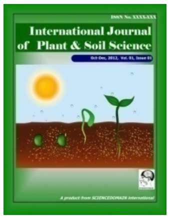

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Effects of Wastewater Irrigation on Quality of Urban Soils in Kano, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author UMD conceived and designed the study, wrote the protocol, and wrote the first draft of the manuscript. Author AUD headed the supervisory team, guided the technical and scientific research protocol. Authors SSN and UA both verified data integrity and managed the experimental process. All authors read and approved the final manuscript.

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ABSTRACT

This study used the soil management assessment framework (SMAF) to evaluate the quality of wastewater irrigated soils in urban Kano, Nigeria in the dry season of 2012. Three sites each on Challawa and Jakara rivers receiving industrial and domestic wastewaters respectively were sampled for water and soil; and compared with three sites at Watari river that receives no wastewater thereby serving as control. Heavy metals pollution and fertility indices were used to establish minimum data set (MDS) because of their effects on yield and safety of crops. Soil fertility and pollution indices used as indicators included pH, EC, bulk density (BD), organic carbon, NPK, total heavy, exchangeable and soluble heavy metals. Physical and chemical properties of irrigation waters were also evaluated and correlated with soil properties. There were variations from low to medium or medium to high for many of the parameters and P was excessively high at Jakara (213.52g/kg). The increased tendency for the wastewater irrigated soils to be saline was also observed due to higher Na content (3.20 and 1.11cmol/kg at Jakara and Challawa respectively).

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The Jakara sites were lower in BD (1.30) thereby making them easier to till especially against the control (1.60). There was a downstream decreasing pattern in the concentrations of all heavy metals across Challawa and Jakara sites and a reverse phenomenon at the control. The PO_4^{3-}, NO_3^-, HCO_3^-, B and Cl^- as well the heavy metals contents in irrigation waters across all sites have all exceeded the increased hazard limit with quality generally in the order Watari>Challawa>Jakara. Many water properties were significantly and positively correlated with soil properties. All the quality indexes were within same marginal range (0.53, 0.498 and 0.485 for Challawa, Jakara and Watari respectively) due to the counterbalancing effect of fertility and pollution indices.

Keywords: Soil; quality; fertility; pollution; urban; Kano.

1. INTRODUCTION

Soil Quality which has been defined by [1] as the capacity of a soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality and support human habitation. The quality of soil borders on its physical, chemical and biological properties; and is in turn affected by other factors that include agro-climatic, hydrogeology and cropping/cultural practices [2].

Urban agriculture is a century's old common practice in Kano, Nigeria [3] and involves the use of stream water to irrigate land at the banks with the objective of producing fruits and vegetables for the city [4].

The quality of the soils in this land use could be affected through two principal ways; pollution and fertility depletion. The former could be due to the fact that the streams used for irrigation flow through densely populated and/or industrialized areas while wastes from landfills and sewage sludge are used as fertilizer [5]; This in addition to exposure to exhausts from motorized vehicles, which have been shown to be a source of heavy metal contamination [6]. The continuous use of these lands throughout the year for both irrigated and rain-fed farming is what may likely lead to fertility depletion [4] as has been shown for other similar land uses [7].

The use of wastewater for irrigation is a common phenomenon across cities and rural areas and its consequent effects on environmental quality have been well documented especially in poor regions and draught prone areas of the world [8,9,10]. In Nigeria and in Kano especially, previous studies have highlighted both the potential economic gains and probable hazards associated with wastewater irrigation; Especially as they affect environmental quality and human health [4,11,12]. These previous works however failed to capture and highlight in clear empirical terms, the extent of the impact of wastewater use on principal environmental components, especially soil, which may be resource with the longest lifespan.

The aim of this study was therefore to assess the quality of wastewater irrigated soils in relation to the land use, specifically in relation to soil fertility and heavy metals pollution because of their tendency to affect yield and safety of produces.

2. METHODOLOGY

2.1 The Study Area

This work was conducted at the banks of the Jakara, Challawa and Watari Rivers within metropolitan Kano and its suburb (Fig. 1). These areas were selected based on wastewater type and consistency of wastewater use for irrigation by daily surface flooding in at least the last twenty (20) years. Jakara is a domestic wastewater drain while Challawa drains industrial wastewater. Watari was used as a control because it is not a wastewater drain. Areas between latitude 11° 59' and 12° 08'N and longitude 8°34' and 8° 42'E were sampled. Yansama, Sharada and Rafin Kuka; Akija, Airport Road and Magami; and Lambu, Langel and BUK irrigation sites respectively were selected to represent up, mid and downstream sectors of the Challawa, Jakara and the Watari rivers respectively. Global Positioning System (GPS) and ground truthing were used for sites geo-referencing. Kano is in the dry-sub-humid agro-ecological zone of Nigeria [13]. It is characterized by tropical wet and dry climate classified as Aw by W. Koppen [14]. The dominant geology is basement complex [15,16]. The dominant soil of the area is Eutric Cambisol [17]. The dominant crops being irrigated in the areas are leafy vegetables such as lettuce and spinach.

