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Heavy Metals and Physicochemical Properties of Soils in Kano Urban Agricultural Lands

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ABSTRACT: This study was conducted on the urban agricultural soils at the banks of three metropolitan and suburban rivers namely *Challawa*, *Jakara* and *Watari* in Kano, Kano State, Nigeria to determine the total, exchangeable and soluble concentrations of the heavy metals Cu, Cr, Ni, Zn, Pb and Cd . The soils are all slightly alkaline (mean pH 7.42 – 7.77), with moderate CEC (12.63 – 23.11cmol/kg), medium to high organic carbon (7.16 – 11.27g/kg). The mean ranges of total Cu, Cr, Ni, Zn, Pb and Cd were 4.95 – 5.99, 5.85 – 165.66, 54.03 – 57.77, 55.07 – 255.52, 42.84 – 68.12 and 0.59 – 11.81mg/kg respectively. All the values were lower than the maximum allowable concentrations in soils, except for Cd at Jakara and Challawa. The mean ranges of exchangeable metals were 0.57 – 1.18, 1.69 – 29.26, 13.89 – 15.59, 14.16 – 49.01 10.48 – 18.31 and 0.39 – 1.20mg/kg for Cu, Cr, Ni, Zn, Pb and Cd respectively. The mean soluble concentrations were 0.27 – 0.48, 0.61 – 15.91, 5.60 – 7.15, 4.90 – 17.42, 2.78 – 9.36 and 0.00 – 0.60mg/kg for Cu, Cr, Ni, Zn, Pb and Cd respectively. Although appreciable amounts of all the metals were detected in the various forms, variability exists between the sites with concentrations found to be significantly higher ($p \leq 0.05$) in areas irrigated with waters receiving industrial and domestic sewages namely, *Challawa* and *Jakara* than *Watari* which was the control and significant relationship ($p \leq 0.05$) exists between exchangeable and total metal forms on one hand and such soil properties as organic carbon, available P, total N and basic cations on the other.
Keywords: Heavy metals, bio-avaliable, Kano, Urban, Agriculture

INTRODUCTION

An understanding of the form of any soil pollutant and its dependence on soil's physico-chemical properties provides a basis for careful soil management that limits as far as possible, the negative impact of the pollutant on the ecosystem. Heavy metals in the soil have been classified into dissolved (in soil solution), exchangeable (in organic and inorganic components), as structural components of the lattices of soil minerals and insoluble precipitates with other soil components (Aydinalp and Marinova, 2003).

Of the various forms of heavy metals in the soil, of greatest concern are the exchangeable and the soluble, because these, are the forms that are available to plants (Calace *et al*., 2002). All negative effects of heavy metals start from their absorption by plants, and to a lesser extent by ground water contamination through leaching. As metals are absorbed by plants, they are thereby introduced into the food chain (Calace *et al*., 2002). Once metals are ingested through contaminated food, they pose all sorts of dangers to human health including hepatic diseases, aneamia, nausea etc (Calace *et al*., 2002); if the recommended daily allowances are exceeded. The effects of heavy metals in soil could be enormous. Major amongst them is their effects on microbial activities (Wyszkowska and Wyszkowska, 2002).

The use of wastewater for irrigation has for long been acknowledged as a source of metals into the soil. Kollender-Szych *et al.* (1998) showed soil concentration of some heavy metals in the Yellow river area of China to vary for Cd, Cr, Pb, Ni and Cu across the profiles from the surface to the depth of 100cm. The average values for five sites were 135mg/kg, 82mg/kg, 41mg/kg, 82 mg/kg and 23mg/kg. Except for lead, all the other detected metals were outside the approved limit for German soils which were used as basis for comparison. Urban and peri-urban agriculture (UPA) (Binns *et al.*, 2003) in Kano uses stream water that flows through industrialized and residential areas to irrigate vegetable crops. The impact of this land use system on the physical environment has not received much attention. Previous studies have established the presence of heavy metals in some of the areas due to this activity. A study of three irrigation sites in Kano Nigeria namely Jakara, Tomas and Tiga dams for Cd, Cr, Cu, Ni and Pb in the soils indicated that the values ranged from 2.8 -71mg/kg Cd, 15.3 -24 .6 mg/kg Cr, 3 .3 – 8.4 mg/kg Cu, 19.6 -27.9 mg/kg Ni and 19.6 - 41.7 mg/kg Pb, all of which were appreciably higher than the expected values (Audu and Peacock, 2003). Binns *et al.* (2003) also detected heavy metals in the waters of the Jakara river while Ya'u, (1995) and Wakawa *et al*. (2008) detected these metals in some of the plants tissue grown in or around the Jakara and Challawa rivers. There is, however, little understanding of their forms in soil.

