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Assessment of Soil Properties and Heavy Metal Contamination Status in Vegetable Farms along River Sauna

Aishat Ayobami Mustapha and Idris Surajo
Department of Soil Science, Bayero University Kano, Kano, Nigeria

ABSTRACT

Background and Objective: The use of wastewater for irrigation is a common practice among low-income farmers and is raising serious concerns about the status and contamination level of these farms with heavy metals. This research was carried out to identify the type and amount of heavy metals on the bank of River Sauna. **Materials and Methods:** The content of heavy metals, cadmium, copper, chromium, nickel and lead in five vegetable farms along River Sauna in Kano State was investigated. Data obtained were subjected to statistical analysis using the JMP package ecological risk assessment of each metal was also carried out. **Results:** Highly significant differences ($p<0.001$) in the soil properties across the farms were observed. Most of the farms were sandy loam, slightly acidic with low amounts of organic matter and high amounts of phosphorus. Significant differences in the amount of heavy metals across all the farms were observed with the highest amount of chromium (6.21 mg kg^{-1}) and copper (3.11 mg kg^{-1}) observed in farm 4. No significant difference was observed in the concentration of cadmium ($p = 0.10$) and nickel ($p = 0.7$) across all the farms. Generally, the concentrations of the metals were below the limits expected for arable lands. **Conclusion:** The amount of heavy metals was observed to be far below the permissible limit and pose a low ecological risk. Practices and legislation to prevent heavy metal build-up in the soils are suggested to be adopted.

KEYWORDS

Soil contamination, urban agriculture, ecological risk, heavy metals, pollution, wastewater

INTRODUCTION

The increasing urbanization and industrialization have resulted in the release of a high amount of heavy metals such as Copper (Cu), Iron (Fe), Zinc (Zn), Lead (Pb) etc., into agricultural soils[1]. These metals are highly bioavailable and are not easily degradable, hence they tend to accumulate in agricultural soils[2]. Some of these heavy metals e.g., Zn, Fe and Cu, are beneficial to plants and involved in various enzymatic activities, however, in high concentrations, they may be toxic and even affect plant growth and development while indirectly health concerns to humans and animals[3,4].

Most reports have classified savannah soils as fragile and of poor fertility status[5,6] and in the course to meet the increasing demand on agriculture, farmers tend to source for external nutrients in a bid to

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preserve soil quality. One of the most common practices by low-income farmers is the use of wastewater for irrigation as this serves a dual purpose on those farmlands, (i) Provide water for growing crops and (ii) Source of nutrients. However, despite the advantages of the use of wastewater, the risk of contamination with heavy metal may also occur[7].

The use of wastewater for irrigation has been identified as one of the major sources of heavy metal contamination in agricultural soils in Kano and there have been many reports on the type and amount of concentration[7–9]. However, despite these reports, farmers having access to wastewater persist in the use for irrigation in a bid to save money on fertilizer and the same time boost production. This research was carried out to characterize the soil, identify the type of heavy metals, contamination as well as their ecological risk assessment in some cultivated farmlands along the bank of River Sauna.

MATERIALS AND METHODS

Study area: The research was carried out in the research and experimental laboratory of the Department of Soil Science, Faculty of Agriculture, Bayero University Kano, from February, 2022 to March, 2023.

Description of the sampling area: This study was conducted along the bank of the river, laying between Sauna at Nasarawa local government area further extends to Dan Sarai, Gezawa Local Government Kano State. All the samples were collected in the area lying between Latitude 12°00' and 12°01'N and Longitude 8°35' and 8°36'E. The sampling points in the study area were identified using Global Positioning System.

The study area is located within the central district of Kano and it is characterized by a hot semiarid climate with a mean temperature of 29°C and receives about 657.3 mm of rainfall annually[5]. The dominant parent material has been identified as basement complex rocks[7]. The dominant crops irrigated in the area are leafy vegetables such as lettuce and spinach.

Soil sampling: Five farms were randomly selected for soil sample collection, four of which use river water for irrigation and one farm (control) does not receive water from the river for irrigation. Soil was sampled using the simple random composite sampling method. In each of the five farms, five different samples were collected from a depth of 0-15 and 15-30 cm each. These samples were then combined into one composite sample for each farm, resulting in a total of 10 composite soil samples. The samples were appropriately labelled, placed in polyethylene bags and transported to the laboratory for analysis.

