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Research Article

Impacts of Treated Wastewater on the Physico-Chemical Properties, Microbial Community and Heavy Metals Distribution in the Soils

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Abstract

This study aims to study the soils adjoining the WUPA sewage treatment Plant in Abuja so as to assess the influence of treated wastewater on the physical, chemical properties, microbial community, and the accumulation of some heavy metals in the soils. 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 heavy metals, following standard laboratory procedures. The soils were generally sandy loam in texture with a high proportion of sand and a low clay fraction. The sand content ranged from 642 to 772 g/kg, while the clay ranged from 47 to 61 g/kg. Soil pH ranged from 5.58 to 6.29, placing the soil into the range of moderately acidic to slightly acidic. Electrical conductivity ranged from 9.63 to 43.00 μScm^{-1}. Exchangeable cations were generally low; however, exchangeable acidity was influenced by the soil's contact with treated wastewater since the lowest value of 9.63cmolkg^{-1} 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 the lowest values were only observed in the control site. However, the range of values observed for the trace and heavy metals was within permissible environmental 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. The infiltration rate of the soils ranged from 7.6 to 21.4 cmhr$^{-1,}$ rated as slow (at the control site) and rapid and very rapid (at the sites which had contact with treated wastewater). Soil microbial population showed that live bacterial counts were lower in the soils that had contact with treated wastewater, while in the control site, live bacterial count (32 %) was higher in the soils of the control site. It was concluded that there is a need for the adoption of improved sewage treatment processes that will eliminate toxic metals such as Ni, Cr, Zn, and Mn, among others. There is a 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. Fishes from the Wupa River and vegetables grown in the area should be studied for possible bioaccumulation of heavy metals.

Introduction

The use of raw wastewater and treated wastewater for crop production is a common practice in many parts of the world, especially in the arid and semi-arid regions where access to fresh water for irrigation is a challenge [1]. As the world's population is growing at a geometric rate, the water resource is becoming more scarce [2], and this has made the practice of using treated wastewater for irrigation popular [3]. Also, the belief that wastewater has nutrients that will benefit crops by minimizing dependence on fertilizers is another known reason that could account for the wide use of wastewater for crop production, especially in peri-urban and urban agriculture. However, most users of wastewater for agricultural production often pay little or no attention to other attendant effects on the soil, groundwater quality, food quality,

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and safety [4,5]. Basic soil resource inventory is an important tool for effective management of soils, especially in the face of a growing population and the threat of scarcity of land. Soil is a finite resource. It is a dynamic and fragile body that performs ecological functions such as water cycling, nutrient cycling, housing biodiversity, and support for structures [6]. Over the years, however, these important functions performed by the soils have been drastically altered due to soil quality degradation and pollution [7]. Principally, the activities of man have continued to release substances that cause pollution, thus hampering the normal function and quality of the soils. This is because changing land-use patterns and uncontrolled siting of industries have disrupted the physical, chemical, and microbiological balance and properties of the soil [8]. The soils are very fragile, dynamic, and respond to changes as materials are added or accumulate in them. The soil functions as a sink and storehouse for substances introduced to it by human activities or occurrences of nature.

Irrigating soils with treated wastewater has been seen as a means of reducing heavy reliance on applied nutrients to vegetables and crops; however, this has not been without some negative consequences in terms of accumulation of pollutants or substances that alter the inherent physical and chemical behaviours of the soils [9]. Pasquini and Harris [7] reported changes in soil chemical properties irrigated with wastewater from abattoirs in Northern Nigeria. Also, Daloure, et al. [10] observed that the use of treated wastewater for irrigation has long been acknowledged as a source of changes in soil behaviours such as increased heavy metals concentration, changes in microbial population and activities, changes in physical and chemical characteristics of the soils, and groundwater quality impairment. It has, therefore, become imperative to investigate the long-term effects of the use of treated wastewater for irrigation.

This work is aimed at assessing the influence of treated wastewater on the physical and chemical properties, as well as the distribution of some heavy metals in soils of the Wupa sewage treatment plant in Abuja. This is in a bid to provide sustainable soil management options that will increase the productivity of the soils and ensure the production of quality and safe food for the growing population. The specific objectives of this work therefore include: to assess the changes in some physical and chemical properties of the soil, to assess the influence of the treated wastewater on the hydraulic characteristics of the soils, to assess the influence of the treated wastewater on the distribution of some heavy metals in the soils, to assess the effects of the treated wastewater on the microbial community (bacteria and fungi) of the soil, and to assess the rate of infiltration on the soils as influenced by treated wastewater.

Materials and methods

Study area

The study area, the Federal Capital Territory, is located within the community using treated wastewater from Wupa Sewage Treatment Plant for irrigation. The treatment plant is located at the Idu Industrial Area. It is geographically situated within latitudes 9º1ᴵ19.20ᴵᴵ – 9º1ᴵ24.28ᴵᴵN and longitude 7º22ᴵ43.67ᴵᴵ – 7º22ᴵ49.74ᴵᴵE.

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 that discharges the treated wastewater 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 preserved in customised soil sampling bags, labelled and taken to the Laboratory. The collected samples were air-dried at room temperature, crushed, and sieved with a 2mm sieve for analysis.

As part of the field work, Infiltration measurements were carried out in two locations along the earth channel (due to the homogeneity of the field conditions) and one location on the control site (about 50 m away from the earth channel. A double-ring Kamphort infiltrometer using the falling head method described by Mbagwu [11] was used.

Laboratory analysis

Particle size distribution was done using the hydrometer method as described by Udo, et al. [12]. Soil bulk density, total porosity, and soil moisture content were determined using the technique described by Mbagwu [11]. Saturated hydraulic conductivity was determined as described by Mbagwu [11]. Soil pH was determined using a glass electrode pH meter in a suspension of soil/water in the ratio of 1:2.5, as explained by McLean (1982), while soil electrical conductivity was determined by a 1:2.5 soil-water ratio using a Beckman Conductivity Bridge. Soil organic matter was determined by the [13] wet oxidation method, while total nitrogen was determined as described by [14]. Cation exchange capacity and exchangeable cations were determined using ammonium acetate extraction and saturation techniques, as determined by Adepetu, et al. [15]. Available phosphorus was determined using the Bray-1 method, as explained by Udo, et al. [12].

