EVALUATION OF SOIL SALINITY ALONG TUTTUDAWA MAIN CANAL OF WURNO IRRIGATION SCHEME, SOKOTO, FOLLOWING THE SEPTEMBER 2020 FLOOD

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Abstract

The research evaluated the salinity status and variation patterns of soils along Tuttudawa Main Canal of the Wurno Irrigation Scheme after the September 2020 flood. The scheme is located in the Sudan Savannah, about 45 km north of Sokoto town (latitude 13°20'N and longitude 4°55'E). Wurno irrigation scheme comprises of a storage reservoir with design capacity of 19,501,200 m³ supplied from Goronyo dam. The reservoir is linked to two main canals, namely; Lugu main canal that passes through Lugu village and Tutudawa main canal that passes through Tutudawa village, a main drain and a number of secondary canals. Four transects at 50 m intervals were purposively selected, and soil samples were collected at two depths (0–15 cm and 15–30 cm). Parameters analyzed included pH, total N, organic carbon, available P, CEC, and exchangeable bases, while EC, ESP, and SAR were calculated. Results showed high levels of Ca^{2+}, K^{+}, and Na^{+} across all sampling points and depths. pH and EC values indicated soils within the saline range, posing risks for crop production. Sustainable soil amendments and controlled irrigation are recommended to maintain favorable soil conditions for plant growth.

***Keywords*:** Salinity, soil gertility, irrigation, Tuttudawa, Wurno Scheme

Introduction

Soil is one of the most important natural resources covering much of the land surface. It is crucial to life and human survival. However, as societies become increasingly urbanized, fewer people maintain direct contact with soil. As a result, many lose sight of its essential role in supporting prosperity and survival (Brady & Weil, 2010). Continuous cropping without adequate nutrient restoration threatens agricultural sustainability. Soil nutrient depletion results in widespread deficiencies, undermines the foundation for high-yield and sustainable farming, and increases the cost of restoring degraded soils (FAO, 2014; SFE, 2014). Proper soil testing is therefore vital. It supports sound soil management decisions, ensures efficient fertilizer use, maintains soil fertility, and minimizes environmental risks (FAO, 2014). Proper soil testing would help reach the goal of sound soil management decision, that best meet crop needs and maintain the nutrient supplying power of the soil, while making the most efficient use of fertilizer and avoiding environmental problems (FAO, 2014).

Several government and private farming initiatives have failed due to failure to understand the values and significance of soil evaluation and monitoring through proper sampling and testing techniques which could be the bedrock of sound soil management decision while making the most efficient use of environmental resources (FAO, 2010). Irrigation has contributed significantly to poverty alleviation, food security, and improving the quality of life. Inadequate attention to soils salinization factors and projected economic implications of large-scale irrigation schemes like the Wurno irrigation project has frequently led to great difficulties in soil management decisions. Thousands of hectares are going out of production worldwide each year due to salinity problems. Despite the immense importance of Wurno Irrigation Scheme, the yield obtained in recent years by farmers from most cultivated crops in the scheme (rice, onion, tomatoes, pepper and potato) is low compared to the previous years.

A quantitative assessment of soil nutrient status and salinity-related parameters within the Wurno Irrigation Scheme is therefore necessary. Such an assessment provides insight into soil fertility and guides corrective measures. This information forms the foundation for efficient and sustainable use of soil and water resources (Elke, 1998). The broad objective of this research is to provide the scientific knowledge on the current status of soils quality along Tuttudawa Main Canal of the Wurno Irrigation Scheme after September 2020 Flood with a view to offer suggestions on appropriate management strategies for sustainable utilization of the soils of the study area.

Literature Review

Soil Salinity in Irrigation Schemes

Irrigation is an indispensable strategy for enhancing food security in semi-arid and dryland environments, yet it remains one of the leading causes of secondary salinization. Soil salinity refers to the accumulation of soluble salts—primarily sodium (Na^{+}), calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+})—within the root zone. This process is often triggered by inadequate drainage, over-irrigation, capillary rise of groundwater, and seasonal flooding (FAO, 2018). When evapotranspiration exceeds rainfall, salts concentrate in the upper soil layers, creating unfavorable conditions for crop growth. Elevated salinity modifies soil structure by dispersing clay particles, reducing porosity, and restricting aeration, while simultaneously impairing plant physiological functions such as water and nutrient uptake (Rengasamy, 2010). Globally, more than 20% of irrigated lands are estimated to be affected by salinity, making it one of the most pressing threats to irrigated agriculture (Qadir et al., 2014).

