



Occurrence and diversity of mycobiota in heavy metal contaminated sediments of Mediterranean coastal lagoon El-Manzala, Egypt

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Abstract

An investigation was conducted to assess the concentration of heavy metals in sediments in five selected locations along Manzala lagoon and correlate the effect of metal concentrations on benthic fungal population. Physicochemical analysis showed that pH values ranged between 7.93 and 8.1 while electric conductivity ranged between 5.64 and 12.76 dSm⁻¹. The mean values of organic matter percentage ranged between 1.0 and 2.6%. The parent material of studied sediment samples is classified as fluviolacustrine type. Different concentrations of heavy metals (Zinc, lead, cadmium, iron, manganese and copper) recorded in soil samples reflect the degree of pollution in all studied sites. The concentrations of heavy metals are relatively high in all sites e.g. Zinc (6.4 to 17.3 µg/g), lead (0.6 to 7.2 µg/g), copper (1.1 to 2.1 µg/g), manganese (98.5 to 150.3 µg/g) and iron (560.8 to 694.1 µg/g) respectively. Site 4 showed the highest absolute value for Zn content (17.3 µg/g), while site 5 recorded the highest absolute value of lead (7.2 µg/g). Site 1 and 2 were recorded the highest value of cadmium and copper content respectively. Taxonomically, 30 taxa of fungi were isolated and assigned to three phyla with five classes, eight orders and families. In view of species richness, site no.1 showed the highest richness index of fungi species (species richness=12) among all studied sites and followed by site no.5 (11 species). Other sites showed moderate to low species richness e.g. site no.4 (9 species), site no.2 (8 species) and site no.3 (7 species) respectively. Based on recovered total CFU site number 4 came first among all studied sites by recording (6870 CFU), while site number 3 showed the lowest count (4360 CFU). Based on the results of mycobiota isolated from the different sites throughout the study, site no. 1 showed the highest Simpson's species diversity index of 0.859 while site no. 3 showed the lowest value (0.690). The values for heavy metals for all zones are of public health significance and pose a threat to the survival of both humans and aquatic life. An immediate attention from concerned authorities is required in order to protect the Manzala lagoon and its dependants from further pollution and diseases.

Key words – Bioaccumulation – biosorption – clean up-fungi – legislation – metal tolerance.

Introduction

Rapid urbanization and industrialization has led to increase disposal of heavy metals and

radionuclide into the environment (McIveen & Negusanti 1994, Bishnoi & Garima, 2005). Heavy metals pose a significant threat to the environment and public health because of their toxicity and their accumulation in soil and food chains (Ceribasi & Yetis 2001, Chen et al. 2009, Gurel et al. 2010).

Water and soil pollution are considered to be one of the most dangerous hazards affecting Egypt and the majority of world countries. By the beginning of 1950s, heavy industries were born in Egypt along the Nile Delta in Cairo and Alexandria metropolitan areas and as a result pollution in the Nile River System has increased (Abdel-Azeem et al. 2007).

Manzala's lagoon is the largest brackish water body of the Nile Delta coastal lakes lies between 31° 00" and 31° 30" latitude and 31° 45" and 32° 20" longitude and is shallow with depth rarely exceeding one meter with a total area ~700km² (Tahoun 2007). It is a rhombohedral-shaped water body formed in the actively subsiding delta plain and lies in the northern quadrant of the delta between the Mediterranean Sea to the north, the Suez Canal, Port Said to the east, the Damietta Branch of the River Nile and the governorates of Sharkiya and Dakahliya to the west (Stanley 1988, Zahran, 2010). The lagoon is connected with the Mediterranean Sea by five straits permitting exchange the water and biota between the lake and the sea (Rashad & Abdel-Azeem 2010). The Lake is considered an important and valuable natural resource ecosystem for fish catch, wildlife, hydrological and biological regime in Egypt. There are about 12,000 fisherman-representing families with a population about 50,000 people living on the islands of the lake and (Zaky et al. 2011).

Over the last few decades, the lake has undergone dramatic environmental changes (Zyadah 1995, Shakweer 2005). The conditions have not been improved, which was clear from the deteriorious physicochemical and biological characteristics due to continuous steady flow of pollutants through numerous drains that discharge heavy load of organic and inorganic pollutants into the lake (El-Enany 2004, Abdel-Azeem et al. 2007, Rashad & Abdel-Azeem 2010). The effluents of drains cause the Lake to become almost stagnant or at least current less. The heavy load of the suspended solids and organic matter creates shallow water depth and raises the bottom of the Lake. The Lake is continuously being eutrophicated and will soon die off unless a rapid efficient rehabilitation plan takes place (Rashad & Abdel-Azeem 2010).

