Afropolitan Journals

This open-access article is distributed under Creative Commons Attribution 4.0 license

ISSN: 3027-2637 www.afropolitanjournals.com

Assessment of Water Quality for Irrigation in Dutsin-Ma Dam, Katsina State, Nigeria

Sufiyanu Sani [1]; Abdulkadir Aliyu [1]; Babangida Abubakar [1]; Salisu Muazu [2]; Dahiru Wakili Habib [3]; Mahmud Sani [4]; and [5]Hamza Haruna

[1]Department of Soil Science, Federal University Dutsin-Ma, P.M.B. 5001 Dutsin-Ma, Katsina State, Nigeria. [2]Center for Dry Land Agriculture, Bayero University Kano, Nigeria. Department of Soil Science, Federal University Dutsin-Ma, P.M.B. 5001 Dutsin-Ma, Katsina State, Nigeria. [3]Department of Soil Science, Bayero University Kano, P.M.B. 3011 Kano, Kano State, Nigeria. [4]Department of Agronomy, Federal University Gashua, P.M.B. 5001 Gashua, Yobe State, Nigeria. [5]Desert Research Center, Yobe State University, Damaturu, Yobe State, Nigeria.

Corresponding author: sufiyanusanii@gmail.com

***DOI**: https://doi.org/10.62154/ajasfr.2025.020.01022*

Abstract

Water quality is a critical determinant of agricultural productivity, particularly in semi-arid regions where irrigation is essential. This study assesses the physicochemical characteristics of Dutsin-Ma Dam water to evaluate its suitability for irrigation. With growing reliance on the dam for year-round farming in Dutsin-Ma Local Government Area, Katsina State, understanding water quality is vital to safeguarding soil health and optimizing crop yield. The research employed field-based quantitative methods involving the collection of water samples from three strategic points the inflow, mid-reservoir, and outflow zones. Standard laboratory analyses were conducted to determine parameters such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), nitrate, phosphate, sulfate, bicarbonate, sodium, potassium, calcium, magnesium, and boron. Furthermore, key irrigation suitability indices including Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Magnesium Adsorption Ratio (MAR), Kelly's Ratio (KR), Potential Salinity (PS), and Total Hardness (TH) were calculated using established equations. Results indicated that the dam water exhibits neutral pH (mean = 7.00), low salinity (mean EC = 0.21 dS/m), and low sodium hazard (mean SAR = 0.003), making it suitable for irrigation. However, nitrate levels were significantly high (mean = 14.04 Mg/L), exceeding FAO's safe threshold for irrigation water. This suggests potential non-point source pollution, likely from agricultural runoff or sewage discharge. Other parameters such as phosphate, sulfate, and boron were within acceptable limits. The correlation analysis revealed strong relationships between sodium and SAR, magnesium and SSP, and chloride and PS, indicating the dominant influence of these ions on water suitability. Overall, Dutsin-Ma Dam water is safe for irrigation under current conditions, but long-term usage may pose risks without proper management. The study recommends regular water quality monitoring, improved fertilizer management to curb nitrate contamination, and awareness programs for farmers on sustainable irrigation practices.

Keywords: Irrigation Water Quality, Sodium Adsorption Ratio, Soluble Sodium Percentage, Salinity, Nitrate, Semiarid Agriculture, Dutsin-Ma Dam, Katsina State.

Introduction

Water is a crucial resource for agricultural productivity, particularly in regions with irregular rainfall like Northern Nigeria. Irrigation is essential for year-round farming and food security in arid and semi-arid areas. However, the quality of water used for irrigation is critical, as poor chemical characteristics can harm soil health and crop productivity (FAO, 2020; Hussaini et al., 2021).

Agriculture in Dutsin-Ma relies heavily on irrigation due to erratic rainfall. Farmers in the region depend on water from Dutsin-Ma Dam to sustain crop production throughout the year. Despite this reliance, there is a notable lack of scientific data on the physicochemical characteristics of the dam's water, presenting a risk to soil quality and crop productivity (Usman et al., 2020; Bello et al., 2021).

Dutsin-Ma Dam in Katsina State, Nigeria is a vital water body used for both domestic consumption and agricultural purposes. The increasing population pressure, climate change effects, and intensifying agricultural activities have heightened the reliance on this dam. However, the quality of water from this dam has not been extensively evaluated for its suitability in irrigation, which is a significant concern (Abdullahi et al., 2021; Sani et al., 2020 and Suleiman et al., 2022).

Using poor-quality irrigation water can lead to soil-related issues like increased salinity, sodicity, and nutrient imbalances. These problems compromise soil structure, reduce permeability, and limit plant root access to water and nutrients. This can result in land degradation and diminished agricultural yields, which is particularly concerning in a region facing food insecurity (Rahman et al., 2019; Yusuf et al., 2023).

The lack of routine water quality monitoring means that farmers and agricultural extension workers lack critical information to guide irrigation management decisions. This knowledge gap hinders the development of effective agricultural policies and adaptation strategies necessary for climate resilience (Abubakar et al., 2021).

There is an urgent need to evaluate the irrigation suitability of water from Dutsin-Ma Dam. This study will provide the necessary data for sustainable agricultural planning and resource management in the area (Suleiman et al., 2022). The findings will provide scientific evidence on whether Dutsin-Ma Dam water is chemically suitable for irrigation, which is essential for preventing soil degradation and enhancing agricultural productivity (FAO, 2020; Ibrahim et al., 2020).

This research is aligned with several Sustainable Development Goals (SDGs), including SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), and SDG 13 (Climate Action). Assessing the chemical composition of irrigation water is vital for ensuring long-term agricultural sustainability (UN-Water, 2023).

The objectives of this study are to evaluate the suitability of the water for irrigation purposes by analyzing the key water quality parameters of Dutsin-Ma Dam Katsina State Nigeria and to assess the suitability of the dam water for irrigation using standard indices such as SAR, SSP, MAR, KR, and PS.

Methodology

Study Area Description

The study was conducted at Dutsin-Ma Dam, situated within Dutsin-Ma Local Government Area (LGA) of Katsina State, Northwestern Nigeria. The dam is a key hydrological structure primarily constructed for both irrigation and domestic water supply. Geographically, Dutsin-Ma lies approximately on latitude 12°27' N and longitude 7°29' E, with an average elevation of about 605 meters above sea level. The region falls within the Sudan savannah agro-ecological zone, characterized by seasonal rainfall, moderate vegetation, and high evapotranspiration rates. The area experiences a tropical continental climate, with two distinct seasons: the wet season (May to October) and the dry season (November to April). Annual rainfall ranges between 700 mm and 1000 mm, which supports agricultural activities including irrigation, particularly during the dry season (Abaje et al 2020). The surrounding communities rely heavily on the dam for farming, fishing, and domestic uses, making the assessment of its water quality critical to food security and health in the area (Aliyu *et al* 2025).

Research Design

This study employed a quantitative, field-based experimental design, focusing on empirical measurement and laboratory analysis of water samples collected from Dutsin-Ma Dam. The approach was structured to identify, quantify, and interpret the levels of key water quality parameters that determine the suitability of water for irrigation. The research design incorporated both descriptive statistics (to summarize data) and inferential correlation techniques (to evaluate relationships among chemical constituents and irrigation indices).

