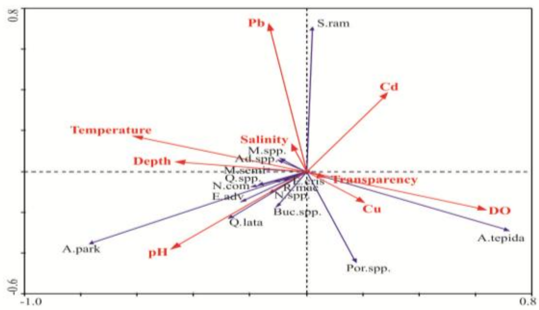

Fig. 6. Redundancy Analysis (RDA) for all surface samples showing species-environment relationships. Abbreviations: Ad.spp.: *Adelosina* spp., A.park: *Ammonia parkinsoniana* (d'Orbigny, 1839), A.tepida: *Ammonia tepida* (Cushman, 1926), Buc.spp.: *Buccella* spp., E.adv: *Elphidium advenum* (Cushman, 1922), E.cris: *Elphidium crispum* (Linnaeus, 1758), M.semi: *Miliolinella semicostata* (Wiesner, 1923), M.spp.: *Miliolinella* spp., N.com: *Nonion commune* (Kassel, 1963), N.spp.: *Nonion* spp., Por.spp.: *Porosononion* spp., Q.lata: *Quinqueloculina lata* (Terquem, 1876), Q.spp.: *Quinqueloculina* spp., R.mac: *Rosalina macropora* (Hofker, 1951), S.ram: *Sacchoriza ramosa* (Brady, 1879).

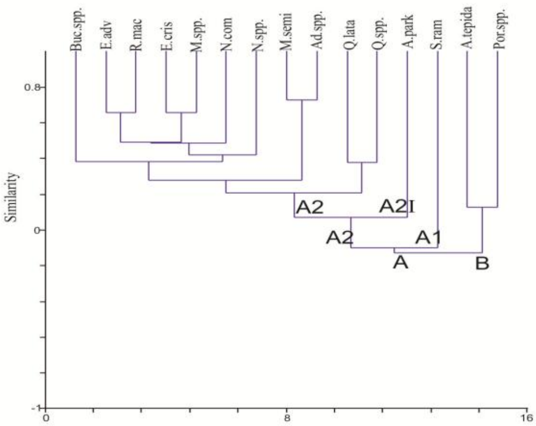

Fig. 7. Dendogram produced by R-mode cluster analysis using Rho Correlation Spearman's for the investigated species. Species abbreviations are listed in Figure 12.

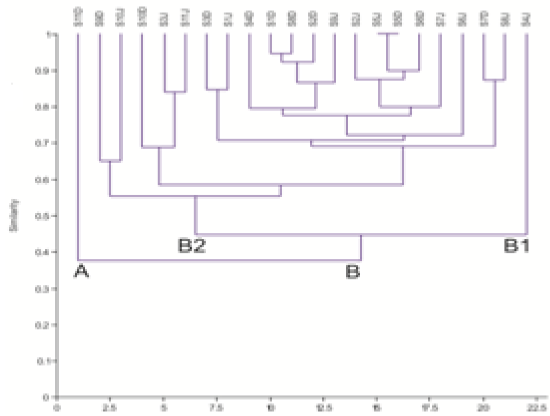

Fig. 8: Dendogram produced by Q-mode cluster analysis using Rho Correlation Spearman's for sediments of the investigated stations.

DISCUSSION

Variability of environmental parameters in the study area

High values of Pb, Cu and Cd were recorded in the sediment of Lake Edku. The most of these values exceed the permissible limits according to U.S. EPA (1999) and Environmental Canadian standards (2002). Some previous studies in Lake Edku recorded lower values of heavy metals compared to the present study (Masoud *et al*., 2005; Gu *et al*., 2013; Abdalla and Morsy, 2013; El-Said *et al*., 2014), while other previous studies reported lower values of Pb and Cu but higher values of Cd (Abdel-Moati and El-Sammak, 1997; El Zokm *et al*., 2015) (Table 4). This could be related to the increased pollution levels in the lake as a result of accumulated continuous discharge.

Table 4: Comparison between the heavy metal data (µg/g) observed in the present study and the previous heavy metal data in Lake Edku (µg/g.)