The biosorption potentialities of many microorganisms have been examined and different types of biomass have shown high levels of metal uptake (Merroun et al. 2001, Volesky 2007, González Bermúdez et al. 2012). Biosorption has other advantages over conventional treatment methods as low cost, a minimal amount of chemical and biological sludge and the possibility of biosorbent regeneration and metal recovery (Lesmana et al. 2009).

The contaminated sites are the principal sources of metal-resistant fungi (Malik 2004, Iskandar et al. 2011); therefore, it is important to explore autochthonous fungi from such contaminated niches for the bioremediation of heavy metals. The introduction of heavy metal compounds into the environment generally induces morphological and physiological changes in the microbial communities (Vadkertiova & Slavikova 2006).

Fungi are known to tolerate and detoxify metals by several mechanisms including valence transformation, extra and intracellular precipitation and active uptake (Ashida 1965, Gadd 1993). This is may referred to the high surface to volume ratio of microorganisms and their ability to detoxify metals (Kapoor et al. 1999, Magyarosy et al. 2002).

Currently, scientists are exploring the bioremediation techniques by exploiting microbial and associated biota within the ecosystem, to degrade, accumulate and/or remove the pollutants (Khan & Khoo 2000), and strains isolated from contaminated sites have this excellent ability. El-Morsy (2004) and El-Morsy et al. (2013) studied fungal species isolated from polluted water in Egypt for their resistance to metals and found that *Cunninghamella echinulata* and *Mucor racemosus* biomass could be employed as biosorbents of metal ions in wastewater. Vadkertiova & Slavikova (2006) have studied metal tolerance of yeasts isolated from polluted environments and found that there was an interspecific and intraspecific variation in the metal tolerance among tested strains. In the same way, Zafar et al. (2007) reported promising biosorption for Cd and Cr by two

filamentous fungi, *Aspergillus* sp. and *Rhizopus* sp., isolated from metal-contaminated agricultural soil.

Only limited studies have been conducted in Lake Manzala, Egypt to systematically screen filamentous fungi from metal polluted sites for their diversity, metal tolerance and their biosorption potential (Rashad & Abdel-Azeem 2010). The purpose of this study was therefore to: 1- ascertain the presence and concentration of heavy metals in sediments of selected sites along Lake Manzala, 2- speculate their toxic effects on fungal distribution, 3- isolate the metal resistant fungi and their characterization to explore their prospect to clean up of heavy metal contaminated soil, and 4- alert inhabitants of Manzala's lagoon islands and its surrounding governorates on the danger these heavy metals pose to their health and the consequences of the consumption of benthic macrobiota obtained from the Lagoon.

Materials & Methods

Sampling

Fifty soil samples were collected from five sites in Lake Manzala (Fig. 1). Samples were collected from the subsurface layer (10-20 cm) and transferred to the laboratory, air dried and kept till plating and subsequent analysis. Soil sub-samples from different locations within each uniform sampling area were mixed to make a composite sample. The Global Positioning System (GPS) readings of sampling sites were presented in (Table 1).

Table 1 GPS data of sediment sampling sites

No.	Site name	GPS	
		N	E
1	Navigation Canal	31°14'15.33"	32°16'34.66"
2	Ashtoum El-Gamil inlet	31°17'24.48"	32° 9'51.65"
3	El-Kowar	31°15'26.08"	32°12'23.89"
4	El-Bashtier	31°12'7.87"	32° 09'39.45"
5	Bahr El-Baqar drain	31°11'53.23"	32°12'20.34"



Fig. 1 – Sampling sites within Lake Manzala.

Edaphic characteristics

Soil samples were air dried and passed manually through a 2-mm sieve to evaluate gravel percent (USDA 1993). The pH values of water extracts of soil samples were measured electrometrically using pH meter (Cole-parmer model Chicago II.60648) in soil suspension of ratio 1:2.5, soil to water (Maiti 2003). Electrical conductivity (EC) was measured in soil water extract 1:1 using electrical conductivity meter (Cole-parmer model Chicago II.60648) according to (Maiti 2003). Organic matter (OM) content was determined by using loss-on-ignition (LOI) method (Nelson & Sommers 1996). Soil classification up to the sub-great group was described according to Soil Survey Staff (2003).

