Environmental Burden of Heavy Metal Contamination Levels in Soil from Sewage Irrigation Area of Geriyo Catchment, Nigeria

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Abstract

The heavy metal concentration levels and contamination/pollution index of agricultural soils taken from 0 – 30 cm depth from site I and II of sewage irrigation area and from a control site of Geriyo catchment in Adamawa State, Nigeria was determined using atomic absorption spectrophotometer standard method. The mean concentration levels of trace and heavy metals (Fe, Zn, Mn, Cu, Cd, Cr and Pb) at site I are 89.90 mg/kg for Fe, 74.39 mg/kg for Zn, 12.79 mg/kg for Mn, 15.09 mg/kg for Cu, 9.86 mg/kg for Cd, 11.2 mg/kg for Cr and 7.18 mg/kg for Pb, while at site II, the concentrations levels of 294.7 mg/kg for Fe, 310.2 mg/kg for Zn, 131.9 mg/kg for Mn, 254.8 mg/kg for Cu, 240.2 mg/kg for Cd, 199.6 mg/kg for Cr and 159.2 mg/kg for Pb were observed. The concentration levels of trace and heavy metals of site II soil is significantly higher than site I and the control site with values of (Cu, Cd, Cr and Pb) mostly above the maximum permissible heavy metal concentration levels in soil set out by EU, UK and USA. The contamination/pollution index assessment of the soils revealed that the soils belong to slight pollution to excessive heavy metal pollution soil category with the potentials of negative effect on plants and ground water reserve contamination. Leaching and liming of the soil to reduce the level of metals is recommended in the context of very high land competition for sustainable agricultural productivity.

Keywords: Sewage irrigation, heavy metal, pollution index, soil, Geriyo catchment

1. Introduction

One of the identified greatest challenges facing the production of food through irrigation today is the contamination/pollution of water and soil (Hong et al. 2014). The contamination/pollution problems resulted from the high increase in human population, industrialization, urbanization which is as a result of human and animal activities causing environmental pollution problems. The indiscriminate disposal of industrial, domestic and agricultural wastewater without treatment to comply with the safe and standard disposal regulatory limit on agricultural lands, into rivers, stream and lakes are the obvious pollution type that are of serious concern due to the negative effect of heavy metals in water and soil (Burmamu, B.R, Law, P.L, Aliyu, H.H, and Ibrahim, 2014).

Heavy metals are defined as elements in the periodic table having atomic number more than 20 or having densities more than $5g/cm^3$. The environmental burden with heavy metal are that they are non degradable and most of them have toxic effect on living organisms when they exceeded a certain concentration level either in water, soil or food substances (Hong et al. 2014).

Soils, weather in urban or agricultural areas represent a media and sink for the release of metals into the environment and also a media on which agricultural crops are produced and the possibility of these crops to take up these metals becomes obvious. Heavy metals once in soil, some would be persistent because of their immobile nature, while other metals however would be more mobile therefore the potential of transfer through soil infiltration down to ground water aquifer or plant – root uptake and subsequent transfer into the food chain, to cause biochemical defects in body organs like liver, kidney, spleen and lungs is highly likely to occur.

Heavy metal contamination levels in agricultural soil are of major significance because of the potential to accumulate in soil for a long period of time (Iwegbue et al. 2013). High concentration of metal ions in soil environment may pose a significant risk to the quality of soils, plants, natural waters and human health (Wu and Zhang, 2010). Excessive accumulation of heavy metals in agricultural soils may result not only in soil contamination but also consequences for food quality and public health safety issues. Evidence of heavy metal contamination/pollution of agricultural soils and uptake of the heavy metals in vegetables and fruits in Romania and Brazil were reported by Lacatusu, 2008; Guerra et al. 2012, they further added that the toxic effects of some

heavy metals in vegetables like Cu and Pb focus on several human body organs such as liver, kidneys, spleen and lungs causing a variety of biochemical defects. Therefore it is essential to monitor the heavy metal contamination/pollution levels of sewage irrigated soil of Geriyo catchment area in order to reduce the possible transfer of metals into irrigated crops and the potential of heavy metal contamination of ground water reserve in this   area.