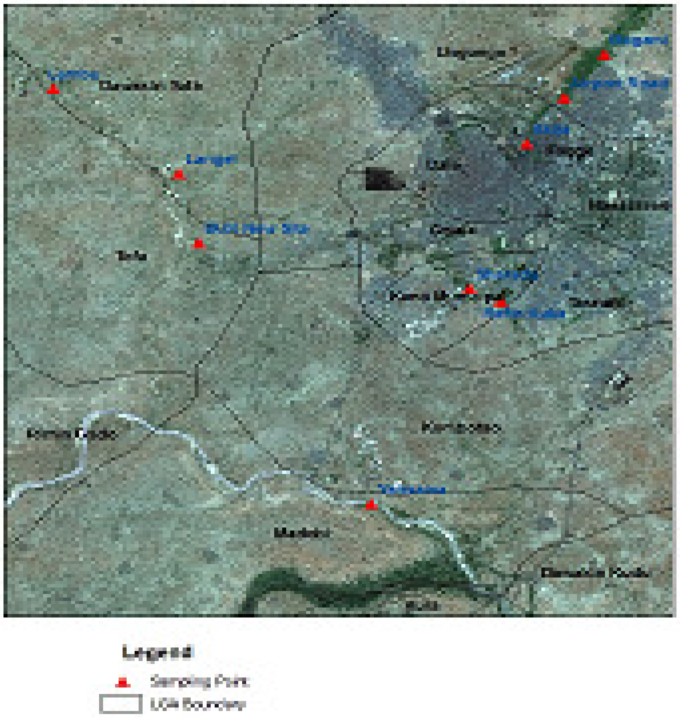

Fig. 1. Map of the study area

2.2 Sampling and Sample Treatment

Stratified grid soil sampling method [18] was employed and five (5) 100m long transects were taken parallel to the course of the river on the side with higher irrigation activity. A sample was collected at each 20m along the transect from the surface 0 to 20cm, being the rooting zone for most vegetables. A core sampler weighing 124g and a volume of 71.58cm^3 was used to take three random core samples at each site.

On the assumption that the waters of the rivers are well-mixed [19,20], three samples were collected randomly across the width of the river each, from the up, mid and downstream parts of the rivers.

All samples were collected at the peak of irrigation activities in the months of February. Water samples were collected in this period in the mid-afternoon when discharges are at peak from both domestic and industrial sources. Soil samples were put in polythene bags to minimize chances of contamination and were labeled serially based on proximity to water source. Samples were air-dried, crushed with mortar and sieved with 2mm sieve. Water samples were collected in plastic containers and refrigerated prior to analysis.

2.3 Soil Quality Evaluation

Soil quality evaluation was based on the Soil Assessment Framework [21]. The minimum data set (MDS) used included soil functions such as ease of tillage, salinity, pollution and support for plants' growth (SPG). Sets of soil parameters were selected as indicators for each of the properties. Bulk density (BD) was evaluated as indicator for ease of tillage, EC as indicator for salinity, total and soluble heavy metal contents were evaluated as indicators for pollution, total N, available P, exchangeable K and total organic carbon were used as indicators for SPG.

The indicators were divided into two: 'more is better' which included NPK and O.M; and 'less is better' which included BD, EC and total and soluble metals. The values for each indicator were converted to a unit-less value between 0 and 1 as weighted values using the formula proposed by [22] as follows;

$y = \frac{x-s}{t-s}$ for indicators for which 'more is better'; and

$y = \frac{x-s}{[[t+\frac{t}{10}]-s]}$ for those indicators for which 'less is better';

where;

y = the converted unit-less value
x = the actual reading for the indicator
s = the lowest possible reading for the indicator which is taken to be 0
t = the highest reading for the indicator

The quality of the soil, Q was evaluated as;

$Q = \sum[qi \ldots n]$ where $i \ldots n$ are those quality indicators measured above and q is its corresponding weighted value.

