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CHARACTERISTICS OF EFFLUENTS FROM AQUACULTURE FARMS IN KANO STATE AND SUITABILITY AS IRRIGATION WATER

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ABSTRACT
This work assessed the physicochemical characteristics of aquaculture effluents generated in aquaculture farms in Kano State to establish their suitability as irrigation water. Samples were collected from different aquaculture farms in the urban and peri-urban areas where the farms are clustered, and the physicochemical parameters, including the concentrations of nutrients, heavy metals, electrical conductivity (EC), and sodium adsorption ratio (SAR) were evaluated. The physicochemical characteristics of the effluents vary across the farms and the differences in the mean values were statistically significant at the 0.05 confidence interval. However, post hoc analysis based on the Fisher LSD test showed that the concentrations of certain individual parameters were not statistically different at the 0.05 interval. The concentrations of heavy metals were mostly within the standard limits. The EC values of the samples ranged from 0.85 dS/m to 2.4 dS/m, which are classified as having 'slight to moderate restriction' based on the FAO guidelines. Based on the combined EC and SAR analysis, some effluents fall under the "none" degree of restriction and are, therefore, suitable for irrigation. However, for some samples, such as that obtained from Farm No. 8 with SAR of 4.48 and a corresponding EC of 104 dS/m, the effluents are classified as having "slight to moderate" degrees of restriction, and should therefore be used with caution. The results show that although aquaculture effluents can be used as irrigation water, high SAR and EC may pose challenges. Thus, it is necessary to evaluate the suitability of the effluents before using them.

Keywords: Irrigation water quality, Wastewater reuse, Sustainability, Aquaculture effluents

INTRODUCTION
Aquaculture production is a fast-growing sector in food production that contributes significantly to global dietary demands and provides sources of livelihood to many people. Estimates show that aquaculture production directly employs about 20.6 million people globally (Mair et al., 2023). While China has remained the largest aquaculture producer in the world, Nigeria dominates the aquaculture production in Sub-Sahara Africa (Diyzee et al., 2022). Fisheries and aquaculture contribute about 3-4% of Nigeria's GDP whilst supplying about 50% of the animal-based food demands (Subasinghe et al., 2021). These indicate that aquaculture will continue to play a significant role in the protein demand-supply dynamics in the context of the rapid increase in population.

Although the aquaculture industry has a huge positive impact on global and local economies, intensive aquaculture production poses a significant challenge of environmental pollution. Aquaculture production consumes large volumes of fresh water and generates huge quantities of effluents that have the potential to pollute the environment (Coldebella et al., 2018). Aquaculture effluents contain diverse organic pollutants from feed leftovers, antibiotics, and pesticides, and byproducts from the fish's metabolic activities (Ogunfowora et al., 2021). The composition of aquaculture effluents includes suspended solids, nutrients (nitrogen, phosphorous, ammonia), pharmaceutical compounds, heavy metals, and other oxygen-demanding compounds that may cause significant water pollution.

In Nigerian cities, aquaculture farms are mostly located in urban and peri-urban areas, leading to indiscriminate discharge of aquaculture effluents into urban drainage and water channels (Abubakar et al., 2023; Mgbemena et al., 2021). Several studies have assessed the characteristics of aquaculture effluents from various aquaculture farms, including potential impacts on the surrounding environments. Mgbemena et al., (2021) evaluated the physicochemical characteristics of aquaculture effluents from fish farms in Anambra, Imo, and Lagos states and reported variations in the characteristics of the effluents. (Akinsulire et al., 2018) assessed the impact of fish farm effluents in Lagos and reported incidences of environmental pollution due to improper handling of the effluents. A recent study by Famoofo and Adeniyi (2020) reported the detrimental effect of aquaculture effluents on the receiving environment around peri-urban areas in Ogun State.