Pb	Cu	Cd	References
61.28–141.69	0–96.79	0–1.175	Present study
20	19	7.30	Abdel-Moati and El-Sammak (1997)
1.15–2.41	1.83–2.57	0.62–1.56	Masoud *et al*. (2005)
2.4±0.6	2.2±0.4	1.1±0.5	Abdalla and Morsy (2013)
15	62	1.19	Gu *et al*. (2013)
-	62.26	-	El-Said *et al*. (2014)
0.783–81.079	2.16–47.266	0.157–2.939	El Zokm *et al*. (2015)

These metals distribute in Lake Edku as a result of anthropogenic activities; The use of $CuSO_4$ as an algicide in treating and controlling the massive macroalgal blooms in the Nile, especially during summer, which makes navigation nearly impossible, is the main source of Cu to the Nile water, streams and drains and its transfer through the drainage water to the Nile delta lakes (Abdel-Moati and El-Sammak, 1997). El-Khairy and Barsik Drains are the major sources of pollution in Lake Edku. They transport huge amounts of mostly agricultural drainage enriched with Cd as by-products of fertilizers and Cu which used in the manufacturing of fertilizers and algicide (Sanita di Toppi and Gabbrielli, 1999; Badr and Fawzy, 2008). Therfore we focused in the current study on the analysis of Pb, Cu and Cd. Metal concentrations in sediments of Lake Edku varies spatially and temporally. Spatial variations of trace metals in sediments are likely caused by discharges of sewage, industrial activities, and surface runoff along the coastal areas (Tang *et al*., 2008). The distribution and accumulation of heavy metals are influenced by complex factors, such as sediment composition and structure, grain-size, and the hydrodynamic conditions (Christophoridis *et al*., 2009; Qiao *et al*., 2013). Due to these multiple factors, heavy metal concentrations in sediment change spatially and temporally (Liu *et al*., 2011). El-Said *et al*. (2014) revealed that the variation of heavy metal concentrations in Lake Edku was reliant on lithology and anthropogenic activities sources.

The current water depth data indicate that it is a shallow lake; the water depth is low especially in December, but it increases towards Lake-Sea connection which is in agreement with Shakweer (2006) and Badr and Fawzy (2008). Lake Edku shows low salinity with a range of 0.1‰ to 5.5‰. The low salinity recorded for Lake Edku indicates the discharge of drainage water from agricultural lands surrounding the lake (Badr and Fawzy, 2008). The drainage water plays an important role in decreasing the salinity of the lake water (Shakweer, 2006(. Water temperature undergoes huge seasonal variations but it has narrow spatial variations in both seasons. Shakweer (2006) revealed that the shallow Lake Edku follow water temperature variations parallel to those of air temperature. The shallowness of these lake as well as the effect of blowing winds contribute in mixing the whole water body. Therefore variations in water temperature between surface and bottom water lie in a narrow range. The pH data show that the water of Lake Edku is slightly alkaline which is in agreement with Badr and Fawzy (2008) and Abdalla and Morsy (2013). They attributed the elevation of pH to the relative abundance of aquatic plants in the lake which increases the rate of photosynthesis which in turn causes an increase in the CO_2 consumption and hence increase in pH values. Lake Edku is an oxygenated lagoon which is in agreement with Shakweer (2006) and Badr and Fawzy (2008). On the other hand, Abdallah and Morsy (2013) recorded lower values of DO. It is a matter of fact that in shallow water bodies the dissolved oxygen is greatly affected by air and water temperatures, wind mixing and photosynthetic activity. The oxidation processes in water and sediments can be also considered as an important factor controlling the dissolved oxygen in water. The importance of dissolved oxygen for aquatic plants and animals is directly related to the respiration process or indirectly with the oxidation of organic matter in water and sediments (Shakweer, 2006). The Water transparency of Lake Edku increases toward the sea at S9, S10 and S11 as the depth increases. Due to the shallowness of Lake Edku, the seasonal variation of wind directions and duration affects greatly the transparency of this lake (Shakweer, 2006). Shakweer (2006) observed also that the sechi depth reached its minimum value during spring and this can be attributed to the maximum flourishment of phytoplankton which plays an effective role in decreasing the visibility in the shallow lake water. The stagnancy of the water during summer and autumn decreases the turbidity in the whole area of the lake and therefore higher sechi depths were recorded during these two seasons in comparison with winter where the wind actions increase the turbidity of the water especially in the shallower water of the eastern basin.

Foraminiferal species density and diversity

Higher foraminiferal density values were recorded in the seaward direction. In the current polluted study area foraminiferal diversity is generally low with the exception of seaward stations. The decreased species diversity and density in polluted stations of Lake Edku is in agreement with Samir and El-Din. (2001), Armynot du Châtelet *et al*. (2004), Bergin *et al*. (2006) and Li *et al*. (2014) who concluded that density and species diversity of the assemblages decrease with an increase in heavy metal concentration and may be used as pollution indicators. Banerji (1992) recorded that species diversity is less in sediments with Co–Ni–Pb. Jayaraju and Reddy (1996) proved that pollution from industrial effluent causes reduced diversity and population. Nigam *et al*. (2002) reported decline in total foraminiferal number and species diversity as a result of increased suspended load from mining activities. Martins *et al*. (2010) reported that higher total available concentrations of As, Cd, Cu, Ni, Pb and Zn have an adverse effect on the living assemblages of benthic foraminifera inducing not only low diversity but also higher dominance. Benthic foraminifera respond negatively at the site of high intensity of pollution (Naidu *et al*., 2000). Armynot du Châtelet *et al*. (2011) also concluded that the concentration of heavy metals (Cr, Cu and Zn) had a strong negative impact on species richness patterns in benthic foraminifera. A reduction in species diversity and specimen density was probably induced by increasing pollution (Cherchi *et al*., 2009). Ferraro *et al*. (2006) observed a reductions in foraminiferal density and species richness were revealed as a response to an increase in trace element pollution. In particular, they documented a completely barren area which corresponded to the greatest concentrations of trace elements (Pb, Hg, Ni and Zn) from two to nine times higher than at the other stations. In the current work, S6 could be considered more or less as a barren area. This poor foraminiferal density could be related to high Cu value. On the other hand, some previous studies showed that population density of foraminifera may increase in vicinity of sewage outfalls (Watkins, 1961; Nikulina *et al*., 2008). Alve (1995) stated that the increased abundances have been reported from areas that receive effluents primarily from pulp and paper industries.

