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Research Article

Heavy Metal Concentrations in Cyanobacterial Mats and Underlying Sediments in Some Northern Western Desert Lakes of Egypt

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Abstract

Sixteen trace metals were measured for the first time in cyanobacterial mats and its underlying sediment in eight lakes in the Northern Western desert, Egypt. Al, Ba, Cr, Fe, Pb, Mn, Ni, Cu and Zn concentrations in sediments were many times higher than in cyanobacterial mates. Fe, Al, Mn, Cu were the highest trace metals recorded in the lakes. Geo-accumulation and pollution load indices were applied to assess the human impact in lake sediments, whereas the enrichment factor index was applied for both sediment and cyanobacterial mats. The geo-accumulation index indicated that Siwa lakes sediments were unpolluted with most metals, whereas it fluctuated from unpolluted to moderate polluted with Cu and from moderated to extremely polluted with Cd. The pollution load index revealed that the lakes sediments are unpolluted. The enrichment factor index indicated that all Siwa lakes sediments are extremely enriched with Cd, Cu and Se, whereas, they are impoverishment with As, Sb, Ba, Fe, Sn and V. Cyanobacterial biofilms were highly enriched in Maraqi, Sheata and El-Bahrien, whereas the mats were highly impoverishment in Zieton and Temera. The results suggest that the natural geochemical processes may generate the high concentrations of Fe, Al, Mn and Cu in these aquatic primary producers.

Key words: Cyanobacterial mats, metals, pollution indices, enrichment factor, Siwa

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Western desert of Egypt is one of the major aquifer systems in northeast Africa. The Western desert contains large depressions where the emerging water has created a number of oases of various sizes. Now a days some of them have been turned into vast cultivations (Salheen, 2011). The only source of irrigation in Western desert oases is the springs which are spread all over the oases. The current annual groundwater abstraction in the Western desert is about 0.7 bcm, most of which is being utilized in irrigated agriculture and for domestic uses (MoI., 2008). The continuous flow of springs and wells in the short-term produces water in excess of demand makes oases suffers many environmental problems related to water use management and thereafter overall water balance such as; water logging, soil salinization, increase in the surface area of the saltwater lakes, marshes and the rise of soil water levels by 4.5 cm year^{-1} (Abo Ragab, 2008).

The agricultural drainage effluents discharged into many of natural lakes which, as consequence of the harsh climatic conditions of the desert, become hyper saline marshes. The combined stress by the simultaneous effect of multiple extreme factors (hypersalinity, very high temperatures, UV and light intensity and desiccation) constitutes strong selective pressure (Abed *et al*., 2011). Specialized cyanobacterial mats often develop under these extreme conditions (Farmer, 1992). Cyanobacteria are readily adaptable and thus comprise the most successful mat-builders within clastic sedimentary realms; essentially, they are able to grow on any moist clastic sedimentary surface where their nutritional and energy requirements are met, within settings where metazoan grazers and burrowers are either absent or ineffective (Schieber *et al*., 2007).

Most microbial mat studies have focused on C, N and S metabolic processes (Bebout *et al*., 2004; Decker *et al*., 2005), but very few, if any have dealt with trace metal distributions despite the fact that microbial mats can have potential uses in bioremediation of environmental pollutants, especially dissolved nitrogen (Paniagua-Michel and Garcia, 2003), radio nuclides (Bender *et al*., 2000) and trace metals (Mehrabi *et al*., 2001; Bender *et al*., 1995). The very unique environmental conditions in the hypersaline sediments have an important influence on depositional and post depositional processes and on the behavior of accumulated metals that need to be studied (Soto-Jimenez and Paez-Osuna, 2001). Microbial mats were dominant features forover 85% of Earth's history (Grotzinger and Knoll, 1999) and were capable of regulating the biogeochemical cycling of not only the major elements like C, O_2 and N at a global scale (Dupraz *et al*., 2009) but also trace metals as well (Huerta-Diaz *et al*., 2011). Microbial mats create a unique environment where their photic zone can play a key role in the cycling of trace metals (Huerta-Diaz *et al*., 2011).

A comprehensive research program was designed by the Freshwater and Lakes Division (FLD), National Institute of Oceanography and Fisheries (NIOF) to determine how we can economically utilize these dense grow of cyanobacterial mats. Their metal accumulation, their production of biofuel, antimicrobial agents and other industrial hopeful products will be our concern. In this study, the heavy metals in surface sediments and overlying cyanobacterial mats in some hyper-saline lakes of the northern Western Desert have been investigated.

MATERIALS AND METHODS

Study area: The study area covers about 7333 km^2 in the Siwa region that lies in the Northwest of the Egyptian Western Desert, 120 km East of the Libyan-Egyptian border, 300 km to the South of Mersa Matruh on the Mediterranean Sea and approximately 600 km to the West of Cairo (Fig. 1). The oasis extends in an east-west direction, 23 m below sea level. The oasis surface has an overflow of about 146 springs and more than 1,000 wells that all are naturally flowing (MoI, 2008). Three geomorphologic units are distinguished: the northerly bounding limestone plateau and the steep escarpment running E-W; areas of mobile sand dunes to the South and closed flat depressions with cultivated land, playas and saline lakes (Masoud and Koike, 2006).

Two main groundwater aquifers exist in the studied zone: The upper Siwa shallow aquifer and the deep Nubian sandstone aquifer; springs are hosted in the shallow Middle Miocene carbonate which are effectively isolated from the deeper aquifer. Linear features in the depression are seen in the form of surface ponds and springs. Such linear features could affect water movement between the lakes and the subsurface aquifers or provide zones of enhanced infiltration (Masoud and Koike, 2006).

Eight lakes were studied (Fig. 1), three lakes inside Siwa Oasis (Aghormy, Maraqi and Zieton), one to the North-Western of the oasis (Lake Sheata), one to the Eastern-North (Lake Temera) and three lakes to the Eastern-South (Nawamisa, Setra and El-Bahrien). The lakes main characters are presented in Table 1.

