INFLUENCE OF TREATED WASTEWATER ON TRACE AND HEAVY METALS IN SOILS OF WUPA, ABUJA, Nigeria

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ABSTRACT

The soils adjoining a sewage treatment Plant in Abuja were studied to assess the influence of treated wastewater on accumulation of some trace and heavy metals in the soil. Soil samples were collected from five locations in the entire area (four locations along the main canal conveying the treated wastewater into the Wupa River and a location 50 m away from the canal to serve as a control site). Samples were collected and analysed for particle size distribution and some selected chemical properties as well as some trace and heavy metals following standard laboratory procedures. The soils were generally sandy loam in texture with high proportion of sand and low clay fraction. The sand content ranged from 642 to 772 g/kg while clay ranged from 47 to 61 g/kg. Soil pH was ranging from 5.58 to 6.29 fitting the soil into the range of moderately acidic to slightly acidic. Electrical conductivity ranged from 0.963 to 4.30 dScm^{-1}. Exchangeable cations were generally low; however, exchangeable acidity was influenced by soil's contact with treated wastewater since the lowest value of 9.63 was recorded from the control site. The distribution of trace and heavy metals showed that there was an increase in the concentration of the trace and heavy metals in the soils as lowest values were only observed in the control site. However, the range of values observed for the trace and heavy metals were within permissible environmentally safe limits except for Ni which was higher than the permissible safe limit for plants. Fe ranged from 23.22 to 415.40 mg/kg, Mn ranged from 19.36 to 157.97 mg/kg, Cu ranged from 0.59 to 2.92 mg/kg while Zn ranged from 2.21 to 8.87 mg/kg. For the heavy metals, Cr ranged from 12.69 to 29.77 mg/kg, while Ni ranged from 16.94 to 25.53 mg/kg. Cadmium in all the samples was below detectable limits. It was concluded that there is need for adoption of improved sewage treatment processes that will eliminate toxic metals such as NI, Cr, Zn and Mn among others. There is need for further study on the quality of treated wastewater discharged into the Wupa River where it eventually ends up as part of irrigation water in the area. Fish from the Wupa River and vegetables grown from the area should be studied for bioaccumulation of heavy metals.

INTRODUCTION

The soil is an important natural resource upon which human lives depend. It is the base for both agricultural and non-agricultural productions the world over. Soils have over the years remained a crucial component of both rural and urban environments, and so basic information about it is a prerequisite for proper land management.

The status and distribution of heavy and trace metals in soils are important considerations in assessing soil and environmental quality. Fernando *et al*, (2012) observed that the main natural sources of these metals in soils are chemical weathering of minerals, and the anthropogenic sources are associated mainly with industrial, agricultural, mining, land disposal of wastes, waste incineration, mechanic workshops and fuel filling stations among many others. Heavy metals contamination of soils has remained a principal concern, especially considering their toxicity, their persistence in soils and their non-degradability status. This has continued to pose threats to environmental quality and human health. Trace metals are also known as micronutrients (Fe, Mn, Zn and Cu). Besides their essentiality as nutrients required for effective plant growth and yield, micronutrients have the potential of becoming toxic in the soil leading to problems of impaired soil quality by way of polluting underground water as well as becoming injurious to most crops (Wapa and Olowookere, 2013). Heavy metals accumulate overtime in soils which serve as sink from which these toxicants are released to the groundwater and plants and end up in the food chain, thus causing many toxicological effects. Some of these heavy metals include Pb, Ni, Cr and Cd among others.

Treated wastewater has been a very good alternative source of water in urban agriculture and in semi-arid regions for irrigation especially owing to scarcity of water. While this re-used resource serves an important role in nourishing crops with nutrients, it also has the problem of increasing heavy metal concentration and accumulation in soils. These heavy metals accumulate in plant tissues and are consumed by man. Studies have also reported significant changes in some physical and chemical properties of soils as influenced by long term contact with treated wastewater (Lobna, *et al*., 2010; Selassie *et al*., 2015 and Mohammed, 2018).