For the trace and heavy metals, air-dried samples of soil were sieved to pass through a 2mm sieve. Thereafter, 2g 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 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). Bacterial isolates obtained were identified based on their cultural, microscopic, and biochemical characteristics.

Result and discussion

Physico-chemical properties of the soils

The results of some physical and chemical properties of Soils from Wupa Treatment Plant in Abuja are presented in Table 1.

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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	
Bd gcm^{-3}	1.71	1.81	1.45	1.54	1.44	0.06
TP %	35.67	32.00	50.33	42.00	45.67	2.28
MC %	11.08	10.46	15.92	9.33	5.03	1.04
Saturated hydraulic conductivity cmhr^{-1}	6.58	4.28	6.62	6.42	0.03	0.30
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 µScm^{-1}	32.00	26.00	43.00	21.33	9.63	3.50
Organic carbon g kg-1	4.80	2.6	4.10	5.50	1.50	0.49
Organic matter gkg^{-1}	8.30	2.6	7.10	9.40	2.60	0.92
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 cmol kg-1	0.21	0.40	0.40	0.19	0.08	0.04
Cation exchange capacity cmol kg-1	8.61	6.45	9.40	7.04	6.57	0.43
Base saturation	975.8	937.8	954.8	990.7	971.4	5.88

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

The results showed that the texture of the soil was uniformly sandy loam with a high proportion of sand. Sand content of the soils ranged from 642 g/kg to 772 g/kg, while silt content ranged from 174 g/kg to 301 g/kg, and clay content ranged from 47 g/kg to 61 g/kg. These ranges of values suggest that the sand content was high while the clay was very low. The trend in the results for particle size distribution did not show any particular trend of increasing or decreasing according to location.

Soil pH (H_2O) ranged from 5.58 to 6.29, which correlates with 4.88 to 5.59 (pH in KCl). This range of pH values is rated as moderately acidic to slightly acidic [16]. There was no significant difference ($p > 0.05$) in the pH values across the different locations, suggesting that treated wastewater did not influence the pH of the soils across the locations. These ranges of pH values were favourable for the availability of most plant nutrients and a thriving microbial population in the soil. Soil pH is often considered a master property of the soil because of its influence on many other soil physicochemical parameters and behaviour [17,18]. The soil pH in KCl was generally lower than the values of pH in H2O. This could be attributed to dissolution and displacement of H^+ into the soil solution by KCl, which is a salt. KCl has the potential to displace hydrogen ions into solution more than ordinary distilled water; hence, the solution becomes more saturated with H^{+}, thus reducing the pH values so determined.

The results of the electrical conductivity of the soils (Table 1) showed that EC ranged from 9.63 to 43.00 µScm^{-1} and is below the critical limit of 450 µScm^{-1} [19]. A lower value of EC was observed in the control site (9.63 µScm^{-1}), suggesting an influence of treated wastewater on the soils in locations L_1 – L_4. Also, there was a significant difference ($p < 0.05$) (Table 2) between the control site and the other sites that had contact with treated wastewater. Electrical conductivity is a measure of the number of soluble salts present in the soil. Even though the values in all the locations were lower than the permissible limit, there is a potential danger of developing salinity in the soil due to continuous and gradual deposition of salts by the treated wastewater. Over time, this may compromise the quality of the soil.

Soil organic carbon and organic matter in the soils were rated as moderately low, and the values ranged from 1.50 to 5.50 g/kg and 2.6 to 9.40 g/kg for organic carbon and organic matter, respectively. The lowest values of organic carbon and organic matter were observed in the control site that had no contact with treated wastewater. This implied that the treated wastewater had influenced the amount of organic matter in the soil. This could be due to the presence of dissolved organic matter in the treated wastewater, and as the treated wastewater is continuously being used for irrigation, accumulation over time could result in a build-up of a significant level of organic matter in the soil [18]. It is observed that organic carbon and organic matter displayed similar trends.

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Table 2: Effects of Treated Wastewater on some chemical properties of Soils of Wupa Treatment Plant.

Location 25m apart from Each other	pH H2O	pH KCl	EC μScm^{-1}	O.C. %	O.M. %	Ca cmolkg^{-1}	Mg cmolkg^{-1}	Na cmolkg^{-1}	EA cmolkg^{-1}	CEC cmolkg^{-1}	BS %
Location 1	6.167	5.467	32.000^{bc}	4.84^{b}	8.34^{b}	6.915^{b}	0.982^{b}	0.212	0.213^{a}	8.610^{ab}	975.87^{bc}
Location 2	5.727	5.027	26.000^{b}	2.71^{ab}	4.67^{ab}	4.301^{a}	1.695^{c}	0.351	0.400^{b}	6.447^{a}	937.77^{a}
Location 3	5.580	4.880	43.00^{c}	4.12^{ab}	7.11^{ab}	7.396^{b}	1.138^{abc}	0.246	0.400^{b}	9.403^{b}	954.77^{ab}
Location 4	6.290	5.590	21.333^{ab}	5.46^{b}	9.41^{b}	5.383^{ab}	0.690^{a}	0.259	0.187^{a}	7.043^{a}	990.67^{c}
Control	5.980	5.147	9.667^{a}	1.49^{a}	2.57^{a}	4.658^{a}	1.225^{abc}	0.185	0.080^{a}	6.567^{a}	971.43^{bc}
Significance (0.05)	NS	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; EC: Electrical Conductivity; O.C: Organic Carbon; O.M: Organic Matter; Ca: Calcium; Mg: Magnesium; Na: Sodium; EA: Exchangeable Acidity; CEC: Cation Exchange Capacity; BS: Base Saturation.

The results of total nitrogen (TN) were presented in Table 1. The results showed that TN ranged from 0.70 mg/kg to 2.20 mg/kg, and the values are rated as low [16]. The low TN values of the soil reflect the low organic matter status of the soil. Nitrogen is very mobile in soils and is prone to losses due to leaching, high temperatures, and continuous cultivation of the soil. The soils are characterized by high sand content, which makes them prone to excessive leaching and nutrient losses.

