SIMULTANEOUS COMPETITIVE ADSORPTION OF HEAVY METALS BY SOME EGYPTIAN SOILS

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H eavy metal cations can be introduced into agricultural soils by application of sewage sludge, composts and industrial wastes which is commonly and increasingly used in Egypt. Therefore, heavy metal adsorption reactions, in a competitive system, are important to determine heavy metal availability to plants and their mobility throughout the soil. This study was conducted to evaluate the selectivity sequence and estimates the competitive adsorption of several heavy metals in seven soil samples having different chemical and mineralogical characteristics. The competition affected the behavior of heavy metal cations in such a way that the soils adsorbed less Zn, Cd and Ni and more Pb and Cu with increasing their total concentrations. On the other hand, the occupancy of the adsorption complex by the heavy metals was proportional to the relative concentration applied. As the applied concentration increased Pb and Cu adsorption increased, while Zn, Cd and Ni adsorption decreased. The maximum adsorption capacity (b) for the heavy metal cations was calculated. The soils of Wadi El – Tumeilat and Wadi El-Arish showed the highest maximum adsorption values, in the order of 77.52 and 71.94 mmol l^{-1}, respectively, whereas the soils of El-Bahariya Oasis (El-Heiz) and El-Hammam showed the lowest values, in the orders of 14.08 and 24.10 mmol l^{-1}, respectively. On the basis of the proportion of increase or decrease in heavy metals adsorption, the selectivity sequence was evaluated. The most common sequence was Pb > Cu > Cd > Ni > Zn. Lead, Cu and Cd were the heavy metal cations most strongly adsorbed by all soils, whereas Ni and Zn were the least adsorbed.

Wastes and residues, especially from industrial and urban sources, constitute one of the greatest problems to modern society due to their large daily production and high contamination effect. The disposal of these wastes needs to be accomplished with the minimum hazardous impact in the wider environment. Among the practices currently used, the disposal of waste onto agricultural lands is the most common. Materials such as sewage sludge, composts and many industrial wastes are increasingly used in Egyptian agriculture. In this situation, several heavy metal cations can be available at the same time in the soils and, therefore their selective retention and competitive adsorption by the soil becomes of major importance in determining their availability to plants and movement throughout the soil.

Competitive adsorption of heavy metals has been indirectly assessed on synthetic minerals (Brummer *et al.*, 1988; Trivedi and Axe, 2000) and soil samples (Cavallaro and McBride, 1978; Abd-Elfattah and Wada, 1981; Harter, 1983, 1992; King, 1988; Pardo, 2000). The consensus reached in these studies is that Pb and Cu are more strongly retained compared to Zn, Ni and Cd.

Few studies on direct measurement of heavy metal competition using soil samples and multi-component solutions have been reported (Schmitt and Sticher, 1986; Gao *et al.*, 1997; Welp and Brummer, 1999). The general agreement has been that Pb and Cu are more strongly adsorbed than Cd, Zn and Ni.

Matos *et al.* (1994) reported that Cu and Pb were close to immobile in tropical soils, whereas Cd and Zn were translocated almost freely in the A, B and C-horizons of a Brazilian Oxisol. Fontes *et al.* (2000) found that the ionic competition strongly influenced the adsorptive capacity and mobility of several heavy metal cations in soils thus responding differently to the fitting of adsorption equations. As the total concentration increased, there was a decrease in the adsorption of Zn and Cd and quadratic models allowed for a best fit of the adsorption data. On the other hand, competition had a very small effect on Cu and Pb adsorption and the linear, Langmuir and Temkin models, in general, gave the best fit of their adsorption data. Using the same soils utilized in that study but without removing the soil organic matter and calculating distribution coefficients, Gomes *et al.* (2001) have shown that heavy metal selectivity sequences varied among soils but the most common sequence was $Cr > Pb > Cu > Cd > Zn > Ni$, with Cr and Zn exchanging places with Pb and Ni, respectively for some soils.

