Communities of Oribatid Mites and Heavy Metal Accumulation in Oribatid Species in Agricultural Soils in Egypt Impacted by Waste Water

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Abstract

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The continued use of waste water for irrigation of agricultural fields in Egypt may lead to accumulation of heavy metals in soils and adverse effects on soil-living communities. We investigated responses of oribatid communities to heavy metal contamination in mango plantations irrigated by the Ismailia canal in the Suez region. Mean concentrations of heavy metals determined in irrigation water were considerably above the recommended levels. Concentrations of metals in agricultural soil were however below the permissible levels. A comparison with concentrations of a typical uncontaminated soil in this area revealed that the Ismailia water canal used for irrigation of agricultural land has elevated levels of heavy metals. The results of our ecological survey showed that the abundance and structure of the soil oribatid communities were not influenced by levels of heavy metals in the soil. We also showed that the diversity index can be a valuable tool for assessing the possible impact of pollutants on different species of oribatid mites. The oribatid species appeared to be accumulating different amounts of heavy metals when characterised by their bioconcentration factors. Most species were poor zinc accumulators. The accumulation of heavy metals in the body of oribatids was not strictly determined by their body size or by the trophic level. In conclusion, our study showed that mango plantations impacted by waste water from the Ismailia canal are accumulating heavy metals in their soils above the background concentrations, but ecological effects on soil-living communities are not apparent yet.

Keywords: oribatid mites; diversity; bioindicators; soil pollution; water pollution; heavy metals

Oribatid mites have successfully invaded almost all compartments of the biosphere. Their ability to adapt to local conditions is demonstrated by the diversity of habitats colonised, and by their high abundance and species richness. In most habitats, they constitute the largest proportion of microarthropod diversity.

Oribatid mites consume mainly living and dead parts of plants and fungi, however there are also some predators and scavengers (Behan-Pelletier 1999). Oribatids as a group consume a great variety of food items, and therefore, participate in numerous ways in the structure of the soil food web (Lebrun & van Straalen 1995).

Several aspects of the reproduction biology and the life cycle of oribatid mites can be considered extraordinary among arthropods. The slow development, low fecundity and long larval stages of oribatid mites seen in several species can help indicate long-term disturbances. Their low dispersion ability (Lebrun & van Straalen 1995) is also quite important, since most mites can hardly fly from sites affected by some kind of stress. Because of their important role in detrital food webs, there is an increasing interest in their reaction to environmental conditions such as heavy metal pollution (Janssen *et al.* 1990; Denneman & van Straalen 1991; Siepel 1995; Weigmann 1995; Zaitsev & van Straalen 2001).

Several studies have measured the accumulation of pollutants, in most cases heavy metals, in oribatid mites (Ludwig *et al.* 1992; Janssen & Hogervorst 1993; Siepel 1995; Zaitsev & van Straalen 2001; Skubala & Kafel 2004; Gulvik 2007). These studies have shown that oribatid mites easily accumulate environmental pollutants, such as heavy metals, but again there is a clear variation among species according to their diet. For example, copper has been shown to accumulate effectively in oribatid species (Skubala & Kafel 2004). Van Straalen *et al.* (2001) found that among seven different soil invertebrate groups oribatid mites showed the highest heavy metal concentrations. Nevertheless, our knowledge of the direct effects of heavy metals on soil mites is still limited.

In Egypt, drainage water used for irrigation in agriculture is a combination of variable amounts of agricultural drainage water, industrial effluents, and sewage water. Agricultural land drainage is and will continue to be a vital and necessary component of agricultural production systems. Due to the scarcity of water resources, drainage water is being recycled. Heavy metal pollution of water and agricultural soil is one of the most severe ecological problems on a worldwide scale and also in Egypt. Industrial or municipal drainage water irrigation is a common reality in most cities in Egypt. Drainage water from industries or other sources carries an appreciable amount of toxic heavy metals which create a problem for safe utilisation of agricultural soil (Ali & Soltan 1999). The long-term use of industrial or municipal drainage water in irrigation is known to contribute significantly to trace elements such as Cd, Cu, Pb, and Zn in surface soil (Sharma *et al.* 2007). Excessive accumulation of trace elements in water and agricultural soils through drainage water irrigation may not only result in soil contamination but also affect food quality, food safety, and may damage aquatic life (Sharma *et al.* 2007).