Sampling: The sampling program was commenced during 2012. Fresh surface sediment and cyanobacterial mats

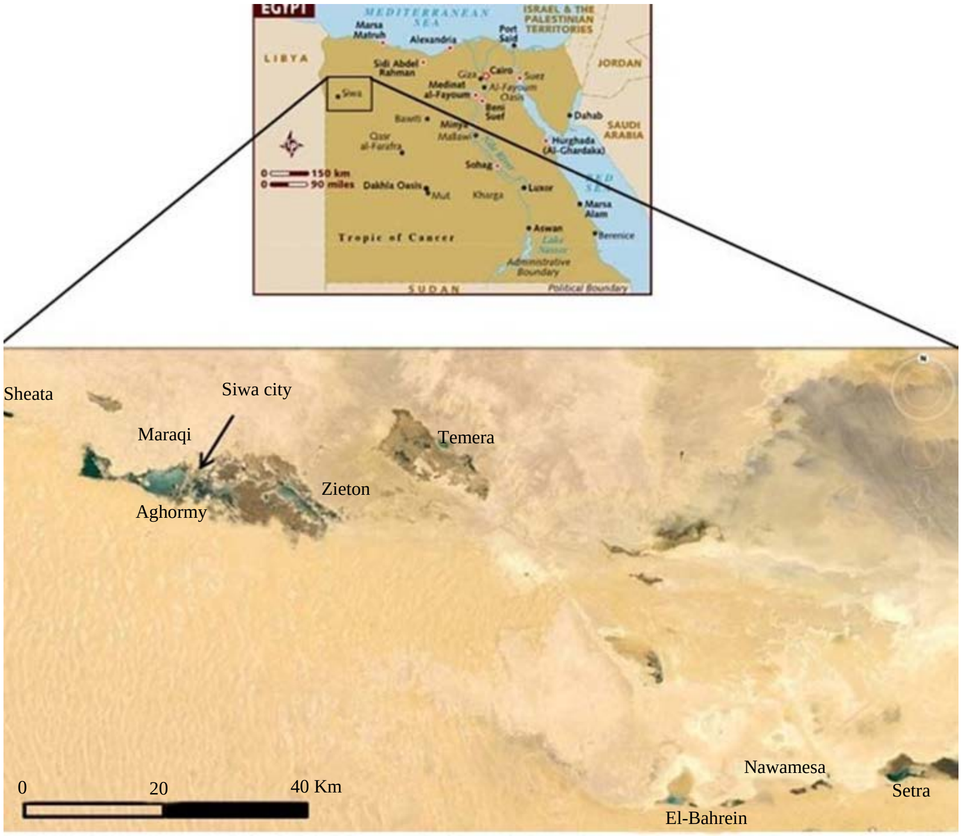

Fig. 1: Map showing the area of study in the Northern Western desert

Table 1: Main features of Siwa lakes

Sites	Sheata	Setra	Nawamesa	El-Bahrien	Temera	Zieton	Aghormy	Maraqi
Depth (m)	8	≈1.7	≈0.7	≈0.7	≈1	≈0.5	≈0.5	≈0.7
Elevation (m)	-12	-24	-12.5	-8	-14	-18	-18	-15
Area (Acre)	470	2000	500	900	2400	30000	20000	13000
pH	7.95	7.38	7.69	7.85	7.83	7.36	7.83	7.61
Temperature (°C)	22.1	27.7	27.3	26.5	20.5	27.5	27.5	25
TDS (g L^{-1})	80.84	257.3	207.59	164.17	172.44	239.29	220.03	280.45

TDS: Total dissolve solids

samples were collected at the margin of the lakes, immediately packed in air tight polythene bags, put in ice box and transported to the laboratory. Subsamples of the sediments and cyanobacterial mats were oven dried at 60°C to constant weight, homogenized with a pestle and mortar. Digestion and measure of the samples were conducted in the central lab. of the Water Research Center, Ministry of Irrigation, El-Kanater El-Khyria. A representative samples (sediment or mat) of 0.5 g was weighted and transferred to PFA vessel. 2 mL of concentrated nitric acid, 2 mL of concentrated hydrofluoric acid and 1 mL of hydrogen peroxide were added to the samples. The digestion vessels were sealed and heated using Milestone microwave digester model MLS 1200 MEGA according to the following program (Table 2).

After cooling, the vessels were opened carefully in a fume cupboard. The sample solutions were transferred to 25 mL calibrated flasks and diluted up to mark with deionized water. After filtration, all metals were analyzed by Perkin Elmer inductively coupled Plasma model Optima 3000XL ICP-OES. Results are expressed as µg/g dry weight. The blank solution, with Suprapur® grade (Merck) regents, subjected to the same treatment as the samples, was prepared as well.

Table 2: Digestion program of dried sediment and cyanobacterial mat

Steps	Time (min)	Power (W)
1	6	250
2	6	450
3	6	650
4	6	250
Ventilation	5	0.00

Table 3: Concentration of studied metals in Siwa lakes sediments, geochemical background and the toxicological reference values for lake sediments

		Geochemical background		NOAA[1]					
Metals	Present result	Shale standard[1]	Earth crust[2]	TEL	ERL	PEL	ERM	WCTMRL[2]	TRV[3]
Al	786-2926	80000	82300						
Sb	0.004	1.5	0.2						
As	0.001	13	1.8	7.24	8.2	41.6	70		6
Ba	8.6-43	580	425	130					
Cd	1-17.6	0.3	0.15	0.68	1.2	4.21	9.6	0.1-1.5	0.6
Cr	3.6-12.2	90	100	52.3	81	160	370	20-190	62
Co	1.2-5.2	68	25						
Cu	32.6-182.6	40	55	18.7	34	108	270	20-90	16
Fe	1020.6-7234	46700	56300						
Pb	0.003-5	20	12.5	30.24	46.7	112	218	10-100	31
Mn	51.8-576	950	850						
Ni	5.4-11.2	68	75	15.9	20.9	42.8	51.6	30-250	16
Se	0.25-0.4	0.6	0.05						
Sn	0.004	6	2.3	48					
V	0.002	130	120						
Zn	2.52-34.8	95	70	124	150	271	410	50-250	110

TEL: Threshold effect level, ERL: Effects range low, PEL: Probable effect level, ERM: Effects range median, WCTMRL: World common trace metal range in lake sediment, TRV: Toxicity reference value, Source: [1]According to NOAA (2009), [2]According to Frostner and Wittman (1981), [3]According to Jones *et al.* (1997)

Data analysis: Statistical analysis, ANOVA and Spearman correlation were carried out using the SPSS 20.0 package.