Studies on adsorption of heavy metals, either individually or in a competitive situation, are also important in determining the capacity of soils to respond to the introduction of these pollutants into soil systems. The effect of soil pollution on the environment is mainly determined by the amount and nature of past and present contaminant loadings and the ability of soils to buffer and transform the pollutants involved (Batjes and Bridges, 1993). The

buffering capacities of soils can neutralize or immobilize acids and heavy metals added to them, so the importance of buffering capacity as a valued environmental resource must be recognized (Stigliani, 1996). Contaminant loadings and buffering capacities for heavy metals are intrinsically linked to soil ability to adsorb and immobilize these pollutants. In a broad sense, the critical load can be defined as the highest input of a particular contaminant that an ecosystem can tolerate without serious damage to its ecological functions (Nilsson and Grennfelt, 1988) and if the critical load is exceeded for a certain contaminant, the soil became a 'supplier' rather than a 'sink' of potentially harmful substances (Batjes and Bridges, 1993).

The main goal of this study is to evaluate the relative retention and mobility of some heavy metals applied together to some Egyptian soils. The specific objectives were to evaluate their selectivity sequence by means of distribution coefficients and maximum adsorption capacity as an approximation of the critical load for heavy metals and to investigate the relationship between soil properties and adsorption of heavy metals by Egyptian soils having different chemical and mineralogical characteristics.

MATERIALS AND METHODS

Seven top soil samples representative of the most common Egyptian soils were collected, air dried, passed through a 2-mm sieve, and selected chemical, physico-chemical and mineralogical properties were determined as given in table (1).

Soil organic matter (SOM) was removed with sodium hypochlorite, according to the method of Anderson (1963).

Adsorption of Ni, Cu, Zn, Cd and Pb by the soils was measured in two replicates, by adding 50 ml of cocktail solutions containing concentrations of 0, 5, 15, 25, 35 and 50 mg l^{-1} of all heavy metal cations in the same concentration to 1 g of soil sample. The metal cations were applied in their $SO_4^{=}$ salts except for Pb and Cd, which were added as nitrates.

A preliminary study was conducted to select the concentrations of metals in the cocktail solutions. The highest concentration (50 mg l^{-1}) was selected because there was no precipitate appearing in the mixture. The mixture was subjected to 1 h. shaking in a horizontal shaker. The suspensions were then centrifuged at 5000 rpm for 5 mins, then pH was measured and the concentration of heavy metals was analyzed in the supernatant liquid by atomic absorption spectrophotometry. The difference between the initial amount of metal in solution and the amount remaining in solution after the reaction period was assumed to be adsorbed by the soil.

TABLE (1). Some chemical, physico-chemical and mineralogical characteristics of the studied soils

Soils	pH 1:2.5	CEC me/100g soil	CaCO₃ %	Clay %	Qualitative mineralogy
Wadi Sudr	7.23	25.60	28.50	41.00	Cal > Kal > feld
Wadi El-Natron	7.01	29.40	26.19	27.50	Cal > Gb > Kal
El-Hammam	8.92	10.80	3.45	5.00	Gb > Kal > feld
El-Bahariya Oasis (El-Heiz)	4.77	0.74	0.15	0.85	Quartz > Gt > Kal
El-Bahariya Oasis (kobala)	8.26	13.50	0.88	5.35	Quartz > Hm > Gt > Kal
Wadi El-Arish	8.50	12.20	59.00	2.22	Cal > Kal > illite
Wadi El-Tumeilat	8.50	38.50	8.59	43.00	Quartz > Mont > Kal

Cal: Calcite, Feld: feldspars, Gb: gibbsite, Gt: goethite, Hm: hematite, Kal: Kaolinite, Mont: montmorillonite

RESULTS AND DISCUSSION

Soil Mineralogy

The mineralogy of the studied soils reflects the environment where these soils were formed. They have been subjected to different weathering intensities that produces variable soil mineralogy. Kaolinite appeared in all soil samples, whereas hematite and goethite appeared only in the red soils (El-Bahariya Oasis), gibbsite is detected only in Wadi El-Natron and El-Hammam, calcite is observed in Wadi Sudr, Wadi El-Natron and Wadi El-Arish, while montmorillonite dominates in Wadi El-Tumeilat.