Up to the now no studies have been done on hazardous effects of long-term irrigation by water from the Ismailia Canal on soil Oribatida in Egyptian agroecosystems. This paper investigates the levels of Cd, Cu, Pb, and Zn in irrigation water, soils, and in oribatid mites from agricultural lands in Ismailia Governorate, Egypt, which is one of the largest areas of mango fruits culture in Egypt. The aim of our work was to highlight the potential of oribatid mites as indicators of ecosystem change in response to contamination and establish baseline data for these metals. The concentrations of heavy metals in water and soil were compared with accepted safety limits, while the concentrations of heavy metals in oribatid mites were compared with previous studies of different authors. This provides a basis for guiding further activities aimed at preventing the exposure of humans through monitoring and control of irrigation water.

MATERIAL AND METHODS

Study area. The investigations were done in Ismailia Governorate, Egypt. Ismailia is located in the Eastern part of the Arab Republic of Egypt near the middle part of the Suez Canal (30°58'N and 32°23'E and elevation above sea level, 13 m). The area is an almost flat landscape with good soil fertility and agreeable climate. It is characterised by aridity with long hot rainless summers, mild winters and a low amount of rainfall (50 mm annually). The most famous fruit cultured in the study area is mango, *Mangifera indica* L. The Ismailia water canal is the main source of fresh water, diverted from the Nile River. It is used for drinking, irrigation and industry (Egyptian Environmental Affairs Agency 2008).

Sampling. Five study sites were chosen along the Ismailia water canal, namely Nefisha (site 1), Abou-Souier (site 2), Old Kasaseen (site 3), Old Mahsama (site 4), and Aldaheriya village (site 5). Using a soil corer, three random soil samples of topsoil (0–20 cm), under mango trees, *Mangifera indica* L. (Family: Anacardiceae) were taken on four occasions from March to October 2009. These areas were cultivated and irrigated by the Ismailia water canal during the whole sampling period. Soil samples were taken from a representative quadrate (5 × 5 m) at each site. Sampling was done four times, with monthly intervals, making a total of 12 samples per date and a total of 480 samples. Oribatida were separated from the soil using the Tullgren method. Mites extracted for heavy metal determinations were preserved in a mixture of water and glycerol with addition of alcohol and kept in a refrigerator to avoid evaporation and development of microflora. Oribatid mites were identified according to Balogh (1972).

Water analysis. Samples were subjected to various analyses including pH measurements (using an electronic pH meter), total soluble salts (TSS) and electrical conductivity (EC) using a conductivity meter. Total nitrogen, total phosphate and heavy metals were analysed according to standard methods for the examination of water and wastewater (APHA 1995).

Soil analysis. Soil classification up to the subgreat group was done according to Soil Survey Staff. To perform chemical analyses, surface layers (0–20 cm) of all examined soil samples were selected. Organic matter content was determined and estimated by the Walkley-Black method (Jackson 1967). Total calcium carbonates were determined volumetrically using Collin's calcimeter and chemical properties (cations, anions, and pH) were determined according to Jackson (1967) and Page *et al*. (1982). Heavy metals (Cd, Cu, Pb, and Zn) were analysed by the total adsorbed metals (5 g soil from each sample was digested with 25 ml DTPA), using an atomic spectrophotometer (Thermo-electron, S Series GE 711838, Thermo Electron Corp, Waltham, USA). The limits of detection and wavelength of different heavy metals are given in Table 1.

Test species and analytical methods. For the analysis of metal body burden the following criteria of chosen species were taken into account:

– The species should be quite numerous and should have a high constancy in the sample collection.
– Larger species are preferable due to easier treatment.
– Species which occur at all sample sites are suitable for searching trends of metal accumulation.

Finally four species were chosen for the present study: *Pergalummna flagellata* Grandjean, *Scheloribates laevigatus* (Koch), *Zygoribatula undulata* Berlese and *Oppiella nova* (Oudemans).

The mite species were pooled (several thousands) and their joint fresh weight (around 1 g) was established, then the sample was dried and digested in a mixture of concentrated nitric and perchloric acid (7:1 by volume) and diluted with distilled water. Determination of metal concentrations was done using an atomic absorption spectrophotometer (Thermo-electron, S Series GE 711838), with background correction using a deuterium lamp at a wavelength of 164.49 nm. The values of relative standard deviation (RSD) for Cd, Cu, Pb and Zn were 0.9%, 1.3%, 417%, and 0.3%, respectively. Wavelength and detection limits of each heavy metal detected are shown in Table 1.