This paper aims to evaluate and compare the total and potentially bioavailable concentrations of some principal heavy metals namely Cu, Pb, Cr, Ni and Zn in the irrigated soils around the Jakara and Challawa rivers whose waters are used in the irrigation and receive domestic and industrial effluents respectively.

MATERIALS AND METHODS

The study area

This study was conducted at the banks of the *Jakara*, *Challawa* and *Watari Rivers* within the metropolitan Kano and its suburb. Site selection was based on difference in terms of effluent source into irrigation water. Jakara predominantly receives domestic effluents while Challawa receives industrial effluents. Watari is not associated with any wastewater and was therefore selected as control. All samples were collected in the area lying between latitude 11^o59' to 12^o 08' N; and longitude 8^o34' to 8^o 42' E. Three irrigation sites each (Yansama, Sharada and Rafin Kuka); (Akija, Airport Road and Magami); and (Lambu, Langel and BUK) respectively were selected to represent up, mid and downstream sectors of the Challawa, Jakara and the Watari rivers respectively. Global Positioning System (GPS) and ground reconnaissance were used for identification of sites and geo-referencing.

Kano is in the dry-sub-humid agro-ecological zone of Nigeria (Ojanuga, 2006). It is typically characterized by tropical wet and dry climate classified as Aw by W. Koppen (Olofin, 1987). The dominant geology is basement complex (Olofin, 1985; KNARDA, 1998). Ahmad (2008) has placed the dominant soil class of the area to be Alfisol according to the USDA soil taxonomy. The dominant crops irrigated in the areas are leafy vegetables such as lettuce and spinach.

Sampling

From each sampling area, the first 1ha under cultivation was selected. Stratified grid sampling method (Adepetu *et al.*, 2000) was employed and 100m long transect was taken parallel to the course of the river on the side with higher irrigation activity. A sample was collected at each 20m distance along the transect from the surface 0 to 20cm. Four more transects were taken at 20m parallel and subsequent to each other and were sampled similar to the first. A total of 25 samples were collected and composited into five samples at each zone of each of the three river banks.

Laboratory Techniques

Samples were air-dried, crushed and sieved through 2mm sieve and subjected to laboratory analyses using standard procedures. The pH was determined using the 1:2.5 soil-distilled water ratio using EL model 720 pH meter. The electrical conductivity (EC) was determined using 1:2.5 soil – distilled water ratio using Beckman Conductivity Bridge. Particle size analysis was done using the hydrometer method as outlined by Jaiswal (2004). The Walkley-Black wet oxidation method was used to determine organic carbon while ammonium acetate extraction and saturation techniques both as described in Adepetu et al. (2000) were used in determining CEC and exchangeable bases. Double acid digestion technique (Anderson, 1974) was used in sample extraction for total heavy metal determination. The fractions of heavy metals that are exchangeable and soluble were determined through the modified Tessier sequential extraction technique of Kashem *et al.* (2007) in which 1g of each sample was mixed with $100cm^3$ of de-ionized water. The resultant mixture was shaken for eight hours, left to stand overnight and then centrifuged for 15 minutes at 10.000 rpm. The supernatant liquid was decanted and used in the determination of the concentration of soluble metals in the soil. The residue from the soluble metal fraction was mixed with $100cm^3$ of ammonium oxalate and shaken for eight hours at 10,000 rpm and left to stand overnight, centrifuged for 15 minutes and decanted. The solution was used to determine the fraction of metals in exchangeable form. All analyses were run in triplicates and the concentrations of the metals were determined using Atomic Absorption Spectrophotometer except Na and K that were determined using flame photometry.

Statistical Techniquess

The data obtained were subjected to both descriptive and inferential statistics. Analysis of variance (ANOVA) was used to compare means and significantly different means were separated using LSD; Pearson moment correlation analysis was also done to relate soil properties and the metals content in the soil all using SAS package 9.2 (SAS, 2007).