In the current study, the dominance of few species was recorded. Since *A. tepida* and *A. parkinsoniana* are representing 83.6% of the total community, and together with *S. ramose* are representing 90.7% of the total community. This may indicate the stressful condition of Lake Edku. Cognetti (1992) reported that the dominance of a low number of species indicates environmental stress. On the other hand, Alve (1995) showed that the high abundance of one species in an area affected by a particular effluent does not necessarily imply that it is the most tolerant species. However, it can be the most successful opportunist, with a rapid turnover rate and the ability to quickly colonize a disturbed area almost independent of the type of contaminant.

Comparing current foraminiferal diversity with previous foraminiferal diversity study in Lake Edku in 2000, we found a remarkable decrease in the diversity. Samir (2000) reported higher species number (9–23) and higher Shannon H values of (1.46–1.82) in Lake Edku. This is may be related to the continuous increased discharge in the lake.

Density and diversity of foraminifera increases towards the sea connection. The highest diversity was observed at S11 (Boughaz El-Meadia), which may be attributed to high salinity, increasing water depth and/or grain size in addition to its far away position from pollution sources. This salinity effect is in agreement with Martins *et al*. (2013) who reported that salinity has significant positive correlation with foraminiferal density and diversity. Foraminiferal density and diversity reach higher values near the lagoon mouth under higher marine influence. Increasing water depth at S11 could attribute to the increasing foraminiferal density and diversity in this station. According to Buzas *et al*. (2007), foraminiferal abundance and species diversity increase with depth. Sediments structure is the most important factor affecting density and diversity of benthic foraminifera (Armynot du Châtelet *et al*., 2009). Khalil *et al*. (2013) revealed that the sediments collected from Lake Edku composed of a mixture of sand silt and clay; the Lake-Sea connection has sand rich sediments derived from the Mediterranean Sea and marine sediment. The eastern basin rich with silt and clay sediments which transported by the drains. The sediment of Barzik drain is rich with sand fraction, while El-Khairy drain is rich with silt and clay sediments. The increasing foraminiferal density and diversity in the sandy station of S11 is in disagreement with Armynot du Châtelet *et al*. (2009) and Sadough *et al*. (2013). They reported that the relatively fine grain-size is associated with a high foraminiferal density and richness.

Living *vs*. dead foraminifera and the effect of seasonality

In the current study, the total foraminiferal density and the percentage of living foraminifera have the same increasing pattern in summer, which could be related to increased temperature rather than to pollution. Morvan *et al*. (2006) showed that temperature may act directly on the biology of foraminifera, or, indirectly, by increasing their food supply (microflora). Reproduction periods have often been considered as a response to the increase in food supply resulting from phytoplankton blooms (e.g., Walton, 1955; Alve and Murray, 1994). Shakweer (2006) reported that maximum flourishment of phytoplankton in Lake Edku occurs during summer. Hence, the increase of density and living foraminifera in summer may be attributed to the increase of phytoplankton. Serandrei Barbero *et al*. (2003) studied the temporal changes in benthic foraminiferal assemblages. They pointed out that the main controlling factor of the productivity of benthic foraminifera is the occasional availability of phytoplankton. The life cycle of shallow-water benthic foraminiferal species may be strongly influenced by seasonality (Murray, 1991)**.** Buzas (1965) observed that the total number of live individuals was greatest in the summer when maximum water temperature and highest abundance of zooplankton and phytoplankton occurred along U.S. Atlantic coast. Nikulina *et al*. (2008) observed that foraminiferal population density showed a patchy distribution and a response to food availability, which is depicted by SiO_2 and Chl-*a* in the sediments. They noticed a positive correlations of population density with biogenic silica and chlorophyll-*a*. On the other hand, Murray and Alve (2000) did not notice any correlation between the size of the standing crop and the chlorophyll *a* content of the surface sediment at either station of the Hamble Estuary.