This study aimed at assessing the trace metals and heavy metals accumulation in the soils of Wupa, in Abuja Nigeria. The Wupa sewage treatment plant is located in Idu Industrial Area of the Federal Capital Territory (FCT) Abuja where the treated wastewater is released into the Wupa River and the locals around use this water for irrigation, fishing and other domestic uses such as laundry.

Materials and Methods

2.1 Description of Study Area: The study area is located within the community using treated wastewater from Wupa Sewage Treatment Plant. The Wupa sewage treatment plant is located in the larger Idu Industrial Area. The treatment plant is geographically situated within latitudes $9^{o}1^{I}19.20^{II} – 9^{o}1^{I}24.28^{II}$N and longitude $7^{o}22^{I}43.67^{II} – 7^{o}22^{I}49.74^{II}$E.

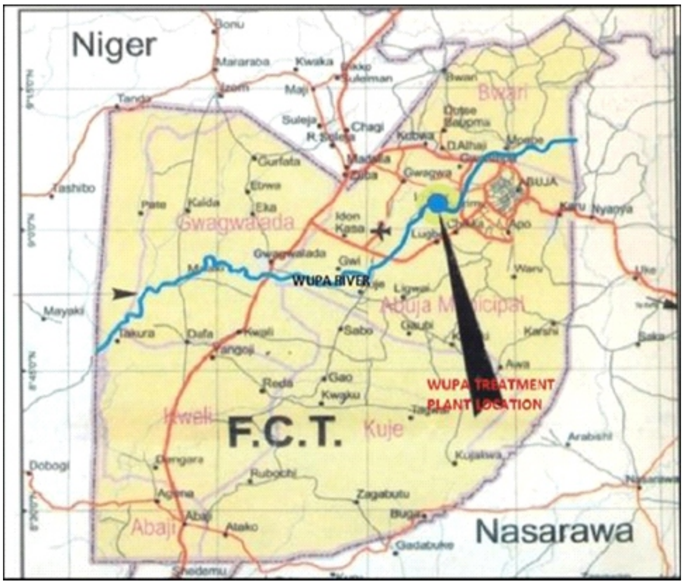

Figure 1. Showing the location of Wupa Treatment Plant. Credit: "Performance Evaluation of Wupa Wastewater Treatment Plant Abuja, Federal Capital Territory, Nigeria" Volume-6, Issue-11, pp-85-90 www.ajer.org

Plate 1: Aerial View of Wupa Treatment Plant showing the discharge canal into Wupa River.
Source: Wupa Treatment Plant Management.Office.

Soil Sampling and preparation

Soil samples were collected using auger borings at three predetermined depths (0-20, 20-40 and 40-60 cm). Sampling points were marked 25m apart along the main canal conveying the treated wastewater that discharges into the Wupa River. Four points were marked along the canal and a fifth point was marked 50 m away from the canal to serve as a control. Auger borings were made, soil samples collected and labelled. The collected samples were air dried at room temperature, crushed and sieved with a 2 mm sieve for laboratory analysis.

Laboratory analysis

Particle size distribution (PSD) was determined using the Bouyoucos (Hydrometer) method as described by Udo *et al*., (2009). The soil dry bulk density was determined using the core method (Oku *et al*., 2012). The constant head method was used to determine K_{sat}. The soil pH in water (1:1) and in KCl (1:1) was determined by electrometric method as described by McLeans (1982). Organic carbon was determined by the modified Walkley – Black method as described by Nelson and Summers (1982) while total nitrogen was determined by the macro-Kjeldahl digestion and distillation procedures as described by Bremner (1965). Sodium bicarbonate {Na $(HCO_3)_2$} extracting solution was used in this analysis (Olsen and Dean, 1965). CEC was determined by neutral 1N ammonium acetate method. Exchangeable cations were determined by ammonium acetate extraction method as described by IITA (1979). For the trace and heavy metals, air dried samples of soil were sieved to pass through a 2 mm sieve. Thereafter, 2 g of the sample was digested using 20 ml of concentrated HNO_3, $HClO_4$ and H_2SO_4 in 2: 1: 1 ratio on temperature controlled hot plate. When the volume was reduced to a clear digested solution, the contents were allowed to cool and then transferred into a 50 ml volumetric flask. The volume was made to mark. The Fe, Mn, Cu, Zn, Pb, Ni, Cr and Cd were then read using an atomic absorption spectrophotometer (AAS UNICAM 969 Model).

