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## SUITABILITY EVALUATION OF SOILS OF RIVER CHANCHAGA DOWNSTREAM FLOODPLAIN FOR RICE PRODUCTION

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### ABSTRACT

*This study assessed the suitability of floodplain soils along the River Chanchaga downstream in Niger State, Nigeria, for sustainable rice production. Three physiographic units (upper, middle, and lower slopes) were identified within the downstream floodplain, with three profile pits dug and sampled at each location according to FAO guidelines. Standard laboratory procedures determined soil properties. Qualitative land suitability evaluation, comparing soil characteristics with rice requirements, indicated the soils were marginally and moderately suitable for rice cultivation, primarily due to limitations in chemical properties. Downstream soils exhibited sandy clay loam, Silty clay, Silty clay loam and clay loam textures, with a dominance of sand (532-842 g kg<sup>-1</sup>). Soil pH ranged from slightly acidic to neutral (5.8-6.8), while organic carbon was low across all sites. Nitrogen and phosphorus distribution varied with depth. Calcium was the dominant exchangeable base, while potassium was moderate (<0.32 cmol kg<sup>-1</sup>). Cation exchange capacity (CEC) and percentage base saturation (BS) were low to high (33 -77%). Quantitative land suitability evaluation using the Storie method also classified the downstream area as unsuitable (N), but the Rabia equation indicated moderate suitability (S2) after amending the fertility status. This comprehensive analysis highlights the need for soil improvement strategies to enhance the suitability of these floodplain soils for rice production.*

*Keywords: Floodplain, qualitative and quantitative, Physical and chemical properties*

### Introduction

Worldwide, floodplain “Fadama in Hausa” soils are useful for agricultural production as they constitute a huge reserve of available nutrients for utilization by crop plants (Sheriff *et al.*, 2008). Floodplain soils refer to soils of wetlands or the seasonally flooded or floodable plains along rivers and/or depressions on adjacent low terraces (Ibrahim and Omotosho, 2012). They are found scattered in all parts of

tropical regions but more importantly in areas with low precipitation, the attention of farmers and government to the exploitation of floodplain, which is believed to have more agricultural potential than the upland soils (Samuel *et al.*, 2023). The process of land suitability classification involves the assessment and categorization of specific areas of land in terms of their suitability for defined uses (Sathiyamurthi *et al.*, 2024). Floodplains

in Nigeria are now becoming the "food basket" because they serve as the main source for growing crops for man and food supply to livestock all year round. With the exponential increase in human population, there is a pressing need to boost food production by utilizing all available land resources. The data that was generated from this study would equip floodplain users with necessary information that would be essential for the management of the floodplain soils for maximum and sustainable agricultural production that could guarantee national food security. However, despite the importance of land evaluation for sustainable land management and for enhanced crop production, specific soil suitability studies; such as suitability assessment for rice production, have not been properly documented; and available ones show locations and ecological bias. Given the importance of soils to past and present societies, there is a need to investigate the soils of River Chanchaga floodplains soils downstream to tap its potential for rice production. Unfortunately, much has not been done to highlight the inherent potential of this natural asset. This study evaluates the potential of the floodplain soil for rice production. Therefore, the result of this resource will guide all stakeholders to determine effective management strategies for sustainable use of the floodplain for rice production.

## Materials and Methods

### Study Site

The study was conducted at the floodplain of the River Chanchaga (downstream), the downstream falls under Katcha Local Government Area on latitude  $09^{\circ} 27.99' N$  and  $09^{\circ} 28.19' N$ , longitude  $06^{\circ} 25.66' E$  and  $06^{\circ} 25.44' E$ , (Fig.3.1), with average elevation between 65 and 81 m above sea level. The selection was also attributed to differences in the geology and vast land mass of the floodplain which was used for rice production