RESULTS AND DISCUSSIONS

Physico-chemical properties of the soil

Table 1 shows the physico-chemical properties of the soils of the three areas. The texture of the soils was sandy loam to loamy sand. The pH across the three areas can be interpreted as slightly alkaline (Esu, 1991). The mean EC values across the three areas are significantly different from one another with the highest value recorded at Jakara. The soils are neither sodic nor saline, but the alkaline pH and the high EC values at Jakara may potent salinity hazard; a problem which was also noted by Binns *et al.* (2003). The organic carbon contents across the three sites were all significantly different from one another ($p < 0.05$). They ranked from low in Watari and Challawa to medium in Jakara as earlier reportedby Esu (1991).

Using the rankings of Esu (1991) and Landon (1991) the calcium and magnesium contents of the soils ranged from medium at Watari, to high at both Jakara and Challawa. Potassium concentrations for all the three sites were within high to very-high range. Sodium concentrations were within the medium to high range, while the CEC values were within the medium ranges based on the rankings of Landon (1991).

The Nitrogen contents of the soils were high by the ranking of Landon (1991) with the value at Jakara site being significantly higher ($p < 0.05$) than both Watari and Challawa. The Phosphorus contents were within the medium at Watari to excessively high range at the Jakara and the Challawa sites. The mean values were all significantly different ($p < 0.05$) from one another, with the Jakara site having the highest value. The high amounts of N, P and organic carbon in Jakara may be due to its association with domestic wastewater (FAO, 1992).

Total heavy metals concentrations

The total concentrations of the metals in the soil are shown in Table 1. The Cu and Ni contents were not significantly different between the three sites although the values of both were higher at the Jakara site. The mean Cr and Zn concentrations were significantly different from one another with the highest Cr content (165.66mg/kg) recorded at Challawa basin and the highest Zn (255.52mg/kg) content recorded at Jakara. The highest Pb concentration (92.98mg/kg) was recorded at the Jakara basin which was different from that of Watari.

The mean Cd concentrations were all significantly different ($p < 0.05$) for the three sites with the highest mean (11.81mg/kg) occurring at the Jakara site. The heavy metals concentrations are within the European Commission's recommended threshold values of 300, 140, 3, 300, 100, and 75mg/kg Zn, Cu, Cd, Pb, Cr and Ni respectively as reported by Wild (1996) and DPR (2002) except for Cd at both Jakara and Challawa.

Table 1: Physicochemical Properties of the Soils of the Three Study Areas in Kano

	Locations			
Parameter	**Challawa**	**Jakara**	**Watari**	**SE±**
pH	7.77a	7.42b	7.48b	0.05
EC (mS/m)	1.79b	4.01a	0.58c	0.24
Sand (%)	76.29ab	80.48a	73.41b	1.08
Silt (%)	16.88a	14.56a	18.48a	0.91
Clay (%)	6.80ab	4.96b	8.11a	0.44
Textural Class	Sandy-loam	Loamy-sand	Sandy-loam	
Ca (cmol/kg)	11.70a	12.67a	7.80b	0.66
Mg (cmol/kg)	2.85a	2.46a	2.15a	0.19
K (cmol/kg)	0.79b	1.85a	0.47c	0.12
Na (cmol/kg)	1.11b	3.20a	0.25c	0.21
CEC (cmol/kg)	19.15a	23.11a	12.63b	1.07
Org. Carbon (g/kg)	8.07b	11.27a	7.16b	0.56
N (g/kg)	0.76b	1.32a	0.74b	0.04
P (mg/kg)	77.67b	213.52a	31.73c	7.80
Cu (mg/kg)	4.95	5.99	5.06	2.05
Cr (mg/kg)	165.66a	112.61b	5.85c	16.05
Ni (mg/kg)	57.03	57.77	54.43	5.75
Zn (mg/kg)	149.03b	255.52a	55.07c	23.97
Pb (mg/kg)	68.12ab	92.98a	42.84b	13.84

Means followed by the same letter in the same row are not significantly different ($p \leq 0.05$)

Despite the variability, the results are in close agreement with the findings of Audu and Peacock (2005) in the soils of the Jakara dam irrigation site in which the concentration of Ni, Cu, Cr and Pb were found to be appreciably high (up to 27.9μgg^{-1}, 8.4μgg^{-1}, 24.6 μgg^{-1} and 41.7μgg^{-1} respectively) and the work of Awode et al. (2008) at the Challawa valley where Ni and Zn concentrations were as high as 99.50 and 204.00mg/kg respectively. The major causes of the presence of these elements in the study sites could be attributed to three factors; addition through fertilizers and agro-chemicals, their use in batteries, alloys, pigments, plastics and their discharge through domestic and industrial sewages from tanneries.