2.   Materials and Method
2.1   Study Area

Adamawa State with a population of 3,737,223 people and land mass of 36,917km^2 is located in the northeastern part of Nigeria. Yola (Jimeta) the Adamawa State capital is located between Longitudes 12° 26' E and Latitude 9° 16' N (http://www.en.wikipedia.org/wiki/jimeta) along the banks of River Benue (Adebayo, 1999). Lake Geriyo lies between Longitude 12° 00' and 12° 28' East of Greenwich and Latitude 9° 16' and 9° 19' north of the equator. Geriyo catchment has devoted land area of 1200 hectares under dry season irrigation. The state is in the Sahel region of Nigeria which is generally Semi arid with low rainfall, low humidity and high temperature. The area experiences wet and dry seasons, the wet season starts from April to October while the dry season starts from November to April. Recorded mean daily temperature normally changes with season and ranges from 25°C to 45°C. The mean annual rainfall received is in the range of (250 – 1000mm). The climate is characterized by high evapotranspiration especially during dry season (Adebayo, 1999). Jimeta/Yola the State capital city is a commercial nerve center of the state and has an estimated population of 600,000 people (NPC, 2006). Dry season farming is normally practiced along the River bank using municipal effluent wastewater and River water to grow edible vegetables by farmers.

2.2   Soil sampling
Reconnaissance survey of the study area was carried out to demarcate the sampling points of soil at the two sites under sewage irrigation practice and a neutral control station soil 15km away which do not receive sewage water for irrigation was selected. At each sampling site, three replicate samples of approximately 1kg of soil were randomly collected and made into composite samples from Site I, Site II and the control site at a depth of 0 - 30cm each using soil sampling spiral auger sampler. The samples were mixed thoroughly and taken in labeled polytene bags to differentiate the sampling points, well mixed, grounded, dried and sieved through 2mm size sieve and taken to the laboratory for heavy metal content analysis

2.3   Digestion and analysis of Soil Samples
One gramme (1g) of dried and sieved soil sample from site I, site II and control site each were taken and digested with 15ml of aqua- regia (mixture of HNO_3 :HCl, 3:1 ratio) and was finally allowed to stand overnight, in the next day the samples were digested at a temperature of 125°C for 2 hours. After cooling to room temperature, it was filtered using whatman No 1 filter paper and was diluted to 25ml with HNO_3 acid. The samples extract were then subsequently analyzed for Fe, Zn, Mn, Cu, Cd, Cr and Pb using fast sequential atomic absorption spectrophotometer Varian model AA240FS after selecting the various wavelengths at which the heavy metals are tested following due calibration process as outlined by APHA, 1992. Quality control was ensured by running blank and standard reference solution of the heavy metals in each soil sample to ensure precision and accuracy of all the tested heavy metals. Analysis of variance of metals concentration in soil was carried out using IBM 19 statistical analysis software and student t test at 95% confidence level was used to compare variance in metal concentrations in soil.

2.4   Quantification of soil heavy metal contamination/pollution index (MPI)

The quantification of contamination/pollution index was derived by adopting the contamination/pollution index of metals in soil as defined by Lacatusu (2000).

$$MPI = \frac{Concentration\ of\ metal\ in\ soil}{reference\ soil(control)}$$

The differences between soil contamination range and soil pollution range is given by the metal contamination/pollution index (MPI). This index value represents the ratio between the heavy metal content effectively measured in soil by chemical analysis and reference value obtained from the control soil. The values of contamination/pollution index of soil greater than 1 (> 1), define the pollution range and those less than 1 (<1) define the contamination range. The two ranges of values were divided into interval of values < 0.1 as very slight

contamination, 0.10 – 0.25 as slight contamination, 0.26 – 0.5 as moderate contamination, 0.51 – 0.75 as severe contamination, 0.76 – 1.00 as very severe contamination, 1.1 – 2.0 as slight pollution, 2.1 – 4.0 as moderate pollution, 4.1 – 8.0 as severe pollution, 8.1 – 16.0 as very severe pollution and > 16.0 as excessive pollution (Table 1). Comparison of the mean concentration values of heavy metals in soil obtained from this study was also done to determine the extent of contamination/pollution with the international maximum permissible levels of heavy metals in soil (Table 2).