Available phosphorus in the soils ranged from 38.28 mg/kg to 64.34 mg/kg, with the control site showing the lowest concentration of available phosphorus. These values are rated as moderate to high. There was a significant difference ($p < 0.05$) in the values of AP between the control site and the other locations. This implied that the treated wastewater had significantly influenced the abundance of phosphorus in the soils. This result suggests that the treated wastewater contains a significant amount of phosphates, probably from the sludge collected before the treatment, and agrees with the report of Mara and Kramer [20]. The high AP values in the soils of locations 1 – 4 could be a result of higher moisture content in the soils. Previous studies by [21] reported that soil moisture enhances the availability of phosphorus in the soil.

The results of exchangeable cations (Ca, Mg, Na, K, and EA) are presented in Table 1. The results showed that the Ca content of the soil ranged from 4.30 to 7.40 cmol/kg, while magnesium ranged from 0.69 cmol/kg to 1.22 cmol/kg. Sodium in the soil ranged from 0.19 cmol/kg to 0.35 cmol/kg, and exchangeable potassium ranged from 0.22 to 0.41 cmol/kg. For Exchangeable acidity, the results showed that EA ranged from 0.08 cmol/kg to 0.40 cmol/kg, with the least value recorded at the control site. The control site had the lowest EA value of (0.08 cmol/kg) while the sites having contact with treated wastewater produced higher values of EA, suggesting that the treated wastewater had raised the exchangeable acidity content of the soil.

The results of cation exchange capacity (CEC) showed that values of CEC across the five locations sampled range from 6.45cmol/kg to 9.40 cmol/kg. This range of values is rated as low, suggesting that the nutrient-holding potential of the soils is low. Baurazanis, et al. [4] reported significant changes in cation exchange capacity and other soil chemical properties arising from irrigation with treated wastewater.

In this current study, however, cation exchange capacity did not show any particular trend of distribution between the control site and the sites where irrigation with treated wastewater took place. The low organic matter reserve of the soil, coupled with the high sand content of the soil, could be possible reasons for the low inherent nutrient reserve.

The ratings for interpreting selected soil properties were presented in Table 3.

The total porosity of the soil ranged from 32 to 49.81%. This range is considered to fall between poor, satisfactory, and good agricultural soils as bulk density increases, porosity decreases, which shows an inverse relationship between porosity and bulk density. Poor agricultural soils indicate that the micropores in the soil that should house air and water are few, probably as a result of compaction. A significant dose of organic manure would be required to enhance aggregation and reduce the compaction, otherwise, plants roots would suffer suffocation and moisture stress [22].

The soil moisture content at field capacity is low and ranged from 5.03 to 15.92%. This suggests that the soils are very prone to easy drying and loss of moisture probably due to the low water-holding capacity of the soil. [9] however reported that treated wastewater increased soil moisture content and attributed this to increase in micropore content of the soil. Crops in these soils are prone to experience moisture stress, especially at the control site. This could be attributed to the time of sampling which was done in the dry season.

Saturated hydraulic conductivity of the soils ranged from 4.28 cm/hr to 6.62 cm/hr. This range of values for Ksat falls within the moderately slow and moderately rapid conductivity class [19]. This rating suggests that water movement into the soil is moderately faster, this could probably result in rapid loss of moisture from the soil owing to a quick passage and that may lead to moisture stress for crops especially in drier weather conditions. Also, leaching of plant nutrients in the soils would be relatively faster leading to poor performance of field crops. The need for large doses of organic manures on the soils will help in reconstructing the soil's physical quality for better productivity. There was no significant difference in the saturated hydraulic conductivity of the soils across the different locations including the control site. This implied that the contact of the soil with treated wastewater did not influence the hydraulic conductivity of the soil.

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Analysis of variance (ANOVA) across the different soil sampling locations were presented in Table 4.

Analysis of variance (ANOVA) showed that there was no significant difference ($p > 0.05$) between sand content across the different locations sampled. The same was observed for clay content. This result is similar to the findings from other studies reported by [23] and [2]. The uniformity in textural distribution of the soils could be as a result of sampling surface soils within the depth of 0 – 30 cm often considered as agricultural layer [9]. Soil texture is often considered a relatively permanent soil property that does not change within a short period of time or is easily influenced by human activities and land use type. This could be the reason for the uniformity in soil textural type in all the units studied, implying that the treated wastewater did not alter the textural class of the soils. High sand content in the soil portends that the soils will have low nutrient and low water-holding potential and will be prone to excessive leaching. Also, the soil engine, which is soil structure will be poor following poor aggregate stability, thus there would be a need for continuous use of organic manures as a means of improving the structural quality of the soil that will in turn, improve soil physical fertility and quality.

The bulk density of the soil ranged from 1.33 to 1.81 g cm^{-3}. The lowest value was observed from the control site that was not irrigated with treated wastewater. This range of bulk density is classified as low to high [24]. Higher bulk densities were observed in the first two locations where treated wastewater was used for irrigation. Normally, the high bulk density of soils suggests that compaction of the soils has occurred and this has negative implications for root development, normal seed germination, and water infiltration into the soil. The high bulk density of some portions of the soil could mean that soil nutrients will be held tenaciously or locked up in the soil due to plants' root's inability to function adequately [25]. There was no significant difference between locations 1 and 2 as well as between locations 3, 4, and 5.

Table 3: Ratings for interpreting selected soil properties.

Parameter	Rating	Range	Source
Organic Matter (%)	Low Moderate High Very high	<2 2-3 >3 >6	Udo, et al. [12]
Porosity (%)	Poor agricultural soil Satisfactory Agricultural Soil Good Agricultural Soil Best Agricultural Soil	<40 41-45 46-50 >50	Kachinskii (1985)
Saturated Hydraulic Conductivity (cm/hr)	Very slow Slow Moderately slow Moderately rapid Rapid Very rapid	<0.8 0.8-2 2.1-6.0 6.1-8.0 8.1-12.50 >12.50	FAO (1963)
Organic carbon (%)	Low Moderate High	≤ 1 1-1.5 ≥ 1.5	Udo, et al. [12]

Table 4: Effects of Treated Wastewater on Bulk Density, Total Porosity, Soil Moisture Content and Hydraulic Conductivity of Soils of Wupa.