Although studies on assessing the characteristics of aquaculture effluents in some parts of Nigeria have been reported, studies evaluating the characteristics of aquaculture effluents in Northern Nigeria are scarcely reported. The potential environmental impact of aquaculture effluent depends on its characteristics, which vary greatly depending on various factors. Thus, the impacts of aquaculture effluents must be considered on a case-by-case basis. In this work, we assessed the physicochemical characteristics of aquaculture effluents from selected fish farms in Kano State, and their suitability as irrigation water. It builds on our previous work (Abubakar et al., 2023) where we reported the generation and handling of aquaculture effluents in aquaculture farms in the State. Our overall goal is towards the utilization of aquaculture effluents as irrigation water for vegetable production in the State. Thus, the objective of this work is to evaluate the physicochemical and irrigation water quality parameters of aquaculture effluents in Kano State.

MATERIALS AND METHODS
Description of the study area and sample collection
The study was conducted in Kano State, located in the Northwestern part of Nigeria and lies at Latitude 12.0022° N and Longitude 8.5920° E. There is a growing number of fish farms in the State, which are mostly located within the metropolitan local government areas (LGAs). In this work, the samplings were carried out across thirteen (13) fish farms

in Gwale, Kano Municipal, Tarauni, Nasarawa, Dala, Fagge, Ungogo, and Kumbotso LGAs. For each sampling campaign, grab samples were collected in plastic bottles previously washed with distilled water. Samplings were done at the discharge points of the effluents and the collected samples were then taken to the laboratory for analysis.

Analysis of physicochemical parameters of effluents

The collected samples were analyzed to determine some physicochemical characteristics of the effluents. Since the effluents are being proposed as irrigation water for vegetable production, the analysis focuses on significant parameters per the irrigation water requirement. These include electrical conductivity (EC), total dissolved solids (TDS), and heavy metals. The EC and TDS of the samples were measured using a JENWAY 3540 Conductivity Meter (Cole-Parmer Ltd, UK). The concentrations of heavy metals, including Cu, Zn, Cr, Cd, and Pb were measured using Agilent Microwave Plasma Atomic Emission Spectrometers (MP-AES) (4210 Agilent Technologies). All analyses were performed according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2005).

To determine the suitability of the aquaculture effluents as irrigation water, additional parameters, including sodium adsorption ratio (SAR), Magnesium Adsorption Ratio, and specific ions such as Sodium (Na^+), Magnesium (Mg^{2+}) Calcium (Ca^{2+}), Potassium (K^+) were evaluated. The SAR is a measure of the amount of sodium (Na^+) relative to calcium (Ca^{2+}) and magnesium (Mg^{2+}) in the water. It is the ratio of the Na concentration divided by the square root of one-half of the Ca + Mg concentration. SAR was computed using Equation 1:

$$SAR = \frac{[Na^+]}{\sqrt{\frac{([Ca^{2+}]+[Mg^{2+}])}{2}}} \qquad (1)$$

Data Analysis

The data collected was subjected to descriptive analysis such as means and standard deviation. Analysis of variance was conducted to test whether there is a significant difference between means of the samples collected from the farms. Post hoc tests were carried out using Fisher's Least Significance Difference (LSD) to separate means that were statistically different from each other. Measurements of statistical difference were performed at the 0.05 confidence interval. All analyses were done using Microsoft Excel and OriginPro 2017.

RESULTS AND DISCUSSION

The physicochemical properties of the effluents from the fish farms were analyzed, with a focus on parameters that have implications for the potential utilization of the effluents as irrigation water for vegetable production. These parameters were categorized based on crop nutrients (macronutrients and micronutrients), heavy metals, and irrigation water quality parameters related to water salinity/sodicity. Thus, the discussion of the results obtained in this study is based on these broad categorizations.

