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Ecological Risk Assessment of Heavy Metal Exposure to River Sauna as Irrigation Water Source in Kano State, Nigeria

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ABSTRACT
The indiscriminate discharge of both domestic and wastewater have a great impact on the quality of water in River Sauna. This assess the quality of the water used for urban agriculture and ecological risk assessments of some heavy metals exposure in River Sauna as irrigation water source in Kano metropolis, Nigeria. Water samples were collected from different sites at distances of 0, 250, and 500 meters from points of discharge. The collected samples were analysed for physicochemical properties and heavy metals in the laboratory using standard methods. The results showed that amongst all the different sources evaluated, the industrial waste water had the highest pH, electrical conductivity and total dissolved solids of 8.26, 4.87 dSm^{-1} and 2.89 gL^{-1} respectively. Higher electrical conductivity (EC), residual sodium carbonate (RSC) and chlorides were observed both in industrial and domestic discharge sites. There is a high potential of salinity and environmental toxicity with the continued discharge of waste water from both industry and homes. The results also indicated a highly significant difference (P<.001) in the concentration of Ca, Mg and Na at varying distances within the sampling sites. The value of computed degree of contamination and pollution load index were observed to be <7 and <1 in all sampling sites respectively. The abundance of the heavy metals was in the order of Cu > Ni > Cd > Pb > Cr and below the WHO permissible limit for surface water, except for Cd, which recorded 0.015 mgl^{-1} in the industrial discharge site and thus necessary treatments and precautions should be put in place to minimize the impacts.

Keywords: Heavy metal contamination; Irrigation; Risk assessment; Water quality; Kano

INTRODUCTION

Water is one of the most important and essential natural resources on earth. Water serves as a critical input in agricultural production, it plays an important role in maintenance of our health, ecological sustainability and stability. One of the core characteristics of the Earth's freshwater resources is the great variability in its distribution in space and time (Gleick and Cooley, 2021). Freshwater must sufficiently be in quantity and quality that would support sustainable development and survival of mankind (Ogoko and Donald, 2018). According to Food and agriculture organization of united nations agriculture accounts for 70% of global freshwater withdrawals (FAO, 2017) majority of which is used for irrigation purposes.

In many developing countries, wastewater is widely used for irrigation purposes and it is deemed as the most conventional and low-cost practice that has been receiving immense attention in the agricultural sector due to the global decline in freshwater resources (Younas and Younas, 2022). Wastewaters generally contain numerous essential inorganic and organic nutrients which are considered necessary for plant metabolism (Shahid *et al.*, 2020). Apart from contamination by heavy metals, waste water may contain higher than appreciable amount of various other elements, salts and pathogenic microorganisms which affect the physicochemical nature of the soil causing disturbed condition such as inadequate infiltration and reduced uptake of water and nutrients from the soil.

The expansion in the population of Kano State due to urbanization has placed greater demands on agricultural production and marketing systems (Gambo and Farouq, 2015). Previous studies have highlighted both the potential economic gains and probable hazards associated with wastewater irrigation (Dawaki *et al.*, 2015; Edogbo *et al.*, 2020; Onoyima, 2021). However, data and information on ecological risk assessment of heavy metal contamination in wastewater irrigation source are either insufficient or absent in the area. The aim of this study is to assess the physicochemical properties and heavy metal exposure in River Sauna as source of irrigation in Kano State, Nigeria.

MATERIALS AND METHODS

Study area

This study was conducted at River Sauna (12°00'N to 12°01'N and 8°35'E to 8°36'E) located in Nasarawa Local Government Area with part of the river extending to Dan Sarai, Gezawa Local Government Area, Kano State within Sudan Savannah Zone of Nigeria (Figure 1). The mean annual rainfall in the region is about 696 mm. with daily temperature of 26°Cto 39°C (Nurudeen *et al.*, 2016).