Table 1: Interval of contamination/pollution index of heavy metals in soil and its significance

M/PI	Significance	Remark
< 0.1	Very slight contamination	No negative effect on soil, plant and environment
0.10 – 0.25	Slight contamination	,,
0.26 – 0.5	Moderate contamination	,,
0.5 – 0.75	Severe contamination	,,
0.76 – 1.00	Very severe contamination	,,
1.1 – 2.0	Slight pollution	Will pose negative effect on soil, plant and environment
2.1 – 4.0	Moderate pollution	,,
4.1 – 8.0	Severe pollution	,,
8.1 – 16.0	Very severe pollution	,,
> 16.0	Excessive pollution	,,

Adapted from Lactusu (2000)

3.   Results and Discussions

Table 2 presents the results of trace and heavy metals concentration levels of soil at the two sewage irrigation sites. The results indicate significant variation in heavy metal levels in soil with respect to sites at 95% probability levels. At all sites higher concentrations of metals were observed as compared to the concentration of heavy metals found at the control site. Site II exhibited higher heavy metals concentration levels more than site I and the control site. Generally, the concentration of heavy metals in the examined site I and II followed the order: Fe >Zn > Cu > Mn > Cr > Cd > Pb and Zn > Fe > Cu > Cd > Cr > Pb > Mn.

Table 2: Mean concentration of heavy metals at Site I, Site II, and Control Site compared with International standard permissible level of heavy metals in soil in mg/kg.

Table 2: Mean concentration of heavy metals at site I, site II, and control site compared to standard limits of heavy metals in Soil in mg/kg

Heavy metals (mg/kg)	Depth (cm)	Range	Site I mean (mg/kg)	Range	Site II mean (mg/kg)	Control site (mg/kg)	EU STD (mg/kg)	UK STD (mg/kg)	USA STD (mg/kg)
Fe	0 - 30	71 – 109.2	86.90	56 – 506.4	294.7	80.98	-	-	-
Zn	0 - 30	61 – 88.6	74.39	123 – 428	310.2	19.51	300	200	200 - 300
Mn	0 - 30	9 – 18.4	12.79	31 – 368.1	131.9	10.44	-	-	-
Cu	0 - 30	10 – 20.6	15.09	135 – 403	254.8	11.47	140	63	80 – 200
Cd	0 – 30	9.0 – 11.4	9.86	86 – 508.2	240.2	9.63	3.0	1.4	3.0
Cr	0 – 30	10 – 13.4	11.2	145 – 298	199.6	10.47	180	6.4	400
Pb	0 – 30	6 – 8.6	7.18	110 – 274	159.2	6.53	300	70	300

EU =European Union Standard, USA =United State of America Standard, UK =United Kingdom standard

Table 3: Contamination/ pollution index for heavy metals in soil at Sewage water irrigation site I

MPI = metal contamination/ pollution index

Heavy metals Mg/kg	Depth (cm)	Site I mean (mg/kg)	Control site mean (mg/kg)	MPI	Class interval According to Lactusu (2000)	Significance
Fe	0 -30	86.90	80.98	1.07	1.1 – 2.0	Slight pollution
Zn	0 - 30	74.39	19.51	3.81	2.1 – 4.0	Moderate pollution
Mn	0 -30	12.78	10.44	1.22	1.1 – 2.0	Slight pollution
Cu	0 - 30	15.08	11.47	1.33	1.1 – 2.0	Slight pollution
Cd	0 −30	9.83	9.63	1.02	1.1 – 2.0	Slight pollution
Cr	0 −30	11.0	10.47	1.05	1.1 – 2.0	Slight pollution
Pb	0 −30	7.17	6.53	1.09	1.1 – 2.0	Slight pollution

Table 3: Contamination/ pollution index for heavy metals in soil at Sewage water irrigation site I

Heavy metals (mg/kg)	Depth (cm)	Site II mean (mg/kg)	Control site mean (mg/kg)	MPI	Class interval According to Lactusu (2000)	Significance
Fe	0 -30	292.7	80.98	3.61	2.1 – 4.0	Moderate pollution
Zn	0 -30	309.2	19.51	15.8	8.1 – 16.0	Very severe pollution
Mn	0 -30	130.9	10.44	12.5	8.1 – 16	Very severe pollution
Cu	0 - 30	253.8	11.47	22.2	> 16.0	Excessive pollution
Cd	0 −30	239.2	9.63	24.8	> 16.0	Excessive pollution
Cr	0 −30	199.2	10.47	19.2	> 16.0	Excessive pollution
Pb	0 −30	158.2	6.53	24.2	> 16.0	Excessive pollution