Pollution indices: Three pollution indices were used for the environmental assessment of Siwa Lake sediments. Two indices, Enrichment Factor (EF) and Geo-accumulation (I_{geo}) are single indices, while Pollution Load Index (PLI) is an integrated index (Qingjie *et al.*, 2008). These indices are used to assess heavy metal contamination in sediment, whereas EF was applied for both sediment and overlying cyanobacterial mats. It is necessary to compare the level of studied metals in lake sediments with the pre-industrial reference level. But in our study the composition of Upper Continental Crust (UCC) and the average Shale were used as a representative of pre-industrial reference level of trace/heavy metals.

Enrichment Factor (EF): The Enrichment Factor (EF) was calculated according to the Eq. 1 developed by Sinex and Helz (1981):

$$EF = (C_M/C_X)_{Sample}/(C_M/C_X)_{Earth's\ crust} \tag{1}$$

where, C_M is the concentration of trace metal M and C_X is the concentration of reference or immobile element. Aluminum has been used as reference element due to its crustal dominance and its high immobility (Chatterjee *et al.*, 2007; Mohiuddin *et al.*, 2010). In the present study, the background concentrations (the reference Earth's crust of the studied metals of (Table 3) were taken from Turekian and Wedepohl (1961).

Index of geo-accumulation (I_{geo}): The geo-accumulation index I_{geo} values were calculated according to Muller (1969) as given in Eq. 2:

$$I_{geo} = \log_2 \frac{C_n}{1.5xB_n} \tag{2}$$

where, C_n is the concentration of examined metal (n) in the sediment sample, B_n is the geochemical background for the metal (n) and 1.5 is the background matrix correction factor which introduced to minimize possible variation of the background values due to lithogenic variations and anthropogenic influences (Chakravarty and Patgiri, 2009; Qingjie *et al.*, 2008). Due to unavailability of the regional background values of the studied metals, the B_n values (Table 3) were taken from the average shale value described by Turekian and Wedepohl (1961).

Pollution Load Index (PLI): The pollution load index-PLI, proposed by Tomlinson *et al.* (1980) has been used to measure PLI in sediments of Siwa lakes. The PLI for a single site is the nth root of the product of n Contamination Factors (CF values) given in Eq. 3:

$$\text{PLI} = \sqrt[n]{\text{CF}_{1X}\,\text{CF}_{2X}\,\text{CF}_{3X}.......\text{CF}_n} \quad (3)$$

where, CF is contamination factor (metal content in the sediment/ background level of metal) and n is number of metals.

RESULTS AND DISCUSSION

Microbial mats occur overall length of the year on the lakes floor as well as along their margin. The mats usually grew under a few millimeter layer of water. When covered by water, laminated coloured mats of cyanobacteria appeared directly on the sediment surface. The mats consisted of a 1-2 mm layer of loosely purple bacteria followed by 1-2 mm thick green layer of Oscillatoriales (*Oscillatoria* and *Lyngbya* spp.) and Chroococcales (*Synechococcus* and *Synechocystis* sp.) cyanobacterial species often followed by a red brown layer of iron oxides underneath of upto 3 mm thick. Below this, the sand was usually grey. Black layers containing decayed organic materials and sulphide minerals were often found at depths below 8 mm. Imhoff *et al.* (1979) observed mass developments of sulphide-oxidizing phototrophic bacteria in the upper sediment layers and in the water of the lakes of Wadi El Natrun. They isolated strains of these bacteria in pure cultures from all Wadi E1 Natrun saline lakes, in mud and water samples yielded approximately 108-109 cells/1 of each species (Imhoff and Truper, 1977).

The concentration of heavy metals in sediments were significantly varied ($p<0.005$) between Northern Western desert hyper-saline lakes. The Sb, As, Sn and V were always below their detection limits in both cyanobacterial mats and underlying sediment, so they are not incorporated in Fig. 2. On the other hand, Al, Ba, Cr, Fe, Pb, Mn, Ni, Cu and Zn were significantly varied ($p<0.005$) between sediment and cyanobacterial mats and their concentrations in sediment were many times higher than their concentrations in cyanobacterial mates (Fig. 2). The Fe, Al, Mn, Cu were the highest trace metals recorded in the sediment of the lakes. Fe concentrations ranged between 1020 and 7234, Al ranged between 786 and 2926, Mn ranged between 52 and 576, whereas Cu ranged between 33 and 183 ppm. Huerta-Diaz *et al.* (2011) indicated that some heavy metals as Cd, Co, Mn and Zn showed number of peaks in the underlying sediment compared with their concentration in the overlying mats. Hypersaline ecosystem sediments are considered as a sink and source for trace metals. Many reports have shown that sediments rich in organic materials operate as a biogeochemical sink for heavy metals, mainly due to the high concentrations of organic matter and sulphides under permanently reducing conditions (Thomas and Fernandez, 1997; Taher and Soliman, 1999). The metal concentrations (Al, Ba, Cr, Fe, Pb, Mn, Ni and Zn) in sediment and cyanobacterial mats showed a moderate to strong negative correlation (-0.39 to -0.76, $p<0.05$). These results disagree with the results obtained from the analysis of heavy metals in wetland plant species, the concentrations of heavy metals in plant tissues of 13 plants had strong positive correlations with the concentrations in soil (Deng *et al.*, 2004; Guo *et al.*, 2014).