In order to study the mineral surface behaviour only, the soil organic matter (SOM) was removed using the procedure introduced by Anderson (1963). The residual SOM was not measured in the oxidized samples, assuming that most of it was removed by the treatment. In this regard, Lavkulich and Wiens (1970) have indicated that NaClO is very effective in destroying SOM, less destructive to oxides, silica coatings or crystalline clay components and that most of the organic matter is removed after 3 treatments with a minimum influence on the mineral surfaces.

TABLE (2). Equilibrium concentration (Ec) in mmol l^{-1}, metal cation adsorbed (Ads) in mmol kg^{-1} and pH of the supernatant solution adsorption onto the minerals, both reactions release H$^+$ in solutions (Schwertmann and Taylor, 1989; McBride, 1994; Brown _et al._, 1995).

| Soils | Metal cations | | | | | | | | | | pH |
| | Ni | | Cu | | Zn | | Cd | | Pb | | |
	Ec mmol l^{-1}	Ads mmol kg^{-1}	Ec mmol l^{-1}	Ads mmol kg^{-1}	Ec mmol l^{-1}	Ads mmol kg^{-1}	Ec mmol l^{-1}	Ads mmol kg^{-1}	Ec mmol l^{-1}	Ads mmol kg^{-1}	
Wadi Sudr	0.070	0.96	0.000	4.05	0.041	1.95	0.007	2.05	0.000	1.30	7.38
	0.215	2.81	0.023	11.18	0.200	2.00	0.038	4.75	0.002	4.50	7.30
	0.308	6.66	0.063	17.11	0.375	0.52	0.138	4.50	0.004	5.94	7.08
	0.487	5.74	0.125	21.92	0.540	0.40	0.250	3.25	0.006	8.21	6.88
	0.810	2.30	0.250	27.16	0.761	0.25	0.408	1.90	0.018	11.42	6.85
Wadi El-Natron	0.034	2.84	0.001	4.00	0.060	1.01	0.017	1.55	0.000	1.30	7.29
	0.225	2.33	0.048	9.92	0.217	1.15	0.025	5.40	0.006	4.30	7.14
	0.334	5.44	0.081	16.23	0.360	1.40	0.121	5.35	0.009	5.70	7.15
	0.519	4.14	0.169	19.70	0.547	0.05	0.250	3.25	0.008	8.10	6.88
	0.800	2.80	0.278	25.74	0.765	0.02	0.412	1.70	0.010	11.80	6.84
El-Hammam	0.066	1.22	0.016	3.20	0.067	0.655	0.025	1.15	0.002	1.20	7.12
	0.233	1.36	0.175	3.55	0.219	1.05	0.043	4.50	0.056	1.80	7.07
	0.323	5.90	0.272	6.76	0.366	1.10	0.135	4.65	0.072	2.55	6.95
	0.507	4.72	0.417	7.31	0.546	0.067	0.310	0.25	0.079	4.55	6.79
	0.790	3.30	0.605	9.40	0.765	0.022	0.445	0.05	0.076	8.50	6.71
El-Bahariya Oasis (El-Heiz)	0.069	1.10	0.062	0.95	0.044	1.80	0.024	1.20	0.013	0.65	6.99
	0.260	1.12	0.210	1.83	0.197	2.15	0.041	4.60	0.058	1.70	6.94
	0.323	2.60	0.363	2.13	0.330	2.90	0.138	4.50	0.075	2.40	6.82
	0.472	4.16	0.506	2.86	0.518	1.50	0.310	0.25	0.114	2.80	6.51
	0.799	2.85	0.717	3.80	0.760	0.30	0.443	0.15	0.122	6.20	6.29
El-Bahariya Oasis (Kobala)	0.018	3.60	0.001	4.00	0.008	3.62	0.009	1.95	0.001	1.25	7.66
	0.175	4.81	0.002	12.21	0.118	6.12	0.025	5.40	0.001	4.55	7.39
	0.323	5.90	0.012	19.71	0.305	4.13	0.108	6.00	0.001	6.08	7.21
	0.505	4.80	0.018	27.27	0.509	1.94	0.260	2.75	0.001	8.43	7.05
	0.810	2.30	0.123	33.51	0.753	0.65	0.410	1.80	0.003	12.16	6.75
Wadi El-Arish	0.014	3.84	0.006	4.05	0.003	3.81	0.001	2.35	0.002	1.29	8.06
	0.132	6.95	0.003	12.10	0.127	5.67	0.007	6.30	0.002	4.48	7.40
	0.280	8.04	0.022	19.19	0.292	4.82	0.107	6.05	0.001	6.13	7.26
	0.465	6.80	0.055	25.42	0.472	3.82	0.163	7.60	0.001	8.48	7.05
	0.796	3.00	0.155	31.88	0.719	2.35	0.271	8.75	0.001	12.26	6.64
Wadi El-Tumeilat	0.002	4.40	0.001	4.00	0.005	3.74	0.001	2.35	0.001	1.29	8.50
	0.058	10.67	0.002	12.20	0.024	10.78	0.007	6.30	0.000	4.60	7.64
	0.158	14.17	0.007	19.92	0.117	25.26	0.125	5.15	0.001	6.14	7.37
	0.365	11.80	0.019	27.22	0.269	13.96	0.132	9.15	0.001	8.49	7.10
	0.745	5.55	0.081	35.58	0.565	10.05	0.246	10.00	0.001	12.28	6.69