Table 1. Wavelength and detection limits of each heavy metal in the AAS analysis

Element	Wavelength (nm)	detection limits (μg/l)
Cd	228.8	0.007
Cu	224.8	0.027
Pb	217	0.085
Zn	213.9	0.008

Data analysis. The oribatid communities were characterised by the following indices: abundance, species richness and dominance, Shannon index of diversity (H') and equitability (J). Differences between the sites were evaluated using one-way analysis of variance (ANOVA); this was followed by a multiple comparison of the means using Tukey's test. The bioconcentration factor (BCF) of heavy metals was calculated according to Skubala and Kafel (2004). To assess the contamination level of heavy metals, mean, minimum, maximum and standard deviation of water, soil and oribatid mites were calculated using Microsoft Excel (Version 2000). All heavy metal analyses were checked by the analysis of standard reference material, and by previous studies for soil, water oribatid mites.

RESULTS

Water analysis

The pH values in the Ismailia water canal ranged between 7.50 and 9.91 in all studied sites along the canal (Table 2). The canal's water salinity ranged between 4.41 mg/l and 8.11 mg/l. Total nitrogen in water samples showed a mean value of 2.61 mg/l, with the highest absolute value of 3.67 mg/l and the lowest value of 1.65 mg/l. Total phosphate content showed a mean value of 4.14 mg/l, with a maximum of 4.86 mg/l and a minimum of 3.11 mg/l. All heavy metals determined in water samples exceeded the standard levels for irrigation water as described by FAO (Pais & Jones 1997).

Table 2. Physio-chemical analysis and heavy metal concentrations in water samples from the Ismailia irrigation canal throughout the period of study

Parameters	FAO recommended maximum concentration*	Present study			
		mean	S.D.	min.	max.
pH	–	7.66	0.18	7.50	7.91
E. C (dS/m)	–	1.17	0.5	0.33	1.52
T.S.S. (mg/l)	–	7.04	1.65	4.41	8.11
Total nitrogen (%)	–	2.61	0.84	1.65	3.67
Total phosphate (%)	–	4.14	0.69	3.11	4.86
Heavy metal (mg/kg)					
Cd	0.01	0.34	0.15	0.13	0.49
Cu	0.20	15.81	3.23	13.52	21.35
Pb	5.00	20.83	6.28	11.54	29.06
Zn	2.00	23.73	8.44	12.21	32.51

*Source: Pais & Jones (1997)

Soil analysis

The texture of soils under investigation is a sandy loam according to the particle size distributions. Across the studied profiles, total calcium carbonate percentages ranged between 0.18% and 1.34% (Table 3). The soil profiles are alkaline while soil pH values ranged between 7.48 and 8.12 and electrical conductivity (EC) ranged between 0.57 dS/m and 1.36 dS/m. The mean values of total organic matter (TOM) percentage ranged between 0.39% and 0.95% while the saturation percentage of soil (SP) ranged between 18.60% and 19.18%. In addition, the contents of calcium carbonate were quite low.

Heavy metals (Cd, Cu, Pb, and Zn) were recorded at elevated concentrations in the soil, which reflects a moderate degree of pollution compared to the concentrations in normal and non-polluted soils in Egypt (Table 2). The zinc content of the studied soil profiles did not however exceed the maximum acceptable concentration in soil (300 m/kg). It varied from 4.97 m/kg to 7.77 m/kg, the highest absolute value for Zn was recorded in sites 2 and 4, and the lowest one in site 5. Lead content did not exceed the maximum acceptable concentration either (100 m/kg), the mean values ranged between 8.50 m/kg and 13.50 m/kg. While the maximum acceptable concentration of cadmium in soils is 5 m/kg, the cadmium content varied from 0.12 m/kg to 0.24 m/kg. The mean value for copper ranged between 11.39 m/kg and 15.59 m/kg within all investigated sites. In general, Cu, Zn, and Pb levels at all studied sites are relatively high, and are also considerably higher than the other levels recorded in Egypt by Aboulroos *et al.* (1996).