at the site. The study area lies within the tropical hinterland climatic region designated as sub-humid, with mean annual rainfall ranging between 1,127 between May to October peaking in August and a dry season of about five (5) months between November to March, with a dry season of about five months Maximum mean temperature range, is  $33^{\circ} C$  with a relative humidity of over 80 % in the morning and falls to between 40 and 70 % in the afternoon (Ojanuga, 2006). The vegetation of Niger State as characterized by Adeboye *et al.* (2011), is Southern Guinea Savanna with various plant species such as *Andropogon gayanus*, *Daniellia oliverii*, *Vitellaria paradoxa* (Shea butter trees) *Isobertina species*, *Hyperti spp* (Weed grass) and *Azadirachta Indica* (Neem tree) which are among the commonest trees, shrubs and grasses. The geology of the area is underlain predominantly by igneous and metamorphic rocks of the pre-Cambrian Basement Complex while granites, gneisses, quartzites, and schist are the dominant rock types. The landscape consists dominantly of undulating terrain with occasional isolated granite and gneiss hills, and steeply rising quartzitic ridges. Lawal *et al.* (2012) observed quartz to be a prominent mineral constituent of the soils around Minna.

### Fieldwork

Soil sample units were identified, mapped and delineated for suitable rice production by using a baseline contour map. The ground control points were measured across the extent of the study area using hand held Global-positioning system (GPSMAP 76) receivers. Soil survey instruments used include Soil description sheets, a Munsell Soil Colour chart (2009), a machete, shovel, spade, soil auger, mallet, digger, plastic bowl, buckets and field book with biro, pencil, ruler and a digital camera. Profile pits were dug to the specification of 2m by 2m by 1.5m and described according to guidelines for soil profile description. The

genetic horizons were identified based on the observed differences in some morphological characteristics of the soils which include colour, texture, structure, depth of horizons, and topography which was used to establish

the soil boundaries Soil samples were analyzed for some physical and chemical properties following the procedures.

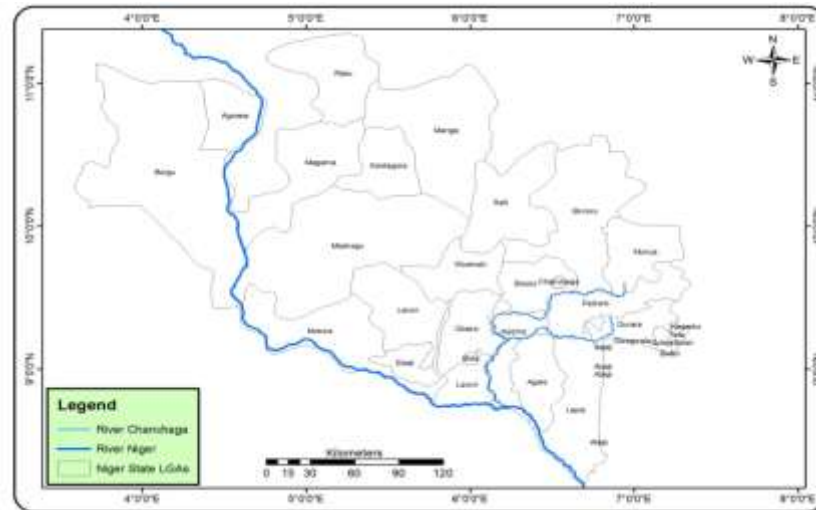


Figure 1: Niger State Map Showing the Study Area

## Land Suitability Evaluation for Rice Production.

### Simple Limitation Method

Land suitability evaluation for rice was carried out using the revised FAO s Framework for Land Evaluation (FAO, 2015) and Sys *et al.* (1991, 1993). Soils of the site evaluated were placed in the suitability classes, using qualitative methods by matching their characteristics with the requirement of rice. The major factors to be evaluated were soil characteristics (soil depth, texture, drainage, pH, organic carbon, available P, CEC, and base saturation). The overall suitability class for each identified soil was determined by using the limitation methods (most undesirable characteristics or quality of the land).

### Parametric method

The parametric land evaluation consists of a numerical rating of different levels of land characteristics and qualities according to a numerical rating between a minimum to

maximum value (Sys *et al.*, 1991; O'geen *et al.*, 2008). The land characteristics and qualities used for the parametric land method were climate (annual rainfall and temperature), wetness (drainage), topography (slope), soil physical characteristics (texture, depth), nutrient availability (pH, N, P, K), and nutrient retention capacity (Organic carbon, CEC).