Heavy metals content in sediment

The total metal (Pb, Fe, Mn, Cd, Cu and Zn) concentrations in soils were determined by using dry ashing technique according to Issac & Kerber (1971) and Hseu (2004) respectively. Total heavy metal concentrations were determined by flame atomic absorption spectrophotometer (Thermo Scientific ICE 3300, UK) according to APHA (2005). The flame atomic absorption spectrophotometer's configuration and quality control procedures were maximized and adjusted before use and the detection limits were beyond the concentration of the studied heavy metal in tissue samples. Standard reference materials (Sigma-Aldrich Co.) were used to determine the accuracy of measurements.

Isolation and identification of native fungi

Soil (Warcup 1950) and dilution plate (Garett 1981) techniques were applied in order to get as good diversity as possible. Czapek's yeast extract agar (CYA), potato dextrose agar (PDA) and modified Leonian's agar (MLA) - as isolation media and supplemented with Rose Bengal (1/15,000) and chloramphenicol (50 ppm) for suppression of bacterial growth (Smith & Dawson 1944). To obtain as much species as possible, 10 plates isolation medium were prepared from every site (5 per each technique of isolation). After plating, plates were incubated at 27⁰C for 10 days, thereafter; developing colonies were identified and counted.

Taxonomic identification of isolated fungi using phenotypic approach down to the species level on standard morphology characteristics of fungal isolates down to the species level on standard media will mainly based on the following identification keys: Pitt (1980) for *Penicillium*; Raper and Fennell (1965), Klich (2002) for *Aspergillus*; Ellis (1971, 1976) for dematiaceous hyphomycetes; Booth (1971) for *Fusarium*, Domsch et al. (2007) for miscellaneous fungi and Guarro et al. (2012) for ascomycetes. The names of authors of fungal taxa are abbreviated according to Kirk and Ansell (1992). The systematic arrangement in the present list follows the latest system of classification appearing in the 10th edition of Anisworth and Bisby's Dictionary of the Fungi (Kirk et al. 2008). Name corrections, authorities, and taxonomic assignments of all taxa reported in this work were checked against the Index Fungorum database (www.indexfungorum.org).

Data analyses

The frequency of isolated taxa is expressed as number of cases of isolation of each species out of the total number of isolation plates. To estimate the similarity of species composition among different sites, the similarity coefficient suggested by Sørensen (1948) have been applied, while species diversity is calculated as Simpson's diversity index (Lande 1996). In order to find out the relationship between edaphic factors and terricolous biota under investigation, ordination in the form of Canonical Correspondence Analysis (CCA; ter Braak 1988) by using PC-ORD version 4 (MJM Software, Gleneden Beach, OR, USA) was applied.

Results

Soil characterization and chemical analyses

The parent material of studied soil samples is classified as fluviolacustrine type. Soil

moisture regime is either aquatic or torric, while the temperature is thermic. According to the Soil Survey Staff (2003) the dominated classification soil order in the studied areas is Aridisols. The texture of soils under investigation is either silty clay or clay according to particle size distributions. The soil samples are slightly alkaline to alkaline where soil pH values ranged between 7.93 and 8.1 while electric conductivity (EC) ranged between 5.64 and 12.76 dSm⁻¹. The mean values of organic matter percentage ranged between 1.0 and 2.6%.

Different concentrations of heavy metals (Zn, Pb, Cd, Fe, Mn and Cu) recorded in soil samples reflect the degree of pollution in all studied sites. Zinc content varied from 6.4 to 17.3 µg/g (mean average is 11.42 µg/g), in which the highest absolute value for Zn content was recorded in site no. 4 soils as 17.3 µg/g, and the lowest one at site no. 3 as 6.4 µg/g in studies samples (Fig. 2).

Lead content values ranged between 0.6 and 7.2 µg/g. The highest absolute value for Pb recorded in site no.5 (7.2 µg/g) and the lowest absolute value was 0.6 µg/g, recorded site no.3 soils. The cadmium content varied from 0.04 to 0.07 µg/g across the studied samples. The highest value for Cd was 0.07 µg/g, recorded in site no.1, while the lowest value was 0.04 µg/g, recorded in site no.5.