Results and Discussion

Selected Physico-chemical properties of the soils

The results of some physical and chemical properties of Soils from the Wupa Treatment Plant in Abuja are presented in Table 1.The result for soil textural distribution showed that soils were predominantly sandy loam with high proportion of sand that ranged from 642 g kg^{-1} to 772 g kg^{-1}, silt content of the soil ranged from 174 g kg^{-1} to 301 g kg^{-1} while clay ranged from 47 g kg^{-1} to 61 g kg^{-1}. Some studies within the FCT (Barnabas and Nwaka, 2013 and Oku *et al.*, 2020) have also recorded very high sand content in soils. The high sand content of the soils could be attributed to nature of parent materials from which the soils were formed. The area is underlain by an undifferentiated basement complex (Ojanuga, 2006) and in this geological formation, quartz is a significant constituent of the parent materials producing the soils, hence the dominance of sand fraction in the textural classification of the soils. With the high sand content, it is believed that the soils specific area is small and this will have effect on the soil cation exchange potential.

The soil reaction in terms of pH ranged from 5.58 to 6.29 (pH in H_2O) as well as 4.88 to 5.59 (pH in KCl). This is an indication that the soils are within moderately acidic to slightly acidic (Chude *et al.*, 2011). This pH range is suitable for the availability of most plant nutrients (Agbede, 2009) and might be favourable for most microbial communities in the soil. Low pH values enhance the solubility and mobility of heavy metals in soils (Akan, *et al.*, 2013). Soil electrical conductivity ranged from 9.63 to 43.00 µScm^{-1} and is below the critical limit of 450 µScm^{-1} (FAO, 2014). Higher EC above the critical limits will drastically affect crop performance due to high soluble salts in the soil.

Soil organic carbon was low and ranged from 1.50 g kg^{-1} to 5.50 g kg^{-1} suggesting low inherent nutrient reserve of the soil. This implies that the soils will also be low in organic matter content. This is because organic matter is stored in soils in the form of carbon. Total nitrogen ranged from 0.70 g kg^{-1} to 2.20 g kg^{-1} and is rated as being low (Udo, *et al.*, 2009). The low nitrogen content could be attributed to low soil organic carbon reserve since soil organic matter is the store house of most nutrients in the soil. Available phosphorus ranged from moderate to high having values that ranged from 38.29 mg kg^{-1} to 64.35 mg kg^{-1}. The control site had the least phosphorus content while the sites in contact with treated wastewater had high P content. The high phosphorus content could be attributed to presence of phosphates in the treated wastewater (Dawaki *et al.*, 2013).

The concentration of exchangeable cations in the soil showed that Ca ranged from 4.30 to 7.40 cmol kg^{-1}, Mg ranged from 0.69 to 1.22 cmol kg^{-1} while Na ranged from 0.19 to 0.35 cmol kg^{-1}. Also, K ranged from 0.22 to 0.41 cmol kg^{-1}, and exchangeable acidity ranged from 0.08 to 0.40 cmol kg^{-1}. Exchangeable acidity and calcium were lowest in the control site than the sites in contact with treated wastewater. Cation exchange capacity of the soil ranged from 6.45 to 8.61 cmol kg^{-1}. The range of values showed that CEC in the soils was very low (Udo *et al.*, 2009 and Chude *et al.*, 2011). The low CEC suggests that nutrient holding potential of the soils is very low. Base saturation of the soils was very high and ranged from 937.8 to 990.7 g kg^{-1}.

Trace and Heavy Metals Concentration

The concentration of some trace and heavy metals in the soils of Wupa sewage treatment plant are presented in Table 2.