Oribatid mite communities

In total, 7746 specimens and 15 species of oribatid mites belonging to 14 genera were found at different sites in the study area. The distribution of oribatid species across sites is shown in Table 3. Site 4 had the highest total density of oribatid mites in comparison with the others. Here mites reached a density of 3024 individuals, while the lowest density was observed in site 1 (659 individuals/500 g soil).

The one-way ANOVA revealed significant differences in oribatid abundance between site 4 and the other sites (P < 0:05). The highest abundance of oribatids was noted in site 4, while the lowest abundance was noted in site 1 (3024 individuals and 659 individuals, respectively) (Table 4).

Differences in species richness were not so pronounced between sites. The highest number of species was recorded in sites 3 and 5 (15 species). However, species richness in these two sites was only slightly higher than in site 2 (14 species). On the one hand, the lowest number of species was recorded in site 1 (10 species) with the highest

Table 3. Mean concentrations of heavy metals and (SD) (mg/kg) in the upper soil layer (0–20 cm) and other characteristics of the five sampled sites throughout the period of study

Parameters	MAC of elements in agricultural soil*	Uncontaminated		Present study									
				site 1		site 2		site 3		site 4		site 5	
		soil#	soil##	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
pH	–	–	–	7.9	0.3	7.48	0.23	7.62	0.33	7.71	0.23	7.12	0.31
E.C. (dS/m)	–	–	–	0.72[a]	0.51	0.57[a]	0.52	1.13[a]	1.06	1.34[a]	0.69	1.36[a]	0.67
TOM (%)	–	–	–	0.45[a]	0.15	0.6[a]	0.17	0.79[a]	0.2	0.59[a]	0.16	0.99[a]	0.25
$CaCO_3$ (%)	–	–	–	0.94[a]	0.43	18.8[a]	0.63	1.24[a]	0.59	0.18[a]	0.43	1.1[a]	1.45
SP (%)	–	–	–	19.0[a]	1.22	1.34[a]	0.81	18.6[a]	0.89	19.2[a]	1.15	18.7[a]	0.83
Heavy metals													
Cd	5	0.014	1	0.13[a]	0.13[a]	0.1[a]	0.06	0.14[a]	0.05	0.18[a]	0.04	0.14[a]	0.02
Cu	100	1.86	30	27.34[b]	0.79	14.9[b]	3.87	13.5[b]	3.01	13.2[b]	3.3	19.9[b]	0.87
Pb	100	1.17	50	10.6[b]	0.55	6.93[c]	0.65	7.95[b]	0.59	8.97[b]	1.12	8.5[c]	1.1
Zn	300	1.56	100	65.46[c]	3.49	53.2[d]	2.65	43.9[c]	3.21	40.4[c]	1.38	45.9[d]	0.61

Means bearing the same litter (a, b, c, d) do not differ significantly from each other at the 5% level
E.C. = Electric Conductivity; TOM = Total organic matter; SP = Saturation percentage
*European Economic Community for Maximum Acceptable Concentration (MAC) in agricultural soils
Source: #Aboulroos *et al.* (1996); ##Kabata-Pendias and Pendias (1994)

Table 4. A list of oribatid mite species with their total and frequency in five sampled sites throughout the period of study

Species	Site 1		Site 2		Site 3		Site 4		Site 5	
	no.	(%)	no.	(%)	no.	(%)	no.	(%)	no.	(%)
Galumna tarsipennata (Grandjean)	98	**14.87**	93	**8.34**	80	**6.34**	161	**5.32**	97	**5.57**
Pergalummna flagellata Grandjean	78	**11.84**	136	**12.19**	102	**8.08**	254	**8.31**	35	2.07
Scheloribates laevigatus (Koch)	91	**13.81**	102	**9.15**	178	**14.1**	871	**28.8**	108	**6.41**
Zygoribatula undulata Berlese	65	**9.86**	153	**13.72**	133	**10.54**	729	**24.11**	270	**16.01**
Zygoribatula tritici El-Badry & Nasr	58	**8.8**	90	0.08	194	**15.37**	159	**5.26**	212	**12.57**
Oppiella nova (Oudemans)	103	**15.63**	161	**14.44**	120	**9.51**	426	**14.09**	210	**12.46**
Oppia sticta Popp	78	**11.84**	66	**5.92**	63	4.99	257	**8.49**	69	4.09
Oppia concolor Koch	0	0	62	**5.56**	63	4.99	17	0.56	303	**17.97**
Epilohmannia cylindrica Berlese	21	**6.53**	26	2.33	27	2.14	13	0.43	27	1.6
Lohmannia egypticus El-Badry & Nasr	23	3.49	39	3.49	47	3.72	25	0.83	147	**8.72**
Papillacarus aciculatus Kunast	0	0	0	0	41	3.25	49	1.62	21	1.25
Cosmochthonius lantus (Michael)	0	0	46	4.13	39	3.09	0	0	54	3.2
Ctenacarus araneola (Grandjean)	0	0	71	**6.36**	94	**7.45**	0	0	25	1.48
Aphilacarus acarinus (Berlese)	0	0	38	3.41	35	2.77	0	0	43	2.55
Phthiracarus sp.	22	3.34	32	2.86	46	3.65	63	2.08	65	3.86
Total individuals/60 samples	659		1115		1262		3024		1686	
Number of species (*S*)	10		14		15		12		15	
Shannon index (*H'*)	2.191		2.277		2.524		1.925		2.373	
Equibatibilty (*J*)	0.951		0.863		0.932		0.774		0.876	