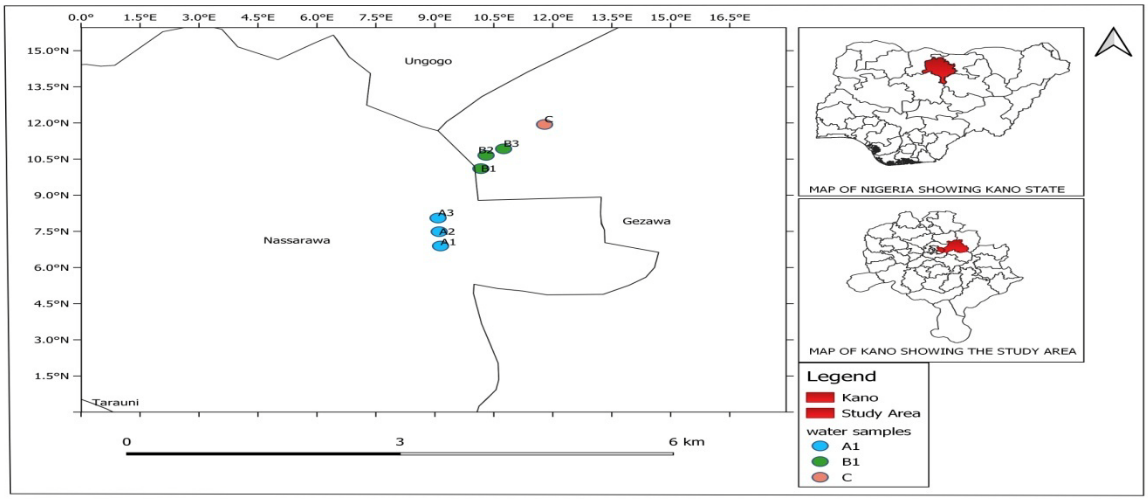

Figure 1: Map of the study area showing sampling points

Sampling

The selection points were based on the immediate sources of effluent into the water body, and the sites were classified into industrial effluent, domestic effluent and control. Three water samples were collected from each site at distances of 0, 250 and 500 meters. A clean plastic bottle was used to collect the water sample by immersing it in the river water. The bottle was then gently closed to prevent trapping air. The water samples were analysed *insitu* on field and *exitu* in the laboratory. Samples were transported to the laboratory as quickly as possible to minimize changes in their composition. The coordinates of all collected samples were noted using Global Positioning System (GPS).

Laboratory techniques

The temperature, pH, and electrical conductivity (EC) of the water samples were determined using a mercury-in-glass thermometer, digital laboratory pH meter (Hanna model), and conductivity bridge, respectively, as outlined and adopted by Jamila and Sule (2019). Total dissolved solids (TDS) were determined by gravimetric method, while carbonate and bicarbonate were determined using titrimetric method. Total exchangeable bases were determined using standard procedures, with Ca and Mg analyzed using an Atomic Absorption Spectrophotometer (Agilent 200 series 240 FS), while Na was determined using a direct-reading flame photometer. The United States Environmental Protection Agency (EPA) vigorous digestion method described by Bala *et al*. (2008), was employed in the digestion of the water samples, and the total concentration of heavy metals was determined using Atomic Absorption Spectrophotometer (Agilent 200 series 240 FS).

Pollution assessment indices

Several pollution assessment indices were developed by many scholars. Some of these indices adopted for this research were presented in Table 1 and include; contamination factor (Loska *et al.*, 1997), degree of contamination (Edet and Offiong, 2002) and pollution load index (Tomlinson *et al.*, 1980). Additionally, the application of ecological risk factor and potential ecological risk index (Tomlinson *et al.*, 1980) was employed to assess the risk posed by the pollutants in the study area.

Data analysis

The data obtained were subjected to statistical analysis using JMP Version 17. Two-way analysis of variance (ANOVA) was used to determine the relationship between the samples at 5% level of significance.