Iron (Fe) Concentration

Extractable Fe content of the soils ranged from 23.22 mg kg^{-1} to 415.40 mg kg^{-1}. The least value for Fe was recorded at the control site (23.22 mg

kg^{-1}). The other sites had much higher values than the control probably due to contact with the treated wastewater. The values for Fe in all the locations were lower than the critical limit set by FAO (2014). Iron and Mn have a high tolerable limit of 1500 mg/kg, however, higher levels than this could be toxic and injurious to plants and animals (Olodade, *et al*., 2015). The higher values of Fe obtained in the sites that had contact with treated wastewater suggest that there are significant traces of Fe in the treated wastewater that has been accumulating in the soil over time.

Manganese concentration

From Table 2, it was observed that manganese in the soils ranged from 19.36 mg/kg to 157.97 mg/kg. The lowest concentration was observed at the control site (19.36) while higher values were obtained in sites that had contact with treated wastewater. Table 3 showed that there was significant difference in the distribution of Mn across the four locations and the control site. The concentration of Mn in the soils were higher than the values reported by other researchers within Nigeria such as Dawaki *et al*, (2013), Olayinka *et al*, (2013) and Olayinka *et al*, (2017). The result of Mn concentration at the sampled areas is lower than the maximum tolerable limits for agricultural soils. This implies that manganese in these soils has no threat risk at the various sites under observation, at least at the current moment.

Copper (Cu) concentration in the Soils

From Table 2, the distribution of copper in the soils ranged from 0.59 to 2.92 mg/kg. The lowest value of 0.25 mg/kg was observed in the control site. The concentration of Cu in the soils that had contact with treated wastewater was higher when compared to the control site. Also, analysis of variance (Table 3) showed that there was significant difference in the concentration of Cu between the control and the four locations that had contact with treated wastewater. The values for Cu concentration in this study were lower than values reported by some researchers within Nigeria especially Dawaki, *et al* (2013 and Odueze *et al*, 2017).

USEPA (1996) set 250 mg/kg as allowable and toxic limit of copper for agricultural lands. Table 2 shows that Cu in all the sampled locations including the control site were far below the toxic limit, hence pose no environmental threats in these soils. The low Cu concentration in the soils could mean that the treated wastewater does not contain harmful amount of Cu. This finding is in consonance with the findings of Lenntech (2009) and Oladade, *et al*. (2015).

Zinc (Zn) concentration

The concentration of Zn in the soils of the study sites ranged from 2.21 mg/kg to 8.81 mg/kg. The least Zn concentration was observed in the control site while the highest was observed in location 3 that is 75 m away from discharge source along the canal.

Zinc is known to be one of the most important trace elements that plays a vital role in the physiological and metabolic process of many organisms. Nevertheless, higher concentration of Zinc can be toxic to organisms. It also acts as an important catalyst in protein synthesis (Ruqia Nazir *et al*., 2015). Reports have also shown that Zn is a metal which shows fairly low surface concentration in surface water due its restricted mobility from place of rock weathering or from natural sources (Dauda and Odoh, 2012, Olayinka *et al*., 2013 and Olayinka *et al*., 2017). The Zinc content of the soils sampled is below the WHO recommended limit for plants pegged at 50 mg/kg (Afzal Sha *et al*., 2011).

Chromium (Cr) concentration in the soil

The concentration of Cr in the soils of the sampled sites as shown in Table 2 revealed that the Cr concentration ranges from 12.69 mg/kg to 29.77 mg/kg. The least Cr concentration was recorded for the control site (12.69 mg/kg). There was significant difference in the concentration of Cr in the soil between the control site and the other sites that had contact with treated wastewater (Table 3). The concentration of Cr in these soils especially for locations, 1, 3 and 4 with values of 29.77 mg/kg, 28.14 mg/kg and 22.80 mg/kg, respectively were higher than the threshold allowable limits for agricultural soils based on Canadian Council of Ministers of the Environment (CCME) (2009) standards set for Canada at 22 mg/kg. The control site was far less than this critical value indicating that the treated wastewater had significantly increased the chromium concentration of the soils.

Lead (Pb) concentration of the soil.

Lead was detectable only on locations 3 and 4 and on the control site. The results showed that the control site had higher concentration of Pb (10.16 mg/kg). At locations 1 and 2, Pb was below detectable limit. The low concentration of Pb in the sites may be due to some gradual decrease and leaching from the soils occasioned by porous texture and excess water flow (Olayinka *et al*., 2017).