Physicochemical Characteristics

Certain cations (e.g. Ca, K, and Mg) and metals are required by plants either in large amounts (macronutrients) or small quantities (micronutrients). The concentrations of plant nutrients, both macronutrients and micronutrients, in the aquaculture effluents were evaluated. Table 1 presents the means and standard deviations of the concentrations of the macronutrients and micronutrients in the analyzed samples. The mean concentrations of K range between 11.97 mg/L to 49.43 mg/L. The highest K was obtained at farm No. 7 (S7) while the lowest concentration was observed in the sample obtained from farm No. 1 (S1). The concentrations of K vary widely across the farms and the differences in the mean values were found to be statistically significant at the 0.05 confidence interval. However, the concentration of K obtained from Farm No. 10 was not significantly different from that of Farm No 2 (S2) based on the Fisher LSD test. The concentrations of K obtained in this work are lower than those reported by Musa et al., (2020) in the evaluation of the physicochemical properties of fish pond effluents in Minna, Nigeria. In their study, the concentrations of K ranged from 61.73 mg/L to 82.34 mg/L across five fish ponds. K is a major crop nutrient required by crops because it helps to regulate the opening and closing of the stomata for the exchange of water vapor, oxygen and carbon dioxide.

Table 1: Physicochemical properties of aquaculture effluents from the 13 farms

	Parameter (mg/L)							
Sample	**Zn**	**Ca**	**Ag**	**As**	**K**	**Mg**	**Na**	**Fe**
S1	7.26±1.1	19.30±0.06	5.92±0.03	10.75±0.04	11.96±0.11	2.87±0.02	38.12±0.07	0.87±0.01
S2	7.79±0.29	20.49±0.02	5.79±0.02	10.51±0.09	21.57±0.03	3.7±0.01	37.51±0.07	0.64±0.01
S3	7.58±0.28	20.10±0.45	5.27±0.00	9.74±0.02	27.1±0.17	3.41±0.02	34.82±0.11	1.01±0.01
S4	7.66±0.34	20.13±0.51	5.52±0.02	9.96±0.09	17.36±0.08	3.82±0.05	41.49±0.36	0.41±0.02
S5	7.66±0.34	18.47±0.52	5.53±0.02	10.09±0.08	22.3±0.05	3.23±0.04	37.97±0.17	0.06±0.01
S6	7.33±1.26	21.21±0.58	5.88±0.03	10.13±0.01	20.78±0.11	3.55±0.03	32.85±0.13	0.51±0.02
S7	7.4±0.59	26.08±0.11	5.15±0.01	9.31±0.17	49.43±0.19	5.32±0.04	44.56±0.17	2.49±0.01
S8	7.69±0.47	18.16±0.02	5.86±0.00	10.17±0.05	20.21±0.13	3.37±0.05	46.52±0.02	0.67±0.02
S9	7.65±0.52	24.35±0.12	5.39±0.01	9.51±0.04	37.16±0.47	4.7±0.06	33.37±0.22	1.69±0.01
S10	7.05±1.1	19.23±0.06	5.63±0.02	9.64±0.14	21.25±0.03	3.91±0.05	34.85±0.06	0.66±0.02
S11	7.87±0.26	19.97±0.02	5.62±0.02	9.83±0.07	28.41±0.25	3.84±0.07	31.68±0.17	0.87±0.10
S12	7.7±0.36	20.76±0.03	5.98±0.02	10.24±0.04	27.54±0.24	4.1±0.05	38.52±0.07	0.65±0.01
S13	7.79±0.35	19.64±0.06	6.03±0.01	10.36±0.09	26.74±0.13	4.07±0.04	39.01±0.04	0.71±0.01