The methods used in calculating soil/ land indices were:

### i-Storie index

$$IP = A \times B/100 \times C/100 \times \dots \times F/100$$

Where I is the index (%) of suitability, A = is the index of the most limiting factor, B, and C are indexes of other ratings besides the minimum rating.

### ii- Rabia equation

$$IP = R_{max} = A/100 \times B/100 \times \dots \times F/100$$

Where I is the index (%) of suitability,  $R_{max}$  = maximum rating and A, B, C.... other ratings besides the maximum rating.

## Results and Discussion

### Morphology, Physical and Chemical Properties of the Study Area

The texture of the studied soils by feel method was generally sandy clay loam, silty clay loam and sandy loam at the surface over clay loam at the subsurface horizon, with presence of poor drainage as indicated by the presence of mottles at the surface. The surface structure is moderately crumb to moderately sub-angular blocky at the subsurface across all the slope levels.

The result in Table 1 depicts the physical properties of the soil of the study sites downstream.

### Soil Texture and Particle Size Distribution of the Soils

The soil texture ranged from sandy loam over loam at all the slope levels of downstream while the Particle size distribution, Table 2 showed that for the three (3) slopes: the upper, middle and lower slope of upstream soil indicates that the sand ranged from 532 to 842  $g\ kg^{-1}$ . The high sand fraction is a feature of most savanna soils due to illuviation and eluviation processes as well as the effect of erosion and lessivage. Soils with high sand content are vulnerable to erosion because they are easily detached by heavy rainfall or running water (Usman, 2021). The silt content ranged from 43 to 393  $g\ kg^{-1}$ . Silt fraction was irregular with depth due to the rate of materials brought by the flood. The clay content of the soil ranged from 75 to 135  $g\ kg^{-1}$ .

### Effective Soil Depth

Horizon differentiation reveals much about soil formation and its processes. In the upper slope downstream, is the Ap (0-28 cm) horizon overlaying the Btg1 horizon. The Btg1 horizon

was not very thick (28-77 cm), likewise Btg2, (77-113 cm) and the BC were so thick extending from 113-200 cm, in the middle slope, Ap (0-18 cm) horizon overlaid Btg1 (18-53cm) over Btg2 (53- 100 cm) horizon over BC (100 - 174 cm) horizon which was thick, waterlogged at >174 cm. At the lower slope, the Ap (0-29 cm) horizon overlaid Btg1 (29-51 cm), Btg2 (51-87 cm), and Btg3 (87-126 cm) horizons, there were not much variations in the horizon but BC (126 - 200 cm) horizon, was very thick.

### Chemical Properties of the Soils

The results of the chemical properties of the Soils are shown in Table 2 and their interpretation was based on the concept of Esu (1991), Chude *et al.* (2011) and Lawal *et al.* (2012). The soil reaction (pH) falls within the range of 5.8 to 6.8 described as strong to neutral acidic, which is considered highly suitable for rice production. Organic carbon (OC) content ranged from 3.2 to 7.3  $g\ kg^{-1}$  rated low. Total nitrogen (TN) content ranged from 0.03 to 0.22  $g\ kg^{-1}$  rated low to high, Available phosphorus ranged from 1 to 3  $mg\ kg^{-1}$  rating low, the low value agrees with the view of Usman *et al.* (2020) that the total quantity of phosphorus in most native soils is low, with most of it present in the form quite unavailable to plants. The low available phosphorus may be attributed to the low organic carbon of the floodplain. For Exchangeable bases (Ca, Mg, K and Na) all rated moderate to high. The exchangeable acidity (EA) ranged from 0.02 to 0.05  $cmol\ kg^{-1}$  at the upper slope, at the middle slope EA ranged from 0.01 to 0.05  $cmol\ kg^{-1}$  and at the lower slope it ranged from 0.01 to 0.03  $cmol\ kg^{-1}$ . Cation exchange capacity (CEC) ranged from 6.0 to 8.4  $cmol\ kg^{-1}$  rated low to moderate. The percentage base saturation (BS) ranged from 33 to 77% all rated low to high. The distribution of base saturation is irregular in all the slope levels, this could be attributed to the plant litter decomposition process which

incorporated cations from litter into the soil surface and also the contribution by harmattan

dust known to contain a high fraction of cations especially Ca (Ali *et al.*, 2022).