Laboratory techniques: The soil samples were dried, sieved and stored in an air tight container before laboratory analysis. The soil $pH_{(water)}$ was determined in a water-soil ratio of 1:2.5 using a glass electrode pH meter (Jenway 3520) while the electrical conductivity (EC) was determined using an EC meter (Jenway 3520) at 1:2.5 soil-distilled water ratio. Particle size analysis was done as outlined by Mukhtar and Samndi[10]. Organic carbon was determined using the Walkley black oxidation method as described by Mustapha *et al.*[11] while cation exchange capacity and exchangeable bases were determined using ammonium acetate extraction and saturation techniques described by Aprile and Lorandi[12].

Heavy metals were determined by digesting soil samples with hydrochloric acid[13,14]. The concentration of heavy metals in the filtrate was determined using Atomic Absorption Spectrophotometer (Agilent 200 series 240 FS).

Statistical analysis: The data obtained was subjected to analysis of variance statistical analysis at 5% significance level. Pearson correlation was also carried out between the soil properties and metal content. All statistical analysis was carried out with JMP Version 17.

Ecological risk assessment: The assessment of ecological risks of heavy metals in soil samples was done using the Ecological Risk factor (Eir) and Potential Ecological Risk Index (Ri) adopted by Sulaiman *et al.*[15].

RESULTS

The results of the particle size distribution of the different fields along the River Sauna bank were shown in Table 1. Highly significant differences (p<0.001) in the distribution of the soil fractions were observed among the different farms, with the farm having the highest content of sand (82.21%). The lowest content of sand (63.88%) was observed in site 3. A reversal of the trend was observed with the silt fraction with site 3 having the highest silt content (22.64) while site 5 had the lowest silt content of 10.97 and similar trends were observed with the distribution of the clay content. There was no significant difference (p<0.001) in the content of the sand fraction with depth, although the sand fraction in the 0 -15 cm depth (75.80) was observed to be higher than the 15- 30 cm depth (72.81). A significant difference (p = 0.067 and p<0.001) was observed in the content of silt and clay respectively with higher contents of each fraction observed with depth.

The pH of the soils across the different farms was shown in Table 2. Significant difference (p = 0.001) in the pH level was observed with site 3 having the highest pH level of 7.34, while site 2 had the lowest pH level of 6.71. The results also showed no significant difference (p = 0.41) in the pH levels with depth. A significant difference (p<0.001) in the electrical conductivity of the different sites was obtained as shown in Table 2, site 4 was observed to have the highest EC content of 1.03 dsm^{-1} while the lowest content of 0.40 dsm^{-1} was obtained in site 5 and statistically similar to the results of site 1 (0.43 dsm^{-1}). A significant difference (p = 0.006) in the EC was observed with depth. The EC value in the 0-15 cm (0.63 dsm^{-1}) layer

Table 1: Particle size distribution across the different farms along River Sauna Bank

Treatment		Sand	Silt	Clay	Texture
Sampling ID	S1	72.80^{c}	16.97^{b}	10.1^{b}	Sandy loam
	S2	74.21^{bc}	15.97^{b}	9.81^{b}	Sandy loam
	S3	63.88^{d}	22.64^{a}	13.48^{a}	Sandy loam
	S4	76.54^{b}	16.64^{b}	6.81^{c}	Sandy loam
	S5	82.21^{a}	10.97^{c}	6.81^{c}	Loamy sand
	SE	0.64	0.53	0.29	
	Problem	<0.001	<0.001	<0.001	
Sampling depth	A	75.80	16.17^{b}	8.74^{b}	Sandy loam
	B	72.81	17.10^{a}	10.08^{a}	Sandy loam
	SE	0.40	0.33	0.18	
	Problem	<0.001	0.067	<0.001	

Means followed by different letters are significantly different at least at p<0.05, Letters in superscript represent the ranking of the parameter means under consideration the letters A and B represent the depth on which each soil sample was collected from each sampling site (A = 0-15 and 15-30 cm), SE: Denotes a standard error and Site 5 is the control

Table 2: pH, electrical conductivity, exchange acidity, organic carbon and available P-across the different farms along River Sauna Bank