2.4 Laboratory Techniques

2.4.1 Soil analyses

Soil samples were analyzeds using established laboratory procedures. The pH was determined using the 1:2.5 soil-distilled water ratio using EL model 720 pH meter. Electrical conductivity (EC) was determined in 1:2.5 soil – distilled water extract using Beckman Conductivity Bridge (Model: RC - 18A). Particle size distribution was by the hydrometer method as reported in [23]. Organic carbon was determined by Walkley-Black wet-oxidation method as described in [23]. CEC and exchangeable bases was determined by the ammonium acetate extraction method described in [18]. Total heavy metals were determined using double acid digestion technique [24]. Exchangeable and soluble forms of these metals in soil were determined by an adapted sequential extraction method of [25].

pH of water was determined at the time of collection while total dissolved solids (TDS) and the EC of the water samples were determined using digital conductivity meter [Jenway Model 4520]. Total metals in water were extracted with HNO_3 as described by [26]. HCO_3^- in water was estimated using acidimetric titration, SO_4^{2-} by turbidimetric method, NO_3^- by Devarda's alloy reduction method, B by azomethine H colorimetric method and Cl by Mohr's titration method all as described in [23]. PO_4^{3-} was determined by the HNO_3-H_2SO_4 digestion and colorimetric method of [18]. Concentrations of metals were throughout determined using Atomic Absorption Spectrophotometry (AAS); while flame photometry was used in determining Na and K concentrations.

2.4.2 Data analyses

Data obtained were analyzed with descriptive and inferential statistics. Means comparisons were done using analysis of variance (ANOVA) as obtained in SAS package 6.0. Means that were significantly different were separated using least significant difference (LSD). Correlation analysis was also conducted using Pearson moment correlation to relate soil and water properties.

3. RESULTS AND DISCUSSIONS

3.1 Soil Physical Properties

Physical parameters for the three sites are presented in Table 1. The texture of the soils is sandy loam to loamy sand. Sandy textured soils are common in the basins of many rivers, as materials brought about by transporting water are segregated. The dominance of sand at the banks of the streams could be explained by the reports of [27] that in Kano region, alluvial sand and gravels are the dominant soils on river terraces.

The bulk density approximately agrees with the values suggested by [28] for cultivated sandy-loams and sand textured soils.

3.2 Soil Salinity

The salinity related properties of the soils are shown in Table 2. The mean pH across the sectors of the areas was slightly alkaline when interpreted by the [29] standards. Using the three parameters and rating the sites according to the criteria of [28], the soils in all the three sites can be described as non saline, although the strikingly higher EC and SAR values at Jakara is worth noting. This variation may be due the fact that the Jakara soils are irrigated with domestic effluents and abattoir wastewaters, both of which could contain appreciable amounts of sodium from detergent use. The lower EC and SAR values at the control site indicate the possibility that discharges into the two latter rivers might have significantly contributed to their higher values.

3.3 Soil Fertility Status

The fertility statuses of the soils are shown in Tables 3. The organic carbon at the Challawa and the Watari sectors were within the low range while those at the sectors of Jakara river were within the low to medium range using the [29] ranking. The findings here confirmed claims that organic matter content of mineral soils of the tropics are always ranging from a mere trace to only as high as 20 to 50% [28,30]. The higher values at the Jakara basin especially at the midstream could be explained by the application of domestic wastes as dumps by the increasingly higher population of the areas; A fact which is noted by [4] and the use of domestic and abattoir waste waters which as claimed by [28] contain high levels of organic waste materials capable of enriching the soil.

Using the ranking of [31] Jakara could be described as having very high P content, Challawa sectors ranged from median to high while Watari sectors ranked from low to medium. The effect of irrigation with waste water could be seen on the different sectors for the three areas. Jakara had much higher P because it has been alleged that typical wastewater effluent from domestic sources could supply all of the nitrogen and much of phosphorus and potassium requirements of many [32]. The extremely high values compared well with those detected by [33] in the Kano River project and the work of [7] in the Jakara valley.

When ranked based on the rankings of [29] all the N values across the sectors of the rivers could be described as high. The availability of nitrogen in the soil is strongly influenced by the organic matter content of the soil as is evident in the Jakara site.

Ca and Mg across the various sectors can be classified as medium to high using the ranking of [31]. The soils in the basins of most rivers contain appreciable Ca especially those under irrigation, if pH values are within the range of neutral to slightly alkaline [34]. It has also being stated that calcium and magnesium are the dominant bases in fadama soils [35-37]. The values found in this study are in close agreement with the those reported by [7] for the Jakara valley and [38] for some sites along the basin of the Challawa river.