MPI = metal contamination/ pollution index

3.1 Iron

The concentration of Fe recorded in soil from site I ranged from 71 – 109.2mg/kg with mean value of 86.90mg/kg, while site II ranged from 56 – 506.4mg/kg with mean value of 294.7mg/kg respectively. The control site has a mean value of 80.98mg/kg of Fe. The result indicates that site II recorded higher Fe than any other site examined. The results of Fe found in this study were lower than value range of 1746.4 to 2839.4mg/kg reported in soils in the vicinity of automobile spare parts market and oil field in Nigeria (Iwegbue et al., 2006a). The source of Fe observed in this study could be from metal scraps in dump sites and leaching of iron from iron smelting and fabrication from small scale industries in the area. The level of Fe in these soil fits into the slight pollution to moderate pollution (Table 3 and 4) with no negative effects of Fe on soil and plants expected (Table 1).

3.2 Zinc

Zinc is ranked as the most abundant metal in this study. The concentrations of Zn ranged from 61 – 88.6 mg/kg and 123 – 428 mg/kg and mean values of 74.39 and 310.2 mg/kg for site I and II respectively. The control site soil recorded lower Zn concentration level of 19.51 mg/kg which indicated variation in the level of Zinc between the tested soil and the control soil. The variation in concentration level of Zinc in these soils showed the impact of pollution from anthropogenic activities rather the lithogenic one. The main source of Zn in these soils be from attrition of motor vehicles, metal fabrication works and lubricating oil found as additives as Zn dithiophosphates. Mean Zn ion concentration recorded at site II have exceeded the permissible standard of 300 and 200 mg/kg set out by EU and UK in soil indicating the extent of Zn pollution in this soil. The contamination/pollution level of Zn was classified into moderate pollution to very severe pollution at both site I and II (Table 3 and 4).

3.3 Manganese

Manganese is ranked as the fourth available metal observed in this work. The concentration levels ranged from 9 – 18.4 mg/kg and 31 – 368.1 mg/kg with mean values of 12.79 and 131.9 mg/kg for site I and II. At the control site, the concentration level of Mn was 10.44 mg/kg. Much lower concentration of Mn was recorded at the

control site than the tested soils (Table 2). With respect to contamination/pollution index, Mn concentration levels in the tested soils were observed to belong to the category of slight pollution to very severe pollution status soil. The concentration of Mn in soils obtained from our study is higher than the concentration value of 79.03 – 244.94 mg/kg reported by (Tahar and Keltoum, 2011) for heavy metal pollution in soil and plants in the industrial area of west Algeria.

3.4 Copper
The concentration of Cu in the soil ranged from 10 – 20.6 mg/kg and 135 – 403 mg/kg with mean values of 15.09 mg/kg and 254.8 mg/kg for site I and II respectively. Copper concentration is the third highest and most abundant metal concentration of heavy metal recorded in the present study with site II having the highest mean concentration value of 254.8 mg/kg than the site I (Table 2). The control site soil has Cu concentration level of 11.47 mg/kg lower than site I and II. The mean concentration level of Cu recorded in site II with value of 254.8 mg/kg was observed to be higher than 140, 63 and range of 80 – 200 mg/kg permissible level of Cu concentration in soil set out by EU, UK and USA Standard. The higher Cu concentration value at Site II signals a potential hazard for crops grown on this soil from Cu contamination and leaching of Cu down the soil profile to affect ground water reserve. The assessment of contamination/pollution index with respect Cu placed site I and II soils into slight pollution to excessive Cu polluted soils (Table 3 and 4). The observed excessive pollution due to Cu in agricultural soil is a source of serious concern. The observed levels of Cu in this study were higher than those reported for soil of waste dump sites by Osakwe and Egharevba, 2008.