Farm No.7 (S7) has the highest concentration of Magnesium (Mg) with 5.4 mg/L and Farm No.1 (S1) records the lowest with 2.8 mg/L. The differences in the mean concentrations of Mg across the farms were statistically significant at the 0.05 confidence level (P-value = 0). However, the Fisher LSD test shows that some of the mean values, such as S8 & S3, S11 & S4, S13 & S1 are not significantly different at the 0.05 level. Mg is an essential nutrient for fundamental physiological and biochemical processes in plants. It is largely involved in chlorophyll synthesis, production, transportation, and utilization of photoassimilates, enzyme activation, and protein synthesis. Zinc (Zn) is an essential nutrient required for the metabolism of plants, enzyme function, and ion transport. Consequently, inadequate Zn availability in soil is a main consideration for plant nutrition, resulting in a significant loss in production and grain nutrient content. From Table 1, Zn concentration ranges from 7.05 mg/L to 7.79 mg/L. However, there is no statistical difference in the mean values of Zn across the sampled farms at the 0.05 confidence level (P-value = 0.95). Although Zn is important for crops, it can be toxic to humans at high concentrations, and the World Health Organization has recommended a concentration of 3 mg/L for drinking water (Onyem, et al., 2015). The concentration levels of Zn in the aquaculture effluents are higher than threshold for irrigation water (2 mg/L) recommended by FAO (FAO 1995), and repeated applications may lead to Zn build-up in the soil.

Calcium (Ca) as an essential element in plants serves as a constituent for the development of the cell walls and membranes and thus, contributes to the structure of the cells and the upholding of physical barriers against pathogens. Ca concentration ranges from 18.16 to 26.08 mg/L. Also, it was noted that farm No. 7 has the highest concentration of Ca while farm No. 8 has the lowest concentration. The mean concentrations of Ca across the sample farm were statistically different at the 0.05 confidence level (Prob>F=0). However, the Fisher LSD test showed that there were no significant differences in mean concentrations of Ca between certain farms such as S3 & S2, S4 & S3, S4 & S3, and S8 & S5.

The samples collected have a wide range of Silver (Ag) concentrations with each farm concentration as shown in Table 1. Farm No. 13 has the highest concentration of silver with a concentration of 6.03 mg/L and farm No. 7 has the lowest where it recorded 5.15 mg/L. The mean values of Ag across the farms were statistically different at the 0.05 confidence level. However, the mean concentrations of Ag of S4 & S5, S6 & S1, S11 & S1, as well as S6 & S8 were not significantly different. A wide range of Arsenic concentrations was observed in the samples. Farm No. 1 has the highest concentration of As 10.8 mg/L while Farm No. 7 has the lowest concentration of 9.31 mg/L. The means values of As were significantly different across the sampled farms at the 0.05 confidence interval. However, there were no significant differences between certain pairs of farms such as S5 & S4, S6 & S5, and S10 & S9.

The farms have a wide range of Fe concentrations with farm No. 7 (S7) having the highest concentration of 2.49 mg/L while farm No. 5 (S5) has the lowest concentration of 0.06 mg/L. However, there was a statistically significant difference between the mean values of Fe across the sampled farms. Based on the Fisher LSD Test, only the Fe concentrations of S10 & S8, S11 & S1, S12 &S2, and S12&S1 are not significantly different. The concentrations of Fe observed in this study are higher than those reported by Omofunmi et al., (2016). Fe is essential for many plants' enzymatic activities and supports various biological functions. Although Fe is required by plants, high concentrations of Fe may have implications, such as clogging irrigation structures (Jaishankar et al., 2014).

Copper (Cu) is one of the essential plant micronutrients. Cu is required for many enzymatic activities in plants and chlorophyll. The deficiency of Cu can lead to increased susceptibility to diseases like ergot, which can cause significant yield loss in small grains. From the samples collected across 13 (Figure 1), farm No. 7 has the highest concentration of Cu with 0.08 mg/L while the lowest concentrations were observed in Farms No. 1, 2, 4, 8, and 10. Cu is also a heavy metal whose presence at certain concentrations could pose hazards to humans, and the World Health Organization has set a maximum permissible level of 2 mg/L in drinking water (WHO, 2004). Thus, the range of concentrations obtained in the aquaculture samples is below the threshold level.

