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APPLICATION OF GEOGRAPHIC INFORMATION SYSTEM (GIS) AND ANALYTICAL HIERARCHY PROCESS (AHP) IN SUITABILITY MAPPING OF SOME SELECTED CEREAL CROPS IN NORTHEASTERN NIGERIA

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ABSTRACT

This research applied Geographical Information System (GIS) and Analytical Hierarchy Process (AHP) in delineation of places that are suitable for cultivation of some selected cereal crops. Climate (mean annual rainfall and temperature), soil texture, soil pH, slope and land use/ land cover maps were the criteria used in this study. In an attempt to produce the map of the selected criteria as layers for the suitability mapping, each selected criterion was analyzed and produced separately and were overlaid using Arc GIS 10.2. AHP was used to generate the priority of the criteria for crop cultivation in the region. Result of the study revealed that the highly suitable zone for cultivation of rice covered 47,152.75km^2 (16.83%) of the total land area while suitability area for the cultivation of maize covered an area of 41,410.58km^2 which represent 14.78% of the total land area in the region. Suitability map for cultivation of Sorghum on the other hand covered a total land area of 107,891.25 km^2 (38.52%). In regards to this, it was concluded that over 70% of the region are highly suitable and suitable for cultivation of Rice, Maize and Sorghums. In addition, it was concluded that cultivation of sorghum is preferable in the region following the fact that it has the highest land area that is highly suitable for it cultivation compared to maize and sorghums. In the same vein, cultivation of rice, maize and sorghum is recommended in zones that are highly suitable in the region. It was also concluded that, analytical hierarchy process (AHP) has been tested to be a vital tool for suitability assessment and decision making in agricultural planning especially regarding the integration of different environmental factors for efficient crop production. Finally, application of GIS and AHP provide better information and guide decision makers on identifying suitable area for cultivation of different types of crops. As such, integration of the tools is recommended in related aggro-climatic.

Keyword: Geographic Information System, Analytical Hierarchy Process, Suitability Mapping, Cereal Crops and Northeastern Nigeria

INTRODUCTION

Climate is one of the major agro-ecological factors influencing the distribution of crops over different regions of the world. It is very sensitive to all stages of crop production; from land clearing and preparation, through crop growth and management to harvesting, storage, transportation, and marketing of the product (Adebayo 2010 and Ayoade, 2005). For example, Tandzi and Mutengwa, (2020) reported that, temperature and rainfall changes significantly have negative impact on wide range of agricultural activities leading to yield losses especially in crop plants which are sensitive to climatic stress (Raza, *et al.,* 2019; Tandzi and Mutengwa, (2020). Climatic event such as high temperature regimes affect the percentage of seed germination, photosynthetic efficiency, crop phenology, flowering times, pollen viability and pollinator populations (Kumaraswamy and Shetty, 2016; Tandzi and Mutengwa, 2020). In the same vein, moisture or drought stress which is climate

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related, accounts for about 30–70% loss of productivity of field crops during crop growth period (Kumaraswamy and Shetty, 2016).

In Nigeria, agricultural sector was observed to be the "mainstay" of the country's economy and provided food for the increasing population, supplied raw materials to industrial sector, provided employment opportunity, source of foreign exchange earnings and a market for the products of the industrial sector (Ayodele, *et al.,* 2013; Felix & Bassey, 2018 and Federal Ministry of Agriculture, Water Resources and Rural Development, 2020). In spite of all this development, the general performance of the sector recorded low growth rate in the recent years which can be attributed to factors such as climate change, soil fertility and landform (Federal Ministry of Agriculture and Rural Development, 2012; Ofozoba, 2019; FMARD, 2020).

Soil fertility is one of the major factors affecting agricultural production. It vary in terms of origin, appearance, characteristics and production capacity and has the ability to support crop production. It is also a major source of micro-nutrients (Fe, B, Cl, Mn, Zn, Cu, Mo, Ni) and macronutrients (N, P, K, Ca, S, Mg, C, O, H) that are needed for plant growth (Tandzi and Mutengwa, 2020). Soil texture is another soil's attribute that is important in crop production. It determines the transmission and storage of water and flow of air in the soil and its capacity to supply nutrients to plant (Surajit, 1981;Six, *et al.,* 2000).