Location 25m apart from Each other	Bd gcm^{-3}	TP %	SMC %	Ksat cmhr^{-1}
Location 1	1.707^{b}	41.667^{ab}	11.077^{b}	6.583^{a}
Location 2	1.810^{b}	32.000^{a}	10.460^{b}	4.282^{a}
Location 3	1.327^{a}	50.333^{b}	15.923^{c}	5.035^{b}
Location 4	1.447^{a}	42.000^{ab}	9.330^{b}	6.419^{b}
Control	1.443^{a}	45.667^{ab}	5.053^{a}	6.035^{b}
Significance (0.05)	*	*	*	*

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

NS: Not Significant: *: Significant; Bd: Bulk density; TP: Total Porosity; SMC: Soil Moisture Content; Ksat: Hydraulic conductivity.

Trace and heavy metals concentration

The concentrations of some trace and heavy metals in the soils of Wupa Sewage Treatment plant are presented in Table 5.

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 of Fe was recorded for 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 of Fe in all the locations were lower than the critical limit set by [19], iron and Mn have high tolerable limit of 1500 mg/kg, however, higher levels than this could be toxic and injurious to plants and animals. 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 accumulated in the soils over a period of time.

Manganese concentration

From Table 5, 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 mg/kg) while higher values were obtained in sites that were irrigated with treated wastewater.

Table 5 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, [26], Pasquini and Harris [7] and Oku, et al. [25]. However,the values obtained are lower than the maximum tolerable limits for agricultural soils and this implies that manganese in these soils have no threat risk at the various sites at the time of the research work.

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 5) showed that there was significant difference in the concentration of Cu between the control and the four locations that were irrigated with treated

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Table 5: Trace and heavy metals contents 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	
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, , European Commission*** 2012
NB: Location 1= 25m away from source of discharge along the canal, Location 2 = 50m away along the canal, location 3 = 75m away along the canal, location 4 = 100 m away along the canal, Control = 50 away from the canal
Fe: Iron; Mn: Manganese; Cu: Copper; Zn: Zinc; BDL: Below Detectable Limit.

wastewater. The values for Cu concentration in this study were lower than values reported by some researchers within Nigeria especially Dawaki, et al. [26] and Olayinka, et al. [27].

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 was far below the toxic limit, hence it poses 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.

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 75m away from discharge source along the canal.

Zinc is known to be one of the most important trace elements that play a vital role in the physiological and metabolic process of many organisms. Nevertheless, higher concentration of Zinc can be toxic to the organism. It also acts as an important catalyst in protein synthesis as reported by Ruqia, et al, [28]. The Zinc content of the soils sampled is below the WHO recommended limit for plants pegged at 50 mg/kg.

Chromium (Cr) concentration in the soil: The concentration of Cr in the soils of the sampled sites as shown in Table 5 revealed that the Cr concentration ranges from 12.69 mg/kg to 29.77 mg/kg. The least Cr concentration was recorded at the control site (12.69 mg/kg). From Table 6, there was significant difference in the concentration of Cr in the soils between the control site and the other sites that were irrigated with treated wastewater. 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 [29] standards, Canada is set 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 soils: Lead was detectable only on locations 3 and 4 and on the control site. The results

Table 6: Effects of Treated Wastewater on trace and heavy metals concentration in Soils of Wupa, Abuja.

Location 25m 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

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 as also reported by Hentati, et al, [9].

Nickel (Ni) and Cadmium (Cd) concentrations: 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 that were irrigated 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 points move 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 in values than the reports of earlier studies by El-Brady, 2016.

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

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Ni toxicity in the soils. Also, the results suggest 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 wastewater 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 Khaskhoussy, et al. [30]. Cadmium is a modern metal that is used in the auto-mobiles instead of Zn to galvanise iron and steel [31]. The allowable limit of Cd by the United Kingdom and Luxemburg is 3mg/kg. Germany, Ireland, Spain, Portugal and Switzerland set the allowable value for cd at 0.8 mg/kg [32] 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 soils 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 soilsto be detectable because cadmium are deposited in the soils when iron metals are weak, and some heavy metals may stay very long before they are detected.

Microbial population of the soil: The microbial population of the soil as influenced by the long- term contact with treated waste water are presented in Table 7.

The result of bacterial count in the soils across the different sampled locations showed that at location 1, a total of 25 bacteria colonies were counted out of which only 44.0 % (11 colonies) were alive while 56.0 % (14 colonies) were dead. At location two of the study area, a total of 99 bacteria colonies were counted of which 44.44 % (44 colonies were alive) while the majority (55.56 %) representing 55 colonies were dead. At location three, 45.24 % (19 colonies of bacteria) were alive and 54.76 % (23 colonies) were dead making a total number of 42 colonies counted. In Location 4, a total of 43 colonies were counted and only 44.19 % (19 colonies) were alive while 55.81 % (24 colonies) were dead. For the control site, a total of 51 colonies were counted of which 62.75 % (representing 32 colonies) were alive and the remaining 37.25 % (19 colonies) were dead. This result is similar to the report of Ibekwe, et al. [1] that the bacterial communities in soils irrigated with treated wastewater were most biased with a high ratio of bacterial community variabilities. They also reported some increase in the Actinibacteria, firmicutes, Acidobacteria, Nitrospira and unclassified bacteria.

For the fungi in the soil, the result showed that at location 1, three species of fungi were observed based on their morphological characteristics. The observed fungi species were *Fusariumoxysporum*, *Aspergillusflavus* and *Aspergillusniger*. At location 2 along the canal conveying the treated wastewater, only two fungi species were characterized and these were *Penicillium camemberti and semitectum.* In the 3rd location of the study area, two fungi species were also identified and were classified as *Aspergillusniger* and *Rhizopusnigricans*. For location 4, three species of *Aspergillus* were noted. These were *Aspergilusniger*, *AspergillusFumigatus* and *AspergillusFlavus*. In the soil of the control site that did not receive treated wastewater, only two species of fungi were observed. These were *Aspergillusniger* and *Rhizopusnigricans.*

The high counts of bacteria and fungi in the soil suggests that the treated wastewater had significant amount of organic and inorganic nutrients that encourage the build-up of microbial communities in the soil. Elifantz, et al. [33] reported that soil micro-organisms show increased metabolic activities under sewage effluent irrigation. Organic carbon, total nitrogen, microbial biomass C and N and microbial activities increased with increase in the time and duration of wastewater irrigation.