LSD 0.05 between sites = 85.154; LSD 0.05 between species = 147.492
Bold type indicates dominant species at a particular site (Dominant species, D > 5 %)

concentration of heavy metals. Site 4 was characterised by the lowest species diversity (H' = 1.925), while the highest value of the Shannon index was found in site 3 (H' = 2.524). Results regarding equitability (J) among all sites followed the same trends as the Shannon index (Table 3).

The most dominant species were *Scheloribates laevigatus* (28%) and *Zygoribatula undulata* (24.1%) in site 4. Meanwhile, *Z. undulata* was the most dominant species in site 5. On the other hand, *Oppiella nova* was the most dominant in site 1 and 2 (15.36% and 14.4 %, respectively) (Table 4).

Some species were not observed in sites 2 and 4; these were *Cosmochthonius lantus* (Michael), *Ctenacarus araneola* (Grandjean) and *Aphilacarus acarinus* (Berlese). On the other hand, *Papillacarus aciculatus* Kunast was not observed in site 1 and site 2.

Metal accumulation by oribatid species

Data on heavy metal concentrations in various species of oribatid mites are represented in Table 5. For most of the metals, oribatid mites had low concentrations.

Although the concentrations of cadmium in soil and water were low (Tables 2 and 3), cadmium concentrations in various species of oribatid mites were detected. The highest concentration was found in *Pergalummna flagellata* (3.73 mg/kg) in site 1, and the lowest in *Oppiella nova* (0.11 mg/kg)

Table 5. Heavy metal concentrations (means with standard deviations, mg/kg) in the body of selected oribatid species from different sites

Species	Sites	Cd		Cu		Pb		Zn	
		mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
P. flagellata	1	**1.73**[a]	0.15	**54.27**[a]	4.91	**47.25**[a]	4.41	52.54[a]	3.56
	2	1.14[a]	1.49	23.81[b]	3.36	27.46[b]	2.65	51.29[a]	1.93
	3	1.56[a]	0.38	27.54[a]	4.64	46.61[b]	2.03	**80.14**[a]	0.72
	4	1.17[a]	0.15	15.17[a]	2.71	20.62[a]	1.47	33.03[b]	3.21
	5	0.89[b]	0.13	11.04[a]	1.21	18.75[a]	0.64	21.33[b]	1.84
S. laevigatus	1	**1.02**[a]	0.25	**25.97**[a]	3.75	**45.4**[a]	5.81	**72.26**[a]	14.32
	2	0.7[a]	0.93	16.76[b]	4.5	24.66[b]	5.25	59.06[a]	9.87
	3	1.03[a]	0.93	22.03[a]	4.0	37.85[a]	6.47	57.63[a]	12.22
	4	0.95[a]	0.29	13.23[a]	4.19	21.64[a]	1.62	34.13[b]	8.29
	5	0.69[a]	0.16	10.79[a]	1.85	14.38[a]	4.35	24.16[c]	5.49
Z. undulata	1	1.44[a]	1.29	**45.52**[a]	1.82	18.05[a]	4.22	**67.97**[a]	9.21
	2	**1.79**[a]	0.84	17.34[b]	3.89	**44.41**[b]	7.87	56.53[a]	11.36
	3	0.55[b]	0.09	22.72[a]	3.71	26.29[a]	6.12	57.8[a]	15.04
	4	0.45[b]	0.27	18.32[a]	4.21	19.05[a]	5.31	26.33[b]	6.29
	5	0.2[b]	0.06	12.92[a]	3.31	14.51[a]	2.15	14.71[b]	4.06
O. nova	1	**1.8**[a]	0.53	25.09[a]	2.49	31.45[a]	5.67	**83.77**[a]	9.64
	2	0.72[b]	0.41	**25.48**[a]	4.8	41.02[b]	8.39	**80.65**[a]	7.01
	3	0.77[b]	0.15	21.63[a]	1.54	**46.29**[b]	6.63	62.1[a]	4.36
	4	0.54[b]	0.16	19.18[a]	1.09	23.78[a]	5.82	35.45[b]	6.03
	5	0.11[b]	0.13	7.7[b]	0.93	12.91[a]	3.61	19.07[c]	3.16