Reproduction occurs annually, but not all species reproduce at the same time. Changes in density are directly related to reproduction patterns (Debenay, 2009). Many studies suggested that reproduction peaks, responsible for higher densities, occur once or a few times a year, but other studies pointed out that foraminiferal assemblages are not always affected by year cycles. Even if maximum standing crop often occurs at some particular time of the year, continuous or nearly continuous reproduction throughout the year is a commonplace (Buzas *et al*., 2002; Morvan *et al*., 2006). In the present work, we will not discuss in detail the seasonal reproduction pattern for each species; since the percentage of living fauna is very small compared to non-living one. This low living foraminiferal percentage may be related to the increased pollution level in the study area. In addition, better understanding of the seasonal variations could be made through sampling in additional seasons and years. Milker *et al*. (2015) demonstrated that seasonal variability has an insignificant influence on the distribution of live species in the intertidal environments of Bandon Marsh, Oregon, USA. They collected samples in summer and fall of two successive years. They attributed this to precipitation as it influences the pore water salinity in salt marshes.

Higher numbers of dead foraminifera were found at El-Khairy and Barsik drains which prove the detrimental effects of pollution on the foraminiferal assemblages. This is in agreement with Setty (1982), who reported that living foraminifers are absent in polluted areas. Cearreta *et al*. (2000) also reported that living foraminifera were absent from surface sediments in the upper Bilbao estuary (North Spain), and were not abundant in the middle and lower estuary, due to persistent anoxia in the estuarine channel, and possibly, high pollutant concentrations.

Closs and Madeira (1968) reported that reproduction periods of the abundant species are diverse and may change from one station to the other. Based on the same kind of observations, Buzas *et al*. (2002) proposed a model where individual foraminifers are spatially distributed as a heterogeneous continuum, forming patches with different densities that are only meters apart. Reproduction is a synchronous causing patches that vary in space and time. One station may exhibit seasonal periodicity while a nearby station may not (Morvan *et al*., 2006). The two extreme total foraminiferal density peaks at S9J and S10D may be interpreted by this foraminiferal patchy distribution.

In the present study no clear seasonal diversity trend was recorded, in spite of some previous studies recorded minimum values of foraminiferal species number and alpha index in the spring to early summer and maximum values in the autumn (Murray and Alve, 2000). Although in the present work foraminiferal assemblages doesn't reflect clear seasonal cycle, on a species level *A. tepida* has higher percentage in December than in June which in accordance with some previous studies. De Nooijer *et al*. (2008) noticed that *A. tepida* is abundant in winter than in summer months. Morvan *et al*. (2006) reported that *A. tepida* was one of the most dominant species at the mouth of a small river of the Atlantic coast of France and it had maximum density in December 2001. A sharp increase occurred in the standing crop during fall and winter 2001.

Foraminiferal assemblages and environmental characterization

The high relative abundance of *A. tepida*, the most dominant species, in the current polluted study area (up to 89.8%) may indicate its tolerance to pollution. The dominance of *A. tepida* in other polluted coastal regions is confirmed by previous studies. For example Ferraro *et al*. (2006) found a relative abundance up to 100% in polluted Naples Harbour (Tyrrhenian Sea, Southern Italy). Burone *et al*. (2006) obtained a relative abundance up to 98% in the Montevideo coastal zone, Uruguay. *Ammonia tepida* has been reported as the dominant species in areas close to outfalls discharging sewage, heavy metals, chemical and thermal pollution, fertilizing products, caustic soda, chlorine complexes and hydrocarbons (Alve, 1991; 1995; Yanko *et al*.,1994; Samir, 2000; Samir and El Din, 2001; Armynot du Châtelet*et al*., 2004; Vilella *et al*., 2004; Burone *et al*., 2006; Ferraro *et al*., 2006; Le Cadre and Debenay, 2006; Frontalini and Coccioni, 2008; Romano *et al*., 2008, 2009; Coccioni *et al*., 2009; Debenay and Fernandez, 2009; Armynot du Châtelet and Debenay, 2010; Frontalini *et al*., 2010, 2011; Elshanawany *et al*., 2011; Aloulou *et al*., 2012 and Martins *et al*., 2013).

Closer inspection to our data show that *A. tepida* correlated positively with Cd and Cu, while negatively correlated with Pb. Therefore this study confirms its tolerance to Cd and Cu pollution rather than to Pb pollution. Frontalini and Coccioni (2008) and Aloulou *et al*. (2012) showed that *A. tepida* has a significant positive correlation with Cd. Frontalini *et al*. (2010) observed that *A. tepida* is the most dominant species in two italian lagoons which had higher values of Cd, Cu, Ni, Pb, Zn, Hg and As. Dimiza et al. (2016) showed that *A. tepida* was positively correlated with several heavy metal (Cu, Ni, Pb and Zn) and metalloid (As) contents. On the other hand, Li *et al*. (2015) reported that *A. tepida* has a weak positive correlation with (Cr, Cu, Ga, Pb, Rb, Zn and Zr)

Foraminiferal faunal community structure has been changed in Lake Edku in the last decade as a result of increased discharge. Samir (2000) reported that in Lake Edku, *A. tepida* showed lower abundance (7.6–22.6%), in contrast to *A. parkinsoniana*, which showed a corresponding increase (39.7–62.5%).