Sample Collection and Preparation

Water samples were systematically collected from three distinct and strategic points within Dutsin-Ma Dam to capture potential spatial variations in water quality. Sampling locations included the inflow zone, mid-reservoir, and outflow point, based on accessibility and representativeness of overall water body conditions. Twenty (20) water samples were collected each making a total of 60 samples. Each sample was taken using 1-liter high-density polyethylene (HDPE) bottles previously washed with nitric acid and distilled water to avoid contamination. Immediately after collection, the samples were stored in a portable icebox (at < 4°C) to preserve physicochemical integrity and transported to the laboratory within 24 hours for prompt analysis. In the laboratory, samples were split for specific tests, filtered when necessary, and prepared according to standard procedures outlined by APHA (2017) and FAO (2020). The water samples were taken in May 2025.

Parameters Measured

The assessment involved the evaluation of the following physicochemical and irrigation-related parameters:The water samples were tested for pH, TDS, and EC using (Jenway PFP7) 3 in 1 pH, TDS and EC meters respectively. Basic cations were measured using flame

photometers for Na+ and K+, and Atomic Absorption Spectrophotometer for Ca2+ and Mg2+. Nitrate of the water samples was determined using UV Spectrophotometry. SO_4^{2-} BO_3^{2-} and PO_4^{3-} were determined using Spectrophotometer HCO_3^- and Cl^- was determined using titrimetric method. Sodium adsorption ratio (SAR) was calculated using Equation as described by (USDA 1954) below:

$$SAR = \frac{\text{Na+}}{\sqrt{\frac{\sqrt{ca^{2+} + mg2 +}}{2}}}$$

where all the concentrations of the cations are expressed in meq/L (milliequivalent per liter).

Soluble sodium percentage (SSP) was calculated using Equation described by (Todd 1959):

$$\text{SSP} = \frac{\text{Na}^+ + K^+}{ca^{2+} + mg^{2+} + \text{Na}^+ + k^+}$$

where all the concentrations of the cations are expressed in meq/L (milliequivalents per liter).

Magnesium adsorption ratio (MAR) was calculated using Equation as described by (Raghunath, 1987).

$$MAR = \frac{mg^{2+}}{ca^{2+} + mg^{2+}} \times 100$$

Kelley's ratio (KR) was calculated using Equation of Kelley (1963):

$$KR = \frac{\text{Na}^+}{ca^{2+} + mg^{2+}}$$

where all the concentrations of the cations are expressed in meq/L (milliequivalents per liter).

Sodium percentage was calculated using the equation:

$$SP = \frac{\text{Na}^+}{ca^{2+} + mg^{2+} + \text{Na}^+ + k^+} \times 100$$

The total hardness (TH) was calculated using Equation as described by (Raghunath 1987):

$$TH = (ca^{2+} + mg^{2+}) \times 50$$

Statistical Analysis

Data obtained were subjected to comprehensive statistical analysis using IBM SPSS Version 25 and Microsoft Excel: Descriptive Statistics was used to compute mean, range, standard deviation, variance, skewness, and kurtosis for each parameter to understand the distribution and variability. For Inferential Statistics: A Pearson correlation matrix was generated to evaluate linear relationships among different water quality parameters and irrigation indices.

Results

Table 3.1: Descriptive Statistics of Water Quality Parameters

Parameter	Minimum	Maximum	Mean	Std. Dev	Variance	Skewness	Kurtosis
pH	6.20	7.30	7.00	0.36	0.13	-1.648	2.287
EC (dS/m)	0.20	0.21	0.21	0.007	0.00005	-0.617	-1.600
NO_3^- (Mg/L)	7.12	36.4	14.04	35.22	1240.4	2.290	6.067
PO_4^{3-} (Mg/L)	0.142	0.208	0.166	0.026	0.0007	0.876	1.034
SO_4^{2-} (mg/L)	11.90	71.42	32.73	15.60	243.36	1.421	3.059
HCO_3^- (mg/L)	30.50	122.00	91.50	18.12	328.32	-1.334	1.561
Na^+ (meq/L)	0.0014	0.0047	0.0051	0.0012	0.0000014	0.288	-1.027
K^+ (meq/L)	0.006	0.037	0.020	0.009	0.00009	0.814	0.311
Ca^{2+} (meq/L)	0.485	0.716	0.601	0.072	0.0052	0.112	-1.035
Mg^{2+} (meq/L)	0.179	0.690	0.385	0.102	0.0104	0.954	0.167
B (mg/L)	0.116	0.448	0.313	0.089	0.0079	-0.357	-0.911
TDS(mg/L)	138	151	160.65	0.157	14.19	-0.346	1.432

pH

The pH of irrigation water is a crucial parameter, influencing nutrient availability and soil health. The pH ranged from 6.2 to 7.3 with a mean of 7.00, suggesting that the water is neutral to slightly acidic, which falls within the acceptable range for irrigation as it allows for optimal nutrient uptake by crops (Boukich et al., 2025; WHO, 2017). The skewness (-1.648) indicates a negatively skewed distribution, and the kurtosis (2.287) suggests light tails, implying most values are clustered around the mean. The comprehensive analysis of the Dutsin-Ma Dam water quality reveals significant insights into its suitability for irrigation. The pH values (6.2 to 7.3) falling within the neutral to slightly acidic range indicate that the water is generally safe for both agricultural use. This aligns with WHO (2017) guidelines, supporting the conclusion that pH is unlikely to adversely affect crop growth or human health. The negative skewness suggests that most pH readings cluster near neutrality, minimizing the risk of extreme acidity or alkalinity. Similar studies in Nigeria have also reported pH values within this range, indicating suitable water quality for irrigation (Magaji et al 2020; Sani et al 2020).

Electrical Conductivity (EC)

The Electrical conductivity (EC) of irrigation water measures its salinity and is one of the most important parameters used to determine the quality of irrigation water, often defined as the capacity of water to transmit electric current, and can impact soil structure and crop productivity (Amankwa et al., 2023; Fipps, 2003). The EC values as observed in the study area were low (0.20- 0.21 dS/m) with a mean of 0.21 dS/m, indicating low salinity hazard. According to FAO (2020), EC values less than 0.7 dS/m are considered safe for irrigation.

This makes the water suitable for use on most soils and crops. This means that the water will not contribute to soil salinization, a critical factor in maintaining soil health for sustainable crop production (Fadl et al., 2024). The low SAR and KR values further corroborate the absence of sodium hazards, which is vital because high sodium concentrations can deteriorate soil structure and reduce permeability, negatively affecting crop yields.The irrigation water's low EC values are likely due to its source being a low-salinity aquifer or surface water body, which naturally has lower salt concentrations; a similar result was obtained by Bashir et al. (2017), which considered the water as excellent for irrigation

Total Dissolved Solids (TDS)

The TDS of irrigation water measures the concentration of dissolved solids, which can impact soil health and crop productivity. The mean TDS value of 160.65 ppm in the study falls below the threshold of 450 ppm, considered suitable for irrigation (Ayers and Westcot, 1985). The moderate variability in TDS levels (coefficient of variation = 14.19%) suggests relatively consistent water quality. The low TDS level may be due to the water source being a surface water body with limited interaction with mineral-rich geological formations. Similar Studies in Nigeria have been reported with similar TDS values, indicating suitable water quality for irrigation (Sani et al 2022; Magaji et al 2020; Bashir et al 2017).

Specific Ions and Elemental Concentrations

The analysis of specific ions and elemental concentrations in irrigation water is crucial for assessing its suitability for agricultural purposes. This study examined the concentrations of various ions, including sodium (Na^+), chloride (Cl^-), boron (B), bicarbonate (HCO_3^-), nitrate (NO_3^-), sulfate (SO_4^{2-}), phosphate (PO_4^{3-}), calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+).

