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Irrigation Soil Analysis in River Katsina-Ala Catchment Areas of North-Central Nigeria

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ABSTRACT

Soil quality analysis for irrigation in river Katsina-Ala catchment areas of Benue State, North-central, Nigeria was carried out in this research. Several soil samples from three selected catchment areas namely, Logo, Ambighir and Katsina-Ala of Benue state, were collected and analyzed. The investigation was carried out in the wet and dry seasons 2013. The mechanical analysis of the soils indicated that Logo had sandy loam texture while Ambighir and Katsina-Ala were of loamy sand to sandy loam textures. The soils had high values of infiltration capacities (0.0096cm/s to 0.053cm/s). They showed moderate values of CEC (3.09Cmol/kg to 8.50Cmol/kg) and high base saturation (91 to 97%). The pH of the soils varied from slightly acidic in the wet seasons to slightly alkaline in the dry seasons (5.3 to 7.8). Risk of infiltration was envisaged as a result of very low values of conductivity (0.04ds/m – 0.25ds/m). At the present time, infiltration problem is minimal because of high proportion of sand (68% - 89%) in the soils but this situation may not be sustained for long. A regression model (R = 0.773) was obtained which showed that the rate of infiltration strongly depended on the sand content of soil. The soil qualities were found to be suitable for irrigation as the values of the parameters fell within the 'tolerable' limits.

Keywords: *Soil Analysis, Irrigation, Rainfall, Topography, Infiltration.*

1. INTRODUCTION

Land, soil, water, vegetation, fish and livestock, rocks, minerals, and different forms of energy with which our environment is endowed by nature are referred to as natural resources (Ojeniyi, 2002). Among the natural resources, soil and water are responsive to human influence, and constitute the resource base for our sustainable future (Adepetu, 1997). The soil is the most important factor in agricultural production being the main medium for plant growth. The manipulation or management of this resource base has significant influence on the environment or ecosystems because of its effects on water resource, human settlement, atmospheric quality, water and land pollution, vegetation type and distribution, fishery and wildlife (Ojeniyi, 2002 and Agbede, 2009).

In the Northern part of Nigeria, subject to the arid conditions, there has been tremendous progress in irrigation development programmes (Ahmed and Tanko, 2000). Benue State is located in the North Central geopolitical zone of Nigeria and lies within the Southern Guinea Savanna agro-ecological zone where rainfall is often erratic and inadequate in amount and distribution for production of some crops. Over 142,200ha of land are cultivated in Benue State (Ayuba *et* al, 2007). In Nigeria, annual rainfall varies from about 500mm in the extreme North to about 3000mm in the south and the rainfall is high in intensity. Annual rainfall in Benue varies from about 900 to 1200mm (Jimba and Adegoye, 2000). In Benue State, rainfed agriculture has suffered varying lengths and intensities of agricultural drought, thus necessitating irrigation in order to satisfy the moisture requirements of crops needed to meet the demands for food and fibre. The arable lands in Benue State consist of upland and fadama lands (flood plains). The upland is cultivated to many high value agronomic and horticultural crops. Fadama farming depends on rain in the wet season and residual soil moisture in the dry season. Poor quality water affects both soil quality and crop production adversely (Bello, 2001; USDA, 2001; FAO, 1994). Considering large hectares of land which are agriculturally productive within River Katsina-Ala catchment areas, there is a felt need to encourage irrigated agriculture. This can support year round crop production on medium and consequently alleviate poverty. Oladele *et al* (2004) observed that stagnation in agriculture has led to an increasing incidence of poverty and food security.