Table 1: Geochemical indices used for assessing metal contamination

Contamination index	Definition	Contamination categories	References
Contamination factor (CF)	$CF=\frac{Cn}{Cb}$ C_n is the concentration of metal in water; C_b is the backgroundvalue of the metal	CF < 1, low contamination; 1 ≤ CF < 3, moderate contamination; 3 ≤ CF < 6, considerable contamination; and CF ≥ 6, very high contamination	Loska *et al*. (1997)
Degree of contamination (DoC)	$DoC= \sum_{i=0}^{n} CF_i$	DoC < 7, low contamination; 7 ≤ DoC < 14, mild contamination), 14 ≤ DoC < 2,considerable contamination; DoC ≥ 21, very high pollution	Edet and Offiong (2002) Loska *et al*. (1997)
Pollution load index (PLI)	$PLI=\sqrt[n]{CF1 \times CF2 \times CF3 \ldots \times CFn}$ CF is the contamination factor and n is the number of metals	PLI < 1, no pollution; 1 < PLI < 2, moderate pollution; 2 < PLI < 3, heavy pollution; 3 < PLI, extremely	Tomlinson *et al*. (1980)
Ecological risk index (ERI)	ERI = Tr*i* × CF*i* Tri represents toxicity response coefficient for *i*th metal. The Tri values are 1, 1, 1, 30, and 5 for Zn, Fe, Mn, Cd and Pb, respectively. $ERIP =\sum_{i=0}^{n} ER_i$ Ecological risk index potential (PERI) is expressed as the summation of entire ERIs of trace metals in water sample taken at a specific position	ER < 5, low ecological risk; 5 ≤ ER < 10, mild ecological risk; 10 ≤ ER < 20, considerable ecological risk; 20 ≤ ER < 40, high ecological risk; ER > 40, very high ecological risk. PERI < 30, low potential ecological risk; 30 ≤ PERI < 60, moderate potential risk; 60 ≤ PERI < 120, considerable potential risk; PERI ≥ 120, very high potential risk.	Tomlinson *et al*. (1980)

RESULTS AND DISCUSSION

Physicochemical Properties of the Water Samples Analyzed

The results of the physicochemical properties of irrigation water collected from different sources and at varied distances were presented in Table 2. The pH of the water samples from industrial (B) and domestic (A) discharge site were observed to be slightly and moderately alkaline, respectively. In contrast, the pH of the control site (C), which do not receive any point source pollutants, was observed to be neutral. Although there was a statistically significant difference in the pH level between the different water samples, no significant difference was observed based on changing distances at each sampling site.Ogwueleka and Christopher (2020) have reported that pH is a regulatory factor that determines the nature of ions present in surface water. However, it should be noted that the pH of irrigation water alone cannot be considered as the sole criterion for determining water quality because the pH levels of water are often influenced by the buffering capacity of the soil, and most crops can tolerate a wide range of pH levels as indicated by Zaman *et al.* (2019). As a result, the influence of surface water pH is more significant when considering its effect on aquatic ecosystems. This is in agreement with the finding of Rouamba *et al.* (2021) which found the higher pH in waste water compared to the water samples from dam and underground well in Ouagadougou, Burkina Faso.

The electrical conductivity (dSm^{-1}) and total dissolved solids (gL^{-1}) of the water samples were also measured. The highest electrical conductivity (4.87 dSm^{-1}) was recorded in the water sample receiving industrial discharge, followed by the domestic discharge water (2.57 dSm^{-1}), and the lowest at the control site (0.74 dSm^{-1}). A significant difference was observed ($P<.0001$) between the water samples taken at different distances at each sampling site. Total dissolved solids showed a similar pattern of changes both with respect to the source of the water or discharge point and the distance at which the samples were collected. The EC and TDS levels obtained in this study were higher than those reported by Jamila and Sule (2020) and Onokebhagbe *et al.* (2021). The high values, especially in the water sample that receive industrial discharge may be attributed to the effluents containing various dissolved salt released directly from industries into the water bodies and this indicate the hazardous potential of the water on causing salinity problems in soil.