Many processes could be influencing the distribution of metals, particularly Fe, most probably wind transport of particles from the surrounding desert. As reported by Kasper-Zubillaga and Zolezzi-Ruiz (2007) and Huerta-Diaz *et al.* (2011) that strong and frequent winds can transport heavy minerals and magnetite which can be deposited on the surface of the microbial mats. Mat may lead to even higher enrichments in the underlying sediments. After death and decomposition of the mat organisms, those metals preferentially associated with organic matter are transferred into the sediment, the final deposit of trace elements, where they will tend to accumulate between the productive mats above and the hard gypsum crust at the base of the pond (Des Marais *et al.*, 1992; Granger and Ward, 2003). Taher *et al.* (1994) had postulated that microbial mat dominated brine sediments concentrated and enriched heavy metal 2-3 times more than sediments lacking microbial mat developments, suggesting that cyanobacteria play a major role in this enrichment via their decomposition.

Pollution indices

Enrichment Factor (EF): The Enrichment Factor (EF) was basely developed to speculate on the origin of elements in the atmosphere, precipitation or seawater but it was progressively extended to the study of soils, lake sediments, peat, tailings and other environmental materials (Qingjie *et al.*, 2008). The EF values of the heavy metals measured are given in Fig. 3. Samples with EF value above 5 are considered to be polluted (Table 4) with that particular element (Atgin *et al.*, 2000). In general, cyanobacterial mats were highly enriched compared to underlying sediment (Fig. 3). The results of EF values indicate that all Siwa lakes sediments are extremely enriched

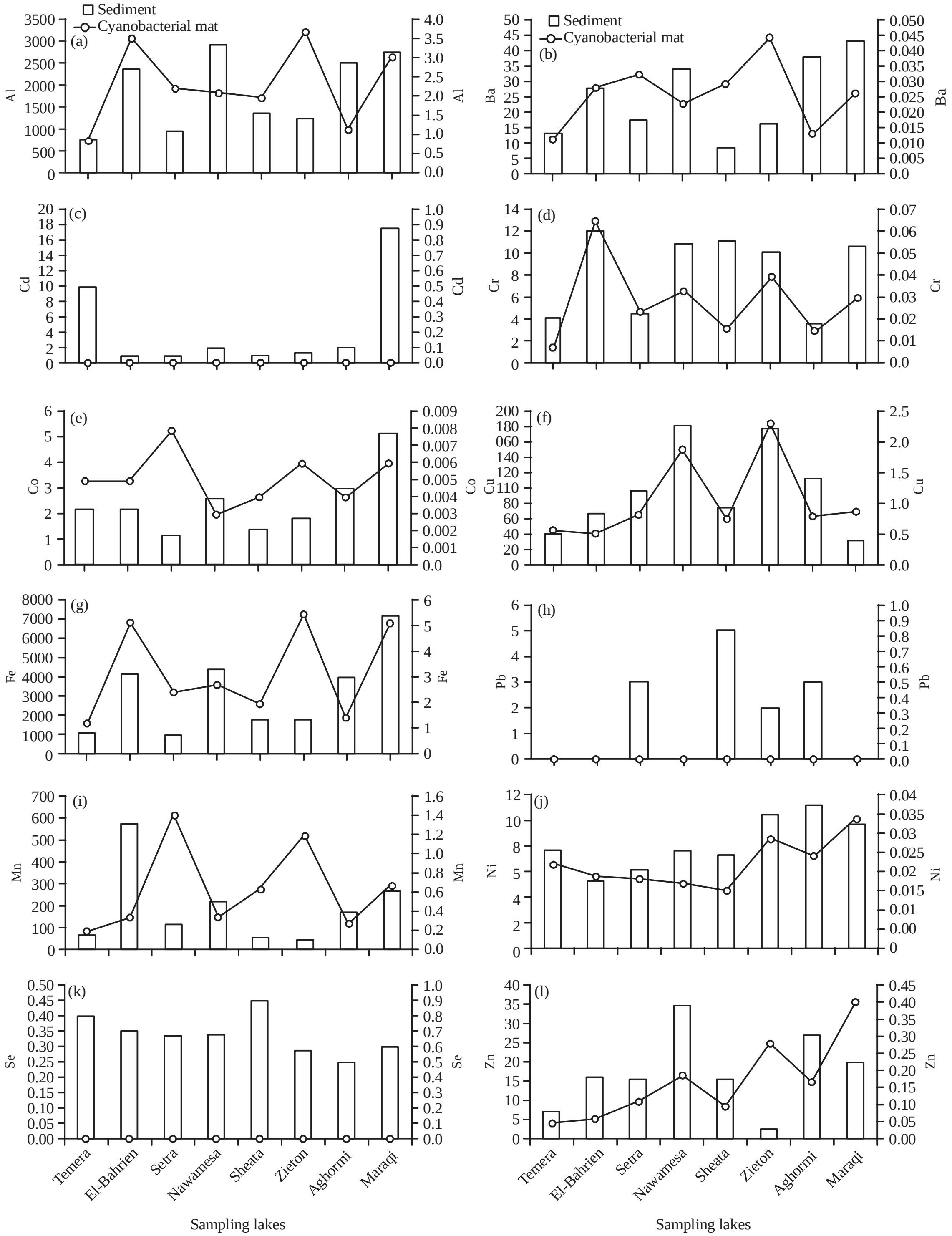

Fig. 2(a-l): Concentration (ppm) of heavy metals (a) Al, (b) Ba, (c) Cd, (d) Cr, (e) Co, (f) Cu, (g) Fe, (h) Pb, (i) Mn, (j) Ni, (k) Se and (l) Zn in surface sediments (column in primary axis) and overlying cyanobacterial mats (line in secondary axis) from Northern West desert hyper-saline lakes

with Cd, Cu and Se, whereas, Siwa lakes sediment are impoverishment with As, Sb, Ba, Fe, Sn and V. On the other hand, Co, Pb, Mn and Zn showed fluctuated regional EF values with significant highly enriched sediments in Maraqi, Aghormy