The result of this study showed that there were more dead colonies of bacteria in the sites irrigated with treated wastewater than in the control. However, the control site had more live colonies of bacteria than the sites with treated wastewater. This implied that irrigating the soil with treated wastewater killed many of the soil bacteria. This result contradicted [34] who reported that microbial community increased under wastewater irrigation. Also, Chowdhury, et al. 2011 [35] observed that the greatest health concern in using reclaimed wastewater for irrigation is directed towards pathogens.

Table 7: The result of microbial community as influenced by long- term usage of treated wastewater.

Location	Soil Depth	Bacterial colonies count			Fungi Name
	cm	Live	Dead	Total	
1	0 – 20	11 (44.0)	14 (56.0)	25	*Fusarium* *Aspergilus Flavus* *Aspergilus Niger*
2	0 – 20	44 (44.44)	55 (55.56)	99	*Penicillium* *Fusarium*
3	0 – 20	19 (45.24)	23 (54.76)	42	*Aspergilus flavus* *Rhizopus Nigricans*
4	0 – 20	19 (44.19)	24 (55.81)	43	*Aspergilus niger* *Aspergilus Fumigatus* *Aspergilus Flavus*
5 (Control)	0 - 20	32(62.75)	19 (37.25)	51	*Aspergilus niger* *Rhizopus*
Total		125	135	260	

NB: Numbers in parenthesis are percentages

Infiltration

The data from the double ring infiltration tests for the study interpreted by the linear plots of cumulative infiltration and the equilibrium infiltration rates against time for the soil units are presented in Table 8 (Figures 1-4 respectively).

It is observed that the instantaneous infiltration rates are moderate to high and ranged from 7.6 to 21.4 cm hr^{-1}. It is characterized by chaotic increase and decrease in the first 4 hours for the first and second units along the treated wastewater canal and just after 3 hours for the third unit. This could be attributed to high hydraulic conductivity observed in the first and second soil units. Gharaibeh, et al [37] and Loy, et al. [2] reported decrease in infiltration rate with increase in irrigation rate with treated wastewater.

The implication of these infiltration assessments is that due to the soil texture that is generally sandy, water infiltration tends to be rapid and very rapid specifically in soils of the first

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Table 8: Cumulative and Equilibrium Infiltration Rate of Soils along the treated wastewater channel at Wupa Treatment Plant.

Elapsed time (t) min.	Unit 1		Unit 2		Unit 3	
	Q (cm)	EIR (cm hr⁻¹)	Q (cm)	EIR (cm hr⁻¹)	Q (cm)	EIR (cm hr⁻¹)
5	4.5	54.0	5.4	64.8	2.5	28.8
10	8.7	50.4	8.2	98.4	5.5	37.2
20	13.2	27.0	12.7	27.0	10.6	30.6
30	18.7	33.0	16.9	25.2	15.6	30.0
40	24.2	33.0	19.6	16.2	20.1	27.0
50	28.2	24.0	23.9	25.8	24.4	25.8
60	30.9	16.2	26.6	16.2	28.4	24.0
80	39.4	25.5	31.9	15.9	37.0	25.8
100	44.7	15.9	36.8	14.7	45.4	25.2
120	51.4	20.1	41.7	14.7	53.8	25.2
150	58.6	14.4	46.6	9.8	64.5	21.4
180	67.4	17.6	50.6	8.0	75.2	21.4
210	71.9	9.0	54.6	8.0	85.9	21.4
240	79.8	15.8	58.6	8.0	96.6	21.4
270	87.7	18.8	62.6	8.0	107.2	21.4
300	95.6	15.8	66.6	8.0	117.8	21.4
330	103.5	15.8	70.4	7.6	128.5	21.4
360	111.4	15.8	74.2	7.6	139.2	21.4
Rating	-	Rapid	-	Slow	-	Very rapid

NB: Q = cumulative infiltration (total infiltration), EIR = equilibrium infiltration rate (projected infiltration), Unit 2 is control site, while units 1 and 3 are in the soil units that had contact with treated wastewater.
Rating based on: FAO, 2009; USDA 2014.

and third units which are along the water canal. As water moves rapidly into the soil, leaching may be high. The soils are well drained and in case of excess application of water during irrigation or heavy down pour, the soil is well able to absorb the excess with minimal surface run-off. Another implication is that more water is required to irrigate the soil at any given time depending on the crop water requirement.

Conclusion

The following conclusions are drawn based on the results obtained from this study:

I. The pH of the soils ranged from moderately acidic to slightly acidic. The soil pH was not influenced by the treated wastewater. This range of pH was however favourable for the availability of most plants' nutrients and other microbial activities in the soil.

II. Soil electrical conductivity, organic carbon/organic matter, available phosphorus, and soil exchangeable acidity were influenced by treated wastewater hence lower values were observed in the soil that was not irrigated with treated wastewater.

III. The soils are generally sandy loam with high sand content and low clay content. Also, the soil aggregate stability was poor. It becomes imperative that high rates of organic manures should be applied to the soils as a way of improving the soils' physical quality and productivity.