Salinity in Northern Nigeria

In northern Nigeria, irrigation schemes developed along major rivers such as the Sokoto–Rima, Hadejia–Jama'are, and Chad basins are increasingly facing salinity-related challenges. Studies indicate that soils in these systems frequently fall within the saline to sodic range due to a combination of seasonal flooding, poor drainage, and high evaporation rates. Abdullahi et al. (2019) reported that the Sokoto–Rima floodplain soils showed high electrical conductivity (EC) and exchangeable sodium percentage (ESP), both of which compromise soil productivity. Similarly, Mohammed et al. (2020) observed that floods in the Wurno irrigation scheme altered the nutrient dynamics of soils, leaving behind concentrated salts, especially along canal-command areas where water stagnates. The Sudan Savannah climate, characterized by a short rainy season (June–September) and a prolonged dry season, exacerbates these problems by intensifying evaporation, thereby accelerating salt accumulation at the soil surface. Over time, this cycle reduces soil fertility, limits crop performance, and threatens the sustainability of irrigation farming in the region.

Indicators of Soil Salinity and Sodicity

Reliable assessment of salinity status is critical for guiding soil management. The most widely used indicators include:

- **Electrical Conductivity (EC)**: Measures the concentration of soluble salts in soil solution. Soils with EC values above 4 dS/m are generally classified as saline (Richards, 1954).

- **pH**: High pH (>8.5) often signals sodic conditions, particularly in soils with excessive sodium relative to calcium and magnesium.

- **Sodium Adsorption Ratio (SAR)**: Indicates the relative proportion of sodium to calcium and magnesium in the soil solution. High SAR values are linked to clay dispersion and reduced hydraulic conductivity (Qadir et al., 2007).

- **Exchangeable Sodium Percentage (ESP)**: Reflects the proportion of sodium ions occupying exchange sites on soil colloids. Soils with ESP greater than 15% are classified as sodic, which implies poor structure and infiltration problems.

- **Cation Exchange Capacity (CEC):** Provides insights into the soil's ability to retain and exchange nutrient cations. High sodium saturation of exchange sites reduces the soil's effective fertility and structural stability.

Soil depth and texture also play critical roles in salinity distribution. Fine-textured soils such as clay loams retain more salts compared to coarse-textured sandy soils (Brady & Weil, 2017). Shallow soils are more prone to rapid accumulation of salts after irrigation or flooding, while deeper layers may act as reservoirs for leached salts.

Management of Soil Salinity

Mitigation of soil salinity requires an integrated approach combining agronomic, chemical, and engineering interventions. The most widely recommended strategies include:

1. **Chemical Amendments**: Application of calcium-based materials such as gypsum is effective in replacing exchangeable sodium with calcium, thereby improving soil structure and permeability (Amezketa, 2006).

2. **Organic Amendments**: Incorporation of organic matter, compost, or crop residues improves soil aggregation, enhances microbial activity, and reduces the negative impact of sodium.

3. **Improved Irrigation Practices**: Controlled and scheduled irrigation reduces the risk of waterlogging and salt buildup. Techniques such as alternate wetting and drying, or drip irrigation, enhance water use efficiency.

4. **Drainage Systems**: Adequate surface and subsurface drainage help remove excess salts from the root zone and prevent secondary salinization.

5. **Crop and Variety Selection**: Cultivating salt-tolerant crops or varieties provides short-term adaptation in affected areas while long-term reclamation measures are undertaken.

6. **Infrastructure Rehabilitation**: Proper maintenance of canals, drains, and reservoirs is essential to prevent water stagnation, reduce flooding, and enhance the efficient distribution of irrigation water.

Materials and Methods

Wurno irrigation scheme is located in the Sudan Savannah, situated 45km north of Sokoto town. The Irrigation scheme is located on latitude 13°20′N and longitude 4°55′E, within dry sub-humid Savannah. The nature of rainfall in the area is poor in distribution, scanty in quantity and erratic in behavior with its peak in August, averaging 704.2 mm per annum.

Temperature ranges from a minimum of 17°C recorded in December/January to 42°C in April/May (NAERL and FDAE, 2014) Wurno irrigation scheme comprises of a storage reservoir with design capacity of 19,501,200 m^3 supplied from Goronyo dam. The reservoir is linked to two main canals, namely, Lugu main canal that passes through Lugu village and Tuttudawa main canal that passes through Tuttudawa village, a main drain and a number of secondary canals.