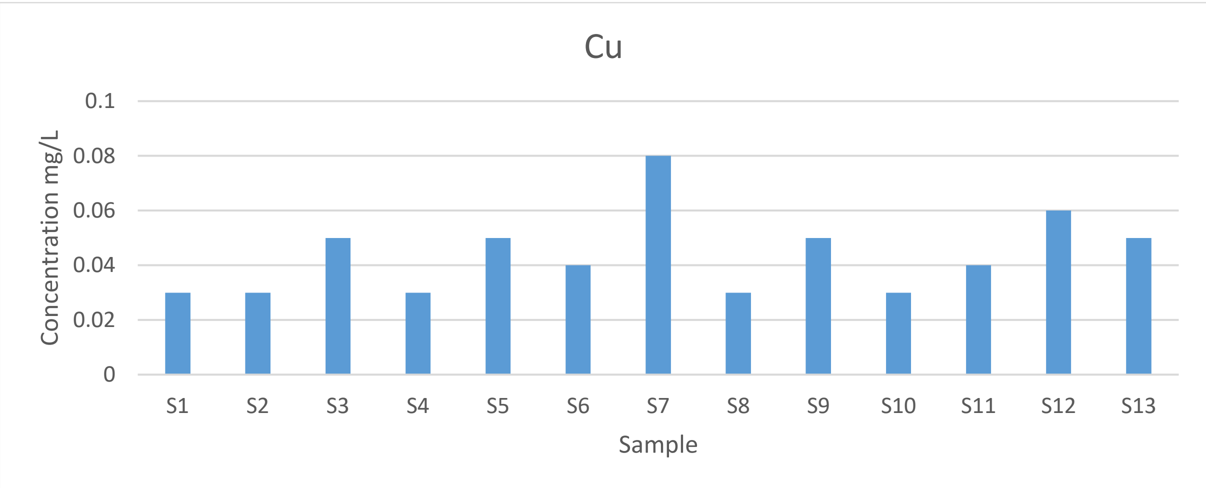

Figure 1: Concentrations of Copper (Cu) in the samples collected from the aquaculture farms

Figure 2 shows the range of concentration of Aluminum across the 13 farms. Aluminum is one of the most abundant elements found on Earth. It has been found to encourage plant growth and increase crop yield in acid soil. However, in certain forms, such as active Al ion it can be toxic to aquatic life and plants. Farm No. 13 recorded the highest Al concentration of 6.2 mg/L whilst no Al was detected in the effluents from Farms No. 1, 2, 4, 5, 6, 9, and 12.

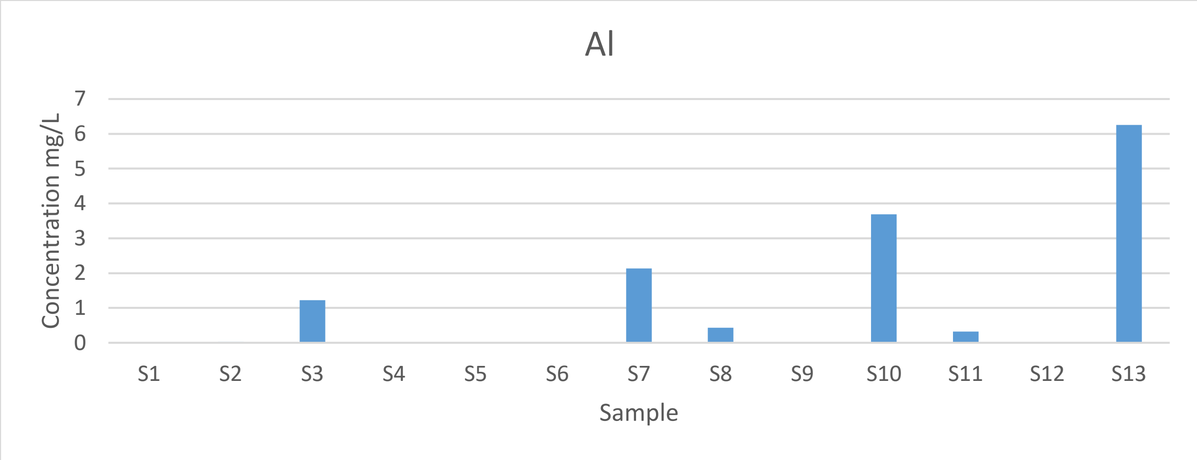

Figure 2: Concentrations of Aluminium (Al) in the samples collected from the aquaculture farms