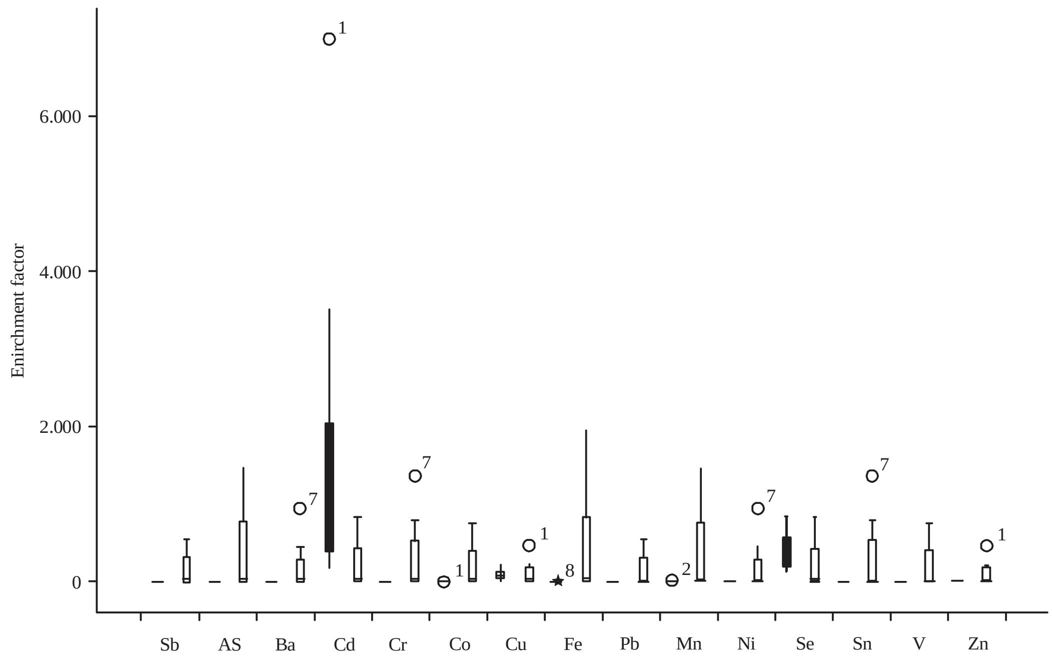

Fig. 3: Box plot of enrichment factor for the trace metals in the cyanobacterial mats (graybox) and underlying sediment (black box) in Siwa lakes

Table 4: Terminology of EF, I_{geo} and PLI pollution classes

EF classes[1]		I_{geo} classes[2]			PLI[3]	
EF value	Pollution	I_{geo}	I_{geo} class	Pollution	PLI	Pollution
EF<2	Depletion to mineral	<0-0	0	Unpolluted	0	Perfection
2≤EF<5	Moderate	0-1	1	Unpolluted to moderated	<1	Baseline levels
5≤EF<20	Significant	1-2	2	Moderated polluted	>1	Polluted
20≤EF<40	Very high	2-3	3	Moderated to high polluted		
EF>40	Extremely high	3-4	4	Highly polluted		
		4-5	5	Highly to extremely polluted		
		5-6	>5	Extremely polluted		

EF: Enrichment factor, I_{geo}: Index of geo-accumulation, PLI: Pollution load index, Source: (1)According to Sutherland (2000), (2)According to Buccolieri *et al.* (2006), (3)According to Tomlinson *et al.* (1980)

and Zieton lakes. Cyanobacterial mats were highly enriched in Maraqi, Sheata and ElBahrien, whereas the mats were highly impoverishment in Zieton and Temera.

One question arises is whether the elevated levels of trace metals in both mat and sediment are of natural or anthropogenic origin. Most lakes of study are tens of kilometers far from Siwa city and any surrounding villages (Sheata, ElBahrien, Setra, Nawamisa and Temera). In the same time, Siwa city is too small (about 10,000 inhabitants) to represent a significant source of anthropogenic emissions to the lakes. Hence, the high enrichment of Cu, Cd and Sn suggest that natural processes may generate the observed enrichments in sediment. Nevertheless, one reasonable assumption is that dissolved trace metals transferred to the mats and sediments via scavenging by dissolved organic matter produced in the overlying water and precipitate as sulfides, given the presence of substantial amounts of H_2S in the matsand sediments (Huerta-Diaz *et al.*, 2011).

Cadmium enrichment factor was reported by Huerta-Diaz *et al.* (2011) in cyanobacterial mats and underlying sediments in hypersaline lake (Guerrero Negro Saltern, Baja California Sur, Mexico) with EF_{Cd} of ≈100. Nava-Lopez and Huerta-Diaz (2001) recorded EF_{Cd} of ≈23 for sediment samples collected in the continental shelf of Baja California. Morel *et al.* (1991) reported that a combination of biological (bioconcentration) and chemical (precipitation) processes may explain the many trace metals enrichment as Mn, Zn, Pb and Co in microbial mats, sediment and phytoplankton. Moreover, mat enrichments may lead to even higher enrichments in the underlying sediments. As mentioned above, after death and decomposition of the mat organisms, those metals preferentially associated with organic matter are transferred into the sediment, the final deposit of trace elements, where they will tend to accumulate between the productive mats above and the hard gypsum crust at the base of the pond (Granger and Ward, 2003).