The higher concentration of Cr in Challawa could be due to the presence of industries especially tanning while the high Zn and Pb contents at Jakara could be due to high releases from domestic sewages and abattoir waste waters as reported by Maldanado et al. (2008); as well as contributions from exhaust releases by motor vehicles that are ever on the increase in the metropolis (Dawaki and Jazuli, 2007).

Exchangeable and soluble metals concentrations

The exchangeable and soluble concentrations of the metals are shown in Tables 2 and 3 respectively. Like the total concentration, the mean values of Cu were not significantly different for the two forms across the sites, while mean exchangeable Cr is significantly higher at Challawa and different from both Jakara and Watari which has the least. Ni, Zn and Pb exchangeable and soluble contents at Jakara were significantly higher ($p < 0.05$) compared to either Challawa or Watari. The mean exchangeable Cd at the Watari site was significantly lower than either Jakara or Challawa; while none was detected in solution.

The principal factors that affect the behaviour of metals in the soil are pH, nature and amount of clays and associated oxides, organic matter and nature of humic substances (Basta *et al*, 2005; Wahba and Zagloul, 2007). As most of the factors that affect the solubility and exchange behaviour of the metals in the soil are low to medium (especially clay and organic matter) that probably might have accounted for the low soluble and exchangeable concentrations despite the higher values in the total concentration (Basta *et al.,* 2005).

Despite the high Pb concentration at the Jakara site, only small fractions were in exchangeable form even with the high organic matter content. The most probable explanation for this is that Pb may be strongly adsorbed by the organic fraction and thereby reducing its availability at the exchange complex. Yusuf (2007) and Adekola *et al.* (2010) reported higher amount of Pb as sorbed by organic matter than the amount found in exchangeable form. Of particular interest are low values of soluble Pb at the Jakara site in comparison to its total and exchangeable concentrations. Whereas higher amounts of total and exchangeable Pb were recorded at the site in comparison to the Challawa site (Tables 1 and 2), yet higher soluble Pb was detected at the Challawa site. The probable explanation for this behaviour of Pb is its association with the significantly high P at the Jakara (Table 1) most probably in the form of phosphate ions. Cao *et al*. (2009) stated that phosphate had been shown to be effective in immobilizing lead in contaminated soils via formation of stable lead phosphate minerals and they are particularly the most insoluble form of lead minerals in soils under a wide range of environmental conditions.

Table 2: Concentrations of Exchangeable Heavy Metals (mg/kg) in the Three Study Areas in Kano

Heavy Metal	Site			
	Challawa	**Jakara**	**Watari**	**SE**
Cu	1.03	1.18	0.57	0.19
Cr	29.26a	18.43b	1.69c	1.97
Ni	14.63a	15.59a	13.89a	0.77
Zn	33.30b	49.01a	14.16c	3.17
Pb	18.31a	16.07ab	10.48b	1.42
Cd	1.12a	1.20a	0.39b	0.05

Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$).

Table 3: Concentrations of Soluble Heavy Metals (mg/kg) in the Three Study Areas in Kano

Heavy Metal	Site			
	Challawa	**Jakara**	**Watari**	**SE**
Cu	0.48a	0.27a	0.39a	0.07
Cr	15.91a	7.00b	0.61c	1.08
Ni	5.60b	7.15a	6.03b	0.20
Zn	7.72b	17.42a	4.90b	1.01
Pb	9.36a	7.90a	2.78b	0.81
Cd	0.52a	0.60a	0.00b	0.029

Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$).

The effect of clay, organic matter and pH could be observed on the exchangeable and soluble concentrations of Cd especially at the Challawa and the Jakara sites. At the Jakara site, the exchangeable and soluble concentrations were additionally affected by total concentration. Similar effect of concentration, organic matter and clay could be observed. Cd is a highly mobile ion (Tokaliolu *et al*., 2003) but here it showed relatively low mobility to the exchange complex in comparison to the total amount in the soil across all the sites. The most probable explanation for the relatively low amounts in this work may be due to sorption by the organic matter which is a possible reverse of behaviour for Cd especially in soils where pH is slightly alkaline to alkaline (Basta *et al,.* 2005).