Topography is another factor affecting crop yield variation for both its direct effect on micro-climate and for related soil factors such as soil temperature, which influences germination, tiller production and crop growth (Godwin and Miller, 2003). For example, Mayumi *et al.,* (2016) observed that uneven field with a depression where rainwater can be accumulated could be advantageous in terms of rice productivity as well as yield stability over a field consisting only of sloping and flat lands, especially in the event of drought. They finally concluded that a lower yield under a sloping condition is mainly due to water runoff and nutrient leaching caused by soil erosion from heavy rains. Another similar research by Saito, *et al.,* (2009) observed a higher plant density in upland rice fields of Laos and that, differences in topographic conditions of the area are the contributing factor to the variations in the plant density. Husson, *et al.,* (2001) in their study discovered that upland rice yield tended to decrease with an increase in the inclination of slopes, and drastic yield decrease occurred above 25–30º. Worou, *et al.,* (2012) finally explain that upland fields with spatial heterogeneity were likely to influence crop management implementation and soil water environment which may lead to poor crop yield.

Since crop cultivation is directly and indirectly affected by climate, soil and relief, there is a need for the application of an efficient tool that will help in the evaluation and integration of those factors and delineate places that are suitable for the yield of crops. In regards to this, Analytical Hierarchy Process (AHP) a Geographical Information System (GIS) based tool was tested to be the accurate and most useful method for evaluating spatial data and land use analysis (Getachew and Solomon, 2015 and Ceballos-Silva and L'opez-Blanco, 2003) was used to delineate zones that are suitable for the cultivation of the selected cereal crops and then select the most favorable cereal crop for cultivation in the region.

Study Area

North-East Nigeria is located between latitude 6º 31′ 26.215″ N to 13º 41′ 28.684″ N and Longitude 9º 7′ 28.005″ E to 14º 41′ 49.274″ E with a total land area of 280,103.93km^2 (Figure 1). The region is made-up of six states which include; Adamawa, Bauchi, Borno, Gombe, Taraba and Yobe with a total population of

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18,984,299 according to 2006 national census (NPC, 2006). According to Ekaete, (2017) and Frederick *et al*., (2010), the area has different vegetation types which include the Sahel, Sudan Savanna, Northern Guinea Savanna, Southern Guinea Savanna, and Montane forest are the major vegetation types in the State. Rainfall and temperature are another climatic characteristic that differ according to location of the places. The area has high mean annual rainfall amount of between 1600mm to 1800mm with mean annual temperature of less that 21.5ºC is common in places around southern Taraba state and small area around southwest of Bauchi State while rainfall of below 600mm which lasted for 3-4 months is common around northern Yobe and northwest Borno (Ekaete, 2017).

The common soil found in the region according to Frederick *et al*., (2010) are undifferentiated ferrisols located in northwestern Gombe and Southeast Bauchi while humic ferrisols and lithosols are found in Gembu, Taraba State. The northern part of the region around northern Yobe and Borno is characterized with Aeolian sand (regosols) while undifferentiated ferruginous tropical soils dominate the major part of the region.

MATERIALS AND METHODS

Data Types and Analysis

The data sets used in this study are climate, soil, slope and land use land cover maps. Maps of the criteria were produced separately using Arc GIS 10.2. Mean spatial climatic map of monthly rainfall, mean temperature were the climatic criteria used in this study. Maps of these variables were downloaded from worldCli-Global Climate data version 2 (*www.worldclim.org*) (Fick and Hijmans, 2017). Northeastern Nigeria was extracted from the maps using extraction by mask in the Arc toolbox and was scaled and reclassified into four (4) classes as highly suitable, suitable, moderately suitable and not suitable area using reclassify tool in Arc toolbox.