Competitive Adsorption

Table (2) shows the equilibrium concentration (Ec), the amount of adsorbed metal cations and the equilibrium pH of the supernatant solutions, of the adsorption experiment. Data show that there was a consistent decline in the pH of the supernatant solution with increasing concentrations applied. This is attributed to both hydrolysis of the metal cations in solution and adsorption onto the minerals, both reactions release H^+ in solutions (Schwertmann and Taylor, 1989, McBride, 1994 and Brown *et al.*, 1995).

For the competitive adsorption, a general trend was followed in all soils, with differences only in magnitudes. For the lower concentrations applied, the equilibrium concentration (Ec) was low for every metal cation, showing that almost all metals were adsorbed by the soils. As the applied concentrations increased, some metals such as Cu and Pb maintained their strong affinity with the surfaces while the others, Ni, Zn and Cd were displaced from the surfaces. For the latter metals, the increase in the applied concentrations leads to corresponding increase of Ec, while proportionally decreases the amount adsorbed. The data show clearly that competition for adsorption sites affected the heavy metal cations behaviour in such a way that the soil adsorbed less Ni, Zn and Cd and more Cu and Pb, with increasing concentrations. In this respect, McBride (1994) mentioned that, two factors might explain the competition behaviour. Firstly, the type of metal-surface interaction: Ni, Zn and Cd retention is more dependent on electrostatic interactions with exchange sites in the solid phase, whereas Cu and Pb retention is less dependent on this type of adsorption and more dependent on covalent interactions with the mineral structures, this reasoning is supported by the results obtained by Berti and Jacobs (1996), Fontes *et al.* (2000) and Gomes *et al.* (2001). They found that simultaneous competition in soils normally favors Cu and Pb, as compared to Ni, Zn and Cd. Secondly, influence the pH where adsorption occurs: in the lower concentrations, pH of the extracts ranges from 7.0 to 8.5, where most of these heavy metals would have their adsorption favored, whereas in the higher concentrations, it ranges from 6.3 to 6.9 where Cu and Pb would be still favored, but not Ni, Zn and Cd (Mckenzie , 1980; Brummer *et al.*, 1988; Naidu *et al.*, 1997).

Considering the non molar equality for heavy metal applied concentrations, the sorption affinity between the metal cations and the mineral surfaces can be calculated as the amount of each metal present in the adsorption complex, *i. e.*, the share of a given metal in the total amount adsorbed by the soil mineral matrix expressed as percentage. Table (3) presents these values of metals in the adsorption complex for each soil.