The water samples were also analyzed for the presence of carbonates (CO_3^-), bicarbonates (HCO_3^-), and chlorides (Cl^-), with the concentrations ranging from 0.33 $meqL^{-1}$ to 10.79 $meqL^{-1}$, 7.0 $meqL^{-1}$ to 42.05 $meqL^{-1}$, and 26.86 $meqL^{-1}$ to 182.44 $meqL^{-1}$, respectively. A highly significant difference was found in their concentrations between and within the sources of the water samples. The trends of these ions were in order of A>B >C. Both carbonates and bicarbonates were much higher in industrial discharge site. This result deviate from the finding of Nzamouhe and Omar (2020) and Onokebhagbe *et al.*(2021), as such there is much likelihood of more precipitation of calcium carbonate and magnesium carbonate when the soil solution become more concentrated by evaporation as explained by Zaman *et al.*(2019).

There were a highly significant differences in the amounts of cations (Ca, Mg, K, Na) detected from different sources of water. The concentrations of Mg and Nawere in the descending order of B >A >C, while that of Ca and K was B >C >A. The results also indicated a highly significant difference ($p<.001$) in the concentration of these elements at varying distances within the sampling sites. In the industrial discharge site, Ca, Mg, and K showed the same pattern, while in the domestic discharge site, Ca and Na had the same pattern (A>B>C), in comparison Mg and K had a pattern of B>A>C. This is in concordance with the report of Nzamouhe and Omar (2020) who attributed the high level of chloride in irrigation water to the application of inorganic fertilizer, landfill leachate and irrigation drainage.

Table 2: Physicochemical properties of water

Source of variation		pH	EC (dSm^{-1})	TDS (gL^{-1})	CO_3 ($meqL^{-1}$)	HCO_3 ($meqL^{-1}$)	Cl ($meqL^{-1}$)	Ca ($meqL^{-1}$)	Mg ($meqL^{-1}$)	K ($meqL^{-1}$)	Na ($meqL^{-1}$)
Source											
	B	8.26^{a}	4.87^{a}	2.89^{a}	10.79^{a}	42.05^{a}	182.44^{a}	0.23^{a}	0.07^{a}	0.50	0.22^{a}
	A	7.77^{b}	2.57^{b}	1.53^{b}	2.05^{b}	9.66^{b}	182.22^{a}	0.01^{c}	0.05^{b}	0.24	0.20^{b}
	C	6.66^{c}	0.74^{c}	0.43^{c}	0.33^{c}	7.0^{c}	26.66^{b}	0.20^{b}	0.01^{c}	0.26	0.10^{c}
	SE	0.10	0.053	0.04	0.36	0.26	6.03	0.004	0.0001	0.0006	0.0002
	Prob.	<0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Distance											
	1	7.60	2.93^{b}	1.69^{a}	5.66^{a}	21.16^{a}	133.33^{b}	0.19^{a}	0.05^{a}	0.42	0.21^{a}
	2	7.60	3.11^{a}	1.69^{a}	4.61^{a}	19.05^{b}	155.55^{a}	0.08^{c}	0.04^{b}	0.30	0.17^{b}
	3	7.47	2.13^{c}	1.48^{b}	2.97^{b}	18.50^{b}	104.44^{c}	0.15^{b}	0.03^{c}	0.28	0.13^{c}
	SE	0.1	0.053	0.04	0.36	0.26	6.03	0.004	0.0001	0.0006	0.0002
	Prob.	0.54	<.0001	<.0001	<.001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
source*distance											
	B1	7.80	5.23^{a}	3.11^{a}	6.22^{b}	41.50^{b}	180.00^{b}	0.38^{a}	0.09^{a}	0.71^{a}	0.24^{b}
	B2	8.48	4.70^{b}	2.89^{ab}	14.33^{a}	44.00a	166.66^{b}	0.05^{d}	0.06^{d}	0.22^{b}	0.21^{d}
	B3	8.49	4.65^{b}	2.68^{bc}	11.83^{a}	40.66^{b}	200.00^{b}	0.25^{b}	0.07^{b}	0.56^{b}	0.21^{d}
	A1	7.95	2.81^{d}	1.64^{d}	2.16^{c}	8.66^{d}	193.33^{b}	0.01^{de}	0.06^{de}	0.30	0.30^{a}
	A2	7.67	3.89^{c}	2.37^{c}	2.33^{c}	12.50^{c}	273.33^{a}	0.004^{de}	0.07^{e}	0.35	0.22^{c}
	A3	7.69	1.00^{e}	0.58^{e}	1.66^{c}	7.83^{d}	86.66^{c}	0.001^{e}	0.02^{e}	0.08	0.08^{f}
	C	6.63	0.74^{e}	0.43^{e}	0.33^{c}	7.00^{d}	26.66^{d}	0.20^{c}	0.01^{c}	0.26	0.10^{e}
	SE	0.17	0.09	0.06	0.62	0.45	10.45	0.01	0.0001	0.001	0.0004
	Prob.	0.07	<.0001	<.0001	<.0001	0.001	<.0001	<.0001	<.0001	<.0001	<.0001