The K content for all the sites were high - very-high. Similarly high values were recorded by [7]. [38] recorded values as high as 2.33cmol/kg in some segments of the Challawa basin. The high K values despite the leaching tendency of the soil may be due excess fertilizer nutrient applied, probably as a compound mixture with the excessively high P, as well as the mineral nature of the parent material from which this soil developed.

The Na contents of the sites were medium to high [31]. Significant amounts of sodium in irrigated soils are common to the extent they are used as one of the criteria to ascertain salt effect in such soils [33]. Similar values were recorded by [7] in the Jakara valley. The values corroborate the slightly alkaline pH of the soils. The higher concentration of the Jakara soils may have been contributed to by the high sodium concentration in domestic waste water which floods the basin from the city as noted by [4].

All the sites had medium CEC using the ranking of [31]. The effect of organic matter content in the soil in relation to CEC is markedly expressed here. The sites with higher organic matter content have significantly higher CEC. The values found across these sites disagreed with many works across soils of many basins of tropical rivers. [39] has found mean CEC as low as 4.35cmol/kg in the basins of some rivers in Bauchi, while [38] established mean values that ranged between 2.2 – 12.52cmol/kg across some locations on the basin of the Challawa river. The difference with the values in this work may be attributed to the relatively better organic matter across the sites.

3.4 Soil Heavy Metals' Pollution

3.4.1 Total metal concentrations in soil

The total concentrations of Pb, Cd, Cr, Cu, Ni and Zn being metals common in wastewaters were determined and their values are shown in Table 3. There is a decrease in the concentrations of all the metals across the sectors of Challawa and Jakara rivers with downstream flow, with the exception of Cr which had its highest concentration at the midstream sector. The reverse phenomenon was however observed at the control Watari river where concentrations of all the metals tend to increase with downstream flow.

Table 1. Physical and salinity related properties of the soils of the sites

Site	Bulk density	Sand [%]	Silt [%]	Clay [%]	Textural class	pH [1:2.5 soil/H_2O]	EC [mS/m]	SAR
Challawa								
'YanSama	1.32b	68.56b	23.28a	8.16a	Sand silty loam	7.70	1.01b	0.20b
Sharada	1.35b	78.56a	17.26a	4.16b	Sandy loam	7.71	2.70a	0.47a
S/Gandu	1.66a	81.76a	10.08b	8.16a	Loamy sand	7.88	1.65ab	0.17b
SE	0.034	3.04	2.90	1.00	1.006	0.131	0.52	0.064
Jakara								
Akija	1.21	80.48	13.28a	6.24a	Sand silty loam	7.19b	3.79	0.66
Airport Rd.	1.33	78.48	17.26a	4.26b	Sandy loam	7.12b	4.43	0.92
Magami	1.35	82.48	10.08b	7.44a	Loamy sand	7.92a	3.81	0.96
SE	0.076	1.80	1.80	1.31		0.12	0.56	0.19
Watari								
Lambu	1.62	69.68b	22.88a	7.44ns	Sand silty loam	7.45	0.64	0.080
Langel	1.59	69.68a	20.88a	9.44ns	Sandy loam	7.39	0.56	0.086
New Site	1.59	80.88a	11.68b	7.44ns	Loamy sand	7.59	0.54	0.088
SE	0.076	4.48	3.23	2.30		0.15	0.12	0.013
Cumulative means								
Challawa	1.45b	76.29ab	16.88	6.80ab	Sandy loam	7.77a	1.79b	0.281b
Jakara	1.30c	80.48a	14.56	4.96b	Loamy sand	7.42b	4.01a	0.847a
Watari	1.60a	73.41b	18.48	8.11a	Sandy loam	7.48b	0.58c	0.084c
SE	0.0499	2.46	2.21	1.00		0.11	0.20	0.073

Means followed by the same letter in the same column for the same area are not significantly different [$p \leq 0.5$]