Four transects were purposively chosen along Tuttudawa main canal and three sampling spots were identified on each transect and soil samples were taken at 0–15 cm and 15–30 cm depth from each sampling spot making a total of 24 soil samples. These were taken to the laboratory, air dried and crushed using pestle and mortar and sieved through 2 mm sieve mesh. The soil samples were finally stored for subsequent analyses to determine the various chemical properties.

Results and Discussions

The soil pH was determined both in water and in calcium chloride ($CaCl_2$) solution using a pH meter. Organic carbon was determined by Walkley and Black method (1934). The cation exchange capacity was determined using ammonium acetate saturation method as described by Hesse (1957). Exchangeable bases were extracted by the ammonium acetate extraction technique and determined by flame photometry (Adepetu et al., 2000). The extract was analyzed for calcium (Ca^{2+}) and magnesium (Mg^{2+}) by atomic absorption spectrophotometry method while potassium (K^+) and sodium (Na^+) by flame photometer (Maclean, 1965). Total nitrogen (N^+) was determined by macro Kjeldahl digestion distillation method (Jackson, 1962). Available phosphorus was determined using Bray No. I method (Bray and Kurtz, 1945) Electrical conductivity (ECe) was determined using conductivity meter, the percentage base saturation, the sodium adsorption ratio (SAR) and the exchangeable sodium percentage (ESP) of the sample were computed using the following expressions:

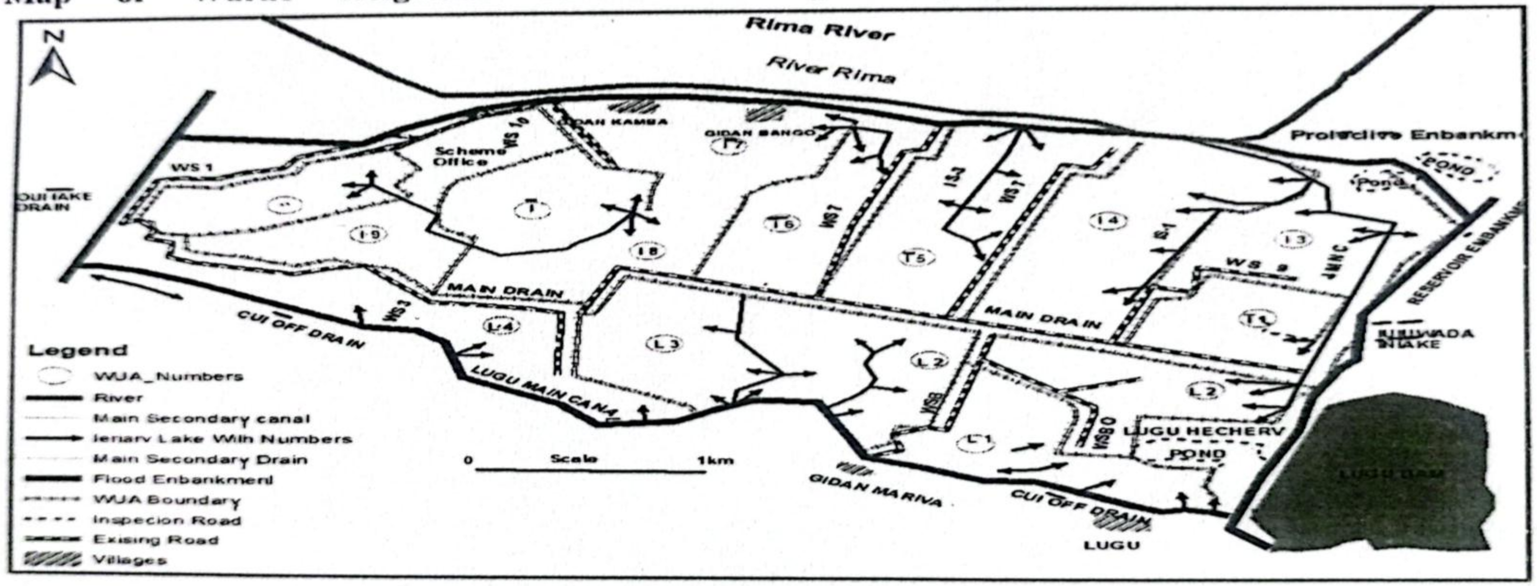
(i) $PBS = \frac{\sum ExchangeableBases}{CEC} \times 100$

(ii) $ESP = \frac{Na^{+}}{CEC} \times 10$

(iii) $SAR = \frac{Na^{+}}{\sqrt{\frac{1}{2}(Ca^{2+} + mg^{2+})}}$

The data collected were analyzed with the aid of analysis of variance (ANOVA) using statistical analysis system (SAS, 2002).