Sodium (Na+) Concentration

Sodium (Na^+) content is a crucial indicator of irrigation water quality. According to Ayers and Westcot (1985), sodium concentrations less than 100 mg/L indicate no restriction for irrigation use. High sodium levels in irrigation water can lead to the displacement of exchangeable cations, such as Ca^{2+} and Mg^{2+}, from soil clay minerals, resulting in reduced soil permeability and fertility (Adegbola et al., 2019). However, the sodium concentration in the water samples is within acceptable limits, with a Very low (0.0014–0.0047 meq/L), and a mean of 0.0051 meq/L indicating no sodium hazard thereby posing no significant risk of sodium toxicity to crops (Bauder et al., 2003; Wilcox, 1955). The low sodium levels may be attributed to the use of surface water and good drainage, allowing for leaching of soluble salts due to the sandy nature of the soil (Bashir et al., 2017). Despite the acceptable sodium levels, high variability in sodium concentrations may pose potential risks to soil health and productivity (Ayers and Westcot, 1985). Similar finding was also observed by Amankwa et al 2023 and Adegbola et al 2019

Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) Concentrations

Ca is an essential nutrient for plant growth and development, and its presence in irrigation water can have positive impacts on plants and soil, when Ca is present in irrigation water, it can help to reduce the negative impacts of other contaminants such as Na, Cl, and heavy metals. Ca competes with these contaminants for uptake by the plant and can help to reduce their accumulation in plant tissues. In addition, Ca can help to improve soil structure and water-holding capacity, which can improve soil fertility and reduce the risk of soil erosion (Adegbola et al 2019) and as such, the 0.60 meq/L of calcium recorded in this study could be a vital mineral in the irrigation water for vegetable farming. The calcium concentration of 0.60 meq/L and magnesium concentration of 0.385 meq/L are essential nutrients for plant growth. This value falls below the maximum contamination limit for irrigation (400 mg/l), this signify that the water is suitable for irrigation use (FAO 2020).

Magnesium (Mg) is essential for plant growth, serving as a crucial component of chlorophyll and an enzyme activator (Zaman et al., 2018; Qadir et al., 2018). The irrigation water in this study has a range between (0.179–0.690 meq/L) and mean magnesium level of 0.385 meq/L, which is sufficient for plant growth and development. This value is below the maximum contamination limit for irrigation (61 mg/L), indicating that the water is suitable for irrigation use (Ayers and Westcot, 1985). The magnesium levels in the irrigation water are therefore conducive to crop production.

Potassium (K^+) Concentration

Potassium (K^+) is a vital nutrient for plant growth, but excessive levels in irrigation water can be harmful. The observed potassium concentration of 0.020 meq/L in the irrigation water is sufficient for plant growth and well below the FAO's 2 mg/L threshold, posing no toxicity risk to crops (Oster et al., 2016). The low and consistent potassium levels suggest that the water source's natural chemistry and limited potassium input are likely reasons for the low K+ levels, making it suitable for irrigation (Adegbola et al., 2019). Furthermore, the sandy or semi-arid nature of the environment may also contribute to the low potassium concentration in irrigation water, due to factors such as limited potassium-rich minerals, low cation exchange capacity, high leaching rates, limited organic matter, weathering and erosion processes, and the source of irrigation water (Bauder, 2003).

Nitrate (NO_3^-)

Nitrogen is a major nutrient needed by the plant, its abundance is desired in irrigation water; Nitrate ranged widely from 7.12 to 36.4 Mg/l with a high mean of 14.04 Mg/l and standard deviation of 35.22, indicating variability in nitrate sources. The recommended value of Nitrate-N in irrigation water varies depending on crop, soil type, and irrigation management practices. According to FAO guidelines, the maximum allowable concentration of nitrate-N (NO_3^--N) is approximately 5-10 mg/L, while the US EPA recommends a maximum of 10 mg/L for sensitive crops. Crop-specific guidelines also exist, with leafy greens and some fruits requiring stricter limits (5-7 mg/L NO_3^--N) and other crops like corn and wheat tolerating higher levels (10-15 mg/L NO_3^--N).The values obtained in the

study area exceeds the recommended limit of 5-10 Mg/l recommended for standard irrigation water (Ayers and Westcot, 1985) suggesting potential health risks (FAO 2007).The Skewness (2.290) and kurtosis (6.067) confirm an extremely skewed and peaked distribution suggest irregular sources, possibly agricultural runoff or sewage contamination. This underscores the need for regular monitoring and possibly treatment if the water is used for domestic purposes. The High level of NO_3-N concentration in the water within the study area could be attributed to an increased use of nitrogen based fertilizer and from run off from the sorrounding farms and possibly from sewage from homes. This is similar to the findings of Keeney et al (2014).

Phosphate (PO_4^{3-})

Phosphate is an essential nutrient for plant growth, but too much of it in irrigation water can be harmful. Excessive phosphate levels can lead to eutrophication, which negatively impacts plant growth and soil health (Ali et al., 2020). To prevent this, the recommended phosphate levels in irrigation water are between 0.5-1.0 mg/L, according to Ayers and Westcot (1985) and the Food and Agriculture Organization (FAO, 1992). Levels above 1.0-2.0 mg/L can cause problems like eutrophication and nutrient imbalances (FAO, 1992). The good news is that the recorded phosphate concentration of 0.166 mg/L having a range of (0.142–0.208 Mg/l) in the study area is within the safe range, indicating that the water quality is high. The low phosphate levels may be due to factors like natural water sources, limited phosphate fertilizer use, soil adsorption, minimal industrial activity, water treatment processes, and sustainable agricultural practices

Sulphate (SO_4^{2-})

Sulphate ions significantly influence water salinity, and high levels of sulphates in irrigation water can impede nutrient uptake in soils (Ali et al., 2020; Sani et al; 2020). While moderate sulphate levels can benefit plant growth, excessive amounts can lead to soil salinity, alkalinity, and toxicity issues (Ashie et al., 2024; Zaman et al., 2018). The sulphate concentration recorded in this study ranged from 11.90 to 71.42 mg/L (mean = 32.73 mg/L), is within the maximum limit of 250 mg/L recommended by the FAO (2023). This relatively low sulphate level may be attributed to the limited use of fertilizers by farmers due to their low-income status and the absence of nearby industrial activities that could otherwise introduce high sulphate levels into the irrigation water (Aliyu et al., 2017).

Bicarbonate (HCO_3^-)

Bicarbonate is a crucial anion in irrigation water, and moderate concentrations, as found in the sampled water, are suitable for plant growth. However, high bicarbonate levels can impact mineral nutrient uptake and metabolism in plants. At near-neutral pH values, dissolved bicarbonate (HCO3-) is the dominant ion, while carbonate and other anions become significant only at pH levels above 9.0 (Elghandour et al., 1985; Sundararajan and Sabarathinam, 2014). The bicarbonate concentration in the irrigation water ranges from

30.5 mg/L to 122 mg/L, with a mean value of 91.50 mg/L, which is within the permissible limit of 500 mg/L set by the FAO (1989). This suggests that the bicarbonate levels in the study area pose no significant toxicity concern for irrigation use. However, the high coefficient of variation (CV) of 328% and standard deviation (SD) of 50 indicate significant variability in bicarbonate levels. The skewness and kurtosis values of -1.334 and 1.561 respectively suggest a non-normal distribution with potential outliers, which may impact soil pH and nutrient availability, potentially affecting crop growth and productivity.

Boron (B)

Boron is an element that is essential in low amounts, but toxic at higher concentrations. In fact, toxicity can occur on sensitive crops at concentrations less than 1.0 ppm. Because B toxicity can occur at such low concentrations, an irrigation water analysis is advised for ground water before applying additional B to irrigated crops. The boron concentration in the study area Ranged from 0.116 to 0.448 mg/L (mean = 0.313 mg/L). The mean 0.313 mg/L falls within the acceptable range of less than 0.7 mg/L, indicating that boron toxicity is unlikely to be a concern for most crops.