The mean value for copper (Cu) ranged between 1.1 and 2.1 µg/g within all investigated samples. The highest absolute value for Cu content was recorded in site no.2 of 2.1 µg/g, and the lowest one recorded in site no.3 of 1.1 µg/g.

The mean value of manganese content ranged between 98.5 and 150.3 µg/g with a highest absolute value at site no.5 soils of 150.3 µg/g, and the lowest absolute value at site no.2 soils of 98.5 µg/g. Manganese occurs in many soils as MnO₂ often in a hydrated form, especially soils covered by seawater, and possibly also trivalent manganese, though the way in which it's held is not known.

Iron content was higher than other heavy metals. The mean value for (Fe) ranged between 560.8 to 694.1 µg/g in the sediment. The highest absolute value of Fe was 694.1 µg/g recorded in site no.5 and the lowest absolute value was 560.8 µg/g, recorded in site no.1.

In summary, Mn, Fe and Pb levels at site 5 are relatively high, and are also considerably higher than at other sites, while Cd, Cu and Zn are relatively high at all sites.

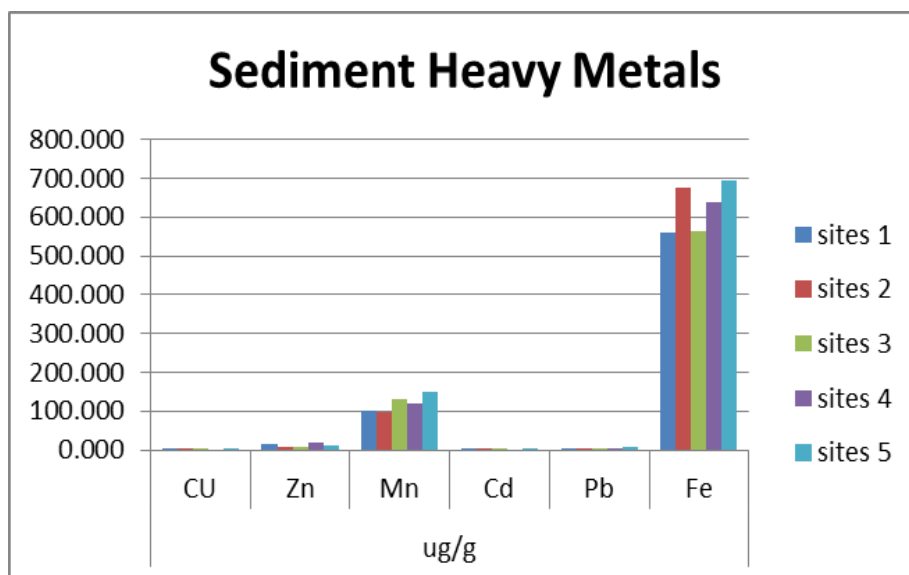


Fig. 2 – Heavy metal values in the study sites.

General features of isolated mycobiota

As shown in Table 2 it was possible to encounter as many as 30 species. A total of 27750 fungi and 470 yeast colony-forming units (CFU) were recovered during the entire study. All identified taxa were deposited on Fungarium of Arab Society for Fungal Conservation, Botany Department, Faculty of Science, University of Suez Canal, Egypt.

Taxonomically, isolated taxa were assigned to three phyla with five classes, eight orders and families (Table 3). While order Eurotiales accommodates the greatest range of species (18 species) followed by Pleosporales and Hypocreales (2 species each), the remaining orders accommodate the lowest range of species (1 species). Family Trichocomaceae had the highest contribution to the isolated fungi (18 species out of 30) followed by Pleosporaceae (2 species) Hypocreaceae (2 species), and the remaining families were represented only by one species.

On the higher taxa level, Zygomycota were represented only by two species (6.6 % of the total species number), teleomorphic Ascomycota (7 species, 23.33 %), anamorphic Ascomycota (20 species, 66.66%) and Basidiomycota (1 species, 3.3 %). Isolated species belonged to 17 genera.

The prevailing genera were *Aspergillus* (11 species including anamorph stages of two *Emericella* species; 36.66% of the total isolates), *Penicillium* (4 species including anamorph of *Talaromyces*; 13.33%) and the remaining taxa were represented only by two to one species each. The species genus ratio (S/G) per family however shows that family Trichocomaceae was the most diverse taxonomical rank by recording a ratio of (3) followed by Hypocreaceae (2), and Pleosporaceae (1).