Map of Wurno irrigation Scheme showing sampling location with tag T



RESULTS AND DISCUSSION: The results of the chemical properties of the soils in the Tuttudawa Main canal of the Wurno Irrigation scheme after September 2020 flood is presented in table 1-4

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Table 1. Chemical properties of soil at Tuttudawa Main canal of the Wurno irrigation scheme after September 2020 flood (0-15cm)

Location	p^H_{H20}	p^H_{Cacl2}	EC	SAR	ESP %
Tt1D1	8.20±0.58[abcde]	6.63±0.58[abcd]	4.50±0.10[bc]	0.60±0.00[abc]	7.83±0.62[bcd]
Tt_2D1	7.93±0.42[def]	7.13±0.35[bcde]	4.13±0.02[c]	0.64±0.10[ab]	7.83±0.34[bcd]
Tt_3D1	7.10±0.17[ef]	6,8±0.58[bcde]	4.30±0.00[c]	0.60±0.02[abcd]	9.3±0.66[a]
Tt_4D1	7.83±0.17[cdef]	7.34±0.15[abcde]	4.03±0.01[c]	0.50±0.00[cd]	8.03±0.73[abcd]
SE	0.5	0.06	0.01	0.01	0.11
Significance	*	*	Ns	*	*

Means followed by the same letters within a treatment column are not significantly (ns) different at 5% level of probability using Duncan multiple range test (DMRT) ns-not significant (P<0.05)

Table 2 Chemical properties of soil at Tuttudawa Main canal of the Wurno irrigation scheme after September 2020 flood (15-30cm)

Location	p^H_{H20}	p^H_{Cacl2}	EC dS/m	SAR	ESP %
Tt1D2	7.20±0.36[a]	6.63±0.46[a]	2.03±0.02[c]	0.56±0.06[abcd]	8.58±1.66[abc]
Tt2D2	7.30±0.17[a]	5.80±0.17[a]	3.93±0.00[c]	0.60±0.06[abcd]	7.52±0.41[cd]
Tt_3D2	7.34±0.21[abcdef]	6.06±0.15[abcde]	2.02±0.02[c]	0.60±0.05[abcd]	8.50±0.16[abcd]
Tt4D2	7.27±0.15[abcd]	6.30±0.00[abcd]	3.02±0.01[c]	0.50±0.04[d]	07.23±0.15[d]
SE	0.05	0.06	0.01	0.01	0.11
Significance	*	*	Ns	*	*

Means followed by the same letters within a treatment column are not significantly (ns) different at 5% level of probability using Duncan multiple range test (DMRT) ns-not significant (P<0.05)

Significance	Ns	*	[illegible]	0.07	0.09	0.02	[illegible]	[illegible]	9.62±0.44[c]
			*	*	*	*	0.01	1.53	0.09
							*	*	

Means followed by the same letters within a treatment column are not significantly (ns) different at 5% level of probability using Duncan multiple range test (DMRT) ns-not significant (P<0.05)

The pH values were neutral to alkaline and ranged from 7.71 to 8.20 and 7.20 to 7.34 at 0-15cm and 15-30cm soil depth respectively. These trends indicate an increase in pH level which could be attributed to seasonal over irrigation and increase in atmospheric temperature and over use of salt forming fertilizers. However, the observed pH values across the sampling locations are within the alkaline range that can poses a serious threat for the best performance of most tropical crops (Brady and Weil, 1999). The values are contrarily to what was previously reported by Singh, 1997 and Singh, 1999 while working on soils of Sokoto Rima River Basin and Kandoli Shein stream valley. Irrigation practices significantly affected the distributions of pH values across the locations and soil depths ($P<0.05$).

Electrical conductivity (ECe) values for the soils ranged from 4.03 to 4.50 dS/m and 2.03 to 3.93 dS/m at the 0-15cm and 15-30cm depths. From the results of the study, it indicated a significance difference in the mean values of (ECe) across the sampling locations and depths. In general, the ECe values suggest that there is accumulation of soluble salts to the depth sampled to such an extent to limit crop production. This was supported by FAO, (2014) and Jaiswal, (2011) who reported EC, values of between (2-4 dS/m) as slightly saline and Ece values 4-8 dS/m as saline. The values revealed that they are within the range to cause salinity hazards.