1.1. Study Area

The research was carried out in three selected catchment areas of the river Katsina-Ala. The River Katsina-Ala, is the tenth most important river in Nigeria (The National Atlas of the Federal Republic of Nigeria, 1978). River Katsina-Ala is located in what could be termed the Lower Benue hydrological area, between $6^0 50'$ and $7^0 48'$N, and $8^0 49'$ and $9^0 50'$E (Fig.1). It arises from the Bamenda highlands, part of the Cameroonian mountains, (1000 – 2000m a.s.l.) meandering North-Westerly and traversing the international boundary into Benue State at Kashimbila ($6^0 55'$N, $9^0 37'$E), before emptying into River Benue at Gbajimba ($7^0 48'$N and $8^0 49'$N) about 160m a.s.l (Ogueri, 2001). River Ambighir catchment area is located at Ambighir in Gboko Local Government. The study areas are bounded by longitudes $8^0 36'$ and $8^0 45'$E and latitudes $7^0 45'$ and $8^0 00'$N, while, River Logo catchment area is located at Logo in Logo Local Government Area which is bounded by longitudes $9^0 16'$E and $9^0 28'$E and latitude $7^0 36'$ and $7^0 50'$N. The maximum elevation of river Katsina-Ala catchment area is 151.5m above mean sea level (a.m.s.l) and minimum elevation is 121.21m a.m.s.l. Ambighir relief ranges from 90 to 262m a.m.s.l., and Logo ranges from about 121 to 159m a.m.s.l. The climate of the study areas is tropical savanna.