Table 3.2: Irrigation Water Quality Indices

Index	Minimum	Maximum	Mean	Threshold	Interpretation
SAR	0.001	0.005	0.003	< 10	Excellent (Low risk)
SSP (%)	21.6	76.0	44.3	< 60% preferred	Acceptable with caution
MAR	0.222	0.588	0.381	< 50%	No magnesium hazard
Kelly's Ratio	0.0013	0.0045	0.0027	< 1	Excellent quality
Potential Salinity	3.22	4.65	3.381	—	Low salinity risk
Total Hardness (mg/L)	40.38	60.54	51.81	—	Moderately hard
Residual Sodium Carbonate (RSC) Meq/L			0.463	<1.25	Low risk

Sodium Adsorption Ratio (SAR)

The Sodium Adsorption Ratio (SAR) is a critical parameter in assessing the suitability of irrigation water for agricultural purposes. Its the estimation of the degree to which sodium will be absorbed by the soil. It reasonably predicts the degree to which irrigation water tends to enter into a cation – exchange reaction in the soil. (Egbueri *et al*., 2021). Irrigation water having high SAR levels can lead to the buildup of high soil Na levels over time, which can adversely affect soil permeability. The Sodium Adsorption Ratio (SAR) is categorized based on its value, with SAR < 10 meq/L considered "Excellent", 10-18 meq/L as "Good", 18-26 meq/L as "Doubtful", and SAR > 26 meq/L classified as "Unsuitable" for irrigation purposes (Maas, 1990; Sadashivaiah *et al*, 2008). Based on SAR values for the study area ranged from 0.001 to 0.005 with a mean of 0.003 meq/L, the irrigation water could be

classified as excellent and would be suitable for irrigation as stipulated by the Food and Agriculture Organization (FAO) guidelines (Ayers & Westcot, 1985). This suggests that the water is likely suitable for irrigation without significant sodium-related issues, thereby minimizing the risk of sodium toxicity for most crops (Bashir, 2017).

Soluble Sodium Percentage (SSP)

SSP is an important factor for studying the sodium hazard. Water with SSP greater than 60% may result in sodium accumulation that will cause a breakdown in the soil's physical properties. It may also cause stunted growth in plants and reduce soil permeability (Joshi et al. 2009). High SSP values can lead to soil structure problems, reduced permeability, and increased risk of soil salinization. The SSP value SSP as found in the study area ranged from 21.6% to 76.0%, with a mean of 44.3%. Although a few values are more than the 50% critical threshold, the average value is acceptable (Raghunath, 2021). However, caution is required in prolonged usage. This indicates that the water is likely suitable for irrigation, as it falls below the threshold of 60%, above which irrigation waters are considered harmful.

Magnesium Adsorption Ratio (MAR)

The Magnesium Adsorption Ratio (MAR) in irrigation water, a key parameter for assessing magnesium hazards and suitability for agricultural use (Raghunath, 1987). Calcium and magnesium maintain a state of equilibrium in natural waters. The increase in one of these ions can be detrimental to soil as this can increase the soil salinity. Magnesium hazard is therefore a way of estimating this hazard as a magnesium level of more than 50% in water can be unsuitable for use in irrigation. The MAR values in the study area ranged from 0.222 to 0.588 (mean = 0.381), was found to be below the critical level of 50%. These indicates the presence of magnesium, essential for plant growth, but its low level suggests minimal impact on soil quality and crop productivity. With low variability and a consistent distribution, the water quality appears suitable for irrigation, posing no significant magnesium-related risks (Ayers & Westcot, 2019).

Kelly's Ratio (KR)

Kelly's Ratio (KR) is a crucial parameter in evaluating irrigation water quality, particularly in assessing the sodium hazard. According to Kelly (1963), groundwater having a Kelly Ratio below one (1) is considered safe for irrigation, between 1-2, it is considered moderate while above 2 it is considered to be unsafe. The Kelly's Ratio (KR) in the study area ranged between (0.0013 to .0045) with a mean of 0.0027 meq/L indicates that the irrigation water is suitable for agricultural purposes without significant sodium-related issues, as it falls below the threshold value of 1 (Kelly, 1940; 1963). A contrasting result for underground water with KR values above 2 Meq/l have been observed by (Adagba et al 2022). Ongoing monitoring is necessary to ensure KR values remain within acceptable limits and prevent soil degradation

Potential Salinity (PS)

According to Doneen (1964), PS is a measure of the concentration of chloride and half the sulfate ions in the irrigation water, which are the primary constituents that contribute to soil salinity. The PS of the irrigation water in the study area ranged from 3.22 to 4.65, with a mean of 3.381 meq/l. A PS value below 5 meq/l is considered excellent for irrigation, indicating a very low risk of salinity hazard and is suitable for all crops. Additionally, the mean Sodium Adsorption Ratio (SAR) value of 0.0051 confirms a negligible risk of sodium-induced soil damage, such as reduced permeability and poor aeration.

Total Hardness (TH)

Total Hardness (TH) is a crucial parameter in evaluating water quality, particularly in assessing its suitability for various uses. The United States Department of Agriculture (USDA) has established the following guidelines for hardness in irrigation water based on the calcium carbonate equivalent (CCE): soft water: less than 60 mg/L, moderately hard water between 60 and 120 mg/L, hard water: between 120 and 180 mg/L and very hard water greater than 180 mg/L (Ashie *et al;* 2024).TH ranged from 40.38 to 60.54 mg/L with a mean of 51.81 mg/L. Based on the results obtained, the Total Hardness (TH) of the water in the study area could be categorized as Soft water as it has a mean value of 51.81 mg/L, indicating soft water suitable for irrigation purposes. Similarly, according to Ayers and Westcot (1985), water with a TH value below 200 mg/L is generally considered suitable for irrigation. The mean TH value in this study falls well below this threshold, suggesting that the water is highly suitable for irrigation without significant hardness-related issues. Ongoing monitoring is necessary to ensure that fluctuations in water hardness do not impact irrigation system performance or soil health.

Residual Sodium Carbonate (RSC)

The Residual Sodium Carbonate (RSC) is a key parameter in evaluating irrigation water quality. It measures the potential for carbonates and bicarbonates to precipitate calcium and magnesium, thereby increasing the relative proportion of sodium in the soil solution. High RSC values can reduce soil permeability. The RSC calculation is: $RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$, with all concentrations in meq/l. The calculated Residual Sodium Carbonate (RSC) value of 0.463 meq/l indicates that the water is safe for irrigation, with a low risk of sodium carbonate hazard. According to Gupta et al. (2015), RSC values less than 1.25 meq/l are considered safe for irrigation, as they do not pose a significant risk to soil health. Studies have shown that irrigation water with low RSC values can improve crop yields and soil fertility. For example, a study by Singh et al. (2018) found that irrigation water with RSC values below 1.25 meq/l resulted in higher crop yields and better soil health compared to water with higher RSC values. Similarly, A study by Kumar et al. (2020) and Sani et al (2022) found that irrigation water with similar quality parameters resulted in higher crop yields and improved soil health in a semi-arid region.