Index of geo-accumulation (I_{geo}): The index of geoaccumulation includes seven grades (Table 4); the I_{geo} class 0 indicates no contamination while the highest class 6 reflects 100-fold enrichment of the metals relative to their background values (Harikumar and Jisha, 2010). The geo-accumulation index (I_{geo}) indicated that Siwa lakes sediment are unpolluted with Al, Sb, As, Ba Cr, Co, Fe, Pb Mn, Ni, Sn, V and Zn (I_{geo} values <0.0), whereas it fluctuated from unpolluted to moderate polluted with Cu and from moderated to extremely polluted with Cd (Fig. 4).

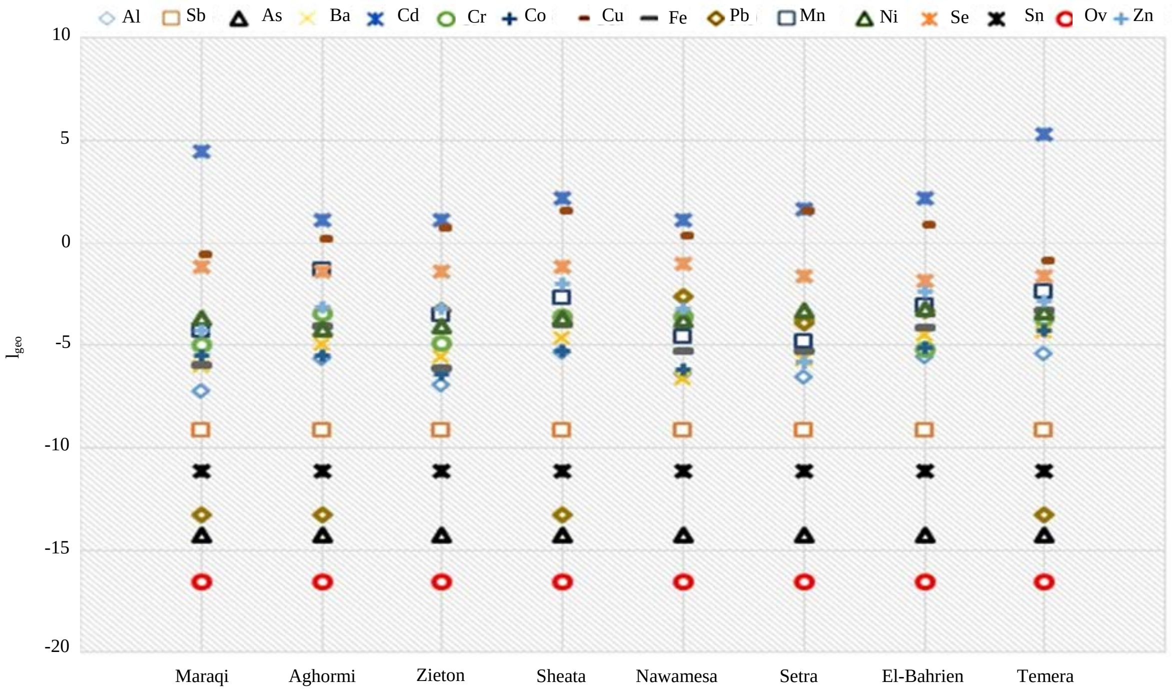

Fig. 4: Geo-accumulation Index (I_{geo}) values of analyzed metals in Siwa lakes sediment

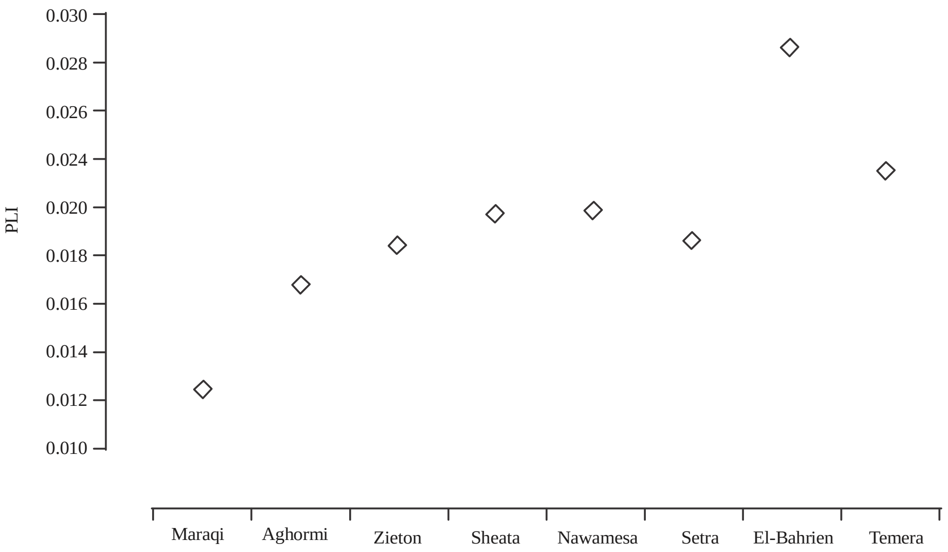

Fig. 5: Pollution Load Index (PLI) values of analyzed metals in Siwa lakes sediment

Pollution Load Index (PLI): The PLI gives relative means for assessing a quality of site (PLI<1.0) indicate only baseline levels of pollutants present (unpolluted area), PLI>1.0 indicate deterioration of the site (Tomlinson *et al*., 1980; Cabrera *et al*., 1999). The pollution load index of Siwa lakes sediment ranged from 0.01-0.03 (Fig. 5) which confirmed that the Lakes sediments are unpolluted.

Although the I_{geo} values of Cu and Cd, we can cited that the results of I_{geo} and PLI indices indicated no perceptible involvement from anthropogenic sources. In addition, the results of I_{geo} and PLI confirm the above observation about EF values.