Treatment		pH (water)	EC (dsm^{-1})	EA (cmol kg^{-1})	O.C (%)	AP (mg kg^{-1})
Sampling ID	S1	6.76^{bc}	0.43^{c}	0.38	0.39^{c}	16.86^{c}
	S2	6.71^{c}	0.58^{b}	0.38	0.55^{b}	27.29^{b}
	S3	7.34^{a}	0.55^{b}	0.41	0.55^{b}	37.46^{a}
	S4	7.19^{ab}	1.03^{a}	0.41	0.80^{a}	37.92^{a}
	S5	6.93^{abc}	0.40^{c}	0.41	0.44^{c}	22.76^{bc}
	SE	0.09	0.02	0.04	0.01	1.84
	Problem	0.001	<0.001	0.97	<0.001	<0.001
Sampling depth	A	7.02	0.63^{a}	0.42	0.53^{b}	37.71^{a}
	B	6.95	0.56^{b}	0.38	0.56^{a}	25.28^{b}
	SE	0.09	0.01	0.02	0.007	1.16
	Problem	0.41	0.006	0.40	0.500	0.0011

Means followed by different letters are significantly different at least at p<0.05, Letters in superscript represent the ranking of the parameter means under consideration the letters A and B represent depth on which each soil samples were collected from each sampling site (A = 0-15 and 15-30 cm), SE denotes a standard error, EC: Electrical conductivity, EA: Exchange acidity, O.C: Organic carbon, AP: Available phosphorus and Site 5 is the control was higher than the 15-30 cm (0.56 dsm^{-1}) layer. There was no significant difference (p = 0.97) in the exchange acidity across the different farms with value found between 0.41 and 0.38 cmol kg^{-1}. There was no significant difference with depth (p = 0.40). The results of the organic carbon showed significant differences ($p<0.001$) across all the sites (Table 2). The highest value of 0.80% (carbon was observed in site 4 while site 1 was observed to have the lowest content of organic carbon (0.39%). Significant difference in the amount of organic carbon between depths was observed as the lower layer had more organic carbon (0.56%) compared to the upper layer (0.53%). The amount of the available P showed a significance difference ($p<0.001$) in the distribution across the sites. Site 4 was observed to contain the highest amount of available P (37.92 mg kg^{-1}) while site 5 had the lowest P-content of 22.76 mg kg^{-1} (Table 2). Significant defense (p = 0.0011) in the level of P was observed with depth. High levels of P (37.71 mg kg^{-1}) were observed in the upper layer as compared to the lower layer of the soil (25.28 mg kg^{-1}).

The results of the exchangeable bases and cation exchange capacity of the different farms were shown in Table 3. A Highly significant difference ($p<0.001$) was observed in the amount of magnesium across the different farms. The lowest amount (0.22 cmol kg^{-1}) and the highest amount (0.75 cmol kg^{-1}), were observed in site 4 and site 2, respectively. Significant difference ($p<0.001$) in the amount of calcium across the different fields was also observed with site 4 having the highest concentration of 2.55 cmol kg^{-1}. The lowest amount (1.32 cmol kg^{-1}) was observed in site 5. Similar trends were also observed in the distribution of sodium across all the sites. Significant differences (p = 0.004) in the amount of potassium across all the sites were observed, though the result showed that the concentrations observed were statistically similar with the highest amount of K (0.34 cmol kg^{-1}) observed in site 3 while the lowest amount of 0.12 cmol kg^{-1} was observed in site 1. All the exchangeable bases showed significant differences with depth ($p<0.001$) except potassium (p = 0.24). Calcium and sodium were observed to decrease with the depth while magnesium increased with the depth of the soil. The CEC values of all the sites indicated a high level of significant differences ($p<0.001$). Site 3 was observed to have the highest CEC value of 3.78 cmol kg^{-1} followed closely by site 4 with a value of 3.73 cmol kg^{-1}. The lowest CEC value of 2.74 cmol kg^{-1} was observed in site 5. There was a significant difference ($p<0.001$) with depth. Cation exchange capacity was observed to decrease with depth.

The amount of heavy metal observed in the soils of farms along the bank were shown in Table 4. Significant differences in the level of chromium across the different sites were observed. Site 4 was observed to have the highest chromium content of 6.21 mg kg^{-1} while the lowest content of 5.20 mg kg^{-1} was observed in site 1. Chromium content was observed to show a significant difference with depth ($p<0.001$) with concentration observed to increase with depth.