Irrigation Water Quality Parameters

To assess the suitability of aquaculture effluents for irrigation, irrigation water parameters including EC, TDS Na, and SAR were evaluated. Plants are sensitive to electroconductivity for the absorption of nutrients and water. Figure 4.3 shows the values of EC across the farms and the FAO recommended for normal irrigation water. Farm No. 1 (S1) recorded the lowest concentration with 0.85 dS/m while Farm No. 10 (S10) recorded the highest with 2.4 dS/m. However, despite the variation in the EC values, there is no significant difference between the mean EC values across the 13 farms at the 0.05 interval (P-value = 0.94). Based on FAO guidelines (FAO, 1995), irrigation waters with EC values below 0.7 dS/m are classified as normal whilst values between 0.7 – 3.0 dS/m pose slight to moderate restriction for irrigation. On the other hand, EC values above 3.0 dS/m severely restrict irrigation. The EC values of these samples fall within the 'slight to moderate restriction' level, and should therefore be used with caution. Other studies have reported lower EC values in aquaculture effluents (Wairimu et al., (2019);Famoofo and Adeniyi (2020).

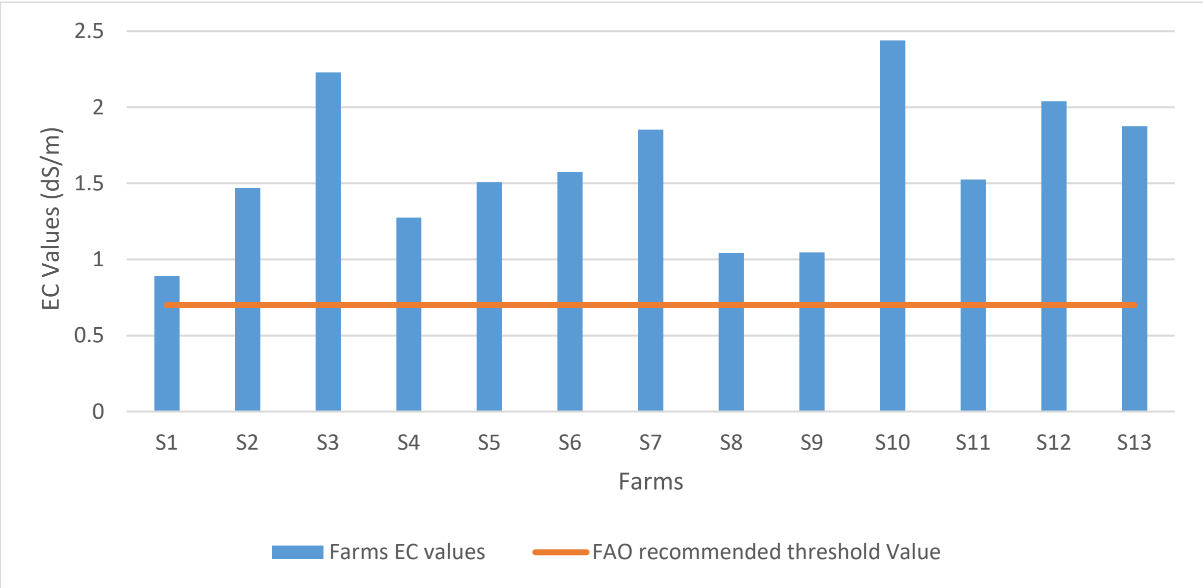

Figure 3: Values of Electrical Conductivity across the sampled farms

TDS is the measure of the total dissolved salts in water and for irrigation purposes, the FAO classified TDS based on the degree of restriction as "no restriction" (TDS < 450 mg/L), "slight to moderate restriction" (TDS > 450–2000 mg/L) and "severe restriction" (TDS > 2000 mg/L)(FAO, 1995). Thus, water with TDS above 450 mg/L is unsuitable for irrigation purposes. Figure 4 shows the TDS values across the farms and the FAO recommended threshold value for irrigation water. From the results, the lowest TDS of 550 mg/L was obtained in Farm No. 1 (S1) while Farm No. 9 (S9) recorded the highest TDS of 1490 mg/L. However, the mean values of the TDS across the farms are not significantly different (P-value = 0.99) at the 0.05 interval. All the samples have TDS values above the 450 mg/L threshold for