Cu is a metal that is predominantly adsorbed at the top soil by clay and/or organic matter, and for most of the metals, this adsorption increases with increasing pH (Wild, 1996). This fact may validate the results here especially when compared with organic matter contents of the areas shown in Table 1. In most of the sampling locations appreciable organic matter occurs and the pH values were slightly alkaline so also the exchangeable values of the metal was also high. Reichmann (2002) stated that the amount of organic matter in the soil can also be a more important factor on Cu solubility than pH or any other factor. Despite the higher total concentration and exchangeable forms at the Jakara site, lower amount was detected in solution compared to the Challawa sectors. This is because some of what was detected as total and exchangeable at the site might have probably been sorbed by the high organic matter content in the site. The equally lower pH at the site compared to the Challawa basin might have facilitated the sorption process.

The most important factor that could have affected the concentration of the exchangeable and soluble Cr according to this result could be the total concentration and pH. This is typified in all the sites but more especially at the Challawa site. The predominant form of Cr in the soil is Cr(III) which is highly stable. As explained by Zayed and Terry (2003) with increasing pH their solubility tends to increase. The variability of Cr solubility and exchangeability here tally well with the findings of Ogbo and Okhouya (2011) in crude oil contaminated soils remediated with mushroom plants and the theory of Basta *et al.* (2005).

The effect of total concentration on the exchangeable form of Ni could also be seen. The high Ni content in the sectors has reflected in its exchangeable form. Similarly, the exchange property of this metal has also been affected by clay and organic matter in addition to the total concentration. The effect of clay content could be observed at the Watari site where despite the lower organic matter content compared to the other two sites, it had appreciable amounts of Ni in exchange complex because of its relatively better clay content. In the cumulative means, the combined effect of concentration, better organic matter content and reasonable clay content in some of its sectors has given the Jakara basin higher amount of Ni in exchangeable form. Significant movement of nickel within the soil matrix and into other media is likely to occur under acidic conditions. This fact is the most obvious factor that affects its solubility here. Despite the relatively high amount of this metal in all the sectors of the sites and its availability in exchange, lesser amounts were detected in all the locations because in all the locations pH tend to incline towards alkalinity which does not favour Ni solubility. McBride *et al.* (2004) reported that all soil amendments that raise pH reduce the solubility of Ni and thereby its extractability from the bio-available fraction.

The exchangeable Zn concentration seems to be predominantly affected by organic matter and total concentration as the amounts decreases in the trend of Jakara > Challawa > Watari much as organic matter. The effect of concentration on the exchangeable Zn content was as reported by Zhao *et al.* (2010): values increasing with increasing total concentration. Exchangeable Zn and CO_3^{2-} associated Zn were high at the sites where organic matter was high in the work of Yusuf (2007) despite the fact that a substantial concentration of it was also found bound (sorbed) to the organic matter. This was in accord with the findings of Muhammad (2006) in irrigated soils in Kano where exchangeable fraction in areas with high organic matter relates almost linearly. Basta *et al.* (2005) reported interaction with other ions as affecting the bioavailable concentrations of Zn in the soil. Contrary to the high total Zn concentration across all the sectors of the sites (Table 1), much lower concentration was found in soluble form across all the sectors of the sites. McBride *et al*. (2004) have shown that alkaline soils produced low Zn extractability, in consistence with the high soil pH (≥ 8). Siebielec (2006) attributed poor total Zn contribution to soluble and other bio-available forms to the fact that most Zn is mostly present as adsorbed or occluded by Fe and Mn oxides (on average 28.6 and 55.1 % of total Zn) and this increases with increasing pH. This explains why Jakara basin with its higher total concentration and relatively lower pH also had more soluble Zn across its sectors especially the midstream sector.

Relationship between metals and soil properties

The relationship between the metals analyzed and some of the soil properties is shown in Table 4. Total and exchangeable metals were correlated with some soil properties which included clay content, pH, total N, organic carbon, available P, Ca, Mg, K, Na and CEC. Negative relationship was shown by both total and exchangeable forms of all the metals with clay content which was significant with Total Zn, Pb and

Cd; and with all exchangeable forms except Cu. Similar trend was observed with pH except with exchangeable Cr and Ni which were positive but insignificant. The negative relationship with pH was only however significant with Total Cu, Zn, Pb and Ex. Zn. The relationship of both metal forms was positive and significant with Total N, organic carbon and P except Ex. Ni which was negative but insignificant and Ex. Pb which was positive but insignificant. Both forms of the metals related significantly with cations and CEC, although negatively and insignificantly between Na, Ca and Total Cu; Ca, Mg, Na, CEC and Total Ni; K, and Exchangeable Ni.