In the present study, Lake Edku has low salinity as a result of the increasing discharge of the drainage water (Shakweer, 2006; Badr and Fawzy, 2008). It is not surprising to find *A. tepida* dominates in this low saline Lake; since *A. tepida* is a cosmopolitan species occurring in brackish lagoons, estuaries and shallow marine areas that are extremely variable environments both temporally and spatially (Murray, 2006). Jorissen (1988) linked the dominance of *A. tepida* within the assemblages to its tolerance to polluted and low salinity environments. It is able to survive a wide range of temperature, salinity and other environmental parameters varying on seasonal or daily scales and to survive severe environmental conditions. (Almogi-Labin *et al*., 1992; Debenay *et al*., 2005; Munsel *et al*. 2010; Geslin *et al*., 2014). Almogi-Labin *et al*. (1992) reported that living populations of *A. tepida* are opportunistic, capable of withstanding a wide range of salinity (5–56‰) and different types of pollution. Martins *et al*. (2013) observed a negative correlation with salinity and *A. tepida* which dominate in lower saline waters.

Another environmental parameter could affect the distribution of *A. tepida*; which is the grain size. Although we have no grain size data, but from previous studies it is known that the sediment of the lake is silt and clay in the eastern part, shelly mud in the transition central part, and sand near Boughaz El-Meadia (Ibrahim, 1994). We found lower percentage of *A. tepida* in the seaward sandy sediment which in agreement with previous studies. Samir *et al*. (2003) showed that *A. tepida* found in samples located in areas with waters of low energy with muddy or sandy mud bottom sediments. Ferraro *et al*. (2012) observed that *A. parkinsoniana* and *A. tepida* on silty, silty sandy and sandy silty sediments, that is limited to the Gulf of Salerno (South Italy).

The current study shows that *A. parkinsoniana* is sensitive to the heavy metal pollution which is in accordance with Samir (2000) and Vidovic *et al*. (2014). Frontalini and Coccioni (2008) reported that *A. parkinsoniana* has significant negative correlation with Pb and Cd. *Ammonia parkinsoniana* is typical for relatively clean environments and appears to poorly tolerate high levels of trace elements (Jorissen, 1988; Frontalini and Coccioni, 2008; Coccioni *et al*., 2009). Almogi-Labin *et al*. (1992) recorded that *A. parkinsoniana* is more sensitive not only to pollution, but also to changes in the natural physical environmental conditions.

The current study indicated that *Porosononion* spp. increases with the increasing Cu content, while with decreasing Pb and Cd content. Elshanawany *et al*. (2011) showed that *Porosononion* spp. is a pollution- tolerant species in polluted Abu Qir Bay, Egypt.

The remarkable appearance of agglutinated foraminifera, represented by *S. ramose*, was recorded mainly at two stations (S4J and S7D). Several previous studies showed the environmental preference of *S. ramose*. It can successfully colonize and dominate the foraminiferal assemblage in low-energy, food limited environments (Koho *et al*., 2007). Fiorini (2015) also observed that *S. ramosa* dominated fine grained substrates, stable bottom with low-energy, normal oxygen levels. Some previous studies indicated that *S. ramosa* prefers an epifaunal microhabitat and thrives in stable environments, under well-oxygenated bottom waters and low food supply and concluded its preference to more oligotrophic areas (Altenbach *et al*., 1988; Koho *et al*., 2007). Koho *et al*. (2007) reported that *S. ramosa* can catch and feed on drifting organic particles. A relation between suspended matter load and occurrence of *S. ramosa* in the Gulf of Lions, Western Mediterranean, has also been hypothesised by Schmiedl *et al*. (2000). This species is practically the only one that was found to survive in the sediments with high Mn concentrations near barite–methane seeps in the Sea of Okhotsk (Khusid *et al*., 2006). The current study indicates that *S. ramosa* is tolerant to Pb-Cd pollution. Although the ecological preference of *S. ramosa* is well known from the previous studies, the relation of *S. ramosa* with pollution was not well documented in the literature. Therefore, this study is considered as a new study in referring to the positive correlation of *S. ramosa* with Pb and Cd. Further studies are requested to confirm this relation.

In the present study Miliolids increase in the less polluted, sandy, higher salinity, seaward stations such as S11. Dimiza *et al*. (2016) reported that miliolids displayed significant negative values with heavy metals. Miliolids are negatively correlated with percent mud as well.