Water Suitability for Irrigation Using USSL and Wilcox Diagrams

The water's suitability for irrigation was evaluated using the USSL and Wilcox diagrams. The USSL (United States Salinity Laboratory) diagram plots the Sodium Adsorption Ratio (SAR) against the Electrical Conductivity (EC) to assess the suitability of water for irrigation. The diagram is divided into 16 zones, each representing a different class of water quality (e.g., C1-S1, C2-S2, C3-S4).According to the USSL diagram, which assesses salinity hazard (EC) and sodium hazard (SAR), the water falls into the C1-S1 category, indicating low salinity and sodium hazards. The mean EC value of 0.21 dS/m places it in the C1 class, suitable for irrigation on all soil types without special salinity control. The SAR value of 0.0051 is very low, categorizing it as S1, with minimal risk of sodium buildup that could damage soil structure. The Wilcox diagram classifies water into categories like "Excellent to Good," "Good to Permissible," and "Unsuitable."The diagram, evaluates water quality based on EC and soluble sodium percentage (SSP), also confirms the water's high quality. With a low EC of 0.21dS/m and a low SSP of 0.4436, the water falls into the "Excellent to Good" category, indicating minimal risk of salinity or sodium-related soil issues. Both diagrams suggest the water is highly suitable for irrigation, posing low risks to soil and crops.

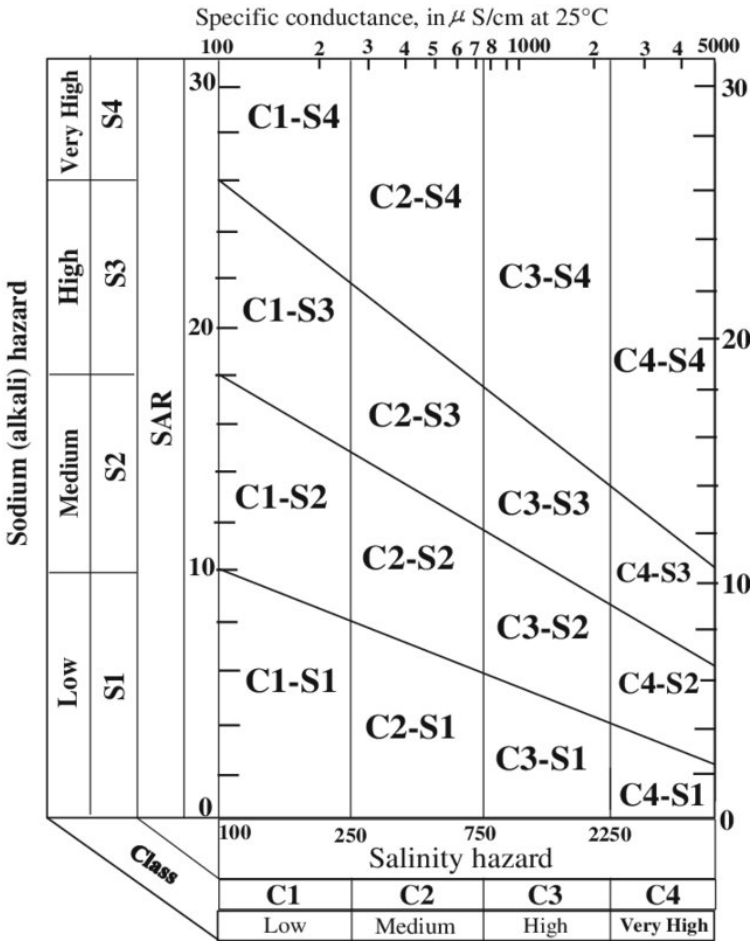


FIGURE 1: USSL DIAGRAM

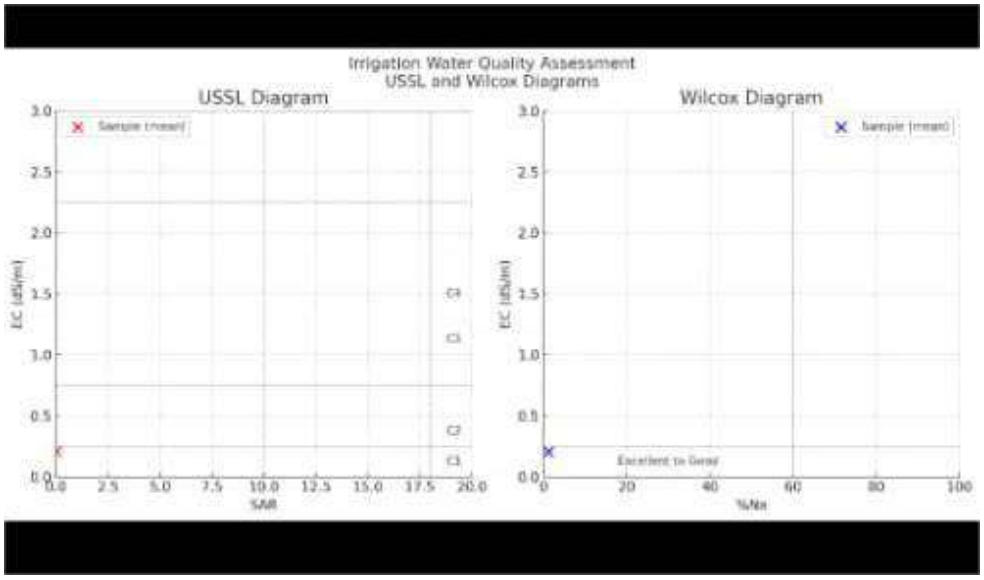


Figure 2: USSL AND WILCOX DIAGRAM FOR DUTSINMA DAM

The USSL Diagram compares the Electrical conductivity and SAR values of the water samples. The EC of the water samples 0.21 dS m^{-1} and SAR Value of 0.005 classify it as C1-S1 which represent low salinity hazard and a very low sodium hazard, making it excellent for irrigation on almost all soil type. For the Wilcox Diagram, the comparison was between EC of the water samples and soluble sodium percentage (SSP) with a mean of 0.4436% which places it in Excellent to Good category, hence confirming its suitability for irrigation. The red point in USSL and blue point in Wilcox Diagram both sits in the Excellent/ No restriction Zone confirming the water suitability for irrigation in the study area. water's suitability for irrigation was evaluated using the USSL and Wilcox diagrams. Both diagrams suggest the water is highly suitable for irrigation, posing low risks to soil and crops.

Table 4: Correlation coefficient of properties measured

Properties	Ph	EC (dS/m)	No3 (Ppm)	Po3	SO4	HCO3 (Mg/l	Cl (Mg/l)	Na meql	k meql	ca meql	mg meql	Bo (Mg/l)	MAR	KR	PS	TH	SSP	SP	SAR
Ph	1																		
EC (dS/m)	0.212	1																	
No3(Ppm)	0.060	-0.285	1																
Po3	0.617*	0.427	-0.251	1															
SO4	0.368	-0.386	0.519	-0.221	1														
HCO3(Mg/l	0.000	0.169	-0.476	0.281	-0.469	1													
Cl(Mg/l)	0.010	-0.061	0.662*	-0.327	0.480	-0.283	1												
Na meql	-0.429	0.302	-0.205	-0.407	-0.259	-0.105	0.099	1											
k meql	-0.134	-0.429	-0.136	-0.192	0.221	-0.459	-0.245	-0.257	1										
ca meql	0.741**	0.104	0.064	0.341	0.463	-0.058	0.021	-0.244	-0.045	1									
mg meql	-0.539	-0.375	-0.136	-0.102	-0.117	-0.318	-0.400	-0.077	0.442	-0.489	1								
B(Mg/l)	-0.373	0.069	-0.826**	-0.003	-0.391	0.326	-0.579*	0.247	0.349	-0.281	0.361	1							
MAR	-0.607*	-0.335	-0.103	-0.116	-0.204	-0.291	0-.340	.016	0.350	-0.621*	0.979**	0.319	1						
KR	-0.323	0.370	-.0179	-0.408	-0.245	0.015	0.202	0.958**	-0.321	-0.211	-0.321	0.185	-0.217	1					
PSI	0.087	-0.136	0.693*	-0.334	0.635*	-0.349	0.983**	0.032	-0.170	0.117	-0.378	-0.592*	-0.343	0.126	1				
TH	-0.198	-0.371	-0.120	0.077	0.127	-0.398	-0.447	-0.227	0.481	0.006	0.870**	0.255	0.771**	-0.488	-0.367	1			
SSP	-0.535	-0.409	-0.150	-0.138	-0.087	-0.362	-0.404	-0.093	0.559	-0.477	0.991**	0.395	0.960**	-0.327	-0.374	0.865**	1		
SP	-0.321	0.373	-0.178	-0.403	-0.244	0.021	0.204	0.958**	-0.333	-.208	-0.323	0.182	-0.218	1.000**	0.128	-0.488	-0.331	1	
SAR	-0.428	0.317	-0.199	-0.419	-0.274	-0.071	0.129	0.995**	-0.271	-.286	-0.124	0.238	-0.020	0.977**	0.055	-0.304	-0.138	0.977**	1