normal irrigation water ("no restriction"), but below the "severe restriction" threshold (2000 mg/L). However, these TDS values indicated that if the aquaculture effluents are to be used for irrigation, they may pose a slight to moderate restriction. Famoofo and Adeniyi (2020) had reported lower EC values in their assessment of aquaculture effluents in Ogun, Nigeria.

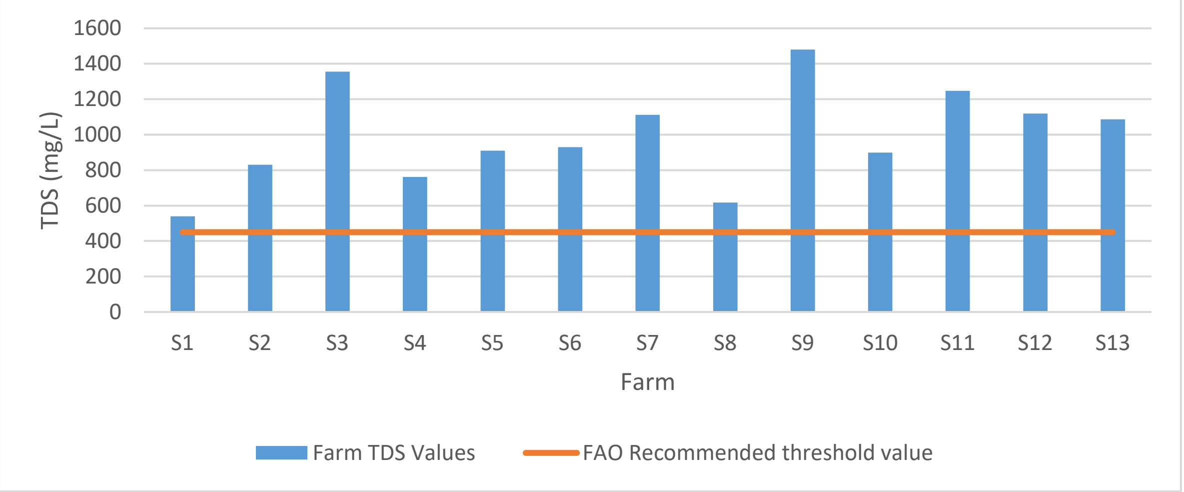

Figure 4: Values of total dissolved solids across the farms

The Na concentrations in the aquaculture effluents range from 31.56 mg/L to 46.52 mg/L, with sample with Farm No. 8 having the highest concentration. The concentrations of Na were statistically significant at the 0.05 confidence interval (P-value = 0). However, there is no significant difference between the mean concentrations of Na in S5 & S1 and S10 & S3. Concentrations of Na above 100 mg/L pose restrictions to the use of water for irrigation purposes, particularly for salt-sensitive crops (Adeyemi et al., 2019).

SAR is a significant irrigation water quality parameter in assessing the potential sodium hazard. The values of SAR of the aquaculture effluent samples with the corresponding FAO recommended threshold for normal irrigation water are depicted in Figure 6. SAR values below 3 are considered normal for irrigation water. Farm No. 9 (S9) has the lowest SAR of 2.35 while farm No. 8 (S8) has the highest SAR of 4.48. However, there is no significant difference between the mean SAR values across the farms. SAR values are normally analyzed alongside the values of EC as indicated in Table 2 (FAO, 1995). Considering the lowest SAR obtained in Farm No. 9 (2.35) and its corresponding EC of 1.05 dS/m, the samples fall under the “none” degree of restriction and are therefore suitable for irrigation. However, for S8 with the highest SAR (4.48) and a corresponding EC of 104 dS/m, the sample is classified as a “slight to moderate” degree of restriction (Table 2). Thus, some treatment may be required if it is used as irrigation water. Similar analysis can be applied to all the samples of aquaculture effluents.