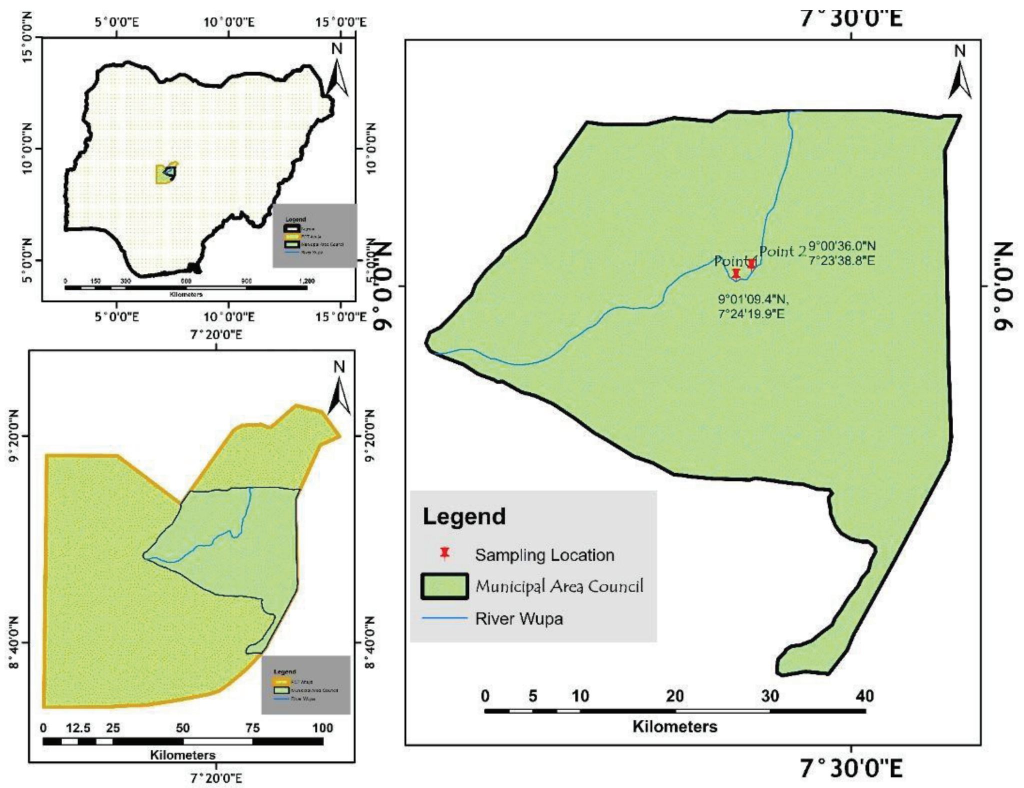

Figure 1: Location of Wupa Treatment Plant.
(Source): "Faiza, et al. 2022 [36]

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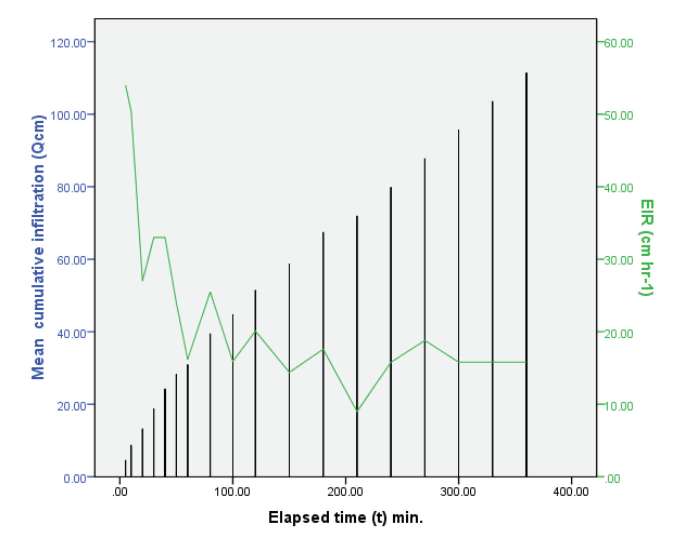

Figure 2: Soil Unit 1 Infiltration Trend
Source: Fieldwork.

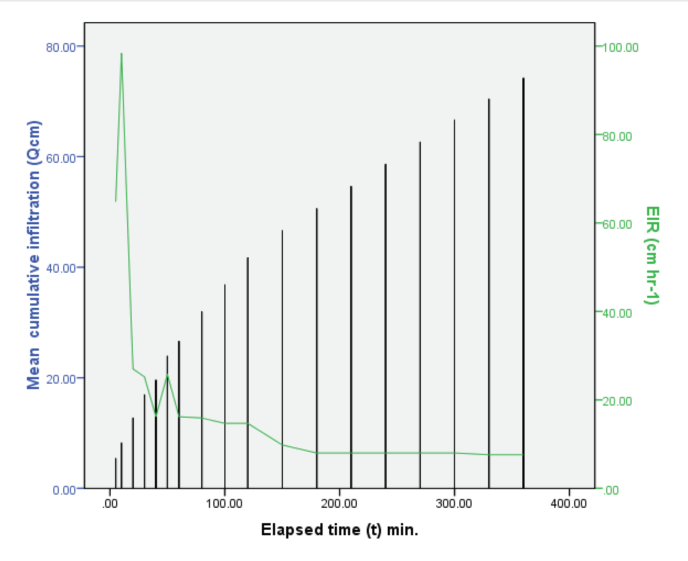

Figure 3: Unit 2 (control) Infiltration Trend
Source: Fieldwork.

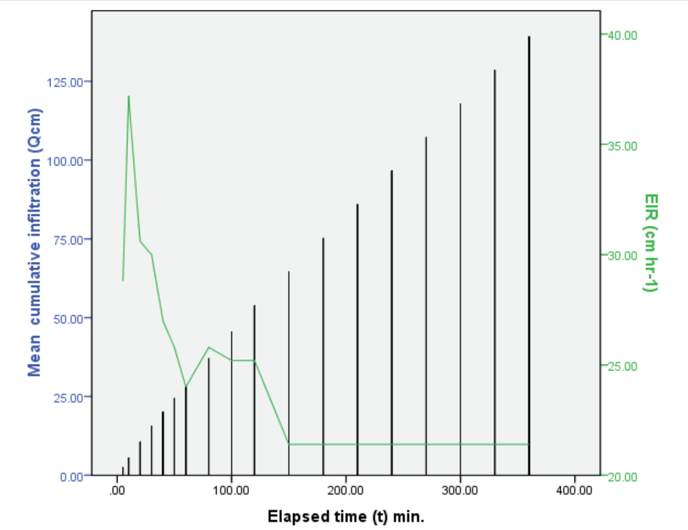

Figure 4: Soil Unit 3 Infiltration Trend
Source Fieldwork.