CONCLUSION

The Sb, As, Sn and V were always below their detection limits for both cyanobacterial mats and underlying sediment. The Fe, Al, Mn, Cu were the highest trace metals recorded in the lakes. The geo-accumulation index I_{geo} indicated that Siwa lakes sediments are unpolluted with Al, Sb, As, Ba Cr, Co, Fe, PbMn, Ni, Sn, V and Zn whereas it fluctuated from unpolluted to moderate polluted with Cu and from moderated to extremely polluted with Cd. The EF values indicate that all Siwa lakes sediment are extremely enriched with Cd, Cu and Se, whereas, they are impoverishment with As, Sb, Ba, Fe, Sn and V. Cyanobacterial mats were highly enriched in Maraqi, Sheata and ElBahrien, whereas the mats were highly impoverishment in Zieton and Temera. The results suggest that the natural processes may generate the high concentrations of Fe, Al, Mn and Cu. It is concluded that for further economical utilization of cyanobacterial mats, Zieton and Temera are the best.

REFERENCES

Abed, R.M.M., S. Dobrestov, S. Al-Kharusi, A. Schramm, B. Jupp and S. Golubic, 2011. Cyanobacterial diversity and bioactivity of inland hypersaline microbial mats from a desert stream in the Sultanate of Oman. Fottea, 11: 215-224.

Abo Ragab, S., 2008. Water management of the Siwa Oasis, Western desert, Egypt. Proceedings of the 33rd International Conference for Statistics, Computer Science and it's Applications, April 24-26, 2008, Atlanta, Georgia, USA., pp: 198-223.

Atgin, R.S., O. El-Agha, A. Zararsız, A. Kocatas, H. Parlak and G. Tuncel, 2000. Investigation of the sediment pollution in Izmir bay: Trace elements. Spectrochimica Acta Part B: Atom. Spectrosc., 55: 1151-1164.

Bebout, B.M., T.M. Hoehler, B.O. Thamdrup, D. Albert and S.P. Carpenter *et al*., 2004. Methane production by microbial mats under low sulphate concentrations. Geobiology, 2: 87-96.

Bender, J., R.F. Lee and P. Phillips, 1995. Uptake and transformation of metals and metalloids by microbial mats and their use in bioremediation. J. Ind. Microbiol., 14: 113-118.

Bender, J., M.C. Duff, P. Phillips and M. Hill, 2000. Bioremediation and bioreduction of dissolved U(VI) by microbial mat consortium supported on silica gel particles. Environ. Sci. Technol., 34: 3235-3241.2

Buccolieri, A., G. Buccolieri, N. Cardellicchio, A. Dell'Atti, A. Di Leo and A. Maci, 2006. Heavy metals in marine sediments of Taranto Gulf (Ionian Sea, Southern Italy). Mar. Chem., 99: 227-235.

Cabrera, F., L. Clemente, E.D. Barrientos, R. Lopez and J.M. Murillo, 1999. Heavy metal pollution of soils affected by the guadiamar toxic flood. Sci. Total Environ., 242: 117-129.

Chakravarty, M. and A.D. Patgiri, 2009. Metal pollution assessment in sediments of the Dikrong river, N.E. India. J. Hum. Ecol., 27: 63-67.

Chatterjee, M., E.V.S. Filho, S.K. Sarkar, S.M. Sella and A. Bhattacharya *et al*., 2007. Distribution and possible source of trace elements in the sediment cores of a tropical macrotidal estuary and their ecotoxicological significance. Environ. Int., 33: 346-356.

Decker, K.L.M., C.S. Potter, B.M. Bebout, D.J. des Marais and S. Carpenter *et al*., 2005. Mathematical simulation of the diel O, S and C biogeochemistry of a hypersaline microbial mat. FEMS Microbiol. Ecol., 52: 377-395.

Deng, H., Z.H. Ye and M.H. Wong, 2004. Accumulation of lead, zinc, copper and cadmium by 12 wetland plant species thriving in metal-contaminated sites in China. Environ. Pollut., 132: 29-40.

Des Marais, D.J., E. D'Amelio, J.D. Farmer, B. Jorgensen, A.C. Palmisano and B.K. Pierson, 1992. Case Study of a Modern Microbial Mat-Building Community: The Submerged Cyanobacterial Mats of Guerrero Negro, Baja California Sur, Mexico. In: The Proterozoic Biosphere: A Multidisciplinary Study, Schopf, J.W. and C. Klein (Eds.). Cambridge University Press, New York, USA., ISBN-13: 9780521366151, pp: 325-334.

Dupraz, C., R.P. Reid, O. Braissant, A.W. Decho, R.S. Norman and P.T. Visscher, 2009. Processes of carbonate precipitation in modern microbial mats. Earth-Sci. Rev., 96: 141-162.

Farmer, J.D., 1992. Grazing and Bioturbation in Modern Microbial Mats. In: The Proterozoic Biosphere: A Multidisciplinary Study, Schopf, J.W. and C. Klein (Eds.). Cambridge University Press, New York, USA., ISBN-13: 9780521366151, pp: 247-251.

Frostner, U. and G.T.W. Wittman, 1981. Metal pollution in the aquatic environment. 2nd Eds. Springer Verlag, Berlin Heidelberg, W. Germany, Pages: 486.

Granger, J. and B.B. Ward, 2003. Accumulation of nitrogen oxides in copper-limited cultures of denitrifying bacteria. Limnol.Oceanogr., 48: 313-318.

Grotzinger, J.P. and A.H. Knoll, 1999. Stromatolites in Precambrian carbonates: Evolutionary mileposts or environmental dipsticks? Annu. Rev. Earth Planet. Sci., 27: 313-358.

Guo, L., D.W. Ott and T.J. Cutright, 2014. Accumulation and histological location of heavy metals in *Phragmites australis* grown in acid mine drainage contaminated soil with or without citric acid. Environ. Exp. Bot., 105: 46-54.