Table 1: Particle Size Distribution of downstream Soils

Horizon	Soil Depth (cm)	Sand Silt Clay			Silt/Clay ratio	Textural Class
$g\ kg^{-1}$						
UPPER SLOPE						
Ap	0 – 28	532	393	75	5.24	Sandy Loam
Btg1	29 – 77	672	231	115	2.01	Sandy Loam
Btg2	78 – 113	682	193	125	1.54	Sandy Loam
BC	114 – 200	822	43	135	0.32	Sandy Loam
MIDDLE SLOPE						
Ap	0 – 18	812	103	85	1.21	Loamy Sand
Btg1	18 – 53	842	83	75	1.11	Loamy Sand
Btg2	53 – 100	692	233	75	3.11	Sandy Loam
BC	101 – 174	762	153	85	1.80	Sandy Loam
LOWER SLOPE						
Ap	0 – 29	692	203	105	1.93	Sandy Loam
Btg1	30 – 51	802	123	75	1.64	Loamy Sand
Btg2	52 – 87	672	243	85	2.86	Sandy Loam
Btg3	88 – 126	582	293	125	2.34	Sandy Loam
BC	127 – 200	642	243	115	2.11	Sandy Loam

### Land Suitability Evaluation for Rice Production

At the downstream, the climatic parameters evaluated were annual rainfall and average temperature which were rated highly suitable S1 (100) in all the sites. The average temperature (33°C) was highly suitable S1 (100) at the upper, middle and lower slopes. The topographic parameter (slope percent) was (0-3%) highly suitable S1 (100). Soil physical parameters evaluated were soil texture and depth, the depth of the downstream sites was highly suitable S1 (100) at all levels while the texture was rated moderately suitable S3 (60) at the upper and lower slope and the middle slope was rated not suitable (N). Fertility parameters evaluated for rice production were soil pH, organic carbon, total Nitrogen, available phosphorus, exchangeable

potassium, CEC and base saturation. Soil pH was rated moderately suitable S2 (85) at the upper, middle and lower slopes. Organic carbon was not suitable N (40) at all slopes. Total nitrogen was rated currently not suitable (N1) at the upper and middle slope, but marginally suitable at the lower slope of the downstream. Available phosphorus at all slopes rated currently not suitable, and potassium rated highly S1 (100) at the upper, middle and lower slopes. CEC was rated marginally suitable S3 (60) at the upper, middle and lower slopes. Base saturation was rated moderately suitable S2 (85) at the upper, middle and lower slopes. The salinity and sodicity that is the exchangeable sodium percentage and Electrical conductivity all rated highly suitable at the upper, middle and lower levels.