Table 3: Exchange acidity and exchangeable bases and CEC across the different farms along River Sauna Bank

Treatment		Mg (cmol kg^{-1})	Ca (cmol kg^{-1})	Na (cmol kg^{-1})	K (cmol kg^{-1})	CEC (cmol kg^{-1})
Sampling ID	S1	0.70^{b}	1.91^{c}	0.11^{d}	0.12^{b}	3.14^{b}
	S2	0.75^{a}	1.54^{d}	0.14^{c}	0.32^{a}	3.16^{b}
	S3	0.24^{d}	2.49^{b}	0.28^{a}	0.34^{a}	3.78^{a}
	S4	0.22^{e}	2.55^{a}	0.25^{b}	0.27^{ab}	3.73^{a}
	S5	0.69^{c}	1.32^{e}	0.08^{e}	0.21^{ab}	2.74^{c}
	SE	0.001	0.005	0.0004	0.03	0.05
	Problem	<0.001	<0.001	<0.001	0.004	<0.001
Sampling depth	A	0.50^{b}	2.07^{a}	0.22^{a}	0.25	3.48^{a}
	B	0.54^{a}	1.81^{b}	0.13^{b}	0.26	3.14^{b}
	SE	0.0007	0.003	0.0003	0.02	0.03
	Problem	<0.001	<0.001	<0.001	0.24	<0.001

Means followed by different letters are significantly different at least at $p<0.05$, Letters in superscript represent the ranking of the parameter means under consideration the letters A and B represent depth on which each soil sample were collected from each sampling site (A = 0-15 and 15 -30 cm), Mg: Magnesium, Ca: Calcium, Na: Sodium, K: Potassium, CEC: Cation exchange capacity and SE: Denotes standard error

Table 4: Heavy metal content CEC across the different farms along River Sauna Bank

Treatment		Cr (mg kg^{-1})	Cd (mg kg^{-1})	Cu (mg kg^{-1})	Ni (mg kg^{-1})	Pb (mg kg^{-1})
Sampling ID	S1	5.20^{b}	0.005	0.95^{b}	0.02	ND
	S2	5.45^{b}	0.01	1.35^{ab}	0.01	ND
	S3	5.41^{b}	ND	1.20^{b}	0.006	ND
	S4	6.21^{a}	0.008	3.11^{a}	0.03	1.17
	S5	5.72^{ab}	ND	0.65^{b}	ND	ND
	SE	0.12	0.004	0.41	0.02	0.10
	Problem	<0.001	0.10	<0.001	0.7	<0.001
Sampling depth	A	5.19^{b}	0.01	1.50	0.03	0.43
	B	6.01^{a}	ND	1.39	ND	0.03
	SE	0.08	0.002	0.26	0.01	0.06
	Problem	<0.001	0.005	0.72	0.09	<0.001

Means followed by different letters are significantly different at least at p<0.05, Letters in superscript represent the ranking of the parameter means under consideration the letters A and B represent depth on which each soil sample were collected from each sampling site (A = 0-15 and 15 -30 cm), SE: Denotes standard error, CEC: Cation exchange capacity and ND: Not detected

Table 5: Ecological risk factors and potential ecological risk indices of the heavy metals in soil samples

Sample	Element	ER^1	ER^2	ER^3	Grading level	Risk indices
S1	Pb	0	0	---	Low ecological risk (LER) = <40 for all computed values	Low potential ecological risk (LPER) = <150 for all computed risk indices
	Cr	0.104	0.052	1.818		
	Cd	0.0375	0.015	---		
	Cu	0.131	0.095	7.307		
	Ni	0.001	0.001	---		
S2	Pb	0	0	---		
	Cr	0.109	0.054	1.05		
	Cd	0	0.003	---		
	Cu	0.187	0.135	10.384		
	Ni	0.001	0.001	---		
S3	Pb	0	0	---		
	Cr	0.1082	0.054	1.891		
	Cd	0.3	0.0003	---		
	Cu	0.166	0.120	9.230		
	Ni	0.001	0.003	---		
S4	Pb	0.069	0.029	---		
	Cr	0.1242	0.062	2.171		
	Cd	0	0.024	---		
	Cu	0.485	0.311	23.293		
	Ni	0.004	0.001	---		