Bold type indicates the highest value of a particular metal for a species
Litters (a, b and c) different significant concentrations of metals by a multiple comparison of means between mite species from each sites at the 5% level

in site 5. Nevertheless, the concentrations of this metal in mites were much higher than in soil and water.

Copper (Cu) accumulation seemed to be very different from cadmium. The highest levels of Cu were found in *Pergalummna flagellata* and *Zygoribatula undulata* in site 2 (25.27 mg/kg and 45.52 mg/kg, respectively). The lowest concentration was observed in *Oppiella nova* in site 5 (7.7 mg/kg) (Table 5).

Lead (Pb) concentrations were more similar among the species, and data showed that site 2 had the highest concentration of Pb in *Pergalummna flagellata*, *Scheloribates laevigatus* and *Zygoribatula undulata* (Table 5). The highest concentration of zinc (Zn) was observed in site 3 in *Pergalummna flagellata* (83.77 mg/kg). However, the differences in zinc concentrations between mite species at the same site were not great.

Microphytophagous mites (e.g. *O. nova*) accumulated in general more zinc than other species. This species had relatively high Zn concentrations (feeding both on fungi and dead organic matter). Only in the case of lead and zinc in *Oppiella nova*, the highest concentrations were observed in site 3 (46.29 mg/kg and 62.1 mg/kg, respectively). The overall trend of the concentrations of heavy metals in different oribatid mites was Zn > Pb > Cu > Cd. However, a different ranking was found for each metal as follows: Cd: *Z. undulata,* > *O. nova* > *P. flagellat*a > *S laevigatus*, Cu: *Z. undulate* > *P. flagellata* > *O. nova* > *S. laevigatus*, Pb: *P. flagellata* > *O. nova* > *S. laevigatus* > *Z. undulata,* and Zn: *P. flagellata* > *S. laevigatus* > *Z. undulata* > *O. nova.*

The bioconcentration factor (BCF) of the metals measured in the oribatid mite species in comparison with the total content of metals in soil is shown Table 6.

BCF is a parameter used to describe the transfer of trace elements from soil to oribatid body. It is notable that different oribatid mite species have quite different concentration ability for certain metals. The highest BCF are found for cadmium

Table 6. Average bioconcentration factors (BCF) of the selected oribatid species

Species	Site	Cd	Cu	Pb	Zn
	1	**25.92**	**3.72**	**4.46**	0.8
	2	**11.4**	0.87	**3.96**	0.96
P. flagellata	3	**11.14**	**1.77**	**5.86**	**1.83**
	4	**6.5**	**1.15**	**2.29**	0.82
	5	**6.36**	0.97	**2.21**	0.47
	1	**15.54**	0.95	**4.28**	**1.1**
	2	**7.0**	**1.15**	**3.56**	**1.1**
S. laevigatus	3	**7.36**	**1.41**	**4.76**	**1.31**
	4	**2.5**	**1.01**	**2.41**	0.85
	5	**4.93**	0.95	**1.69**	0.53
	1	**13.77**	1.66	1.7	1.04
	2	**14.4**	**1.19**	**6.41**	**1.23**
Z. undulata	3	**3.93**	**1.45**	**3.3**	**1.32**
	4	**2.5**	**1.39**	**2.12**	0.65
	5	**1.43**	**1.31**	**1.47**	0.32
	1	**5.54**	0.92	**2.97**	**1.28**
	2	**18.0**	**1.75**	**5.92**	**1.62**
O. nova	3	**5.5**	**1.39**	**5.82**	**1.41**
	4	**3.0**	**1.46**	**2.65**	0.88
	5	0.79	0.68	**1.52**	0.42