Table 2. Soil fertility status of the sites

Site	OC [g/kg]	P [mg/kg]	N [g/kg]	Ca^{2+} cmol/kg	Mg^{2+} cmol/kg	K^+ cmol/kg	Na^+ cmol/kg	Ex. acidity cmol/kg	CEC cmol/kg	ECEC cmol/kg
Challawa										
'YanSama	7.96	64.75	0.63b	11.60b	3.27	0.73	0.79b	0.47	19.38b	16.86b
Sharada	7.86	78.65	1.04a	15.60a	3.38	0.81	2.04a	0.40	24.24a	22.25a
Rafin Kuka	8.38	89.60	0.60b	7.88b	1.90	0.84	0.52b	0.80	13.84b	11.90b
SE	2.25	17.03	0.112	2.26	1.02	0.19	0.30	0.27	3.26	3.19
Jakara										
Akija	11.01	217.70a	1.65a	15.60a	3.07a	2.25	2.82	0.47	26.90b	24.20a
Airport Rd.	13.16	269.20a	1.44ab	12.40ab	2.44b	1.66	3.27	0.47	23.15ab	20.47ab
Magami	9.62	153.65b	0.88b	10.00b	1.88b	1.65	3.51	0.47	19.28b	17.27b
SE	1.92	27.47	0.28	1.62	0.28	0.36	0.66	0.12	2.47	2.30
Watari										
Lambu	10.17a	15.05b	0.56	11.00	2.40	0.48	0.28	0.39	15.26	13.56a
Langel	5.23b	63.35a	0.67	6.68	1.75	0.44	0.24	0.33	11.00	9.44a
New Site	6.10ab	16.80b	0.98	6.72	2.31	0.47	0.23	0.33	11.64	10.07a
SE	1.88	7.81	0.27	2.44	0.94	0.11	0.038	0.057	3.80	3.27
Cumulative mean										
Challawa	8.07b	77.67b	0.76b	11.70a	2.85	0.79b	1.11b	0.55	19.15a	17.00a
Jakara	11.27a	213.52a	1.32a	12.67a	2.46	1.85a	3.20a	0.47	23.11a	20.65a
Watari	7.16b	31.73c	0.74b	7.80b	2.15	0.47c	0.25c	0.35	12.63b	11.02b
SE	1.22	15.51	0.16	1.46	0.48	0.14	0.27	0.10	2.11	1.94

Means followed by the same letter in the same column for the same area are not significantly different [$p \leq 0.05$]

The spatial distribution of the study locations and the sources of the metals into the environment could have caused this mode of distribution. Challawa and Jakara sites are located at increasing distance from the municipal center while Watari sites are at decreasing distance from the city. The implication of these findings therefore is that closeness to the city may be a major factor in pollution of soil resources. This fact is alluded to by [40] who further ascribed the effect to motor vehicles exhausts which deposit metals, especially Pb over the air.

Other factors affecting the concentrations in all the sites include their presence in domestic and industrial sewage sludges (especially the tanning industry) [8,9,41,42]; addition through fertilizers and pesticides [43] and geologic addition through rock weathering [41,44,45]. The significantly lower Pb, Cd and Cr at the control may justify the claims of both industrial and domestic wastewaters being contributors to the deposits in soils, while the substantially high Zn and Ni even at the control may implicate input use and geologic addition. The values recorded here agree with the work of [11] and [46] in the Jakara basin and the work of [47] at the Challawa basin.

3.4.2 Exchangeable and soluble metal concentrations in soil

Tables 4 shows the exchangeable concentrations of the metals while the soluble forms are shown in Table 5. The two forms of the metals were not been distributed in any specific pattern across the sites. The soil pH, clays and associated oxides, organic matter as well as total concentration are some of the factors that regulate exchange and solution of metals in soil. [43,48,49]. Because these factors are mostly medium to low in these soils (Table 1), the soluble and exchangeable concentrations were therefore low, even with the relatively high total concentration. This conforms to the theory of [48]. The most prominent factor here may be total concentration. Similar effect on exchangeable fraction was observed by [45].

3.4.3 Irrigation water quality

The characteristics of the irrigation waters are shown in Tables 6 and 7. By the recommendations of [50] the Jakara river is relatively unsafe for irrigation based on pH, EC and TDS values.

The highest Na value was recorded at the Jakara river probably due to the effect of domestic wastewater. The lower concentrations in Watari river indicates its reduced pollution level. By the criteria of [50], only the downstream sectors of Challawa and Watari have exceeded the recommended calcium value while all the sectors except midstream Watari have exceeded the recommended Mg levels. The general unevenness in the distribution of these ions in the rivers is a common phenomenon as [20] revealed that variability in ions content of open waters could result with time and space.

The PO_4^{3-}, NO_3^-, HCO_3^-, B and Cl^- have all exceeded the increased hazard limit of [50] across the sites. The values are consistent with the values of the cations; as all these, except B are anions that in water and soil, always show close association with the cations. The fact that higher values are recorded at Jakara river indicates the dominance of these ions in domestic wastewater, while the lower values at the Watari shows its reduced pollution tendency. The use of SO_4^{2-} salt of Cr in tanning industries may have facilitated its higher content in Challawa. The values here are consistent with the values of [47] in the Challawa river.