In view of species richness, site no.1 showed the highest richness index of fungi species (species richness=12) among all studied sites and followed by site no.5 (11 species). Other sites showed moderate to low species richness e.g. site no.4 (9 species), site no.2 (8 species) and site no.3 (7 species) respectively (Fig. 3). Based on recovered total CFU site number 4 came first among all studied sites by recording (6870 CFU), while site number 3 showed the lowest count (4360 CFU). Based on the results of mycobiota isolated from the different sites throughout the study, site no. 1 showed the highest Simpson's species diversity index of 0.859 while site no. 3 showed the lowest value (0.690).

The distribution pattern of mycobiota based on the presence/absence in sites under investigation showed that recorded taxa could be tentatively classified into three groups. Group 1, comprises taxa of occurrence restricted to a single site (21 species) e.g. *Byssochlamys nivea*, *Mucor hiemalis* and *Alternaria atra*. Group 2, consists of species occurring in two or more sites (7) e.g. *Aspergillus terreus*, *Fusarium oxysporum* and *Trichoderma viride*. Group 3, contains species of common occurrence to almost all sites (2 species) e.g. *Aspergillus niger*, and *A. flavus*.

The greatest colony count was attributed to *Aspergillus niger* (31.9 % of the total isolate number) followed by *A. flavus* (27.3%), *A. terreus* (9.6%), *Penicillium chrysogenum* (3.7%), *A. fumigatus* (3.12%), *A. ochraceus* (2.9 %) and *Trichoderma viride* (2.6%) respectively. The greatest total colony count was attributed to genera *Aspergillus* (76%) followed by *Penicillium* (6%) and *Trichoderma* (3.2%).



Fig. 3 – Species richness among all sites.

Table 2 Total count (colonies/g dry soil), number of cases of isolation (NCI, out of 5 sites) and percentage frequency of fungal taxa recovered on isolation media at 28°C

Taxa	TC	NCI	% F
<i>Absidia corymbifera</i> (Cohn) Sacc. & Trotter	470	1	2.4
<i>Alternaria alternata</i> (Fr.) Keissl.	690	1	2.1
<i>A. atra</i> (Preuss) Woudenberg & Crous	640	1	1.6
<i>Aspergillus flavus</i> Link	7720	5	27.7
<i>A. fumigatus</i> Fresen.	880	1	3.1
<i>A. nidulans</i> (Eidam) G. Winter	150	1	0.8
<i>A. niger</i> Tiegh.	9030	5	30.7
<i>A. ochraceus</i> G. Wilh.	820	1	5.7
<i>A. oryzae</i> (Ahlb.) Cohn.	30	1	0.2
<i>A. terreus</i> Thom	2710	2	6.0
<i>A. ustus</i> (Bainier) Thom & Church	50	1	0.1
<i>A. versicolor</i> (Vuill.) Tirab.	150	1	0.4
<i>Byssochlamys fulva</i> Olliver & G. Sm.	20	1	0.3
<i>B. nivea</i> Westling	30	1	0.2
<i>Cladosporium cladosporioides</i> (Fresen.) G.A. de Vries	270	1	0.7
<i>Emericella nidulans</i> (Eidam) Vuill.	550	2	2.6
<i>E. varicolor</i> Berk. & Broome	50	1	0.2
<i>Fusarium oxysporum</i> Schldtl.	240	2	0.5
<i>Gymnascella dankaliensis</i> (Castell.) Currah	20	1	0.1
<i>Mucor hiemalis</i> Wehmer	440	1	2.9
<i>Neosartorya fischeri</i> (Wehmer) Malloch & Cain	20	1	0.1
<i>Nigrospora oryzae</i> (Berk. & Broome) Petch.	30	1	0.1
<i>Penicillium brevicompactum</i> Dierckx	100	1	0.3
<i>Penicillium chrysogenum</i> var <i>chrysogenum</i> Thom	1060	2	4.5
<i>Penicillium funiculosum</i> Thom	560	1	1.5
<i>Rhodotorula mucilaginosa</i> (A. Jörg.) F.C. Harrison	470	3	0.6
<i>Stachybotrys chartarum</i> (Ehrenb.) S. Hughes	90	1	0.3
<i>Talaromyces stipitatus</i> C.R. Benj.	10	1	0.1
<i>Trichoderma koningii</i> Oudem.	170	2	1.1
<i>T. viride</i> Pers.	750	3	3.1