Bold type indicates values higher than 1.0

and lead in all oribatid mites. BCF differs between sites. However, it was impossible to find a general rule for the species analysed in all investigated sites. BCF was high for cadmium in all studied sites. A similar trend could be observed for lead (Table 6). The only exception is the cadmium load in *Oppiella nova* (0.79) in site 5. On the other hand, the highest value for cadmium was 25.92 in *P. flagellat*a in site 1. There was no clear trend for copper. Regarding zinc, *P. flagellat*a was not enriched with this metal in all studied sites, except for site 3. The concentration of this metal in the body of oribatids was higher than the concentration in soil and irrigation water.

DISCUSSION

Water analysis

In spite of the great agricultural importance of soils in Ismailia Governorate, little information exists about the present state of these soils, including heavy metal contents. The use of soil mites as indicators of soil contaminated by heavy metals has never been investigated in these sites. This study was therefore undertaken in soils, water and oribatid mites of the area in order to identify the current levels of heavy metals.

In this study, concentrations of Cd, Cu, Pb and Zn were higher than the values (0.06, 2.17, 0.21, and 0.95 mg/kg) reported by Ahmed and Goni (2010). The data obtained for heavy metals in water from the present study agreed more or less with the findings of the other authors (Khan *et al.* 1998). This variation might be ascribed to a variety of industries discharging their treated and untreated waste water into the Ismailia canal, which was the source of water used for irrigation purposes. In comparison with the standard guideline of irrigation water (Pescod 1992), it was found that the mean concentrations of Cd, Cu, Pb and Zn were higher than the recommended permissible level. This result suggests that heavy metal-based industries, domestic wastes and agricultural wastes along the Ismailia canal are sources of heavy metals.

Soil analysis

The sequence of heavy metal concentrations (mg/kg dry soil) in agricultural soils of the study area (Table 2) was Cu > Pb > Zn > Cd. The extent of metals observed in agricultural soils in the present investigation exceeded the permissible levels reported by different authors like Kabata-Pendias and Pendias (1992). However, a comparison of the mean concentrations of heavy metals with the values for non-polluted soils in Egypt (Aboulroos *et al.* 1996) and with the maximum allowable concentrations (MAC) of elements in agricultural soils showed that none of the heavy metal concentrations exceeded the permissible levels. The variation of heavy metal concentrations might be due to the variations of heavy metal concentrations in irrigation water and other agronomic practices of the respective area.

In Egypt, agricultural soils are commonly contaminated by heavy metals through the repeated use of wastewater from different sources for irrigation and also through the application of chemical fertilizers and pesticides. Cd, for example, is found in wastewater and also in phosphate fertilisers. To many agricultural soils, with the use of effluent contaminated water in irrigation, heavy doses of phosphate fertilisers have been applied for more than 45 years, and all of the heavy metals found in these sources keep accumulating in soils. The amounts now present are reaching the toxic level in some places (Aboulroos *et al.* 1996). Several workers have reported that the concentration of Cd was increased by heavy application of superphosphate.

Oribatid mite communities

Studies of oribatid mites stressed by metal contamination were carried out previously (e.g. Lebrun & van Straalen 1995; Zaitsev & van Straalen 2001). Recently, metal concentrations were estimated in more than 30 species of mites along a contamination gradient (Zaitsev & van Straalen 2001; Skubala & Kafel 2004). But unfortunately there are no studies on oribatid mites related to the environmental changes such as soil contamination by heavy metals as well as the validity of the water used in irrigation at least in Egypt.

The highest abundance of oribatids was observed in site 4 followed by site 5 (Table 3). The site is characterised by a moderate contamination by heavy metals. Species richness was also the highest in the oribatid community in sites 5, 3 and 2 compared with the other studied sites. However, the high abundance of mites in sites 4 and 5 was probably due to an increased volume of the habitat as a result of accumulation of large amounts of undecomposed leaf litter. The lowest abundance and number of species were noted in site 1, which is the most contaminated.