Means followed by same letters are not significantly different at least at $p < 0.05$; letters in superscript represent the mean ranking of the parameter under consideration; EC denotes electrical conductivity; TDS denotes total dissolve salt; CO_3 denotes carbonate; HCO_3 denotes bicarbonates; The letters B, A and C stand for industrial, domestic and control respectively, representing the immediate potential source of effluents/pollutants to the water while 1, 2 and 3 are distances on which each water samples were collected from each source (1=0m, 2=250m, 3=500m); SE denotes standard error.

Assessment of water quality for irrigation

Figure 2 present the sodium adsorption ratio of the water samples. The water sample receiving domestic effluents had the highest SAR, followed by that receiving industrial discharge, the lowest value was recorded at the control site. The SAR values recorded at all sampling sites were less than 10. therefore, all samples were classified into the S1 group. The highest residual sodium carbonate (52.11 $meqL^{-}$) was recorded on water sample from industrial discharge site, followed by that containing domestic effluents (11.46 $meqL^{-1}$), the lowest RSC value was recorded in control site with 6.86 $meqL^{-1}$. Similar trend was observed for total soluble salt (TSS) or Electric conductivity (EC), as shown in Figure 3. The water sample containing industrial discharge had the highest electrical conductivity (EC) value of 4.87 dSm^{-1}, indicating very high salinity hazard, based on the USSL Staff 1954 classification. The domestic water sample had an EC of 2.47 dSm^{-1}, while the control site had an EC of 0.74 dSm^{-1}, indicating high and moderate salinity hazard, respectively. The concentration of chlorides was also used as the basis for irrigation water quality classification. Figure 3 revealed the highest amount of chloride (184.44 $meqL^{-1}$) in domestic water sample, with slight decrease in industrial water sample which recorded 182.22 $meqL^{-1}$ and the lowest amount (26.66 $meqL^{-1}$) was recorded in control site.

The sodium adsorption ratio of all water samples was found to be low, which indicate less concentration of Na and higher concentration of Ca and Mg respectively. This is in conformity with the research carried out by Nzamouhe and Omar (2020) which found the less effect of Na because Ca was the dominant cation in irrigation water. Similarly, Onokebhagbe *et al.*(2021) reported the computed SAR mean value of 1.32 mgL^{-1} and concluded that water samples were non sodic and safe for irrigation with regards to sodium hazard. These high RSC values may be attributed to the high presences of dissolved minerals such as carbonates and bicarbonates in the water samples. Nzamouhe and Omar (2020) related the high RSC value to the weathering of basalt which is igneous rock present in the study area. High concentration of the chlorides found in the water samples in this study further reinstate the potential risk associated with using the water for irrigation without necessary treatment.