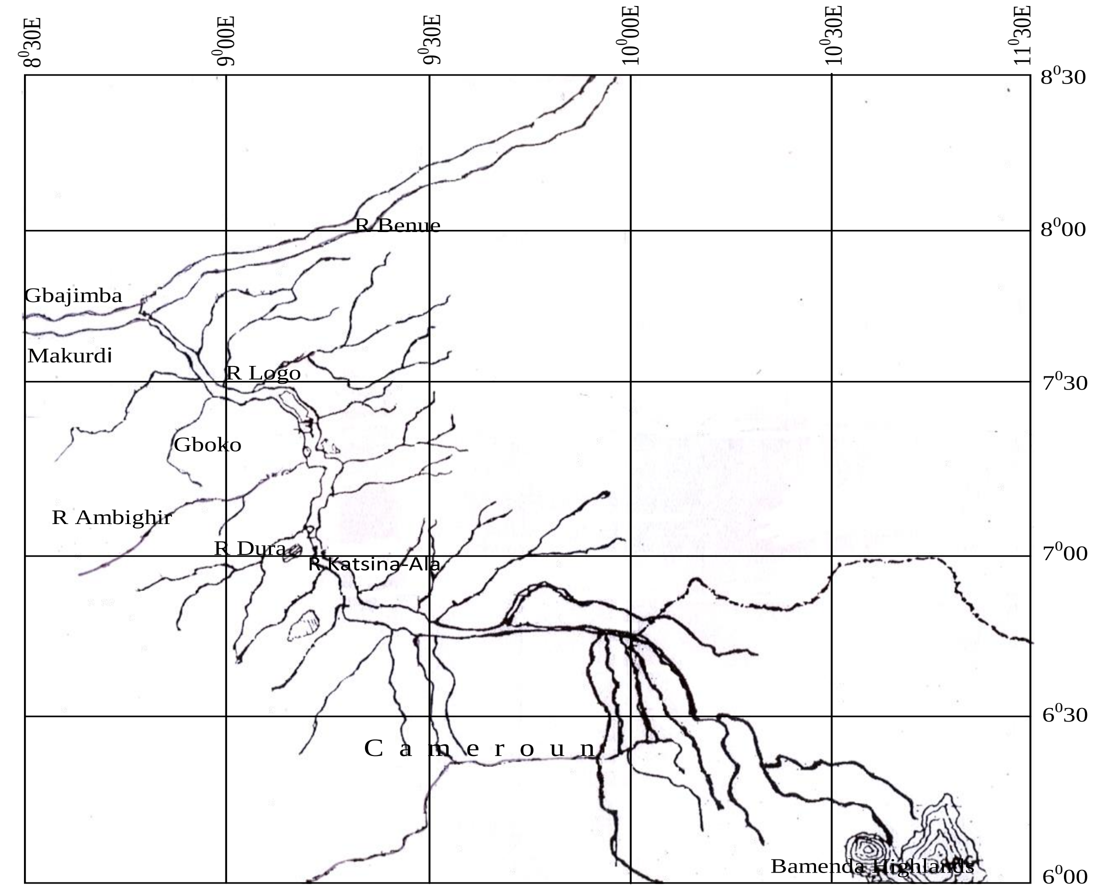

Figure 1: Map of Study Area

The minimum and maximum temperatures are 9.7^0C and 33.5^0C respectively. The mean monthly temperature is 27.3^0C. The study areas have distinct dry and wet seasons with total annual rainfall varying between about 900 and 1200mm. Rainy season starts in April and ends in October/November. The vegetation in the study areas is Guinea Savannah type, characterized by grasses with few scattered shrubs and trees. Commonly cultivated crops include yam, cassava, guinea corn, maize, millet, groundnut, soyabean, benniseed, rice, melon, and other vegetable crops. Trees crops such as mango, palm trees, citrus, cashew and other economic trees are also found in the areas.

The crop mostly produced (Figure 2) is yam(26%) followed by soya bean (16%), groundnut and rice (8.67% each). Though Benue state is subject to erratic rainfall, the intense agricultural activities occurring in the state has made it the "food basket of the nation". The main aim of the research is to assess the quality of soils at some locations along the river Katsina-Ala catchment areas of Benue State, for irrigation purposes and identify crops which are adaptable to or tolerant of the inherent qualities of the soil.

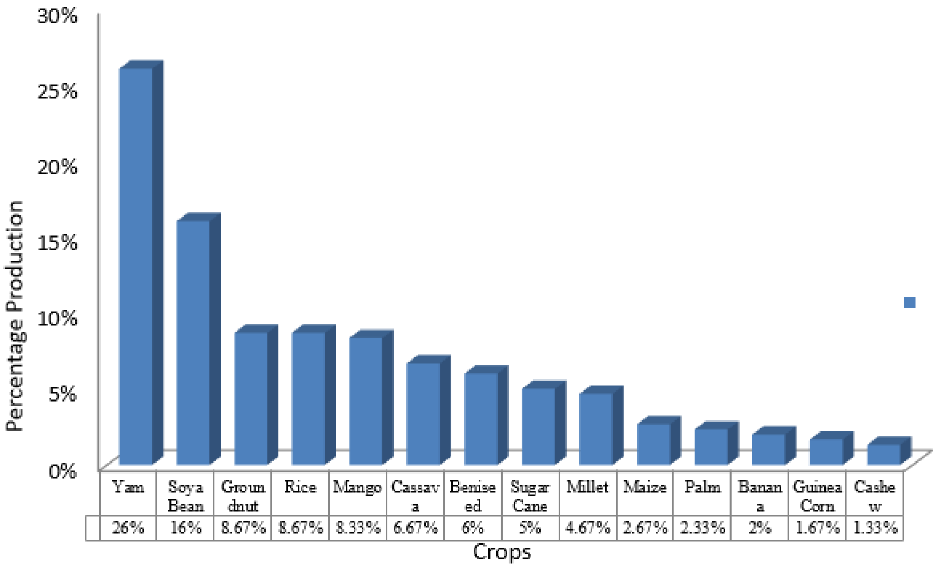

Figure 2: Distribution of Major Crops Produced in Study Area

2. METHODOLOGY

2.1. Infiltration Capacity

Infiltration capacity tests were carried out in the three catchment areas of the river Katsina-Ala. Six (6) locations were determined in each catchment area. Infiltration test was done by digging 10cm X 10cm X 10cm pit at each location. Water volume of 250cm^3 was poured into the pit and the time in second was taken and recorded for water transmission into the soil. This was repeated four times at each location. The random sampling technique was used to collect soil samples from six (6) different locations in each catchment area. Composite soil samples were taken at the depth of 0 – 30cm, 30 – 60cm and 60 – 90cm at each location. The samples were sieved using 2.0mm sieve for physical and chemical analysis. Eighteen soil samples were collected for wet and dry seasons (3 samples x 6 locations), making a total of 108 soil samples collected.