Table 2 Chemical Properties of Downstream Soils of River Chanchaga Floodplain

Horizon	Soil Depth (cm)	pH	EC $\mu\text{S/cm}$	TN $(\text{g kg}^{-1})$	TOC $(\text{g kg}^{-1})$	Avail. P $(\text{mg kg}^{-1})$	Exch. Bases				Exch. Acid	CEC	BS %
							Ca	Mg	K	Na			
							(cmol $\text{kg}^{-1}$ )						
UPPER SLOPE													
Ap	0 – 28	6.3	0.08	0.22	5.90	3	3.60	1.90	0.32	0.30	0.05	8.50	72
B1	29 – 77	6.5	0.07	0.18	5.80	3	3.80	2.40	0.27	0.43	0.02	9.00	77
B2	78 – 113	5.8	0.05	0.08	4.20	1	3.12	1.60	0.20	0.23	0.04	8.20	63
B3	114 – 200	6.4	0.04	0.06	4.20	2	1.84	1.28	0.18	0.27	0.02	7.50	48
MIDDLE SLOPE													
Ap	0 – 18	6.0	0.10	0.12	7.20	3	3.30	1.70	0.20	0.11	0.05	8.00	66
B1	18 – 53	6.3	0.02	0.03	5.80	1	2.80	1.40	0.18	0.07	0.02	7.30	61
B2	53 – 100	6.6	0.05	0.04	5.10	1	2.60	1.50	0.17	0.07	0.01	8.00	54
B3	101 – 174	6.8	0.03	0.07	4.20	2	1.72	0.64	0.21	0.12	0.04	6.00	42
LOWER SLOPE													
Ap	0 – 29	6.2	0.07	0.20	7.30	23	4.20	2.50	0.24	0.25	0.01	7.70	74
B1	30 – 51	6.4	0.06	0.15	3.60	1	3.00	1.60	0.20	0.09	0.03	6.90	70
B2	52 – 87	6.3	0.05	0.06	4.20	2	2.76	0.40	0.23	0.09	0.01	7.00	50
B3	88 – 126	6.4	0.06	0.03	3.40	2	2.32	0.40	0.25	0.08	0.03	8.40	36
BC	127 – 200	6.3	0.07	0.03	3.20	1	1.92	0.24	0.23	0.09	0.01	7.50	33

Table 3: Land Characteristics and Quality of Soil of the Downstream of the Study Sites

Parameters	Upper slope	Middle slope	Lower slope
Rainfall (mm)	1127	1127	1127
Temperature	33	33	33
Slope	3 %	2 %	2 %
Soil Depth (cm)	100	125	130
Drainage	I.D	I.D	P.D
Soil Texture	SL	SL	SL
Soil reaction (pH)	6.3	6.0	6.2
Organic Carbon (g kg <sup>-1</sup> )	5.9	7.2	7.3
Total Nitrogen (g kg <sup>-1</sup> )	0.22	0.12	0.20
Available Phosphorus (mg kg <sup>-1</sup> )	3	3	3
Potassium (cmol kg <sup>-1</sup> )	0.32	0.20	0.24
CEC (cmol kg <sup>-1</sup> )	8.5	8.0	7.7
Base Saturation (%)	72	66	74
ESP (%)	3.5	1.4	3.2
EC (dS/m)	0.07	0.10	0.07

Abbreviation; I.D =Imperfectly drained, P.D = Poorly drained, SL =Sandy loam

### Land Suitability Evaluation for Rice Production

At the downstream, the climatic parameters evaluated were annual rainfall and average temperature which were rated highly suitable S1 (100) in all the sites. The average temperature (33°C) was highly suitable S1 (100) at the upper, middle and lower slopes. The topographic parameter (slope percent) was (0-3%) highly suitable S1 (100). Soil physical parameters evaluated were soil texture and depth, the depth of the downstream sites was highly suitable S1 (100) at all levels while the texture was rated moderately suitable S3 (60) at the upper and lower slope and the middle slope was rated not suitable (N). Fertility parameters evaluated for rice production were soil pH, organic carbon, total Nitrogen, available phosphorus, exchangeable potassium, CEC and base saturation. Soil pH was rated moderately suitable S2 (85) at the upper, middle and lower slopes. Organic carbon was not suitable N (40) at all slopes. Total nitrogen was rated currently not suitable (N1) at the upper and middle slope, but

marginally suitable at the lower slope of the downstream. Available phosphorus at all slopes rated currently not suitable, and potassium rated highly S1 (100) at the upper, middle and lower slopes. CEC was rated marginally suitable S3 (60) at the upper, middle and lower slopes. Base saturation was rated moderately suitable S2 (85) at the upper, middle and lower slopes. The salinity and sodicity that is the exchangeable sodium percentage and Electrical conductivity all rated highly suitable at the upper, middle and lower levels.

### Land Evaluation Using the Storie Index Approach

Results obtained from the evaluation of suitability classification for the study sites for rice production are shown in Table 4. The result showed that the soils of downstream were not suitable for rice production (N1sfn) at the upper, middle and lower slopes in its present status as a result of limitations of nutrient availability, nutrient retention and soil texture, but after amendment it became

marginally suitable (S3) at all the slope positions.