Sodium adsorption ratio ranged from 0.50-0.64 at both 0-15 and 15-30cm depths and can pose any threat to salinity build up. Additionally, irrigation practices and soil depths significantly affected the distributions of SAR values across the sampling locations ($P<0.05$). The results also agree to the rule that values of SAR should always be lower than the values of ESP (%). Values of ESP is presented in (Table 1 and 2). There is also significant difference between the ESP values across all the sampling locations, and depth ($P<0.05$). Also, there was significant difference between the values of organic C across all the sampling locations and depth due to irrigation practices. It was observed that, the distribution of organic carbon was irregular, across the location, but at (TtD_2) the value was relatively higher. This could be attributed to the anaerobic condition of the subsurface layer, as poorly drained soil are typically known to accumulated higher levels of organic matter than well-drained soil, (MacCauley et al; 2003) or may be due to differences in organic matter content of alluvial materials deposited during seasonal flooding (Ojanuga, 2006).

On the general assessment, the low organic C observed in the study area could be due to intensification of cultivation (Greenland et al., 1994) or due to rapid decomposition and subsequent mineralization of organic matter owing to high temperatures which speed-up microbial activities. Total Nitrogen ranged from 0.7 to 0.07. The low values could be attributed to leaching process of N especially under flooded situation. In addition, the finding

confirms the fact that the total N decrease with soil depth (Brady and Weil, 1999). Also, the total N values observed were somewhat higher than those reported by Graham and Singh (1997) who reported value of N as high as 0.4-0.6gkg at 0-15cm depth. The finding also agrees with the work of Mustapha and Nnalee, (2007) who reported low nitrogen levels obtained from Fadama soils in Bauchi state.
Irrigation practice and Soil depth also affected the distributions of Total Nitrogen levels significantly across all the locations ($P<0.05$). The values of Available phosphorus ranged from 1.20 to 1.30 mg/kg and 1.09 to 1.16g/kg at (0-15cm) and (15-30cm) depth respectively. Esu (1999) reported that soils with available P level of <10mg/kg is rated low, 10.0-20.0 mg/kg as medium and > 20mg/k is rated high. This therefore, qualifies the soils of Tuttudawa study sites to be within the low range of available P. The exchangeable bases were generally high except calcium which was found to be low across all the sampling points and depths. The values ranged from 1.81 to 2.86 cmol(+)/kg,1.63 to 2.50 cmol(+)/kg and 1.60 to 3.28 cmol(+)/kg^{1},1.62 to 2.40 cmol(+)/kg^{1} for calcium and magnesium at 0-15 cm and 15-30cm soil depths respectively. The values of exchangeable K and Na" values ranged from 0.92 to 1.13 cmol (+)/kg, 0.92 to 1.00cmol (+)/kg and 0.78 to 1.00 cmol(+)/kg and 0.74 to 0.89cmol(+)/kg at 0-15 cm and 15-30cm depths respectively. Percent base saturation ranged from 49.01 to 75.73% and 50.55 to 65.60% at 0-15cm and15-30cm soil depths.

The values obtained could means that over 50% of the cations could be exchanged into the soil solution for root uptake. Esu, (1991) reported soils with base saturation of <50% (as low), 50-80% (medium) and (>80%) as high and therefore the soil is within the medium range of base saturation. Cation exchange capacity values ranged from 9.94 to 10.80 cmol(+)/kg^{1} and 9.62 to10.24 cmol(+)/kg at 0-15cm and15-30cm)depth respectively. The distribution of the mean values were irregular and were significantly affected by irrigation practices ($P<0.05$). This also translated the soil into a very good index of percent base saturation (PBS).

Conclusion

Soils along the Tuttudawa Main Canal of the Wurno Irrigation Scheme are generally within a low to medium fertility range. Also, The soils also showed clear evidence of salt accumulation. Therefore, periodic soil monitoring is necessary to prevent further degradation.

Recommendations

1. It is highly recommended to adopt sound soil and water management practices, such as controlled irrigation. In addition, the government should prioritize the rehabilitation of damaged water conveyance systems to reduce waterlogging and prevent salt accumulation.

2. Implementing effective soil and water management measures, particularly controlled irrigation, is crucial. The government is urged to promptly repair deteriorated water conveyance infrastructure to curb waterlogging and salinity issues.

3. Proper soil and water management practices, especially through regulated irrigation, are essential. Urgent government intervention is needed to restore damaged water conveyance structures in order to control waterlogging and minimize salt buildup.

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