The concentrations of all the heavy metals in all the waters have exceeded the threshold limits shown in Table 8. Vehicular discharges, atmospheric deposition and industrial effluents might have contributed to the high concentration at the Challawa and Jakara rivers. Municipal solid wastes containing objects such batteries could have dissolved and washed Cd in to the Jakara river thereby increasing its content compared to the other sites while its presence in agro-chemicals could have introduced it in the control. Similarly higher values in domestic and industrial wastewaters were detected by [4,8,10].

Temporal and spatial variations, which are common in water studies, might have caused the variations of the results here with previous works including that of [4] and [47].

Table 3. Total concentrations of the metals for the three locations across the three site

Parameter	Challawa				Jakara				Watari			
	Yan sama	**Sharada**	**Sabuwar gandu**	**SE**	**Akija**	**Airport Rd.**	**Magami**	**SE**	**Lambu**	**Langel**	**New site**	**SE**
Pb [mg/kg]	98.26a	75.01a	31.07b	5.23	132.77a	92.31ab	53.87b	7.16	23.95b	29.12b	75.44a	3.90
Cd [mg/kg]	11.43a	8.81b	7.56b	0.36	13.37a	12.30ab	9.77b	0.36	0.40b	0.43b	0.94a	0.05
Cr [mg/kg]	184.23	185.26	127.21	8.58	127.12a	130.94a	79.76b	7.69	3.70b	5.36b	8.49a	0.40
Cu [mg/kg]	10.44a	1.45b	2.96b	0.91	10.88a	5.82b	1.26c	1.03	1.99b	5.65a	7.54a	0.47
Ni [mg/kg]	45.96	51.82	65.51	3.12	58.89	61.59	52.80	1.47	46.93b	66.48a	57.68ab	2.15
Zn [mg/kg]	118.57	195.77s	132.75	9.24	261.94ab	328.14a	176.47b	13.83	62.02	36.93	66.28	3.88

Means followed by the same letter in the same row for the same area are not significantly different [p≤ 0.05]

Table 4. Exchangeable concentrations of the metals for the three locations across the three sites

	Challawa				Jakara				Watari			
Parameter	**Yan Sama**	**Sharada**	**Sabuwar gandu**	**SE**	**Akija**	**Airport Rd.**	**Magami**	**SE**	**Lambu**	**Langel**	**New site**	**SE**
Pb [mg/kg]	26.18a	12.83ab	9.20b	1.52	27.89a	19.34a	7.71b	1.48	7.01b	6.82b	17.63a	0.89
Cd [mg/kg]	1.37	0.96	1.04	0.06	1.63a	1.07ab	0.91b	0.07	0.01b	0.03ab	0.07a	0.01
Cr [mg/kg]	32.45a	33.00a	22.34b	1.44	19.86ab	22.11a	13.31b	0.92	1.34	1.42	2.31	0.12
Cu [mg/kg]	2.28a	0.29b	0.52b	0.21	2.16a	1.21a	0.19b	0.23	0.22b	0.70a	0.77a	0.06
Ni [mg/kg]	12.63b	12.99b	18.27a	1.25	13.75	13.38	14.53	0.23	13.71b	17.72a	15.36ab	0.38
Zn [mg/kg]	26.87	44.37	29.27	2.26	49.08ab	68.63a	29.31b	3.23	16.94	9.45	16.09	0.87

Means followed by the same letter in the same row for the same area are not significantly different [p≤ 0.05]

Table 5. Soluble concentrations of the metals for the three locations across the three sites

Parameter	Challawa				Jakara				Watari			
	Yan sama	**Sharada**	**Sabuwar gandu**	**SE**	**Akija**	**Airport Rd.**	**Magami**	**SE**	**Lambu**	**Langel**	**New site**	**SE**
Pb [mg/kg]	9.97	11.48	6.62	0.85	12.20a	7.11ab	4.38b	0.79	1.87b	1.54b	4.93a	0.28
Cd [mg/kg]	0.53	0.52	0.52	0.04	0.72a	0.63ab	0.47b	0.03	0.00	0.00	0.00	0.00
Cr [mg/kg]	17.45	18.00	12.29	0.77	5.00b	9.44a	6.56ab	0.46	0.46b	0.57b	0.82a	0.03
Cu [mg/kg]	0.97a	0.14b	0.33ab	0.09	0.46a	0.37a	0.02b	0.06	0.10b	0.29b	0.77a	0.05
Ni [mg/kg]	5.94	5.79	5.08	0.12	6.52	5.84	5.74	0.20	7.51	7.28	6.66	0.22
Zn [mg/kg]	8.16	8.60	6.40	0.36	18.48ab	21.99a	12.13b	0.96	5.63	4.69	4.38	0.18