2.2. Soil Mechanical and Chemical Composition

The relative proportion of the different soil separates in each depth was determined by hydrometer method. The glass electrode method was used to determine the soil pH (both the active and reserved soil pH). The organic carbon content of the soil samples were determined by the chromic acid oxidation procedure of Walkley – Black. The electrical conductivities of the soil samples were measured with electric conductivity meter. The cation exchange capacity, Sodium, potassium, Calcium, magnesium, total nitrogen and phosphorus were determined using appropriate testing meters and in accordance with the standard methods (APHA, 1998).

3. RESULTS AND DISCUSSION

3.1. Mechanical Composition

The particle size distribution of Logo, Ambighir and Katsina-Ala soils is presented in Table 1. From the samples collected from six locations each at the depths of 0 – 30, 30 - 60 and 60 – 90cm, Logo soils were moderately drained and aerated due to the sandy loam texture of the soils. They have moderate water holding capacity and retain nutrients moderately. While, Ambighir have loamy sand texture indicating low water holding capacity, rapid water and air transmission. Ambighir soils possess good drainage and aeration. Katsina-Ala soils have loamy sand texture which indicates low water holding capacity, good drainage and aeration. The soils appear moderately suitable for irrigation, but may be drought prone.

Table 1: Mechanical Composition of the Logo, Ambighir and Katsina-Ala Soils.

Location	Depth (cm)	Average particle size distribution (%)			Textural class (USDA)
		Sand	Silt	Clay	
Logo	0 – 30	72.0	20.0	8.0	Sandy Loam
	30 – 60	71.0	18.0	11.0	Sandy Loam
	60 – 90	71.0	17.0	12.0	Sandy Loam
Ambighir	0 – 30	69.0	20.0	11.0	Loamy Sand
	30 – 60	69.0	19.0	12.0	Loamy Sand
	60 – 90	68.0	17.0	15.0	Loamy Sand
Katsina-Ala	0 – 30	75.0	17.0	13.0	Sandy Loam
	30 – 60	73.0	17.0	14.0	Sandy Loam
	60 – 90	73.0	17.0	14.0	Sandy Loam

3.2. Chemical Composition

Table 2 presents the chemical composition of soils in the study area. Salinity was measured above 4mmhos/cm. Saline and sodic soils are referred to collectively as halomorphic soils (Agbede, 2009). Electrical conductivity (ECe) of the three catchment areas ranged from 0.04 to 0.25ds/m. The values are generally low and show that the soils are non-saline according to the limits set by Schoeneberger *et al.* (2002). Sodium, which determines the sodicity status of a soil was generally low and ranged from 0.04 to 0.16 Cmol/kg. The low sodium level in the soils was further confirmed by the low ESP. The exchangeable sodium percentage (ESP) ranged from 0.7 to 3.3%. Soils with ESP of less than 15% are said to be non-sodic and thus good for irrigation. The soil pH values of Logo, Ambighir and Katsina-Ala catchment areas were generally slightly acidic (pH: 5.3-6.9) in the wet season, and slightly alkaline (pH: 7.1-7.8) in the dry season (Table 2). Acidity in the wet season was due to the leaching of appreciable quantities of exchangeable base-forming cations (Ca, Mg, K and Na) from the surface layers of the soils and high buffering capacity. In the dry season, there was a comparatively high degree of saturation with base-forming cations and low buffering capacity.

The organic matter contents of soils of Logo, Ambighir and Katsina-Ala in the dry season (0.9 – 4.2%) were higher than in the wet season (0.61 – 4.0%). This is because there was rapid rate of organic matter decomposition due to moisture in the wet season which brought about decline in its content in the soils. The values of organic matter in the soils of the study areas were generally moderate. The organic matter of most soils ranges from 1-5% mostly in the top 25cm of soil (Agbede, 2009). The soil is considered moderately suitable for irrigation due to moderate organic matter contents of the soils. Water holding capacity, granulation, cation exchange capacity, supply and availability of nutrients would improve. The nitrogen content of the soils of the study areas in dry season (0.15 – 1.0 mg/kg) was higher than in the wet season (0.11 – 0.58 mg/kg) (Table 2). These could be as a result of rapid rate of organic matter decomposition, excessive leaching of nutrients down the soil profile, and crop removal and erosion during the rainy season. Most savanna soils of Nigeria have very low total N content (0.04 – 0.05%) as against the normal range of 1 – 6% N (Adetunji and Adepetu, 1990). The soil is considered suitable for irrigation even though they are low in N content but due to moderate organic matter content in the soils, N would be supplied through decomposition of organic matter when water is applied.