IV. Most of the trace and heavy metals values were higher in soils that were irrigated with treated wastewater for a long time. The soils from the control site had lower heavy metals concentration especially, Fe, Mn, Cu, Zn, Cr and Ni. Also, 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. The infiltration rate of water in the soil is rapid in soils that had contact with treated wastewater and slow in soils that had no contact with treated wastewater.

VII. The soil microbial community especially bacterial counts were affected by the treated wastewater. Higher counts of dead bacterial colonies were observed in soils that had contact with treated wastewater, whereas soils from the control site that had no contact with treated wastewater had much higher live bacterial counts.

Data availability statement

Some data through which the graphs were derived are available from the corresponding author upon reasonable request.

Compliance with ethical standards

Conflict of interest: In accordance with my ethical obligation as a researcher, this article is self-sponsored and will serve as a guide to Environmentalists, Water Resources Engineers and Irrigation experts. There is no potential conflict of interest in this research work.

Authors' contributions

Ubah Joseph and Tochukwu Ogwueleka wrote the main manuscript. Abba Simon and Barnabas Musa prepared the figures. All authors reviewed the manuscript

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References

1. Ibekwe AM, Gonzalez-Rubio A, Suarez DL. Impact of treated wastewater for irrigation on soil microbial communities. Sci Total Environ. 2018;622-623:1603-1610. Available from: https://doi.org/10.1016/j.scitotenv.2017.10.039

2. Loy S, Assi TA, Mohtar RH, Morgan C, Jantrania A. The effect of treated wastewater on water holding properties of a clayey calcareous soil. Sci Total Environ. 2018;643:807-818. Available from: https://doi.org/10.1016/j.scitotenv.2018.06.104

3. Arroyo J, Shirazi S, McDonald E, Hood K, Plummer A, Brooks B, et al. History of Water Reuse in Texas. Austin, Texas; 2011. Available from: https://www.twdb.texas.gov/innovativewater/reuse/projects/reuseadvance/doc/component_a_final.pdf

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4. Bourazanis G, Katsileros A, Kosmas C, Kerkides P. The effect of treated municipal wastewater and fresh water on saturated hydraulic conductivity of a clay-loamy soil. Water Resour Manag. 2016;30:2867–2880. Available from: https://doi.org/10.1007/s11269-016-1307-9

5. Urbano VR, Mendonca TG, Bastos RG, Souza CF. Effects of treated wastewater irrigation on soil properties and lettuce yield. Agric Water Manag. 2017;181:108–115. Available from: https://doi.org/10.1016/j.agwat.2016.12.001

6. Agunwamba JC. Solid waste management in Nigeria: Problems and issues. J Environ. 2018.

7. Pasquini MW, Harris F. Effective use of resources: Urban waste ash and soil fertility in Jos Plateau, Nigeria. J Environ Manage. 2005;37(1):17-29. Available from: https://doi.org/10.1111/j.1475-4762.2005.00603.x

8. Barnabas IM, Nwaka GIC. Characterization of soils of Jiwa in the Federal Capital Territory Abuja, Nigeria. In: Proceedings of the 38th annual conference of the Soil Science Society of Nigeria; 2013;13–21.

9. Hentati O, Chaker S, Wali A. Effects of long-term irrigation with treated wastewater on soil quality, soil-borne pathogens, and living organisms: case study of the vicinity of El Hajeb (Tunisia). Environ Monit Assess. 2014;186:2671–2683. Available from: https://doi.org/10.1007/s10661-013-3570-z

10. Daloure SY, Mermoud A, Yacoub H, Boivin P. Impacts of irrigation with industrial treated wastewater on soil properties. Geoderma. 2013;200–201:31–39. Available from: https://doi.org/10.1016/j.geoderma.2013.02.008

11. Mbagwu SC. Aggregate stability and soil degradation in the tropics: Lecture notes. Department of Soil Science, University of Nigeria, Nsukka. 2003. LNS0418022. Available from: https://www.osti.gov/etdeweb/servlets/purl/20946965

12. Udo BU, Utip KE, Inyang M, Idungafa MA. Fertility assessment of some inland depression and floodplain (wetland) soils in Akwa Ibom State. J Trop Agric Food Environ Ext. 2009;8(1):14–19. Available from: http://dx.doi.org/10.4314/as.v8i1.44108

13. Walkley A, Black IA. Determination of organic carbon in the soil. Soil Sci. 1934;7:29–38. Available from: https://www.scirp.org/reference/referencespapers?referenceid=186446

14. Bremner JM, Mulvaney CS. Nitrogen–Total. In: Page AL, Miller RH, Keeney DR, editors. Methods of soil analysis. Part 2. Chemical and microbiological properties. Madison, Wisconsin: American Society of Agronomy, Soil Science Society of America; 1982;595–624. Available from: https://www.scirp.org/reference/ReferencesPapers?ReferenceID=181829

15. Adepetu JA, Nabhan H, Osinubi A, editors. Simple soil, water, and plant testing techniques for soil resource management: Proceedings of a training course held in Ibadan, Nigeria. 16–27 September 1996. Ibadan: IITA; 2000.

16. Chude VO, Malgwi WB, Amapu IY, Ano AA. Manual on soil fertility assessment. Federal Department of Fertilizer, FAO and National Programme on Food Security, Abuja, Nigeria; 2011;102. Available from: https://www.scirp.org/reference/referencespapers?referenceid=3522406

17. Assouline S, Narkis K. Effects of long-term irrigation with treated wastewater on the hydraulic properties of a clayey soil. Water Resour Res. 2011;47. Available from: https://doi.org/10.1029/2011WR010498

18. Farhadkhani M, Naz M, Yadegar G, Homaei M, Pereira H, Sulaiman Z, Rezaei HR. Effects of irrigation with secondary treated wastewater on physicochemical and microbial properties of soil and produce safety in a semi-arid area. Water Res. 2018;144:356–367. Available from: https://doi.org/10.1016/j.watres.2018.07.047

19. Food and Agriculture Organization (FAO). World reference base for soil resources 2014: International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Report No. 106. Rome, Italy: FAO; 2014. Available from: https://openknowledge.fao.org/server/api/core/bitstreams/bcdecec7-f45f-4dc5-beb1-97022d29fab4/content