In the current study *Quinqueloculina* spp., *Q. lata*, *Adelosina* spp., *Elphidium crispum*, *Elphidium advenum*, *Miliolinella* spp., *Miliolinella semicostata*, *Buccella* spp., *Rosalina macropora*, *Nonion* spp. and *Nonion commune* are distributed in the center of RDA diagram. They don't show significant relation with the environmental parameters. *Quinqueloculina* are more sensitive to environmental pollution (presence of heavy metals), so that in the presence of increasing pollution their abundance decreases (Samir and El-Din, 2001; Jamil, 2001; Ferraro *et al*., 2006; Valenti *et al*., 2008). Li *et al*. (2015) reported that *Quinqueloculina* spp. is negatively related to (Cr, Cu, Ga, Pb, Rb, Zn and Zr). In contrast to the previous studies, Romano *et al*. (2009) reported that *Q. lata* has a positive correlation with Cu, Pb and Zn, therefore, it may be considered as a pollution-tolerant species. On the other hand, Elshanawany *et al*. (2011) reported the sensitivity of *Quinqueloculina* spp. to pollution, while the tolerance of *Q. lata* to pollution. Romano *et al*. (2009) reported that *Q. lata* dominated sandy sediments with high concentrations of Fe, Pb, Zn, Ni and PAHs. They considered it as a pollution tolerant species. Concerning the other environmental parameters, Fiorini (2015) observed that *Quinqueloculina* prefers coarse grain sediment. *Quinqueloculina* spp. found in samples collected from depths bathed by turbid inner shelf conditions with some fresh water inflow and sandy bottom sediments (Samir *et al*., 2003).

In particular miliolids generally prefer high oxygen concentration in the shelf area waters while *Elphidium* spp. are more tolerant to stressed environmental conditions for changes in salinity and high levels of nutrients (Sen Gupta, 2003). Valenti *et al*. (2008) concluded that *Quinqueloculina* spp. and *Adelosina* spp. appeared to be more sensitive to pollution, whereas *Elphidium* spp. was more tolerant and can be regarded as opportunistic. *E. advenum* dominates in shallower water on muddy to sandy substrate in the Adriatic Sea (Jorissen, 1987). *Elphidium crispum* associates with muddy sands and it has a certain preference for a low input of clay (Murray, 1991; Mendes *et al*., 2004). *Miliolinella* spp. is epifaunal foraminifera, it distributes in different environments such as: hypersaline lagoons, normal marine lagoons and marshes, innershelf, and deep-sea (Murray, 2006). *Millionella semicostata* is dominated in stations which had relatively low concentrations of heavy metals, TOC, but high values of DO (Elshanawany *et al*., 2011). *Buccella* spp. is infaunal free genus, distributes in muddy sediment, marine, cold-temperate water, lagoons-innershelf ecosystem (Murray, 2006). *Rosalina macropora* is distributed in nearshore stations with high energy environmental conditions and low organic matter content (Samir and El-Din, 2001). *Nonion* spp. migrate to the surface in experiments, if oxygen in sediment decrease. It seems to be more adaptive to change in oxygenation (Panchang *et al*., 2006). *Nonion* spp. prefer muddy-silty sediments (Murray, 1991; Nigam and Chaturvedi, 2000). Elshanawany *et al*. (2011) reported that *Nonion* spp. is negatively correlated with DO and sand content.

Test deformation

In the polluted study area, relatively high percentages of deformed tests (up to ~21%) and many different abnormal modes (10 modes) are recorded. Moreover, in the present study, the percentage of abnormalities decreases towards the seaward direction; away from the drainage sources. Coccioni *et al*. (2009) concluded that the relative abundance of abnormal tests may be a useful proxy for the reconstruction of ecological changes especially in paralic environments where it may not be easy to distinguish between the effect of natural stress and anthropogenic impact. They showed that statistical analysis reveals a strong relationship between trace elements (in particular Mn, Pb and Hg) and the occurrence of abnormalities in foraminiferal tests. They also observed greater proportions of abnormal specimens at stations located close to the heaviest polluted industrial zone of Porto Marghera, Italy. Yanko *et al*. (1998) suggested that heavy metals can penetrate the foraminiferal cell together with food (e.g., algae, bacteria) and then affect the foraminiferal cytoskeleton, which defines the shape of the organism. Le Cadre and Debenay (2006) revealed that an increase in copper contamination may lead to a delay in growth and reproduction, which is then reflected in more frequent dwarfism and the occurrence of new chamber deformations. Cosentino *et al*. (2013) proposed that anthropogenic trace element pollution could be considered as one of the most important causes of the modifications of foraminiferal assemblages and of the presence of deformed specimens. Romano *et al*. (2008) revealed a significant correlation between the percentage of deformed *Elphidium advena* and Pb. Di Leonardo *et al*. (2007) found a reduction in benthic foraminiferal abundance, an increase in the percentage of abnormal species, and the dominance of opportunistic species in the more affected sediment by pollution.