Table 3 Taxonomic assignment of the isolated taxa according to Kirk et al. (2008)

Phylum	Class	Order	Family	Genus	Species
Zygomycota	Incertae sedis	Mucorales	Cunninghamellaceae	1	1
			Mucoraceae	1	1
Ascomycota	Dothideomycetes	Pleosporales	Pleosporaceae	2	2
			Capnodiales	Cladosporiaceae	1
	Eurotiomycetes	Eurotiales	Trichocomaceae	6	18
			Onygenales	Gymnoascaceae	1
	Sordariomycetes	Hypocreales	Hypocreaceae	1	2
			Nectriaceae	1	1
Incertae sedis			1	1	
Basidiomycota	Microbotryomycetes	Trichosphaeriales	Incertae sedis	1	1
		Sporidiobolales	Incertae sedis	1	1
Total	4	8	8	17	30

Table 4 Similarity coefficient among sites

Sites	1	2	3	4	5
1	1.0	0.4	0.21	0.28	0.26
2		1.0	0.26	0.23	0.21
3			1.0	0.37	0.22
4				1.0	0.5
5					1.0

Similarity coefficient values (Table 4) indicated that sites 3 and 4 are less similar to the other studied sites by showing the lowest similarity values. Other sites showed moderate similarity index values ranging from 0.26 to 0.5.

The CCA biplot (Fig. 4) reflects the effect of edaphic factors on the distribution of terricolous mycobiota in the examined sites. The Eigen values of the used axes were 0.230, 0.366 and 0.481 for axis 1, 2 and 3 respectively. Important variables tend to be represented by longer arrows. Based on the length of vector (ter Braak 1986) it was found that the patterns of fungi abundance were influenced positively by changes in six factors out of nine. Species at the edges of the axes were usually non-correlated with any variables.

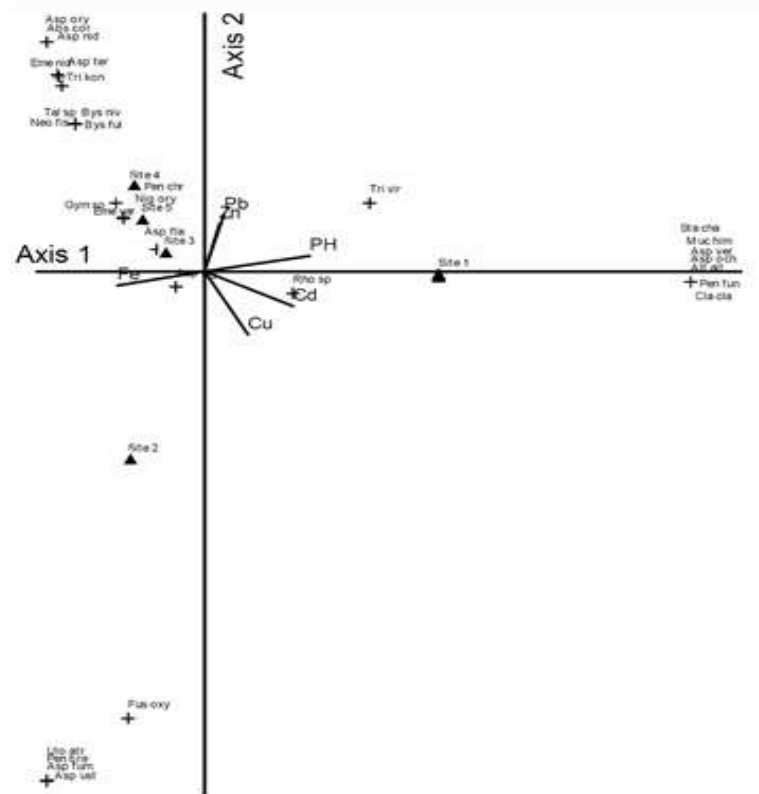


Fig. 4 – Canonical Correspondence Analysis (CCA) ordination biplot showing relationship between edaphic factors and terricolous mycobiota entities (+) among all studied sites.

Sites with high concentration of heavy metals are characterized by low number and diversity of fungi. Few species of fungi were able to colonize under these circumstances *viz*: *A. niger*, *A. flavus*, *E. varicolor*, *N. oryzae* and *P. chrysogenum*.