Nickel (Ni) and Cadmium (Cd) concentration

The concentration of Ni in the soils of the study area ranged from 16.94 mg/kg to 25.53 mg/kg. The least concentration of Ni was recorded in the control site (16.94 mg/kg). The sites in contact with treated wastewater had higher values suggesting that the treated wastewater actually increased the Ni content of the soil. The distribution of Ni decreased as the sampling point moves farther from the discharge source of treated wastewater along the canal. This trend could be attributed to restricted mobility of Ni. These results were far higher than the reports of earlier studies by Pam *et al*, (2013) and Yahaya *et al*, (2009).

The element Ni has significant impact on human and animal health, thus high concentrations of Ni in soils and plant tissues is considered a threat to environmental quality and human health. World Health Organization pegged 10 mg/kg as the permissible limit of Ni in plant tissues. The results in Table 2, however, showed that the concentration of Ni in all the points sampled including the control site is far above the permissible limit. This implies that there is potential danger of Ni toxicity in the soils. Also, the result suggests that the treated wastewater is far from being safe from Ni, thus there is need for improved treatment processes that will eliminate Ni from the treated water to a bearable minimum. The concentration of cadmium in the soils was below detectable limits in all the sampling points including the control site. The result is similar to the findings of earlier studies by Oguntimehin and Ipinmoroti (2008) and Olayinka *et al*, (2017). Cadmium is a modern metal that is used in the auto-mobiles instead of Zn to galvanise iron and Steel (Alloway, 1990 and Tucker *et al*., 2003). The allowable limit of Cd by the United Kingdom and Luxemburg is 3 mg/kg. Also, 1 mg/kg of Cd for agricultural soils is set by Norway (Reman *et al*., 1997), Germany, Ireland, Spain, Portugal and Switzerland set the value at 0.8 mg/kg (ECDGE, 2010) while Sweden set the value at 0.4 mg/kg. Since Cd is below detectable limit, it suggests that cadmium is not present in the soil and since it is a modern metal at use, it may be that its usage is not in large quantities or it has not stayed long enough in the soil to be detectable because cadmium is deposited in the soil when iron metals are weak, and some heavy metals may stay very long before they are dictated.

Table 1: Physical and chemical properties of soils of Wupa Sewage Treatment Plant

Properties/Sampling location	Location 1	Location 2	Location 3	Location 4	Control	SE±
Sand *gkg*$^{-1}$	685	679	642	772	645	19.56
Silt *gkg*$^{-1}$	261	274	297	174	301	18.22
Clay *gkg*$^{-1}$	54	47	61	54	54	1.95
Textural class	SL	SL	SL	SL	SL	
pH in H_2O	6.17	5.73	5.58	6.29	5.98	0.14
pH in KCl	5.47	5.03	4.88	5.59	5.15	0.15
Electrical conductivity *dScm*$^{-1}$	3.200	2.600	4.300	2.133	0.963	0.350
Organic carbon *gkg*$^{-1}$	4.80	2.6	4.10	5.50	1.50	0.49
Total nitrogen *gkg*$^{-1}$	2.20	0.70	1.00	1.00	0.70	0.91
Available phosphorus *mgkg*$^{-1}$	53.29	64.35	64.34	61.81	38.29	2.78
Calcium *cmolkg*$^{-1}$	6.91	4.30	7.40	5.38	4.66	0.40
Magnesium *cmolkg*$^{-1}$	0.98	1.09	1.14	0.69	1.22	0.05
Sodium *cmolkg*$^{-1}$	0.21	0.35	0.25	0.26	0.19	0.03
Potassium *cmolkg*$^{-1}$	0.29	0.41	0.22	0.32	0.31	0.04
Exchangeable acidity *cmolkg*$^{-1}$	0.21	0.40	0.40	0.19	0.08	0.04
Cation exchange capacity *cmolkg*$^{-1}$	8.61	6.45	9.40	7.04	6.57	0.43
Base saturation *gkg*$^{-1}$	975.8	937.8	954.8	990.7	971.4	5.88

NB: Location 1= 25 m away from source of discharge along the canal, Location 2 = 50m away along the canal, Location 3 = 75 m away along the canal, Location 4 = 100 m away along the canal, Control = 50m away from the canal.