Means followed by the same letter in the same row for the same area are not significantly different [p≤ 0.05]

Table 6. Some physical and chemical properties of the irrigation water

Site	pH	EC [mS/m]	TDS [g/l]	PO_4^{3-}	NO_3^-	HCO_3^-	B	Cl^- [mg/l]	SO_4^{2-}	Ca^{2+}	Mg^{2+}	K	Na
Challawa	7.57a	1.96b	1.78b	21.108b	4.232b	41.512b	0.0393b	91.250b	13.248a	23.78a	14.94a	13.57b	28.63b
Jakara	7.29a	6.71a	4.35a	27.616a	5.488a	72.016a	0.0434a	126.220a	12.413a	13.67b	14.89a	33.53a	46.98a
Watari	7.60a	0.40c	0.24c	15.457c	1.900c	26.870c	0.0239c	18.133c	3.884b	20.44a	5.83b	4.48c	5.78c
SE	0.18	0.49	0.50	1.332	0.604	3.894	0.0014	7.315	0.625	0.77	0.97	1.45	1.97
FAO [1992] recommended threshold													
	8.4	0.75	450	10.00	150.00	<61	6.00	<355	100	20	5	2.00	<207

Means followed by the same letter in the same column are not significantly different at 0.05LSD

3.4.4 Correlation between water and soil properties

Table 8 shows the relationship between soil and water properties. Significant correlation was found among many of the soil and water properties. All the cations in water correlated positively and significantly with soil properties except Ca that exhibited negative, but significant relationship with the soil properties. These relationships have been well portrayed by the soils, especially when compared with the control sites. The TDS showed positive and significant relationship with all the soil properties which was an expected phenomenon because of its obvious effect on the organic and inorganic contents in soil. This effect has translated into its effect on all other fertility indicators of the soil. The relationships between the anions in water and soil properties were also positive and significant except with the pH which was mostly negative and insignificant. This may also be justified because of their association with cations both in soil and in water especially in soils with alkaline pH [51]. The wastewater use has therefore significantly improved the fertility status of these sites. These findings further support the assertion of [32] and explained why the farmers in this system of land use are rarely constrained by input costs and produce year round [7].

3.4.5 Correlation between metals in water and concentration in soil

Table 9 shows the relationship between the metals concentration in irrigation water and the total concentration detected in soil. Pb, Zn, Cr and Cd in water significantly correlated soil's; while Ni in water and in the soil correlated insignificantly. Similar insignificant correlation was shown by Cu, although negatively. Similar observations were made by [8]. They found significant correlation for Pb, Cd, Cr, Ni and Cu in all sites and areas with previous and current histories of wastewater use for irrigation recorded higher and significantly different means than the control soils. There was however variations in the relationship with metal types. This individual metal variation could explain the behavior of Ni and Cu in this work.

3.4.6 Soil quality ratings

The soils of the three sites were cumulatively rated for quality based on the SMAF protocol and the results are shown in Table 10. Cumulatively put together, the Challawa soil had the highest score index followed by the Jakara soil and the Watari soil respectively. This is explained by the fact that although the Jakara site had higher values for the indicators for which 'more is better' [NPK and organic matter], it also had higher values for which 'low is better' [total and soluble metals, as well as salinity] and only its bulk density was the lowest among the 'low is better' indicators. Therefore, although it can support plant growth better and is easier to till, it has the highest tendency to be polluted with heavy metals and become saline. The Watari soil had lower values for those indicators in which less is better [pollution indicators and salinity], but it also had the lowest values for most of the indicators in which more is better [SPG and organic matter] and it has the least ease of tillage quality because of its higher BD. All the values were however within the same range and the quality index difference among the three sites is only marginal. This situation is typical of soils that are being managed with the same management strategies such as irrigation and/or arable crop production under rainfed condition as highlighted by [22] who reported similar marginal quality index difference among soils being managed under different tillage practices namely zero-till, minimum-till and chisel-plough till. The ease of tillage of the Jakara and the Challawa soils was better because of the lower bulk densities and hence the scores. Jakara soil was the most saline hence the lowest score.