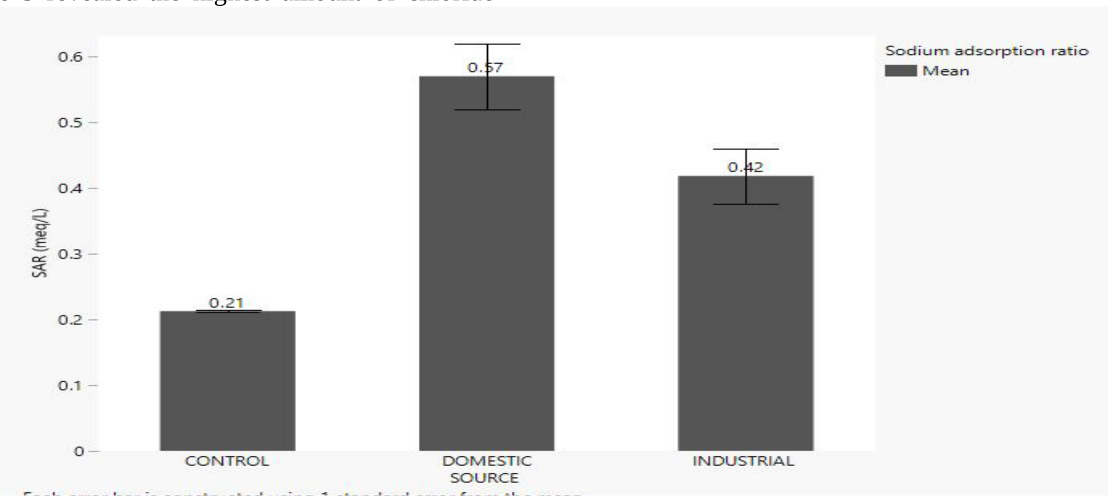

Figure 2: Sodium adsorption ratio in irrigation water of the study area

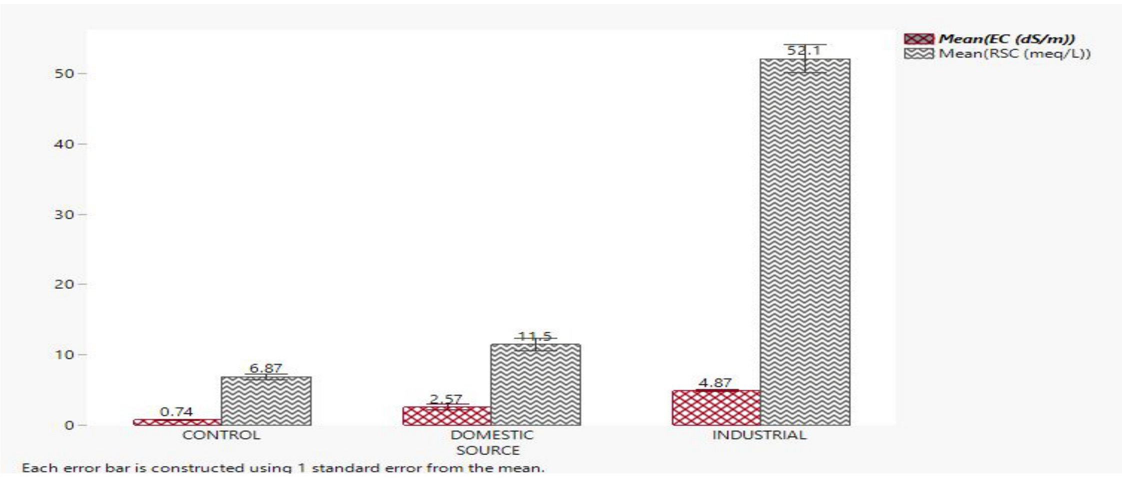

Figure 3: Residual sodium carbonate and EC in water samples

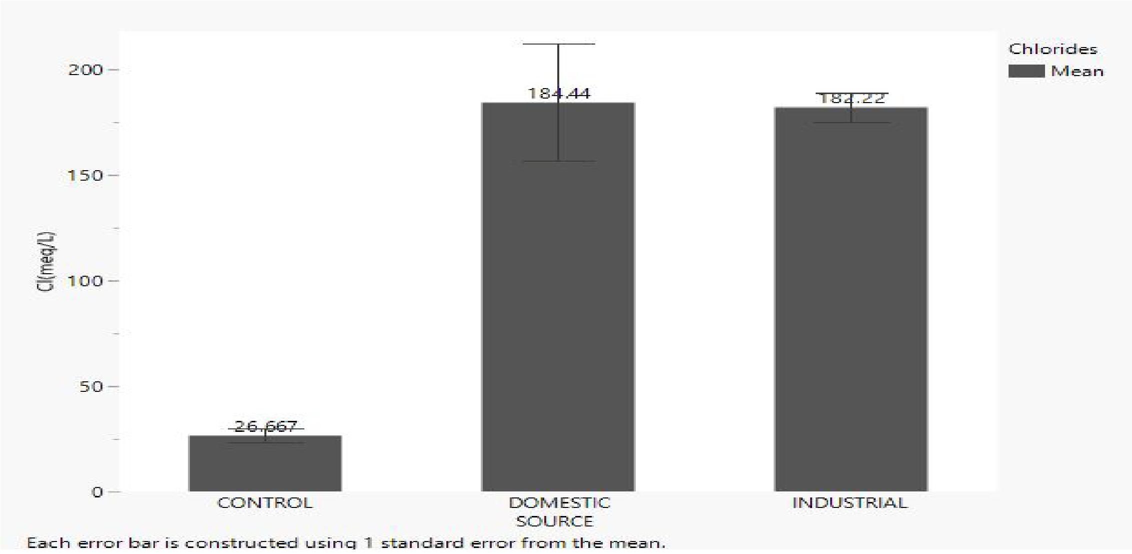

Figure 4: Concentration of chlorides in the water samples

Heavy metals in water

The concentrations of Pb, Cr, Cd, Cu, and Ni in water samples from different sampling sites were displayed in Table 3. Chromium was not detected in any of the sampling sites. Lead was only detected in the water receiving industrial discharge. On the other hand, Cadmium was detected in all samples and the concentration ranged from 0.0008 mgl^{-1} to 0.015 mgl^{-1}, with the highest concentration of 0.015 mgl^{-1} recorded in the industrial discharge site. The p value of 0.001 indicates a significant difference between the samples, however, no significant difference was observed with change in the distances of sample collection. Copper and Nickel were also detected in the water samples and ranged from 0.016 mgL^{-1} to 0.028 mgL^{-1} and 0.009 mgL^{-1} to 0.025 mgL^{-1}, respectively. Both Cu and Ni had the highest concentration in the industrial discharge site. However, there was no significant difference in their concentration between the different sampling sites and sampling distances. The abundance of the heavy metals in water samples of the study area were in the order of Cu > Ni > Cd > Pb > Cr and were below the WHO (2022) permissible limit for surface water, except for Cd, which recorded 0.015 mgl^{-1} in the industrial discharge site, exceeding its limit of 0.01 mgl^{-1}.

Generally, the concentration of heavy metals in the water samples were low and are below world health organization permissible limit for surface water except for cadmium (Cd) in industrial discharge site which was observed to be slightly higher than its permissible limit of 0.01 mgL^{-1} and thus poses more potential ecological risk than other heavy metals in the study area. Similar result was observed by Sharafi *et al.* (2022) and attributed the higher concentration of heavy metals in Gharasou river, karmenshah Iran to the existence of various treated and untreated industrial waste water which increases the concentration of heavy metals in it.