Table 4: Factor Rating of Land Use Requirement for Rice Production

LAND QUALITY	UNITS	HIGHLY SUITABLE (S1)	MODERATELY SUITABLE (S2)	MARGINALLY SUITABLE (S3)	NOT SUITABLE (N)
Rainfall (mm)	mm	>1200	1000- 1200	850- 1000	<850
Temperature	°C	29- 32	21- 29	18-21	<18
Texture		SL,SCL,L,CL	SiL, SC	SiC, LS	S,C
Effective depth	Cm	>100	75- 100	50- 75	<50
Soil reaction		5.5- 7.0	4.5-5.4 7.0-8.5	4.0- 4.5 8.5-9.0	<4.0, >9.0
Organic carbon	g/kg	20- 40	10- 20	5- 10	<5
Total Nitrogen	g/kg	>2	1-2	0.5- 1	<0.5
Available phosphorus	mg/ kg	>15.0	10.0- 15.0	5.0- 10.0	<5.0
Potassium	g/kg	>0.2	0.1- 0.2	<0.1	<0.1
CEC	cmol/ kg	>18.0	12- 18.0	6.0- 12.0	<6.0
Base saturation	%	>75	50- 75	30- 50	<30
ESP	%	<15	15- 40	40- 50	>50
EC	dS/m	<3	4- 8	8- 12	12- 16
Slope	%	0 - 2	2 - 4	4-7	7- 12
Drainage		Imperfectly/ moderately	Well, poorly	Very poorly	Excessively

SL= Sandy Loam; SCL= Sandy Clay Loam; L= Loamy; CL= Clay Loam; SiL= Silty Loam; SC= Sandy Clay; SiC= Silty Clay; LS= Loamy Sand; S= Sandy; C= Clay

### Land Suitability Evaluation Using the Rabia Equation Approach

Rabia equations apply the maximum rating to evaluate the equation. Results derived from the evaluation are shown in Table 4. The results stated that downstream soils were marginally suitable (S3) at the upper and lower slope but

currently not suitable (N1sf) at the middle slope, for rice production as a result of limitations of nutrient availability, nutrient retention and soil texture. Moreover, downstream after amending the fertility limitations, it became moderately suitable (S2) at the upper, middle and lower slopes.

Table 5: Suitability Evaluation of Downstream soil for Rice

**Production Using Storie Index**

Parameters	Upper Slope		Middle Slope		Lower slope	
	Actual	Potential	Actual	Potential	Actual	Potential
Rainfall (mm)	100	100	100	100	100	100
Temperature (°C)	100	100	100	100	100	100
Slope (%)	100	100	100	100	100	100
Drainage	100	100	40	100	100	100
Texture	60	60	60	60	60	60
Soil depth (cm)	100	100	100	100	100	100
TN (g/kg)	40	100	40	100	40	100
Available P(mg/kg)	40	100	40	100	40	100
K (g/kg)	60	100	60	100	60	100
Org. Carbon (g/kg)	40	100	40	100	40	100
CEC (cmol kg <sup>-1</sup> )	60	60	60	60	60	60
BS (%)	85	85	100	100	100	100
ESP (%)	100	100	100	100	100	100
EC (dS/m)	100	100	100	100	100	100
Suitability index	1.41	18.8	.90	20.40	4.90	20.40
Suitability Class	N1f	S3s	N1f	S3s	N1f	S3s

N1f= N1= currently not suitable, fertility; S3= marginally suitable, s= soil physical characteristics

**Table 6: Suitability Evaluation of downstream for Rice Production  
Using Rabia Equation**

Parameters	Upper Slope		Middle Slope		Lower slope	
	Actual	Potential	Actual	Potential	Actual	Potential
Rainfall (mm)	100	100	100	100	100	100
Temperature (°C)	100	100	100	100	100	100
Slope (%)	100	100	100	100	100	100
Drainage	100	100	100	100	100	100
Texture	60	60	60	60	60	60
Soil depth (cm)	100	100	100	100	100	100
Available P(mg/kg)	40	100	40	100	40	100
K (g/kg)	100	100	100	100	100	100
Org. Carbon(g/kg)	40	100	40	100	40	100
CEC (cmol/kg)	60	60	60	60	60	60
BS (%)	85	85	100	100	100	100
ESP (%)	100	100	100	100	100	100
EC (dS/m)	100	100	100	100	100	100
Suitability index	38.39	65.84	22.13	71.41	34.99	71.41
Suitability Class	S3f	S2	N1f	S2	S3f	S2

N1f= N1= currently not suitable, fertility; S3= marginally suitable.