At the lowest applied concentrations, the heavy metals were adsorbed proportional to their relative molar concentration. Nickel with the highest molar concentration, represents 9-28 % of the adsorption complex, whereas

Pb, with the lowest molar concentration, had the smallest portion (8-16 %). As the concentration increased, competition started to occur and the proportion of Cu and Pb increased compared to Ni, Zn and Cd. Fig. (1) illustrates as an example the plot of (a) Wadi El-Natron, which shows strong competition and, (b) the plot of Wadi El-Tumeilat with weak competition.

Table (3) and Fig. (1) show that competition is weaker in soils with higher affinity to adsorb cations (Fig. 1b), where there are available sites for almost all the metal cations in the adsorption complex. On the other hand, competition among heavy metals is very strong in soils with lower capacity to hold metal cations (Fig. 1a), where more Ni, Zn and Cd are dislocated from the adsorption complex and substituted by Cu and Pb. In a field status, this could impose a much higher risk of contamination of aquifers, creeks, groundwater, etc., through leaching of these heavy metals in the soil profile and also a much higher risk of making them available for plants uptake.

Data tabulated in table (3) show that there is an increase in the adsorbed amount of each Cu and Pb and a decrease in the amount of each Ni, Zn and Cd. In order to estimate the differences in the adsorption strength among heavy metals and soils, the difference between the adsorption in the first level and the last of applied concentrations was calculated as percentage.

In table (4) it is possible to visualize the relative strength of each heavy metal in the overall competition. For most soils, Pb and Cu showed the greatest increase in adsorption, whereas, Zn and Ni showed the greatest decreases.

Based on these values, a competitive adsorption order could, therefore be derived (Table 5). The general selectivity sequence was: Pb >> Cu >>> Cd > Ni > Zn which was observed in the soils of Wadi El-Natron, El-Bahariya Oasis (Kobala) and Wadi El-Arish.

Langmuir isotherms were constructed using the sum of equilibrium concentration and the sum of adsorbed cations for each applied concentration (Table 6). Maximum adsorption values or (b) parameter of the Langmuir equation, which estimates the maximum amount of heavy metals that the mineral surfaces can adsorb, is calculated. Data show that the soils differed clearly in their maximum adsorption capacity for heavy metals, suggesting that they could have different buffering capacities for these pollutants. This could be explained on the premise of clay minerals' assemblages, particularly the presence of illite and montmorillonite in these soils. Wadi El-Tumeilat and Wadi El-Arish soils had the highest maximum adsorption values and could probably receive and hold higher heavy metals loadings. On the other hand, data show that soils, such as El-Bahariya Oasis (El-Heiz) and El-Hammam, due to their low maximum adsorption and low buffering capacity, will more easily reach their critical load and be more vulnerable to heavy metal inputs. Continuous application of sewage sludge,

industrial wastes or composts and location of landfills, for example, would benefit from taking into consideration these soil characteristics, when planned.

TABLE (3). Sum of metal cations adsorbed (Σ Ads) in mmol kg^{-1} and percentage of each metal cation adsorbed on the adsorption complex