20. Mara D, Kramer A. WHO guidelines for wastewater and greywater use in agriculture: A practical interpretation. In: Efficient Management of Wastewater. Berlin: Springer; 2008;1–17. Available from: http://dx.doi.org/10.1007/978-3-540-74492-4_1

21. Balkhair KS. Impact of treated wastewater on soil hydraulic properties and vegetable crop under irrigation with treated wastewater: field study and statistical analysis. J Environ Biol. 2016;37:1143–1152. Available from: https://pubmed.ncbi.nlm.nih.gov/29989747/

22. Bardhan G, Russo D, Goldstein D, Levy GJ. Changes in the hydraulic properties of a clay soil under long-term irrigation with treated wastewater. Geoderma. 2016;264:1–9. Available from: https://doi.org/10.1016/j.geoderma.2015.10.004

23. Tunc T, Sahin U. The changes in the physical and hydraulic properties of a loamy soil under irrigation with simpler-reclaimed wastewaters. Agric Water Manag. 2015;158:213–224. Available from: https://doi.org/10.1016/j.agwat.2015.05.012

24. Landon JR, editor. Booker Tropical Soil Manual: A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. New York: John Wiley and Sons Inc.; 1991;465. Available from: https://www.scirp.org/reference/referencespapers?referenceid=1234510

25. Oku EE, Emmanuel SA, Odoh NC, Barnabas IM. Soil physical fertility status and management prescription for soil sustaining farms and ranches in Abuja, Nigeria. J Environ Agric Sci. 2020;22(1):57–63. Available from: https://jeas.agropublishers.com/wp-content/uploads/2020/04/JEAS-221-57-63-460-Soil-Physical-fertility.pdf

26. Dawaki UM, Dikko SU, Noma SS, Aliyu U. Heavy metals and physical and chemical properties of soils in Kano Urban agricultural lands. Niger J Basic Appl Sci. 2013;21(3):239–246. Available from: http://dx.doi.org/10.4314/njbas.v21i3.9

27. Olayinka OO, Akande OO, Bamgbose K, Adetunji MT. Physicochemical characteristics and heavy metal levels in soil samples obtained from selected anthropogenic sites in Abeokuta, Nigeria. J Appl Sci Environ Manage. 2017;21(5):883–891. Available from: http://dx.doi.org/10.4314/jasem.v21i5.14

28. Ruqia N, Khan M, Masab M, Shaheen Z. Accumulation of heavy metals (Ni, Cu, Cd, Cr, Pb, Zn, Fe) in the soil, water, and plant, and analysis of physico-chemical parameters of soils collected from Tanda Dam Kohat. J Pharm Sci Res. 2015;7(3):89–97. Available from: https://www.researchgate.net/publication/282950298

29. Canadian Council of Ministers of the Environment (CCME). Canadian Environmental Quality Guidelines. Ottawa, Ontario; 2009.

30. Khaskhoussy K, Kahlaoui B, Nefzi BM, Jozdan O, Dakheel A, Hachicha M. Effect of treated wastewater irrigation on heavy metals distribution in a Tunisian soil. Eng Technol Appl Sci Res. 2015;5(3):805–810. Available from: https://etasr.com/index.php/ETASR/article/view/563

31. Guo H, Nasir M, Lv J, Dai Y, Gao J. Understanding the variation of microbial community in heavy metals contaminated soil using high throughput sequencing. Ecotoxicol Environ Saf. 2017;144:300–306. Available from: https://doi.org/10.1016/j.ecoenv.2017.06.048

32. European Commission Director General Environment (ECDGE). Heavy metals and organic compounds from wastes used as organic fertilizers. Final report. WPA Consulting Engineers Inc.; 2010. Ref. Nr. TEND/AML/2001/07/20. p. 73–74.

33. Elifantz H, Kautsky L, Mor-Yosef M, Tarchitzky J, Bar-Tal A, Chen Y, Minz D. Microbial activity and organic matter dynamics during 4 years of irrigation with treated wastewater. Microb Ecol. 2011;62:973–981. Available from: https://doi.org/10.1007/s00248-011-9867-y

Citation: JI U, Ogwueleka TC, Simon AA, Musa BI. Impacts of Treated Wastewater on the Physico-Chemical Properties, Microbial Community and Heavy Metals Distribution in the Soils. Glob J Ecol. 2025;10(2):012-022. Available from: https://dx.doi.org/10.17352/gje.000111

34. Brady NC, Weil R. The Nature and Properties of Soils. Washington, DC: Pearson; 2002.

35. Chowdhury N, Marschner P, Burns R. Soil microbial activity and community composition: Impact of changes in matric and osmotic potential. Soil Biol Biochem. 2011;43:1229–1236.

36. Faiza M, Adamu KM, Mohammed YM. Anthropogenic impact on some water quality characteristics of Wupa River, Federal Capital Territory, Abuja, Nigeria. Issues Biol Sci Pharm Res. 2022;10(3):30–38. Available from: https://doi.org/10.15739/ibspr.22.006

37. Gharaibeh MA, Ghezzehei TA, Albalasmeh AA, Alghzawi MZ. Alteration of physical and chemical characteristics of clayey soils by irrigation with treated wastewater. Geoderma. 2016;276:33–40. Available from: https://doi.org/10.1016/j.geoderma.2016.04.011

38. Alloway BJ. Heavy Metals in Soils. London, United Kingdom: Halsted Press, John Wiley and Sons Inc.; 1996. Available from: https://www.scirp.org/reference/referencespapers?referenceid=1984898

39. El-Bady MS. Spatial distribution of some important heavy metals in the soils south of Manzala Lake in Bahr El-Baqar region, Egypt. Nova J Eng Appl Sci. 2016;3:1–12.

40. Yaylali-Abanuz G. Heavy metal contamination of surface soil around Gebze industrial area, Turkey. Microchem J. 2011;99:82–92. Available from: https://doi.org/10.1016/j.microc.2011.04.004

Citation: JI U, Ogwueleka TC, Simon AA, Musa BI. Impacts of Treated Wastewater on the Physico-Chemical Properties, Microbial Community and Heavy Metals Distribution in the Soils. Glob J Ecol. 2025;10(2):012-022. Available from: https://dx.doi.org/10.17352/gje.000111