Table 3: Concentration of analyzed heavy metals in water samples

Source of variation		Pb (mgl^{-1})	Cr (mgl^{-1})	Cd (mgl^{-1})	Cu (mgl^{-1})	Ni (mgl^{-1})
source						
	B	0.0038	ND	0.015^{a}	0.028	0.025^{a}
	A	ND	ND	0.009^{b}	0.016	0.013^{b}
	C	ND	ND	0.008^{b}	0.017	0.009^{b}
	SE	0.002	-	0.0005	0.0038	0.003
	Prob.	.38	-	<.0001	.078	.0068
Distance						
	1	ND	ND	0.012^{a}	0.021	0.019
	2	ND	ND	0.011^{ab}	0.018	0.012
	3	0.0038	ND	0.009^{b}	0.021	0.016
	SE	0.002	-	0.0005	0.0038	0.003
	Prob.	.38	-	.013	.75	.32
Source*Distance						
	B1	ND	ND	0.017^{a}	0.033	0.034
	B2	ND	ND	0.014^{ab}	0.021	0.015
	B3	0.011	ND	0.013^{ab}	0.030	0.026
	A1	ND	ND	0.010^{bcd}	0.015	0.014
	A2	ND	ND	0.011^{bc}	0.016	0.012
	A3	ND	ND	0.006^{d}	0.018	0.013
	C	ND	ND	0.008^{cd}	0.017	0.009
	SE	0.0038	-	0.0009	0.0066	0.005
	Prob.	.43	-	.041	.86	.45

ND signifies not detected; SE denotes standard error; letters in superscript denotes the mean rank

Pollution assessment of the analyzed heavy metals determined

The extent of heavy metals pollution based on contamination factor, ecological risk index, degree of contamination, pollution load index and potential ecological risk were presented in Table 4. The contamination factor of Pb, Cr, Cu and Ni were within <1 category which according to Loska *et al.* (1997) were described as low contamination class in all sampling sites. However, Cadmium was observed to have CF value of 1.5 in industrial discharge site which indicate moderate pollution, with low pollution level in both control and domestic discharge sites respectively. Similarly, the results of ecological risk assessment were all observed to be within low contamination classes except for cadmium which showed a mild ecological risk and moderate potential risk. The value of computed degree of contamination and pollution load index (PLI) were also observed to be <7 and <1 in all sampling sites respectively. This further explain the low contamination and or pollution by the analyzed heavy metals in the study area. Iyama *et al*. (2021) found similar result of ecological risk by heavy metals in three agricultural farm in Port Harcourt, Nigeria, of which only Cadmium was observed to have moderate ecological risk in two stations and recommend further studies. Cd is a known human carcinogen and when it is extensively dispersed in water environment, it has the capacity to bio-accumulate in fishes, aquatic plants, and the sediment. (Kieri, 2021).

Table 4: Contamination factor, ecological risk index, Degree of contamination, pollution load index and Potential ecological risk index of the heavy metals in irrigation water in Kano

Sample ID	CF					ERI					DoC	PLI	PERI
	Pb	Cr	Cd	Cu	Ni	Pb	Cr	Cd	Cu	Ni			
B	7.6×10^{-4}	-	1.5	.014	.009	.0038	-	45	.07	.625	1.64	.06	45.69
A	-	-	0.9	.008	.125	-	-	27	.04	.325	1.033	.24	28.39
C	-	-	0.8	.0085	.045	-	-	24	.0425	.225	1.25	.19	25.90

CONCLUSION

The high electrical conductivity, residual sodium carbonate (RSC) and chlorides both in industrial and domestic discharge sites, may potentially introduce a significant problem of salinity and environmental toxicity if used without necessary treatments and precautions. The study also revealed the low concentration of heavy metals in water samples collected in the study area. This also showed that river water in the area was not at risk of contamination by the analyzed heavy metals with exception of cadmium from industrial waste which showed a slight buildup of the metals than other samples and hence have moderate contamination risk. As such, Farmers need to be enlightened about the adverse effect of using contaminated water for irrigation. Additionally, Government and regulatory agencies should take necessary action to regulate and monitor the release of the effluent from both domestic and industrial sources into the water bodies.

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