The sulphur content of the soils of the study areas in the dry season (0.1 – 0.72 mg/kg) was higher than in the wet season (0.07 – 0.37 mg/kg). Generally, the sulphur content of the soils was low. Sulphur deficiency could result from the parent materials, high leaching rates, crop removal and low level of atmospheric sulphur-bearing air. The available P content of the soils during the dry season (0.29 – 4.0 mg/kg) was higher than those of the wet season (0.19 – 3.62 mg/kg) (Table 2). The moderate level of phosphorus content of the soils is due to moderate organic matter content, parent material and degree of weathering. The exchangeable bases are generally moderate in all the soils of the three study areas (Logo, Ambighir and Katsina-Ala). Calcium and magnessium are the dominant cation. Potassium and sodium are low in concentration (Table 2). The Cation Exchange Capacity (CEC) is moderate in all soils of the study areas and ranged from 3.09 Cmol/kg to 8.50 Cmol/kg (Table 2). The base saturation (BS) of the soils of the study areas is generally high and ranges from 91 to 97%. Base saturation values greater than 50% indicate fertile soils while values less than 50% indicate low fertility (FAO – UNESCO, 1998). Based on this, the soils of three catchments areas could be considered fertile.

Table 2: Chemical Properties of Logo, Ambighir and Katsina-Ala Soils (Average values)

Location	pH	OC	N	S	P	Ca	Mg	K	Na	CEC	ESP	EC
		%	(mg/kg)			(Cmol/kg)					%	(ds/m)
						Wet Season						
Logo	5.30	0.61	0.11	0.07	0.19	2.28	1.82	0.09	0.08	4.46	2.20	0.08
Ambighir	6.15	3.20	0.36	0.18	2.89	1.80	1.03	0.28	0.04	5.80	3.30	0.04
Katsina-Ala	6.90	4.00	0.58	0.37	3.62	4.00	2.80	0.48	0.16	3.72	0.96	0.15
						Dry Season						
Logo	7.10	0.90	0.15	0.10	0.29	3.82	1.63	0.72	0.18	7.24	0.70	0.25
Ambighir	7.50	2.95	0.45	0.54	0.31	4.20	2.90	0.64	0.07	8.50	1.08	0.20
Katsina-Ala	7.80	4.20	1.00	0.72	4.00	2.08	2.04	0.16	0.13	3.09	2.24	0.18

3.3. Infiltration Capacity

In river Logo catchment area the values of infiltration capacities were generally high and varied from 9.56 x10^{-3} cm/s to 1.04 x 10^{-2} cm/s (34.4 cm/hr to 37.4cm/hr) (Table 3). The soils of the study areas would transmit water at a rate of nearly 10m/day. According to Shoeneberger et al, (2002) a coarse sandy soil with K value of 10^{-2} cm/s would lose water at the enormous rate of nearly 10 m/day while a fine loam soil with a K value of 10^{-4}cm/sec would lose "only" about 10 cm/day. Logo soils show high transmission of water and moderate water holding capacity.

Ambighir catchment areas have high values of infiltration capacities varying from 1.53 x 10^{-2} to 5.32 x 10^{-2} cm/s (55.1 to 191.5 cm/hr). The soils of the study areas indicate high transmission of water, low to moderate water holding capacity, well drained and suitable for irrigation (FAO, 1994).

The soils of river Katsina-Ala catchment area have high infiltration capacities varying from 1.05x10^{-2} to 1.81x10^{-2} cm/s (37.7 to 65.2 cm/hr) (Table 3). The soils of the study areas would transmit water at a rate of about 16 m/day. These soils show high transmission of water, moderate water holding capacity. They are well drained and good quality for irrigation.