| Soils	Σ Ads mmol kg^{-1}	Metal cations (%)				
		Ni	Cu	Zn	Cd	Pb
Wadi Sudr	10.31	9.31	39.28	18.91	19.88	12.61
	25.24	11.13	44.29	7.92	18.82	17.83
	34.73	19.18	49.27	1.50	12.96	17.10
	39.52	14.52	55.47	1.01	8.22	20.77
	43.03	5.35	63.12	0.05	4.42	26.54
Wadi El-Natron	10.70	26.54	37.38	9.44	14.49	12.15
	23.10	10.09	42.94	4.98	23.38	18.61
	34.12	15.94	47.57	4.10	15.68	16.71
	35.24	11.75	55.90	0.14	9.22	22.99
	42.06	6.66	61.20	0.05	4.04	28.06
El-Hammam	7.43	16.42	43.07	8.82	15.48	16.15
	12.26	11.09	28.96	8.56	36.70	14.68
	20.96	28.15	32.25	5.25	22.19	12.17
	16.90	27.93	43.25	0.40	1.48	26.92
	21.27	15.51	44.19	0.10	0.24	39.96
El-Bahariya Oasis (El-Heiz)	5.70	19.30	16.67	31.58	21.05	11.40
	11.40	9.82	16.05	18.86	40.35	14.91
	14.53	17.89	14.66	19.96	30.97	16.52
	11.57	35.96	24.72	12.96	2.16	24.20
	13.30	21.43	28.57	2.26	1.13	46.62
El-Bahariya Oasis (Kobala)	14.42	24.97	27.74	25.10	13.52	8.67
	33.09	14.54	36.90	18.50	16.32	13.75
	41.82	14.11	47.13	9.88	14.35	14.54
	45.19	10.62	60.35	4.29	6.09	18.65
	50.42	4.56	66.46	1.29	3.57	24.12
Wadi El-Arish	15.34	25.03	26.40	24.84	15.32	8.41
	35.50	19.58	34.08	15.97	17.75	12.62
	44.23	18.18	43.39	10.90	13.68	13.86
	52.12	13.05	48.77	7.33	14.58	16.27
	67.85	18.59	46.99	3.46	12.90	18.07
Wadi El-Tumeilat	15.78	27.88	25.35	23.70	14.89	8.17
	44.55	23.95	27.38	24.20	14.14	10.33
	70.64	20.06	28.20	35.76	7.29	8.69
	70.62	16.71	38.54	19.77	12.96	12.02
	73.46	7.56	48.43	13.68	13.61	16.72
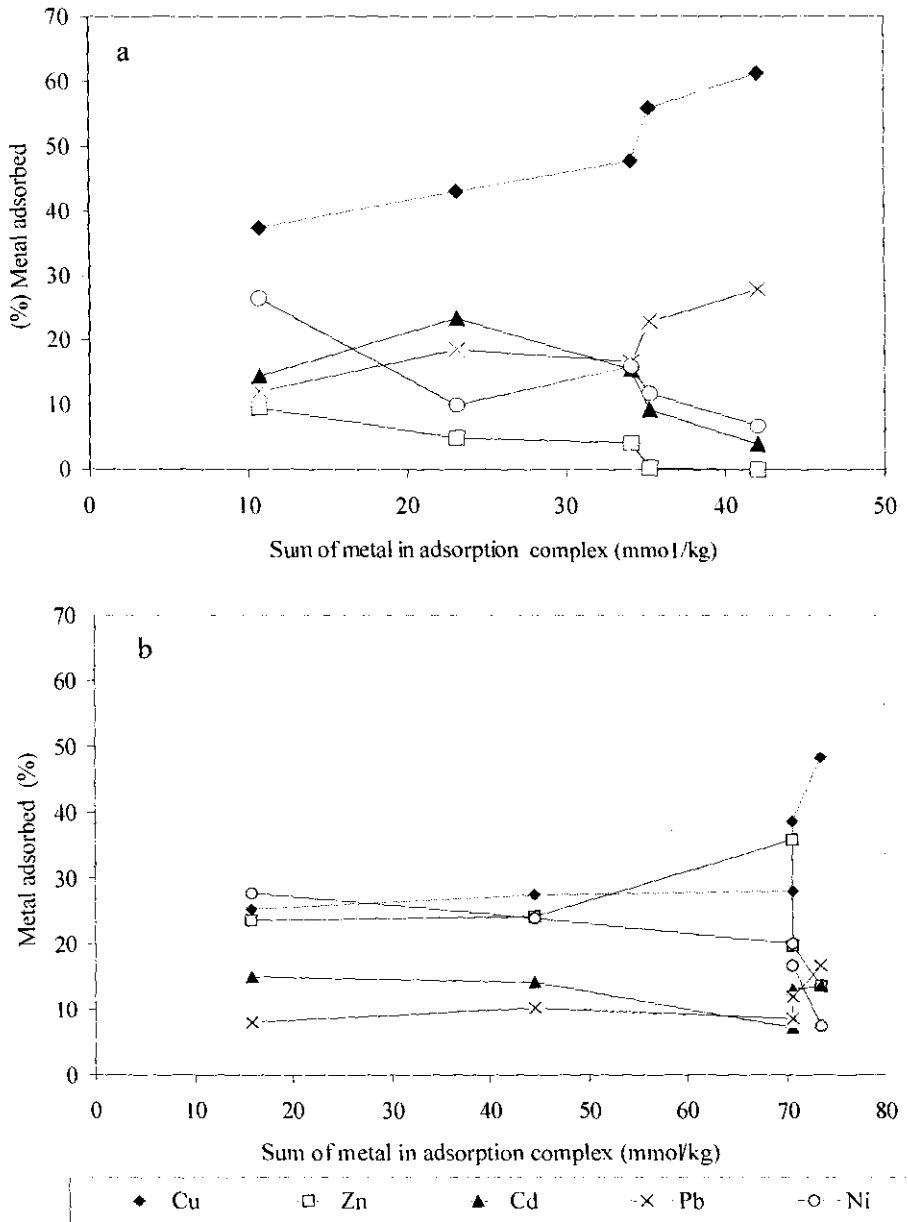
Fig. (1). Percentage of heavy metal cations adsorbed as related to the sum of metal cations in the adsorption complex in mmol kg^{-1} (a) Wadi El-Natron and (b) Wadi El-Tumeilat.