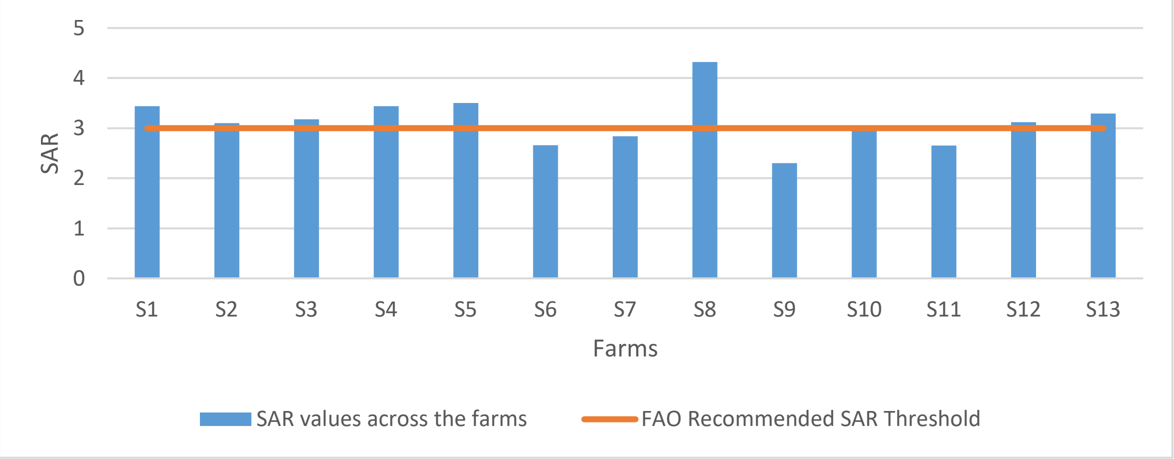

Figure 6: Values of Sodium adsorption ratio (SAR) across the farms

Table 2. Guidelines for interpretations of water quality for irrigation (adapted from FAO, (1995))

SAR	Degree of restriction EC		
	None	**Slight to moderate**	**Severe**
0 – 3	>0.7	0.7 – 0.2	<0.2
3 – 6	>1.2	1.2 – 0.3	<0.3
6 – 12	>1.9	1.9 – 0.5	<05
12 – 20	>2.9	2.9 – 1.3	<1.3
20 – 24	>5.0	5.0 – 2.9	<2.9

CONCLUSION

This work assessed the characteristics of aquaculture effluents generated in farm fish in Kano State with the view of its potential use as irrigation water. Samples were collected from different fish farms and the physicochemical characteristics, including irrigation water quality parameters, were evaluated.

The results showed that the characteristics of the aquaculture effluent vary across the farms and the differences in the mean values of most of the parameters were statistically significant at the 0.05 confidence interval. However, post hoc analysis based on the Fisher LSD test indicated the concentrations of certain individual parameters were not statistically different. The EC values of the samples (0.85 dS/m - 2.4 dS/m) fall within the 'slight to moderate restriction' level, and should therefore be used with caution. Based on the EC and SAR analysis, some samples fall under the "none" degree of restriction and are, therefore, suitable for irrigation. However, for some samples, such as that obtained from Farm No. 8 (S8) with SAR 4.48 and a corresponding EC of 104 dS/m, the effluents are classified as having a "slight to moderate" degree of restriction. The results of this work show that for aquaculture effluents to be used as irrigation water, it is necessary to evaluate the physicochemical and irrigation water quality parameters to minimize potential hazards to soil and crops. Cost-effective treatment technologies, such phytoremediation, could be employed to treat the aquaculture utilizing it as irrigation water.

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