The results here portray a variable behavioural pattern for the elements. The low clay content in the soil as shown in Table 1 has significantly affected the relationship of the two forms of the metals with it, especially the exchangeable forms which were supposed to have shown closer association with it. This was however favourably compensated by the high organic matter content of the soil as shown by the largely positive relationship with it. The affinity of the metals for exchangeability and retention is largely towards either organic matter or clay and therefore the dominance of organic matter over clay in the soil played a significant role in regulating the two forms of the metals. The particular affinity of Ni for clay sites might have influence its relationship with the clay content in the soil. The result here deviates from the findings of Abdu (2010) for similar soils due particularly to the higher clay contents of his soil. The slightly alkaline nature of the soil here strongly influenced the relationship between the metals and the pH of the soil. This is because moderately acidic pH tends to favour the exchangeable and other forms of heavy metals in the soil as observed by by Manta *et. al.* (2002) and Tume *et. al.* (2006). The largely significant relationship between metals and cations on one hand and metals and P and N on the other could have been influenced by an association at the level of the parent material and nutrient incorporation and release in the case of N. This association is probable due to the variable composition of the basement complex formation (Ahmad, 2008) from which this soil was formed as well as the high organic matter content in the soil especially at the Jakara sites (Table 1). Metallic association with other cations and anions in the soil is a common phenomenon especially in slightly acidic to slightly alkaline soil (Yusuf, 2007). Similar observation was made by Abdu (2010).

Table 4: Relationship between total (T) and exchangeable (Ex.) metals with some soil parameters

	T. Cu	T. Cr	T. Zn	T. Ni	T. Pb	T. Cd	Ex. Cu	Ex. Cr	Ex. Zn	Ex. Ni	Ex. Pb	Ex. Cd
Clay	-0.024	-0.158	-0.429**	0.115	-0.344**	-0.327**	-0.050	-0.187*	-0.388**	0.178*	-0.217*	-0.225**
pH	-0.204*	0.142	-0.273**	-0.062	-0.248**	-0.046	-0.158	0.158	-0.303**	0.109	-0.079	-0.020
TN	0.174*	0.226**	0.594**	0.201*	0.359**	0.445**	0.225**	0.192*	0.571**	-0.038	0.144	0.375**
OC	0.193*	0.195*	0.478**	0.045	0.246**	0.403**	0.245**	0.132	0.422**	-0.137	0.102	0.310**
P	0.216*	0.345**	0.835**	0.091	0.464**	0.675**	0.277**	0.317**	0.743**	-0.109	0.148	0.485**
Ca	-0.023	0.451**	0.509**	-0.142	0.368**	0.493**	0.027	0.496**	0.533**	-0.356**	0.362**	0.448**
Mg	0.069	0.315**	0.246**	-0.089	0.251**	0.183*	0.075	0.367**	0.312**	-0.273**	0.325**	0.146
K	0.190*	0.337**	0.729**	0.080	0.508**	0.646**	0.225**	0.308**	0.655**	-0.072	0.230**	0.516**
Na	-0.020	0.353**	0.758**	-0.008	0.422**	0.646**	0.064	0.374**	0.655**	-0.175*	0.177*	0.448**
CEC	0.027	0.505**	0.657**	-0.057	0.440**	0.600**	0.079	0.541**	0.654**	-0.299**	0.363**	0.506**

** Significant at $p \leq 0.01$ * Significant at $p \leq 0.05$

CONCLUSION

The results show that the soils of the studied areas are at risk of contamination from these metals, especially given the high total concentrations which are gradually being released into exchange and subsequently into solution and probable absorption into the plants system. This is especially given the low to medium values of CEC, organic matter, clay and the slightly alkaline nature of the pH; as well as the higher levels of the metals detected at some sites of the study. The tendency for their bioavailability may also not be ruled out as appreciable contents have also been detected in exchangeable fractions which may likely affect the content in solution from which plants absorbs.

Recommendation

Based on the findings it could be recommended that an improvement of the soils' organic matter content through incorporation of non-pollutant sources of carbon such as animal manure may reduce the tendency of metals for bioavailability. This is evident in the case of Jakara which despite of its high total metal content has appreciably low bioavailable forms due to its relatively high organic matter. Furthermore an irrigation management system that encourages other water sources such as underground water may also be recommended to reduce the rate of introduction of the pollutants through wastewater.

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