Table 3: Infiltration Capacity (K) in Study Location

Location	Proportion of Sand (%)	Range of K (cm/s)	Effects on land use (Marshall and Holmes, 1988)
River Logo Catchment Area	68 – 75	0.00956 – 0.0104	Wide range for crops/irrigation
River Ambighir Catchment Area	83 – 89	0.0153 – 0.0532	Wide range for crops/irrigation
River Katsina-Ala Catchment Area	79 – 86	0.0105 – 0.0181	Wide range for crops/irrigation

3.4. Risk of Infiltration

The soil problems most commonly encountered and used to evaluate water quality are those related to salinity, water infiltration rate and toxicity problems (Rogers *et al.*, 2003; FAO, 1994; Ayers and Westcot, 1994; USDA, 2001; Yakubu *et al.*, 2006). Irrigation water of high salinity content can cause salt accumulation in soils which leads to soil structure problems. SAR and electrical conductivity can be used to assess the risk of infiltration as suggested by Ayers and Westcot (1994). However, the extent of infiltration risk resulting from irrigation water depends on soil characteristics with the risk being higher as clay content of the soil increases. Despite the high risk of infiltration problem posed by the water, the soils have not yet developed infiltration problems because of the high sand content (Table 3). Table 3 shows the results of the infiltration capacity tests carried out in Logo, Ambighir and Katsina-Ala respectively. The values of the infiltration capacity fell within the range suitable for a wide range of crops and irrigation. Table 3 shows that the soils had high values of infiltration capacities varying from 9.56 x 10^{-3} cm/s to 5.32 x 10^{-2} cm/s.

The infiltration capacity was found to be proportional to the percentage of sand in soil and the clay content increased with depth. A multiple regression model (R= 0.773) relating infiltration capacity to proportion of sand was obtained (Equation 1).

$$K = 0.1Sand + 0.076Silt - 0.089 \quad (1)$$

K is the infiltration capacity while *sand* and *silt* are the proportions (fraction) of sand and silt respectively. Including clay content in the model did not improve the model, hence it can be inferred that clay content should not be of concern when present in the quantities found in these soils. Infiltration problems can also result from extremely low electrical conductivity (too little dissolved salt). The range of conductivity observed in the water samples (0.04ds/m to 0.25ds/m) can cause disintegration of soil aggregates.

4. CONCLUSION

An assessment of the quality of soils at some locations along the river Katsina-Ala catchment areas of Benue State was carried out to determine the suitability of the soils for irrigation purposes. The study areas were rivers Logo, Ambighir and Katsina-Ala catchment areas. Topographical map was used for physiographical analysis of the study areas. Infiltration capacity test was carried out in the fields. Soil samples were taken at the depths of 0 – 30, 30 – 60 and 60 – 90cm for mechanical and chemical analysis. The investigation was carried out in the wet and dry seasons of 2013. The soils of Logo catchment area were of dominantly sandy loam texture while Ambighir and Katsina-Ala were of loamy sand to sandy loam textures. The soils have high values of infiltration capacities. The soils of the study areas indicate no salinity problem as the values of pH, electrical conductivity and exchangeable bases fall within the tolerable limit. The soils are rated moderate in fertility status. This is because of their moderate levels of cation exchange capacity, organic matter, exchangeable bases and high base saturation.

The levels of organic matter, CEC, and base saturation show that the soils are moderately fertile. The soil pH, ESP and EC show that the soils are non-saline and therefore, suitable for irrigation. Because of the agricultural potentials of these soils, crops like legumes, cereals and vegetables could be adaptable to or tolerant of the inherent quality of the soils. Therefore, it is advisable to construct tube well at the flood plain to exploit groundwater for irrigation during drought/dry seasons in the study areas. In the catchment areas underlain by weathered basement complex with low coefficient of soil conductivity, an earth dam is recommended to impound surface water for agricultural use. However, soil structure problems are likely to develop if proper management practices are not initiated.

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