3.5 Cadmium
The examined concentration of Cd in soil at site I and II showed a range of 9 – 11.4 mg/kg and 86 – 508.2 mg/kg with respective mean values of 9.86 and 240.2 mg/kg, while the control site has mean value of 9.63 mg/kg. Site II significantly exhibited higher mean Cd concentration value of 240.2 mg/kg than site I and the control site soil. The observed Cd concentration recorded at all sites, I, II and the control site are all above the maximum permissible concentration of 3.0, 1.4 and 3.0 mg/kg set out by EU, UK and USA Standard for Cd concentration in soil. The observed high mean concentration of Cd in soil also revealed a potential hazard of heavy metal exposure for crops grown through irrigation on this soil. The source of Cd in the soil could be through the addition of phosphate fertilizers, domestic and sewage sludge, wear of automobile tyres, lubricants, mining and metallurgical activities. The contamination/pollution index revealed that site I and II soils belongs to the category of slight pollution to excessive pollution with the consequence of posing negative effect of soil and particularly plants raised on this soils. The mean values of Cd concentration level recorded in this study was observed to be higher than the Cd concentration values of 115.27 mg/kg and 9.11mg/kg reported by (Jagtap et al, 2010; Babatunde and Steve, 2014) for Cd concentration in soil irrigated with urban wastewaters and soils around NNPC oil depot in India and Jos in Nigeria.

3.6 Chromium
The concentration values recorded in respect of Cr at site I and II soils revealed the range of 10 – 13.4 mg/kg and 145 – 298 mg/kg with mean concentration values of 11.2 and 199.6 mg/kg respectively. The control soil has a mean value of 10.47 mg/kg (Table 2). The mean concentration of Cd observed in both site I and II were significantly higher than the concentration recorded at the control site revealing the impact of Cd pollution in soil due to anthropogenic sources. The mean concentration of Cd recorded from site II with value of 199.6 mg/kg is comparatively higher than 180 and 6.4 mg/kg standards maximum permissible concentration of Cd in soil set out by EU and Uk Standards. However all the recorded concentrations of Cd were observed to be lower than 400 mg/kg set concentration standard in soil by the United State of America (Table 2). The observed high concentration of Cr in these soils could be due to discharge of Cr in wastewater and sludge from dyeing and tanning industries might be the major sources of Cr pollution to the environment.

3.7 Lead
Lead concentration levels in soil of site I and II are in the range of 6 – 8.6 mg/kg and 110 – 274 mg/kg with mean values of 7.18 and 159.2 mg/kg, while the control site soil has Pb concentration of 6.53 mg/kg respectively. Site II soil showed significantly higher Pb concentration value than site I and the control site (Table 2). The mean value of Pb concentration recorded at site II with value of 159.2 mg/kg is found to be comparatively higher than the mean values of Pb concentration of 34.32, 1.11±0.28, 10.0 and 8.5, 0.84±0.05 mg/kg reported by (Liang and Liang, 2011; Osakwe, 2013; Bichi and Bello, 2013; Majolagbe and Duru, 2014), indicating the high impact of Pb pollution in the studied soils. However, the concentration of Pb in soil recorded were found to be lower than the standard limit of 300 mg/kg in soil set out by EU and USA, while the Pb concentration value obtained from site II is higher than UK standard of 70 mg/kg (Table 2). The major sources of Pb pollution are exhaust gases of petrol engines, pesticides, and fertilizer impurities, emissions from mining and smelting operations and atmospheric fallout from the combustion of fossil fuels.

4. Conclusion

The heavy metal contamination levels of sewage irrigated soils of Geriyo catchment area were analyzed and determined. The results of heavy metal concentration levels in soil revealed that the soil contains substantially high level of heavy metals (Mn, Cu, Cd, Cr and Pb) due to sewage water irrigation application on soil. The heavy metal load level and metal contamination/pollution index assessment revealed that the soil mostly belongs to the class of severe contamination to excessive pollution category soil with the potentials of the negative effect on plants and the environment. The study indicates that plant raised on this soil via irrigation stand the high potentials of bio accumulating these metals and may subsequently transfer these toxic metals into the food chain to affect body organs such as kidney, spleen, lungs, liver with time. Leaching and liming of heavy metals in soil and provision of adequate wastewater treatment plant is recommended to treat wastewater to the minimum safe reuse and disposal level for sustainable productivity of soil in the context of acute water scarcity in the sahelian region of Nigeria.

5. Acknowledgement

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