The presence of abnormal foraminiferal tests has been attributed to environmental fluctuations or extreme values of environmental parameters such as salinity, sedimentation, hydrodynamics changes and mechanical damages (Boltovskoy and Wright, 1976; Geslin *et al*., 2000; Bergin *et al*., 2006; Jayaraju *et al*., 2008; Coccioni *et al*., 2009). In the current work, if abnormalities are because of the previous fluctuations, abnormal test should has more frequency close to the sea connection at Boughaz El-Meadia, but the opposite trend is recorded. This may increase the probability that these recorded abnormalities are related to pollution.

In the present study, the highest deformation percentage was recorded in Rotaliina (11.24%). *Ammonia tepida* is the highest deformed species (7.5%) within this suborder which is in agreement with Geslin *et al*. (2002) and Coccioni *et al*. (2009). Geslin *et al*. (2002) observed most abnormalities were observed in *A. tepida* such as protruding chambers, additional chambers or complex forms, aberrant shape or size of chambers, double or triple tests, or complex forms. Miliolina showed very low deformation percentage (0.1%). Within this suborder, only *Q. lata* and *Quinqueloculina* spp. were deformed. This is in contrast to previous literatures such as: Samir and El-Din (2001), Di Leonardo *et al*. (2007), and Elshanawany *et al*. (2011). They observed that Miliolids dominated the abnormal assemblages and were reported to be very sensitive to pollution.

A trial to compare the current foraminiferal study with the previous foraminiferal work in Lake Edku has been done; Samir (2000) recorded less percentage of deformed tests with maximum value 5% in the eastern part of Lake Edku. He reported also that the deformities include only one smaller chamber of the last whorl or twinned specimens. He reported that the abnormalities are too infrequent to indicate environmental stress caused by pollution. We can conclude that the increasing of the percentages of abnormal tests and numbers of deformation, in addition to previously mentioned shifting in foraminiferal assemblages, confirm the increasing level of pollution in the lake in the last decade. This confirms the huge foraminiferal potentiality to trace and monitor pollution.

CONCLUSION

The present study investigated the response of benthic foraminiferal assemblages to heavy metal pollution and some environmental parameters in Lake Edku. The resulted data indicate that Lake Edku is highly affected by heavy metal pollution especially Pb, Cu and Cd as it receives huge amounts of domestic, agricultural and industrial wastewater. Benthic foraminiferal assemblages are severely affected by heavy metal pollution. Limited number of living foraminiferal specimens, low density and diversity were observed in Lake Edku. Relatively high percentage of deformed foraminiferal tests (~ 21%) was detected in the lake. In addition, the distribution pattern of benthic foraminifera shows great dominance of *Ammonia tepida* which supports its tolerance to heavy metals pollution. *Ammonia tepida* is positively correlated with Cu and Cd, while it is negatively correlated with Pb. The current study also indicates that *Prosononion* spp. is tolerant to Cu pollution, while *Saccorhiza ramosa* is tolerant to Pb-Cd pollution. *Ammonia parkinsoniana* is considered as a sensitive species, it correlates negatively with all recorded heavy metals. This paper showed that benthic foraminifera can be used as a useful inexpensive tool for biomonitoring of heavy metals pollution of Lake Edku.