Trace elements and soil properties of site 1 may play a more important role in forming the mite community diversity, and many species have disappeared in comparison with other sites. Reduction of the abundance and species richness of oribatid mites in sites with high heavy metal concentration is not uncommon and well documented in the literature (Bengtsson & Rundgren 1984). In other studies, a high diversity of oribatid mites in most sites suggested that the metal contamination was not a leading factor affecting the species density and diversity (Zaitsev & van Straalen 2001).

Metal accumulation by oribatid species

Reactions of oribatid mites to soil contamination were studied previously but not very extensively (van Straalen *et al.* 1988; Lebrun & van Straalen 1995). The chemical composition and the indicator value for the impact of heavy metal pollution were estimated for some species (Siepel 1995).

Only one species, *P. peltifer*, has been studied relatively well. It is a model species in various laboratories and it is considered for use in a standardised soil toxicity test (van Gestel & Doornekamp 1998). It was identified as the most responsive species to heavy metal pollution in a survey of nine different forest sites (Khalil *et al.* 2009). Concentrations of more than ten elements including cadmium and lead were measured in *P. peltifer* (Janssen & Hogervorst 1993). Seasonal dynamics of metal accumulation by this mite was also studied (Janssen *et al.* 1990; Ludwig *et al.* 1992). Some data on the cadmium content of *Diapterobates humeralis*, *Steganacarus magnus*, and *Chamobates cuspidatus* are known from the literature (Lebrun & van Straalen 1995). Metal concentrations were estimated in thirty species of mites, the suitability of using this group for ecotoxicological purposes is discussed in the literature (Lebrun & van Straalen 1995; van Straalen 1998).

In the present study, zinc concentrations varied from 14.36 mg/kg in *S. laevigatus* (site 5) to 83.77 mg/kg in *O. nova* (site 1). The accumulation of zinc could be related to feeding on fungi and mites because zinc is known to be an essential element in metabolism (Zaitsev & van Straalen 2001). The variation in copper content in oribatids was not higher, except in *P. flagellata* and *Z. undulata* in site 1. Only, the variation of cadmium load was slight in most species (from 0.11 mg/kg in *O. nova* in site 5 mg/kg to 3.73 mg/kg of *P. flagellata* in site 1). The body concentration of metals in invertebrates differs largely between taxonomic groups, species and even individuals within one species (Bengtsson & Tranvik 1989).

Concentrations of zinc and copper were higher in microphytophagous species (*O. nova*) compared with the panphytophagous (*P. flagellata*) feeding groups. The accumulation of zinc could be related to feeding on fungi, which is an important part of the microphytophagous diet. Also, fungi are known as effective heavy metals accumulators (Khan *et al.* 2000). Heavy metals accumulating in fungi appear to be concentrated in cell walls (Siepel 1995). The present study did not reveal such a clear relationship between mite species and their feeding habits. However, the content of zinc in *O. nova* was generally higher than in the other species studied. Nevertheless, it is difficult to draw some general conclusions about the relationship between feeding type and heavy metal bioaccumulation because of the lack of precise information on feeding habits of many oribatid species.

The bioconcentration factors (BCF) increased in the sequence: Cd > Pb > Cu > Zn for most of the species in almost all sites (Table 6). Zaitsev (1999) investigated nine oribatids in the surroundings of a metallurgical plant and revealed the highest concentration factors for cadmium followed by zinc and copper. The highest bioaccumulation factors were found for cadmium in all oribatid species, for example it was 25.92 in *P. flagellata*. Skubala and Kafel (2004) reported the highest concentration factors in *Pergalumna nervosa* for cadmium (0.04). A low concentration factor for copper was noted in this study. A high concentration factor for copper may be limited to species which use haemocyanin as an oxygen carrier, such as snails, isopods and some arachnids (Janssen & Hogervorst 1993). As oribatids do not possess haemocyanin (Krantz 1978), high copper concentrations may indicate the presence of other substances capable of accumulating copper, or may point at a crucial role of this element in the metabolism of oribatids.

The low concentration factors of heavy metals may be explained by the ability of the species to prevent a high internal metal concentration, either by low uptake through the gut wall or by rapid excretion (Janssen & Hogervorst 1993). In conclusion, we can use oribatid mites to assess the environmental changes, particularly in the soil such as heavy metal pollution; this is due to the low fecundity of most oribatids and their poor power of dispersal (Behan-Pelletier 1999). The findings from this study suggest that, among soil arthropods, oribatid mites have a high potential as bioindicators of environmental changes (including pollution).

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