Table 2: Trace and heavy metals content of soils

Heavy metals/Sampling point	Location 1	Location 2	Location 3	Location 4	Control	SE±	Critical level
Fe mgkg^{-1}	331.41	246.01	415.40	193.23	23.22	48.58	1500 mg/kg*
Mn mgkg^{-1}	157.97	78.86	156.40	56.92	19.36	19.15	1500 mg/kg
Cu mgkg^{-1}	1.78	1.57	2.92	2.09	0.59	0.25	250 mg/kg*
Zn mgkg^{-1}	5.85	3.15	8.87	7.02	2.21	0.74	50 mg/kg**
Cr mgkg^{-1}	29.77	21.06	28.14	22.80	12.69	2.20	100 mg/kg***
Pb mgkg^{-1}	BDL	BDL	5.83	3.73	10.16	1.56	10 mg/kg
Ni mgkg^{-1}	25.53	24.34	21.79	18.11	16.94	1.52	10 mg/kg**
Cd mgkg^{-1}	BDL	BDL	BDL	BDL	BDL	0.00	3 mg/kg*

NB: FAO* 2014, WHO ** 2009, European Commission*** 2012

NB: Location 1 = 25 m away from source of discharge along the canal, Location 2 = 50 m away along the canal, location 3 = 75 m away along the canal, location 4 = 100 m away along the canal, Control = 50 m away from the canal

Table 3: Effects of Treated Wastewater on trace and heavy metals concentration in Soils of Wupa, Abuja.

Locations (25 m apart from each other)	Fe $mgkg^{-1}$	Mn $mgkg^{-1}$	Cu $mgkg^{-1}$	Zn $mgkg^{-1}$	Cr $mgkg^{-1}$	Pb $mgkg^{-1}$	Ni $mgkg^{-1}$
Location 1	331.407^{ab}	153.967^{b}	1.777^{abc}	5.847^{bc}	29.771^{b}	0.000	25.534
Location 2	246.010^{ab}	78.863^{ab}	1.567^{ab}	3.147^{ab}	21.057^{ab}	0.000	24.335
Location 3	515.400^{b}	156.400^{b}	2.923^{c}	8.870^{c}	28.128^{b}	5.828	22.786
Location 4	192.233^{ab}	56.917^{ab}	2.090^{bc}	7.017^{c}	22.795^{ab}	10.159	18.105
Control	23.217^{a}	19.357^{a}	0.593^{a}	2.210^{a}	12.685^{a}	3.734	16.964
Significance (0.05)	*	*	*	*	*	NS	NS

NB: Numbers followed by the same superscript within a column are not statistically different at 0.05 level using DMRT

NS = not significant

- = Significant

Fe = Iron, Mn = Manganese, Cu = copper, Zn = Zinc.

Conclusion

The conclusions drawn from the results obtained are as follows:

I. The soils sampled were uniformly sandy loam in texture with high proportion of sand and low silt and clay contents. These soils are prone to leaching and low water holding potentials.

ii. Soil pH was moderately to slightly acidic which makes it conducive for the availability of most elemental trace and heavy metals. This is because at lower pH values, the solubility and mobility of most heavy metals is enhanced.

iii. Most of the trace and heavy metals were higher in soils that had prolonged contact with treated wastewater. The soils from the control sites had lower heavy metals concentration especially for Fe, Mn, Cu, Zn, Cr and Ni.

iv. The soils are free from Cd deposits as the results showed that there is no trace of such metals in the soils.

v. There is need for adoption of improved sewage treatment processes that will eliminate toxic metals such as NI, Cr, Zn and Mn among others.

vi. There is need for further study on the quality of treated wastewater discharged into the Wupa River where it eventually ends up as part of irrigation water in the area. Fish from the Wupa River and vegetables grown from the area should be studied for bioaccumulation of heavy metals.

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