On the other hand, the amount of cadmium showed no significant difference across all the sites and with depths (p = 0.10 and p = 0.005, respectively). Similar results were observed with nickel. Significant difference (p<0.001) in the amount of copper across all the sites were observed. The highest content of 3.11 mg kg^{-1} of Cu was observed in site 4 while the lowest content of 0.65 mg kg^{-1} was observed in site 5. There was no significant difference in depth. Lead (Pb) was not detected in all sites except in site 4. A significant difference was observed (p<0.001) between the concentrations in the topsoil, which recorded the highest value (0.43 mg kg^{-1}), compared to the subsoil (15-30 cm), with a concentration of 0.03 mg kg^{-1}.

Table 5 showed the result of ecological risk assessment of the heavy metals in soil samples. It was observed that values obtained for all heavy metals were below 40, indicating low potential ecological risk. Among all heavy metals detected, Copper (Cu) was observed to have the highest values ranging from 47.89-71.09% of the total ecological risk. However, Cadmium (Cu) was observed to highest value in sample 3 accounting for 52.15% compared to 28.85% of Copper (Cu). Lead (Pb) is detected only in site 4 and accounts for 10.11% of the ecological while Chromium is detected in all samples and ranges between 18.20 and 38.02%. Nickel was also observed to contribute to<1% of the Ecological risk in all soil samples.

DISCUSSION

Differences in the distribution of the particle size across all the sites were observed with sand being the dominating fraction in all the sites. Most of the sites were classified as sandy loam. The high content of sand in most of the fields may be related to its origin from the basement complex rock[7,16]. The high level of sand in these soils may also be a result of wind erosion[5]. The pH of the soils was observed to be slightly acidic to neutral which may be due to the silica-rich parent material[17]. Poor levels of drainage of the soil, as well as upward movements of solutes due to irrigation activities could also account for the observed pH level[18].

The amount of organic carbon in the soils across all the sites was <10 g kg^{-1} and fall under the low category. The intensive cultivation of these soils has resulted in a low amount of organic carbon as well as the removal of soil cover[6]. The amount of available P was observed to fall under the medium to high class probably due to wastewater irrigation resulting in P accumulation in these sites[5,10]. The low cation exchange capacity of the soil sample may be related to the very low organic matter of the soil in addition to the dominance of the soil by low-activity clays[5,16].

The concentrations of heavy metals (Pb, Cr, Cd, Cu and Ni) determined in the soil across the sites were below the permissible limit set by Sulaiman *et al.*[15]. Pollution caused by heavy metals occurs when the concentration in a given soil exceeds the reference limit. Despite the presence of these metals in some soils of the study area, their concentrations were low and thus indicating a low possibility of pollution and ecological risk as they do not surpass the reference limit. The results of this study showed that the concentrations of heavy metals in soil irrigated with wastewater were below the maximum permissible but were higher than those obtained from the control site that was not irrigated with any wastewater. This is also consistent with the report of Dawaki *et al.*[7], who concluded that the major sources of heavy metal introduction in the soils of Kano is the use of fertilizers and agrochemicals. The low content of these heavy metals in these soils is an indication low risk of environmental pollution as the concentration in soil solution may not be high enough for absorption and uptake by plants. Hence having little or no effect on the food chain.

Management practices that could prevent the build-up of these metals overtime such as incorporation of organic material as well provision of quality water for irrigation especially for urban based farming.

CONCLUSION

This study shows the amount of heavy metals (Cu, Cd, Cr, Pb and Ni) in the surface and subsoil of some vegetable farms along the bank of River Sauna. The amount of heavy metals was observed to be far below the permissible limit and pose a low ecological risk. However, there is still a need for legislation to restrict the heavy metal loads in the wastewater that farmers will continue to use for irrigation to prevent the buildup in the soil.

SIGNIFICANCE STATEMENT

The use of wastewater for irrigation is a common practice in urban centers as an alternative to fertilizer used by low-income farmers. Hence the need to identify and determine the types and amounts of heavy metals that are b een introduced into the soil on some vegetable farms along the bank of River Sauna. The amounts of heavy metal determined were below the permissible limit. The low amounts observed indicate that the threat of pollution by heavy metal is low with no or little damage to the flora and fauna and properties of the soil. Agricultural management and practices that can prevent build-up are suggested.

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