Table 7. Levels of heavy metals in irrigation water

Site	Pb	Ni	Cu [mg/l]	Zn	Cr	Cd
Challawa	14.56	40.74a	8.43	24.64a	83.76a	3.33ab
Jakara	13.79	33.33b	7.28	26.57a	37.61b	4.58a
Watari	8.04	26.98ab	6.51	18.36b	5.98c	1.11b
SE	3.47	6.08	2.57	2.73	7.45	0.30
FAO [1992] recommended threshold						
	5.00	0.20	0.20	2.00	0.10	0.01

Means followed by the same letter in the same column are not significantly different [p ≤ 0.05]

Table 8. Correlation between soil and water properties

Soil properties	Water properties										
	K^+	Na^+	Ca^{++}	Mg^{++}	Ece	Tds	HCO_3^-	Cl^-	SO_4^{2-}	PO_4^{3--}	NO_3^-
Total N	.589**	.505**	-.290**	.101*	.629**	.592**	.618**	.464**	.412**	.627**	.473**
OC	.450**	.447**	-.350**	.189	.488**	.423**	.406**	.433**	.260*	.383**	.230*
P	.801**	.744**	-.367**	.241*	.788**	.762**	.744**	.725**	.574**	.710**	.501**
CEC	.651**	.729**	-.366**	.316**	.623**	.700**	.610**	.687**	.620**	.596**	.338**
pH	-.178	-.081	.232*	.059	-.233*	-.267*	-.208	-.071	-.004	-.240*	-.107
Ece	.862**	.816**	-.247*	.259*	.758**	.804**	.625**	.752**	.456**	.617**	.323**
Ca	.522**	.613**	-.307**	.258*	.500**	.602**	.498**	.629**	.561**	.500**	.255*
Mg	.147	.252*	-.044	.138	.119	.242*	.208	.221*	.287**	.282**	-.003
K	.799**	.734**	-.409**	.244*	.802**	.691**	.831**	.566**	.486**	.619**	.475**
Na	.805**	.804**	-.417**	.303**	.762**	.790**	.571**	.731**	.468**	.523**	.302**

*** Significant at 0.01, * Significant at 0.05*

Table 9. Correlation between metals in water and total metals in soil

	Pb in H_2O	Ni in H_2O	Cu in H_2O	Zn in H_2O	Cr in H_2O	Cd in H_2O
Soil Pb	.487**					
Soil Ni		.069				
Soil Cu			-.369			
Soil Zn				.405*		
Soil Cr					.787**	
Soil Cd						.556**

** significant at 0.005 level of significance, ** significant at 0.001 level of significance*

Table 10. Quality rating indexes for the soils of the three basins

Function	Indicator	Weight	Challawa	Jakara	Watari
Ease of tillage	BD	0.05	0.011	0.012	0.008
Salinity	EC	0.05	0.021	0.014	0.026
Pollution	Total Cu	0.05	0.04	0.038	0.022
	Total Cr	0.05	0.014	0.029	0.022
	Total Ni	0.05	0.03	0.014	0.015
	Total Pb	0.05	0.024	0.029	0.027
	Total Zn	0.05	0.027	0.02	0.026
	Total Cd	0.05	0.016	0.018	0.028
	Soluble Cu	0.05	0.04	0.037	0.03
	Soluble Cr	0.05	0.02	0.022	0.02
	Soluble Ni	0.05	0.012	0.016	0.014
	Soluble Pb	0.05	0.025	0.03	0.031
	Soluble Zn	0.05	0.021	0.018	0.02
	Soluble Cd	0.05	0.023	0.021	0.05
SPG*	Total N	0.1	0.066	0.049	0.032
	Available P	0.05	0.028	0.036	0.022
	Exchangeable K	0.05	0.031	0.027	0.026
	Total O.M	0.1	0.054	0.068	0.066
	Total [Index]	1	0.503	0.498	0.485

** SPG = Support Plant Growth*

4. CONCLUSION AND RECOMMENDATION

Results obtained here revealed that use of wastewater has affected fertility of soils in some areas due to high levels of N, P and K; but has also resulted in elevated levels of toxic metals in the soil. Water from the findings here is the major factor affecting soil properties although air deposit, agrochemicals and solid waste disposal may also be making contributions to the metal pollution. They could be the main sources in the control sites.

The marginality of the overall quality of the soil could be as a result of the counter-balancing effect of fertility and pollution indices. By this therefore, yields obtained may be contaminated with detectable doses of toxic elements that may accumulate in human systems.

It could be recommended that production could be safer at the lands with the farthest distances from the municipality and should therefore be encouraged as there is the tendency for produce to be safer without compromising fertility levels. Lands close to the municipal could then be put to other uses such as recreational parks. It could also be recommended that since water plays a significant role in determining the properties of the soil as shown by the correlation here, irrigation activities should avoid peak discharge periods to lessen the tendency for the introduction of contaminants.

COMPETING INTERESTS

The authors hereby declared that no competing interests exist with regards to this article.

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