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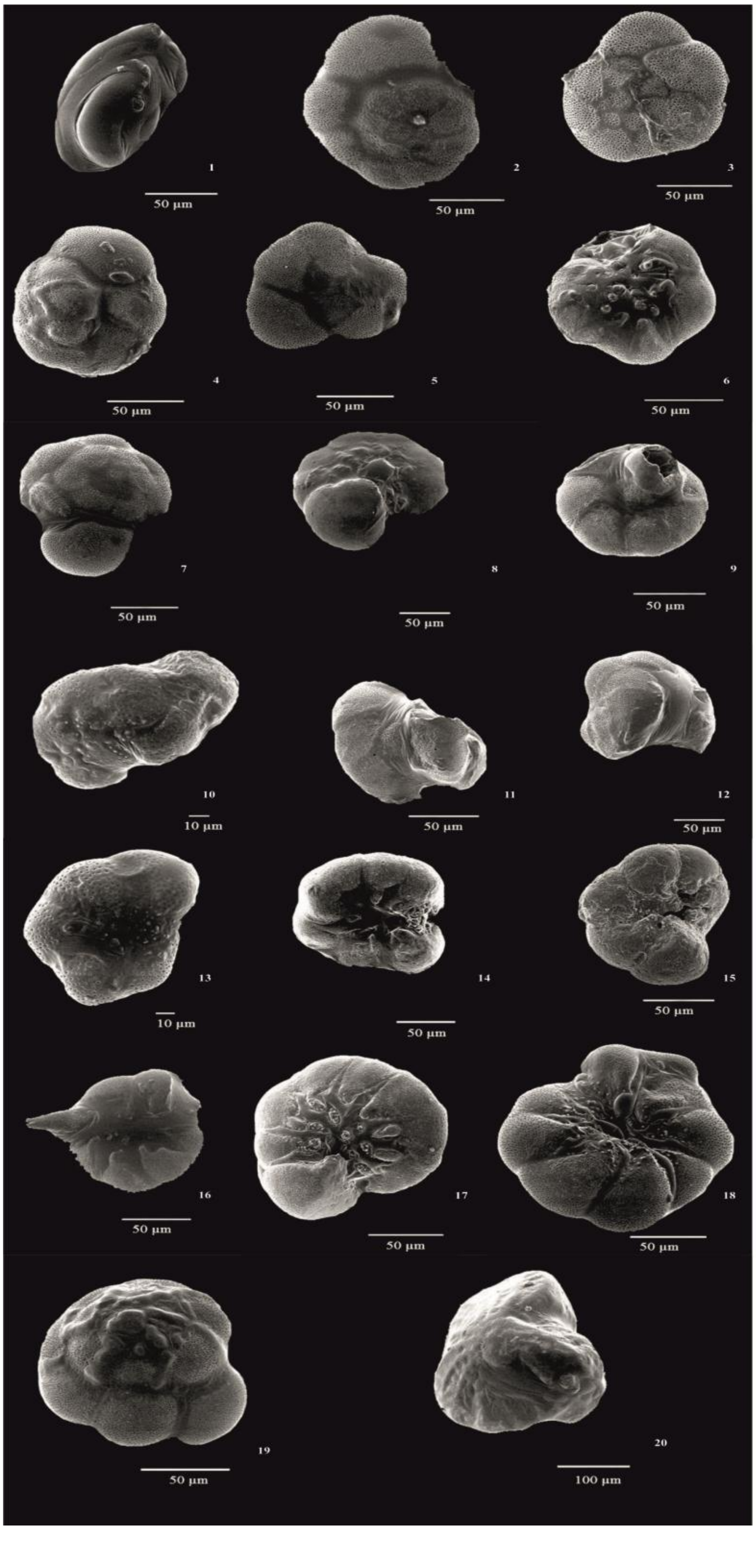

Fig. 5: SEM photographs of deformed benthic foraminifera from Lake Edku, Egypt. 1 *Quinqueloculina* spp. shows lose milioline coiling, S11J. 2-5 *Ammonia tepida* spiral view shows not rounded periphery, S1D, S6D, S11D. 6 *A. tepida* shows protruding and not rounded periphery, S9J. 7-8 *A. tepida* shows protruding in last chamber, S9J, S11D. 9 *A. tepida* shows additional chamber, S3J. 10 *A. tepida* shows additional chamber and distortion in coiling, S1D. 11-12 *A. tepida* shows twins (broken tests), S11D. 13-15 *A. tepida* shows abnormal growth, S7D, S10J, S1D. 16 *A. tepida* shows abnormal growth (spine), S9J. 17 *Ammonia parkinsoniana* shows abnormal growth, S9D. 18 *A. parkinsoniana* shows division in last chamber, S1D. 19 *A. parkinsoniana* shows spiroconvex shape, S11D. 20 *Elphidium advenum* shows highly deformed specimen, S11D.

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ARABIC SUMMARY

استخدام توزيع الفورامينيفرا القاعية والعناصر الثقيلة للتوصيف البيئي لبحيرة ادكو بجمهورية مصر العربية

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تتعرض بحيرة ادكو للتلوث بالملوثات الزراعية والصناعية. وعليه تقوم هذه الدراسة بتقييم تاثرالفورامينيفرا القاعية بالمعادن الثقيلة. تم جمع عينات الرسوبيات من احدي عشر محطة خلال فصلي الربيع والشتاء. تم قياس كلا من الملوحة ودرجة الحرارة والاس الهيدروجيني والاكسجين الذائب والشفافية وعمق المياه وبعض المعادن الثقيلة وتم اجراء بعض التحاليل الاحصائية. اوضحت الدراسة ببحيرة ادكو انه يوجد عدد قليل من الفورامينيفرا القاعية الحية بالبحيرة وذات كثافة وتنوع بيولوجي منخفض. التنوع البيولوجي يزداد باتجاه البحر نتيجة زيادة الملوحة وعمق المياه دون تغير ملحوظ بين فصلي الربيع والشتاء. اوضحت الدراسة انه يوجد نسب عالية من الفورامينفرا المشوهة تصل الي ٢١% . تعد اكثر الانواع انتشارا في رواسب بحيرة ادكوهي امونيا تيبيدا مما يدعم قدرتها علي تحمل التلوث بالمعادن الثقيلة حيث يوجد علاقة مباشرة بين انتشارها وبين ارتفاع تركيزات النحاس والكادميوم. واشارت الدراسة الي العلاقة الايجابية بين نوع ساركوريزا راموزا وتلوث الرواسب بالرصاص. كما يعد نوع امونيا باركينزونيانا من الكائنات الحساسة للتلوث.