KEYWORDS: EC= Electrical Conductivity; MAR; Magnesium Adsorption Ratio; KR= Kelleys Ratio; PSI= Potential Salinity Index; TH= Total Hardness; SSP= Soluble Sodium Percentage; SAR= Sodium Adsorption Ratio

The correlation matrix shows the relationships between the different water quality parameters. The analysis reveals strong correlations between various water quality parameters. Chloride (Cl) is strongly correlated with potential salinity (PS) (0.983) and moderately correlated with nitrate (NO_3) (0.662), indicating that increased chloride and nitrate concentrations contribute to higher salinity. Calcium (Ca) is positively correlated with pH (0.741), suggesting that higher calcium levels lead to more alkaline water. Magnesium (Mg) is strongly linked to soluble sodium percentage (SSP) (0.991) and magnesium adsorption ratio (MAR) (0.979), implying that magnesium plays a key role in determining these parameters. Additionally, a perfect correlation exists between sodium percentage (SP) and Kelly's ratio (KR) (1.000).

The strong correlations between various water quality parameters have significant implications for crop production in the study area. The positive correlation between chloride and potential salinity suggests that increased chloride concentrations contribute to higher salinity levels, which can negatively impact crop yields. According to Ayers and Westcot (1985), salinity affects crop water availability, and high salinity levels can reduce

crop yields. Therefore, it is essential to monitor and manage chloride levels in irrigation water to prevent soil salinization and promote sustainable crop production.

Similarly, the positive correlation between calcium and pH indicates that higher calcium levels lead to more alkaline water. This finding is consistent with recent studies that highlight the importance of calcium in maintaining soil pH and structure. Singh et al. (2023) noted the importance of assessing water quality and its impact on crop production, emphasizing the role of parameters like calcium in determining soil health. However, high pH levels can also lead to nutrient deficiencies and reduced crop growth. Therefore, farmers in the study area should consider implementing management practices that balance calcium levels and maintain optimal soil pH.

The strong positive correlation between magnesium and soluble sodium percentage suggests that magnesium plays a key role in determining soluble sodium levels. High levels of soluble sodium can lead to soil sodicity, reducing water infiltration and affecting crop growth. As noted by Doody (2011), irrigation water quality significantly affects crop production and soil health. Therefore, farmers in the study area should implement best management practices, such as crop selection, irrigation management, and soil monitoring, to mitigate the risks associated with poor irrigation water quality.

3.2 Conclusion

The study concludes that the water from Dutsin-Ma Dam is largely suitable for irrigation purposes. Key parameters such as EC, SAR, and KR fall within safe limits, ensuring minimal risk of salinity and sodicity hazards to the soil and crops. The soft hardness and low levels of trace elements further support its usability for agricultural activities. However, nitrate contamination above the recommended threshold indicates a potential health hazard if used untreated for drinking. This necessitates caution and possibly water treatment or alternative water sources for domestic use. Regular monitoring of water quality is essential, especially for parameters with high variability such as nitrate and soluble sodium percentage. Sustainable irrigation practices must be implemented to prevent accumulation of sodium and bicarbonate, which can degrade soil properties over time.

Recommendations

Based on the findings from the study the following are recommended for sustainable water usage for improved crop productivity; Therefore, to ensure the safe use of Dutsin-Ma Dam water for irrigation purposes, authorities should establish regular water quality monitoring programs. This should focus on key parameters like nitrate, sodium, and chloride levels to detect changes early and prevent potential health and agricultural impacts. Regular monitoring is crucial for maintaining water quality standards.

Since nitrate concentrations exceed the threshold limits, measures should be taken to mitigate nitrate runoff. This can be achieved by promoting proper fertilizer use, implementing wastewater treatment, and creating buffer zones around water sources. These measures will help reduce the risk of nitrate pollution.

Farmers should also be educated on best irrigation practices to minimize the risks associated with sodium accumulation and soil sodicity. This includes adequate drainage and crop rotation to ensure sustainable agricultural practices. Proper irrigation management is key to preventing soil degradation.

References

Abaje, I. B., Bello, Y., & Ahmad, S. A. (2020). A Review of Air Quality and Concentrations of Air Pollutants in Nigeria. Journal of Applied Sciences and Environmental Management, 24(2), 373–379. https://doi.org/10.4314/jasem.v24i2.25

Abdulkadir, A, Halilu, Y., & Sani, S. (2022). Evaluation of Physical and Chemical Properties of Soils at Bichi Local Government Area, Kano State, Nigeria. IREJournal, 5(9), 556–562.

ABDULKADIR, A., MANNE, I. Z., & SANI, S. (2025). Impact of distance from the water body on the point of zero charge of Dutsin-Ma Dam floodplain soils, Katsina State, Nigeria. International Journal of Bonorowo Wetlands, 15(1). https://doi.org/10.13057/bonorowo/w150101

Abdullahi, A., Usman, M. A., & Ibrahim, Y. (2021). Assessment of irrigation water quality in Northern Nigeria: Implications for food security. *Nigerian Journal of Soil Science*, 31(2), 74-81.

Abubakar, S., Mohammed, A., & Musa, L. (2021). Challenges of irrigation farming in semi-arid Northern Nigeria. *Journal of Agricultural Research and Development*, 10(1), 33-42.

Adamu, G. K. ・(2013)・Quality of irrigation water and soil characteristics of Watari irrigation project. American Journal of Engineering Research 2, 59–68.

Adamu, M., & Suleiman, A. (2022). Assessment of Water Resources for Sustainable Agriculture in Northern Nigeria. *Journal of Environmental Management*, 14(3), 210-223. https://doi.org/10.1016/j.jenvman.2022.114562

Adamu, S., & Suleiman, A. (2022). Assessment of surface water quality for irrigation in semi-arid zones of northern Nigeria. *Nigerian Journal of Soil Science*, 32(2), 55-62.

Ahmed, M. B., Musa, U. H., & Gambo, R. (2020). Evaluation of Kelly's Ratio and irrigation water quality parameters in Bauchi State. *International Journal of Agricultural Technology*, 16(5), 1121-1131.

Ahmed, S., Bello, M., & Usman, H. (2020). Evaluation of Kelly's Ratio in Irrigation Water Quality Assessment in Kano State. *International Journal of Agricultural Sciences*, 12(5), 245-252. https://doi.org/10.9734/ijas/2020/v12i530242

Ali, M., Zainab, A., & Mahmud, I. (2021). Impact of poor water quality on soil properties and vegetable yield. *African Journal of Agricultural Research*, 16(8), 1002-1010.