Discussion

Sediment study is very important to fungal ecologists because it gives them a good indication in the environmental changes of water and also about microfungi lived in this substratum. Furthermore, the sediment reflect the degree of pollution in water column and variety of conditions around it, where sediment tend to concentrate the heavy metals and other organic pollutants, particularly organic matter (Guerrin et al. 1990).

Heavy metals have a great ecological significance, due to their toxicity and accumulative behavior (Purves 1985). These elements, contrary to most pollution, are not biodegradable and undergo a global eco-biological cycle, which natural water is the main pathways (Hassouna, 1989). Heavy metals are defined as metals with a density of more than 5 gm/Cm⁻³. It tends to be bounded in stable complexes in organic and inorganic forming a very hard to dissolve, oxides and sulphides (El-Bokhty 1996).

The very important role of heavy metals pollution, the determination and speciation of heavy metals is a primary target in the environmental research today (Goher 1998). Thus, in the present study five of the most important heavy metals (iron, manganese, lead, zinc, cadmium and copper) are analyzed and discussed. The concentration of heavy metals in sediments had the following trend Fe > Mn > Zn > Cu > Pb > Cd. This complies with the previous studies carried by several investigators on Lake Manzala e.g. Abdel-Moati & El-Sammak (1997), Elghobashy et al. (2001), Ibrahim & ElNaggar (2006), Abdel-Azeem et al. (2007) and Saeed & Shaker (2008). Carrol (1958) stated that iron appears in the Lake sediments as an essential component of clay minerals which is the major one in the Lake. Hamed (1998) attributed the high concentrations of trace metals in the Nile sediments near Damietta governorate and Mansoura city to high clay content of sediment and industrial activities. He also added that the sandy sediments showed low concentrations of heavy metals than clayey sediments.

Soil pollution causes a pressure on sensitive microfungi and so changes the diversity of soil biota, representation of trophic groups of microorganisms (Zaguralskaya 1997). The decrease in fungal density caused by a high level of heavy metal contamination found at all studied sites is in agreement with Kikovic (1997). Likely, these heavy metal resistant fungi (*A. niger*, *A. flavus*, *A. terreus*,) form a larger part of total Colony Forming Unit (CFU) in contaminated soil compared to the least contaminated one (Hafez et al. 1997, Del Val et al. 1999, Kapoor et al. 1999, Miersch et al. 2001, Abdel-Azeem et al. 2007).

The overall implications of the concentration of these heavy metals in lagoon sediments is that living organisms (that is fishes, shrimps snails, crabs) especially the benthic population can concentrate these metals in their tissues and pass them back to man on consumption. These toxic metals can bioaccumulate in the human tissues, get to threshold concentrations and consequently cause a lot of damage to humans and affect labor tremendously. Heavy metal accumulation in lakes and natural bodies of water especially Lagoon has been on the increase due to industrial, agricultural and domestic activities (Okoye 1991, Kusemiju et al. 2001, Abdel-Azeem et al. 2007).

Metals analyzed in this study have also been found associated with bottom sediments and they constitute a potential danger to both autotrophic and heterotrophic benthic organisms (Jeng & Hans 1994). Bahnasawy et al. (2009) observed high toxicity of heavy metals in planktons, fish and sediments and they reported that the concentration of the heavy metals in the three different samples were far above the upper permissible limits. An immediate attention from concerned authorities is required to protect the Manzala lagoon from further metal pollution. The need arise for government to strictly monitor the source of discharge of these heavy metals, as the concentrations observed in this study are lethal not only to aquatic life but humans who consume seafood. This finding is therefore of public health significance. Recently, fishermen have been complaining bitterly of decrease in catch in Manzala lagoon as a result of fishes running away from the Lagoon. Hence there is the need to revisit the existing laws and apply them appropriately or amend them to make them more effective in order to save man from a catastrophic situation.

Morgan et al. (1992) observed that bioaccumulation and bio-concentration of various heavy metals in aquatic organisms also need effective monitoring as they have been found associated with several species of living organisms. Another area of concern is biotransformation of organic deposits in sediments. With reduction in benthic population matter recycling will be affected drastically in the Lagoon, which will in turn affect availability of nutrients for both microbiota and macrobiota in the water body. It is therefore, essential that regulatory authority see and ensure that existing laws are strictly obeyed and if need be place heavy fines on defaulters who fail to obey the laws governing the discharge of industrial effluents.

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