TABLE (4). Proportion of increase or decrease in heavy metals adsorption by selective competition from increasing heavy metals contents of solution.

Soils	Metal Cations (%)				
	Ni	Cu	Zn	Cd	Pb
Wadi Sudr	- 42.53	60.69	- 99.74	- 77.77	110.47
Wadi El-Natron	- 74.91	63.72	- 99.47	- 72.12	130.95
El-Hammam	- 5.54	2.60	- 98.87	- 98.45	147.43
El-Bahariya Oasis (El-Heiz)	11.04	71.39	- 92.84	- 94.63	308.95
El-Bahariya Oasis (Kobala)	- 81.74	139.58	- 94.86	- 73.59	178.20
Wadi El-Arish	- 25.73	77.99	- 86.07	- 15.80	114.86
Wadi El-Tumeilat	- 72.88	91.05	- 42.28	- 8.60	104.65

TABLE (5). Selectivity sequence for the different soils studied according to the proportion of increase or decrease in the metals adsorption.

Soils	Selectivity Sequences
Wadi Sudr	Pb >> Cu >>> Ni > Cd > Zn
Wadi El-Natron	Pb >> Cu >>>> Cd > Ni > Zn
El-Hammam	Pb >>>> Cu >> Ni >>> Cd ~ Zn
El-Bahariya Oasis (El-Heiz)	Pb >>> Cu >>> Ni >>> Zn > Cd
El-Bahariya Oasis (Kobala)	Pb >> Cu >>>> Cd > Ni > Zn
Wadi El-Arish	Pb > Cu >>> Cd >> Ni >> Zn
Wadi El-Tumeilat	Pb > Cu >>> Cd >>> Zn >> Ni

TABLE (6). Sum of equilibrium concentration (Σ Ec) in mmol kg^{-1} and sum of adsorbed metal cations (Σ Ads) in mmol kg^{-1} for each applied concentration and Langmuir equations with determination coefficient and parameter for all soils