Ali, S. M., & Bello, I. A. (2021). Evaluation of surface water quality for irrigation in arid regions of Nigeria. *Journal of Environmental and Agricultural Studies*, 3(2), 77-85.

Ali, S., Khan, M. F., & Abbas, Z. (2021). Impact of Irrigation Water Quality on Soil and Crop Productivity: A Review. *Agricultural Water Management*, 250, 106839. https://doi.org/10.1016/j.agwat.2021.106839

American Public Health Association (APHA). (2017). *Standard Methods for the Examination of Water and Wastewater* (23rd ed.). Washington, D.C.: APHA.

Ayers, R. S., & Westcot, D. W. (2020). *Water Quality for Agriculture*. FAO Irrigation and Drainage Paper 29 Rev. 1.

Ayers, R. S., & Westcot, D. W. (2021). *Water Quality for Agriculture*. FAO Irrigation and Drainage Paper 29 Rev. 1.

Ayers, R. S., & Westcot, D. W. (2021). *Water Quality for Agriculture* (FAO Irrigation and Drainage Paper No. 29 Rev. 1). Food and Agriculture Organization of the United Nations. http://www.fao.org/3/a-i7959e.pdf

Ayers, R. S., & Westcot, D. W. (2021). *Water Quality for Agriculture* (FAO Irrigation and Drainage Paper No. 29, Rev. 1). Rome: Food and Agriculture Organization. http://www.fao.org

Ayers, R.S. & Westcot, D.W. (2020). *Water Quality for Agriculture*. FAO Irrigation and Drainage Paper 29 Rev. 1. Rome: Food and Agriculture Organization.

Bello, M. I., Suleiman, M. A., & Lawal, M. A. (2021). Evaluation of physicochemical quality of irrigation water in Katsina State. *Journal of Environmental Studies*, 13(1), 45-52.

Bello, M., Abdullahi, H., & Musa, T. (2020). Influence of irrigation water salinity on tomato production in Kano. *Savannah Journal of Agriculture*, 15(1), 34-41.

Bello, M., Abdullahi, I., & Jibrin, L. (2020). Effects of Soluble Sodium Percentage on Tomato Yield in Kano, Nigeria. *Nigerian Journal of Agricultural Research*, 24(1), 56-65. https://doi.org/10.4314/njar.v24i1.7

Doneen, L. D. (1964). Water quality for agriculture. Department of Water Science and Engineering, University of California.

Doody, D. G. (2011). Water quality for livestock and poultry production. The Ohio State University Extension.

FAO. (2020). *Guidelines for Irrigation Water Quality*. Food and Agriculture Organization of the United Nations. http://www.fao.org/3/a-i7959e.pdf

FAO. (2021). *Guidelines for Assessing Water Quality for Irrigation Use*. Food and Agriculture Organization of the United Nations.

Gupta, S. K., Gupta, I. C., & Singh, R. P. (2015). Effect of RSC water on soil health and crop production. *Journal of Irrigation and Drainage Engineering*, 141(10), 04015021.

Hassan, A., & Sulaiman, M. B. (2022). Assessment of water quality in selected dams in Northern Nigeria for agricultural purposes. *African Journal of Water Resources Management*, 4(1), 35-44.

Hussaini, M. A., Ibrahim, M. K., & Umar, I. (2021). The impact of irrigation water quality on soil and crop production in Northern Nigeria. *African Journal of Agricultural Science*, 17(3), 112-120.

Ibrahim, A. H., Garba, M., & Yusuf, S. (2020). Water quality and irrigation practices in Katsina State: A case study of Dutsin-Ma. *Katsina Journal of Agricultural and Environmental Research*, 8(2), 28-35.

Ibrahim, Y. B., & Musa, S. (2019). Comparative study of water quality in two irrigation dams in Katsina State. *Nigerian Journal of Hydrology and Water Resources*, 8(2), 44-53.

Jibrin, L., Abdullahi, I., & Musa, B. (2019). Influence of Cations in Irrigation Water on Soil Permeability and Crop Performance. *Journal of Soil Science and Environmental Management*, 10(4), 89-98. https://doi.org/10.5897/jssem2019.0737

Jibrin, M., Nuhu, A., & Mohammed, S. (2019). Cationic composition of irrigation water and implications for soil management. *Nigerian Soil and Water Journal*, 24(3), 43-51.

Kumar, P., Singh, R. P., & Kumar, A. (2020). Impact of irrigation water quality on crop yield and soil health in semi-arid regions. *Agricultural Water Management,* 231, 105998.

Mehmood, A., Khaliq, A., & Yousaf, M. (2019). Sodium hazard and its impact on soil under irrigation: a case study. *Agricultural Water Management*, 221, 320-328.

Mehmood, M. A., Arshad, M., & Hussain, S. (2019). Effect of Saline Irrigation Water on Soil Properties and Crop Production: A Review. *International Journal of Environmental Science and Technology*, 16, 3125-3140. https://doi.org/10.1007/s13762-018-1991-7

Muhammad Amin, A., Sani, M., Bello Ahmad, U., Sufiyanu, S., Bashir Shehu, H., Wada Rabiu, A., & Afiya Kabir, L. (2019). Geo-statistical mapping of some soil fertility constraints in sorghum- based cropping system of Sudano-Sahelian zone of Nigeria. Azarian Journal of Agriculture, 6(6), 146–152. https://doi.org/10.29252/azarinj.019

Muhammad, A., Musa, M., Sani, S., & Ibrahim, U. M. (2024). Environmental Contamination by Agrochemicals and Its Indiscriminate Use by Dry Season Farmers in Sudan Savannah of Katsina State. Sahel Journal of Life Sciences FUDMA, 2(1), 67–77. https://doi.org/10.33003/sajols-2024-0201-009

Muhammad, F. (2025). SEASONAL ASSESSMENT OF SOME ANIONS IN SOIL FROM DUTSIN-MA IRRIGATION FARMLANDS KATSINA STATE, NIGERIA. FUDMA JOURNAL OF SCIENCES, 9, 258–263. https://doi.org/10.33003/fjs-2025-09(ahbsi)-3524

Musa, A., & Mohammed, M. A. (2021). Assessment of pH levels of irrigation water and its influence on crop productivity in northern Nigeria. *Tropical Agriculture Journal*, 8(2), 88-95.

Musa, U. A., & Mohammed, I. (2021). Evaluation of Irrigation Water Quality and Its Effects on Soil in Semi-Arid Regions of Nigeria. *Nigerian Journal of Soil Science*, 31(1), 45-56. https://doi.org/10.4314/njss.v31i1.4

NESREA. (2020). *National Environmental (Water Quality) Regulations*. National Environmental Standards and Regulations Enforcement Agency, Abuja.

Obasi, C. N., Nwankwo, L. C., & Eze, C. (2022). Impact of Magnesium Adsorption Ratio on Soil Structure in Southeastern Nigeria. *Soil and Tillage Research*, 210, 105042. https://doi.org/10.1016/j.still.2021.105042

Obasi, K. O., & Lawal, M. (2023). Impact of dam water on agricultural productivity in semi-arid zones of Nigeria. *International Journal of Environmental Research and Public Health*, 20(5), 2102-2110. https://doi.org/10.3390/ijerph20052102

Obasi, N. A., Eze, J. C., & Okoye, C. (2022). Magnesium-induced clay dispersion in irrigated soils of Southeast Nigeria. *Nigerian Journal of Soil and Environmental Research*, 30(1), 20-28.

Okafor, C. J., Ibe, O. A., & Eze, P. C. (2023). Nitrate and phosphate concentrations in irrigation water and vegetable safety in Enugu State. *Journal of Environmental Monitoring and Assessment*, 12(1), 58-67.