Harikumar, P.S. and T.S. Jisha, 2010. Distribution pattern of trace metal pollutants in the sediments of an urban wetland in the Southwest Coast of India. Int. J. Eng. Sci. Technol., 2: 840-850.

Huerta-Diaz, M.A., F. Delgadillo-Hinojosa, X.L. Otero, J.A. Segovia-Zavala, J.M. Hernandez-Ayon, M.S. Galindo-Bect and E. Amaro-Franco, 2011. Iron and trace metals in microbial mats and underlying sediments: Results from Guerrero Negro Saltern, Baja California Sur, Mexico. Aquat. Geochem., 17: 603-628.

Imhoff, J.E., H.G. Sahl, G.S.H. Soliman and H.G. Truper, 1979. The Wadi Natrun: Chemical composition and microbial mass developments in alkaline brines of Eutrophic Desert Lakes. Geomicrobiol. J., 1: 219-234.

Imhoff, J.F. and H.G. Truper, 1977. *Ectothiorhodospira halochloris* sp. nov., a new extremely halophilic phototrophic bacterium containing bacteriochlorophyll b. Arch. Microbiol., 114: 115-121.

Jones, D.S., G.W. Suter and R.N. Hull, 1997. Toxicological benchmarks for screening contaminants of potential concern for effects on sediment-associated biota: Revision. U.S. Department of Energy, November 1997, pp: 1-48. http://rais.ornl.gov/documents/tm95r4.pdf.

Kasper-Zubillaga, J.J. and H. Zolezzi-Ruiz, 2007. Grain size, mineralogical and geochemical studies of coastal and inland dune sands from El Vizcaino Desert, Baja California Peninsula, Mexico. Revista Mexicana Ciencias Geologicas, 24: 423-438.

Masoud, A. and K. Koike, 2006. Tectonic architecture through Landsat-7 ETM+/SRTM DEM-derived lineaments and relationship to the hydrogeologic setting in Siwa region, NW Egypt. J. Afr. Earth Sci., 45: 467-477.

Mehrabi, S., U.M. Ekanemesang, F.O. Aikhionbare, K.S. Kimbro and J. Bender, 2001. Identification and characterization of *Rhodopseudomonas* spp., a purple, non-sulfur bacterium from microbial mats. Biomol. Eng., 18: 49-56.

MoI., 2008. Report for achievements of management of groundwater in Siwa, Egypt. Report Siwa, Ministry of Irrigation (MoI), Egypt, pp: 1-20.

Mohiuddin, K.M., H.M. Zakir, K. Otomo, S. Sharmin and N. Shikazono, 2010. Geochemical distribution of trace metal pollutants in water and sediments of downstream of an urban river. Int. J. Environ. Sci. Tech., 7: 17-28.

Morel, F.M.M., R.J.M. Hudson and N.M. Price, 1991. Limitation of productivity by trace metals in the sea. Limnol. Oceanogr., 36: 1742-1755.

Muller, G., 1969. Index of geoaccumulation in sediments of the Rhine river. J. Geol., 2: 108-118.

NOAA., 2009. SQUIRT, screening quick reference tables for inorganic in sediment. National Oceanic and Atmospheric Administration (NOAA), March 2009.

Nava-Lopez, C. and M.A. Huerta-Diaz, 2001. Degree of trace metal pyritization in sediments from the pacific coast of Baja California, Mexico. Int. J. Mar. Sci., 27: 289-309.

Paniagua-Michel, J. and O. Garcia, 2003. Ex-situ bioremediation of shrimp culture effluent using constructed microbial mats. Aquacult. Eng., 28: 131-139.

Qingjie, G., D. Jun, X. Yunchuan, W. Qingfei and Y. Liqiang, 2008. Calculating pollution indices by heavy metals in ecological geochemistry assessment and a case study in parks of Beijing. J. China Univ. Geosci., 19: 230-241.

Salheen, M., 2011. Taming development in Siwa Oasis: Environment led approach. Proceedings of the URBENVIRON CAIRO 2011 4th International Congress on Environmental Planning and Management, December 10-13, 2011, Egypt.

Schieber, J., P.K. Bose, P.G. Eriksson, S. Banerjee, S. Sarkar, W. Altermann and O. Catuneanu, 2007. Atlas of Microbial Mat Features Preserved within the Siliciclastic Rock Record. Vol. 2, Elsevier, The Amsterdam, ISBN-13: 9780080549309, Pages: 324.

Sinex, S.A. and G.R. Helz, 1981. Regional geochemistry of trace elements in Chesapeake Bay sediments. Environ. Geol., 3: 315-323.

Soto-Jimenez, M.F. and F. Paez-Osuna, 2001. Distribution and normalization of heavy metal concentrations in mangrove and lagoonal sediments from Mazatlan Harbor (SE Gulf of California). Estuarine Coastal Shelf Sci., 53: 259-274.

Sutherland, R.A., 2000. Bed sediment-associated trace metals in an urban stream, Oahu, Hawaii. Environ. Geol., 39: 611-627.

Taher, A.G. and A.A. Soliman, 1999. Heavy metal concentrations in surficial sediments from Wadi El Natrun saline lakes, Egypt. Int. J. Salt Lake Res., 8: 75-92.

Taher, A.G., S. Abd el Wahab, G. Philip, A.M. Wali and W.E. Krumbein, 1994. On heavy metal concentrations and biogenic enrichment in microbial mat environments. Mineralium Deposita, 29: 427-429.

Thomas, G. and T.V. Fernandez, 1997. Incidence of heavy metals in the mangrove flora and sediments in Kerala, India. Hydrobiologia, 352: 77-87.

Tomlinson, D.L., J.G. Wilson, C.R. Harris and D.W. Jeffrey, 1980. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. Helgolander Meeresuntersuchungen, 33: 566-575.

Turekian, K.K. and K.H. Wedepohl, 1961. Distribution of the elements in some major units of the earth's crust. Geol. Soc. Am. Bull., 72: 175-192.