Soils	Σ Ec mmol l^{-1}	Σ Ads mmol kg^{-1}	Langmuir equation	R^2	b mmol kg^{-1}
Wadi Sudr	0.118	10.31	$y = 0.0191\,x + 0.0092$	0.99	52.47
	0.478	25.24			
	0.888	34.73			
	1.408	39.52			
	2.247	43.03			
Wadi El-Natron	0.112	10.70	$y = 0.0201\,x + 0.0099$	0.95	49.77
	0.521	23.10			
	0.905	34.12			
	1.493	35.24			
	2.265	42.06			
El-Hammam	0.176	7.43	$y = 0.0415\,x + 0.0201$	0.97	24.10
	0.726	12.26			
	1.168	20.96			
	1.859	16.90			
	2.681	21.27			
El-Bahariya Oasis (El-Heiz)	0.212	5.70	$y = 0.0710\,x + 0.0149$	0.99	14.08
	0.766	11.40			
	1.229	14.53			
	1.920	11.57			
	2.841	13.30			
EL-Bahariya Oasis (Kobala)	0.037	14.42	$y = 0.0188\,x + 0.0035$	0.99	53.19
	0.321	33.09			
	0.749	41.82			
	1.293	45.19			
	2.099	50.42			
Wadi El-Arish	0.26	15.34	$y = 0.0139\,x + 0.0040$	0.98	71.94
	0.271	35.50			
	0.702	44.23			
	1.156	52.12			
	1.942	67.85			
Wadi El-Tumeilat	0.010	15.78	$y = 0.0129\,x + 0.0008$	0.99	77.52
	0.091	44.55			
	0.408	70.64			
	0.786	70.62			
	1.638	73.46			

CONCLUSION

The simultaneous competitive adsorption experiments showed that, as the applied concentration increased, the soils adsorbed more Pb and Cu and less Zn, Ni and Cd regardless of their relative molar applied concentrations. The type of interaction with the soil phase and pH played major roles on the adsorption phenomenon.

The present share of a given metal on the exchange complex was dependent on the level of the applied concentration. At low levels, the heavy metals occupied a percentage proportional to their relative molar concentration in solution. On the other hand, at higher levels, the occupation increased for the strongest competitors, namely Pb and Cu and decreased for the weakest competitors, Zn, Ni and Cd.

Selective sequences based on proportion of increase or decrease in metal adsorption were derived, indicating that the general sequence being Pb >>Cu >>> Cd > Ni >Zn.

Maximum adsorption capacities for heavy metals, based on Langmuir isotherms, were calculated and showed that the soils of Wadi El-Tumeilat and Wadi El-Arish gave the highest values of maximum adsorption and could receive and hold higher heavy metal loadings. In contrast, soils of El-Bahariya Oasis (El-Heiz) and El-Hammam showed low values of maximum adsorption and low buffering capacities and more easily reach their critical loads.

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الأدمصاص التنافسي للفلزات الثقيلة بواسطة بعض الأراضي المصرية

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اختيرت سبعة عينات تربة مختلفة في صفاتها الكيماوية والمعدنية وتمثل معظم الأراضي المصرية من مناطق وادي سدر ، وادي النطرون ، الحمام ، الواحات البحرية (الحيز ، قبالة) ، وادي العريش ، وادي الطميلات لدراسة التأثير التنافسي بين الفلزات تحت الدراسة وهي : الزنك ، الكادميوم ، النيكل ، الرصاص ، النحاس على سلوكها الكيماوي في الأراضي.

أوضحت النتائج أن زيادة التركيز الكلي للعناصر المدروسة قد أدت إلى التنافس بينها مما أدي إلي نقص إدمصاص كلاً من الزنك والكادميوم وزيادة إدمصاص الرصاص والنحاس، كما أظهرت النتائج أن أعلي قيمة للسعة الأدمصاصية القصوى وهي ٧٧,٥٢ ، ٧١,٩٤ مللي مول/ لتر كانت بأراضي وادي الطميلات ووادي العريش علي التوالي ، بينما كانت ذات قيمة أقل (١٤,٠٨ ، ٢٤,١٠ مللي مول/لتر) بأراضي الواحات البحرية (الحيز) وأراضي الحمام علي التوالي. وقد أمكن ترتيب إدمصاص العناصر تحت الدراسة علي الأراضي المختلفة علي النحو التالي:

الرصاص > النحاس > الكادميوم > النيكل > الزنك