Okafor, P. E., Onwudike, C., & Eke, N. (2023). Sources and Impact of Nitrate and Phosphate in Agricultural Watersheds. *Environmental Science and Pollution Research*, 30, 12587-12599. https://doi.org/10.1007/s11356-023-25200-1

Osinubi, T. M., Bello, A. M., & Lawal, R. (2023). Physiological response of maize to saline irrigation in central Nigeria. *Journal of Agriculture and Food Security*, 11(4), 49-57.

Osinubi, T. O., Adekoya, J. A., & Adeoye, A. O. (2023). Impacts of Salinity and Sodicity on Soil and Crop Productivity in Nigerian Agriculture. *Soil Science Annual*, 74(2), 95-109. https://doi.org/10.2478/ssa-2023-0012

Rahman, M. M., Yusuf, M., & Bako, A. (2019). Suitability assessment of irrigation water in dryland areas. *International Journal of Agriculture and Soil Science*, 6(4), 97-104.

Raji, A., & Abdullahi, M. (2022). Effects of Sodic Water on Soil Physical Properties and Crop Growth in Semi-Arid Zones of Nigeria. *Agronomy Journal*, 114(1), 33-41. https://doi.org/10.1002/agj2.21087

Raji, B. A., & Abdullahi, M. (2022). Long-term irrigation effects on soil structure in Katsina State. *Nigerian Journal of Agricultural Extension and Soil Management*, 27(2), 67-75.

Ravikumar, P., et al. (2020). Hydrochemical assessment of surface water quality. *Environmental Earth Sciences*, 79(15), 360.

Salihu, A., & Musa, S. (2021). Challenges of Irrigation Water Quality in Semi-Arid Zones: Case Study of Katsina State, Nigeria. *Water Resources and Environmental Engineering*, 7(2), 135-144. https://doi.org/10.4236/wree.2021.72011

Sani, M., Alhassan, I., Amin, M. A., Sani, S. and Musa, A. A. (2019) Trends of soil organic matter and cation exchange capacity in Nigerian Northern Guinea Savannah, in relation to the soil texture and depth. *Dutse Journal of Agriculture and Food Security (DUJAFS)* 6(2) 100-108

Sani, S., Abdulkadir A. and Pantami S. A. (2022). Assessment of Water Quality for Irrigation Purposes in Jibia Irrigation Project, Katsina State, Nigeria. IOSR Journal of Agriculture and Veterinary Science, 15(3):54-58 https://doi.org/10.9790/2380-1503025458

Sani, S., Abdulkadir, A., Hmad Pantami, S. A., Sani, M., Amin, A. M., & Abdullahi, M. Y. (2023). Spatial Variability and Mapping of Selected Soil Physical Properties under Continuous Cultivation. Turkish

Journal of Agriculture - Food Science and Technology, 11(4), 719–729. https://doi.org/10.24925/turjaf.v11i4.719-729.5733

Sani, S., Pantami, S. A. and Sani, M. (2019). Evaluation of Soil Physical Properties at Jibia Irrigation Project, Katsina State, Nigeria. Fudma Journal of Agriculture and Agricultural Technology. 5(1) 231-243

Sani, S., Pantami, S. A. and Sani, M. (2019). Evaluation of Soil Physical Properties at Jibia Irrigation Project, Katsina State, Nigeria. Fudma Journal of Agriculture and Agricultural Technology. 5(1) 231-243

Sani, S., Sani, M., Salihu, A. P., Aliyu, A., Yakubu, M., Garba, N. H., & Basiru, L. J. (2022). Spatial variability of soil hydraulic properties in Jibia irrigation project, katsina state, Nigeria. Natural resources and sustainable development, 12(2), 245–254. Https://doi.org/10.31924/nrsd.v12i2.103

Singh, M., Kumar, S., & Singh, R. K. (2023). Assessment of water quality and crop production using SWAT+ model in a watershed. Journal of Hydrology, 616, 128755.

Singh, R. P., Kumar, P., & Singh, A. K. (2018). Evaluation of irrigation water quality for crop production in a semi-arid region. *Journal of Water and Climate Change,* 9(2), 251-264.

Srinivas, K., Reddy, B. M., & Anwar, S. (2020). Overview of irrigation water quality and sustainable agricultural practices. *Journal of Environmental Science and Agriculture*, 4(2), 150-158.

Srinivas, T., Kumar, V., & Reddy, B. (2020). Chemical, Physical and Biological Characteristics of Water for Agricultural Use. *International Journal of Water Resources Development*, 36(4), 523-537. https://doi.org/10.1080/07900627.2019.1707482

Sufiyanu Sani, Aliyu Abdulkadir, Musa Muhammad, Musab Ibrahim, Abdulsalam Sani Nababa, Ahmad Ubaidullah and Aliyu Suleiman (2024a). Assessment of Soil Salinity and Sodicity Status at Jibia Irrigation Project, Katsina State, Nigeria. Life Sciences: an International Journal (LSIJ) Vol.1, No.1, 2024

Suleiman, A. M., Danlami, I. A., & Umaru, L. (2022). Seasonal variation in water quality of surface irrigation sources in Katsina State. *Journal of Agricultural Extension and Rural Development*, 14(5), 99-106.

Tesfaye, H., Alemu, D., & Getahun, D. (2020). Salinity impact on irrigation and soil properties in Ethiopia. *East African Agricultural Research Journal*, 22(3), 98-109.

Tesfaye, S., Alemu, M., & Desta, H. (2020). Effect of Salinity on Maize Yield and Soil Properties in Ethiopian Highlands. *Agricultural Water Management*, 240, 106306. https://doi.org/10.1016/j.agwat.2020.106306

UN-Water. (2023). *Water and Sustainable Development*. United Nations Water Coordination Platform.

USEPA. (2021). *Nutrient Criteria Technical Guidance Manual: Rivers and Streams*. U.S. Environmental Protection Agency.

Usman, S. A., Ibrahim, K., & Garba, U. (2020). Chemical quality of irrigation water and its implications for sustainable agriculture. *Nigerian Journal of Environmental Management*, 24(1), 55-63.

WHO. (2019). *Guidelines for Drinking-Water Quality* (4th ed., incorporating the 1st addendum). World Health Organization. https://www.who.int/publications/i/item/978924154995

WHO. (2022). *Guidelines for Drinking-Water Quality*. World Health Organization, Geneva.

Wilcox, A. (2017). Effects of Dams on Rivers. Environmental Science.

Yahaya, M. A., Sule, R., & Garba, U. (2020). Influence of bicarbonate levels in irrigation water on soil pH in Sokoto. *Journal of Nigerian Soil Research*, 18(1), 30-38.

Yahaya, U., Abubakar, S., & Lawal, M. (2020). Influence of Bicarbonate Ions on Soil pH and Micronutrient Availability. *Journal of Soil Science and Environmental Management*, 11(3), 57-65. https://doi.org/10.5897/jssem2020.0662

Yusuf, A., Umar, I., & Isa, M. (2021). Sodium adsorption ratio and its implications for irrigation in Sokoto. *Journal of Agricultural Water Quality*, 7(3), 101-109.

Yusuf, H. A., Abdullahi, I., & Usman, M. (2021). Assessment of Sodium Adsorption Ratio and Soil Health in Irrigation Schemes in Sokoto, Nigeria. *Environmental Monitoring and Assessment*, 193, 612. https://doi.org/10.1007/s10661-021-09301-8

Yusuf, M. A., Ahmed, H., & Sani, T. (2023). Irrigation suitability and water management practices in Northern Nigeria. *Journal of Sustainable Agriculture and Environment*, 5(2), 88-97.