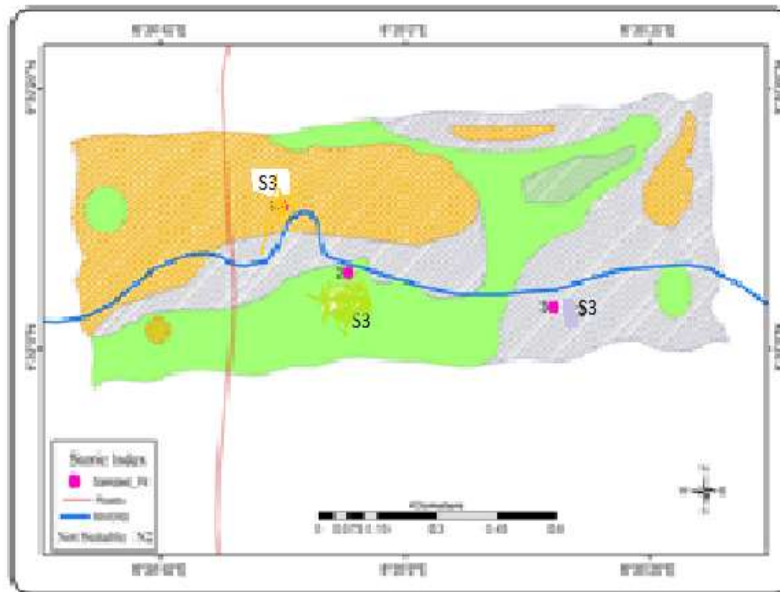


Figure 3: Suitability Map Using Storie index

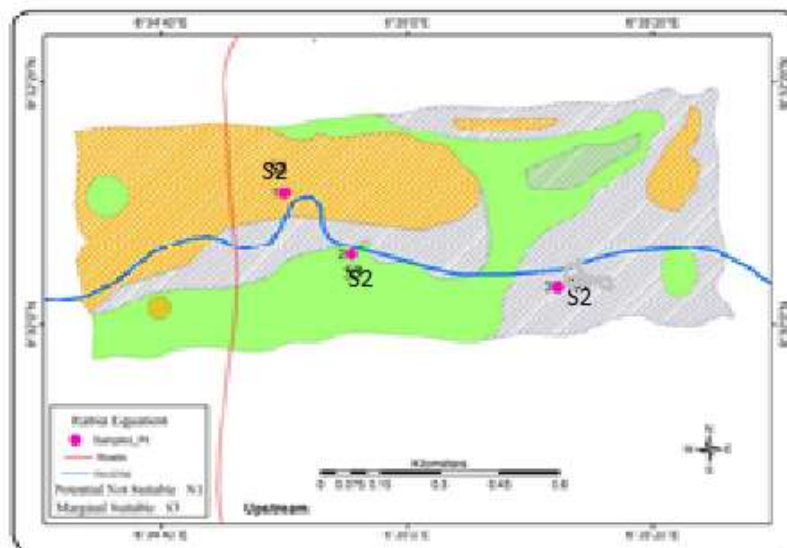


Figure 4: Suitability Map Using Rabia Equation

### Conclusion

This study concludes that, the suitability rating of floodplain soils indicated marginally suitable (S3) under the Storie index but showed moderately suitable (S2) under the Rabia equation method after amending the fertility limitations.

### Recommendation

Management practices such as Fertilizer application and organic matter incorporation into the soil to increase the nutrient availability and retention are hereby recommended for increased rice production in the study area.



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