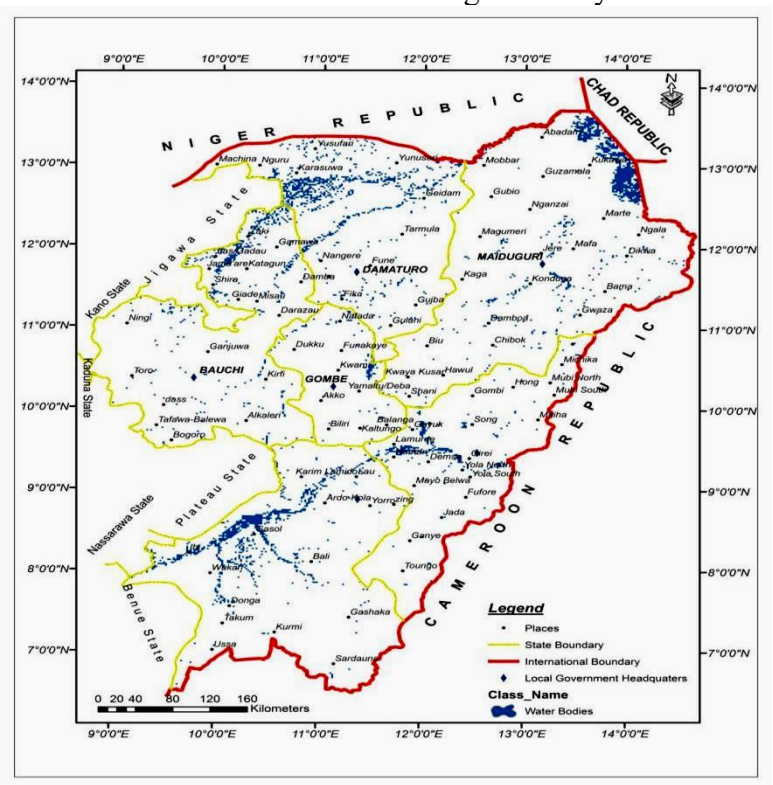

Figure 1: Study Area showing the some towns and boundaries
Source: Ezra *et al*., (2020)

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Soil texture map of Nigeria downloaded from European Digital Archive of Soil Maps **(**EuDASM**)** (2018) on the other hand was added to the Arc GIS environment, Georeference and Digitized. All the digitized layers with the same soil texture characteristics based on the soil requirement for rice, maize and sorghums production were selected and merged together as one class using merge tool in editor menu of the Arc GIS and was then reclassified into four classes (highly Suitable, Suitable, Moderately Suitable and not suitable). This method was also applied to soil pH.

Digital Elevation Model (DEM) data of Shuttle radar topographic mission (SRTM) 30m resolution as one of the criteria was processed and mosaic using Arc GIS 10.2 package. The mosaic DEM and Northeastern States Shape-file were added into the Arc GIS environment using the Add data icon and then extract Northeastern States DEM using Extraction by Mask under Spatial Analysis tool in Arc toolbox. The extracted DEM was then reclassified using the Arc toolbox in Arc GIS were four (4) different classes (highly Suitable, Suitable, Moderately Suitable and not suitable) base on the pixel value of the reclassified DEM was produced. The pixel value was transformed into percentages were high percentage value represents highland and low percentage value represents low lowland area.

Criteria map of each selected variable was generated, scaled and reclassified into four (4) classes as highly Suitable, Suitable, Moderately Suitable and not suitable area as recommended by CSR/FAO, (1983); Joseph *et al.,*, (2013) and Getachew and Solomon, (2015) crop suitability classification. The suitability scale and maps used as criteria are presented in Table 1, Figure 2 and 3.

Table 1: Suitability Rating of the Criteria

		Land Suitability Rating			
Criteria	**Crops**	**Highly Suitable**	**Suitable**	**Moderately Suitable**	**Not Suitable**
Temperature (°C)	Rice	20-26	27-30	31-34	>34 <20
	Maize	20-26	27-30	31-34	>34 <20
	Sorghum	20-30	30-33	34-38	>38 <20
Rainfall (mm)	Rice	>1500	1500-1000	1000-750	<750
	Maize	>1200	900-1200	600-900	<600
	Sorghum	600-1500	600-400	400-250	<250
Soil Texture	Rice	C, SC, SCL	S, CL	SL, LS	Sandy
	Maize	L,SCL,SiL,Si,CLSiCL	SL, SC	LS, SiC	Sandy
	Sorghum	C, CL, SiC, SC	L ,SiL, SiC, SCL	SL, LS	Sandy
Slope (%)	Rice	0-5	5-15	15-24	>24
	Maize	0-5	5-15	15 - 20	>20
	Sorghum	0-5	5-15	15 - 20	>20

Source: CSR/FAO, (1983); Joseph *et al.,*, (2013), Getachew and Solomon, (2015) and Walter *et al.,* (2019).

Application of AHP

The AHP method suggested by Mu and Pereyra-Rojas, (2017) was adopted in this paper; the different steps were identified and applied below;

The goal of this paper is to identify suitable areas for cultivation of the selected cereal crops in the northeastern part of Nigeria and the criteria used to achieve that are mean annual temperature, mean annual rainfall, soil texture, soil pH and slope maps of the study area as identified to be the major factors affecting crop cultivation in Nigeria (FMARD, 2020). The cereal crops selected on the other hand are rice (Upland), maize

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and sorghums. The cereal crops were selected based on the fact that they are the major cereal crops cultivated in the area and demand for increase in local production of the crops in the country (Ragasa et al, 2010; Buhari 2018 and Daniel, 2018).

In an attempt to develop PCM of the criteria, Saaty, (2012) scale was adopted in matrix computation of the criteria (Table 2). In addition, literatures and experts' idea was also applied in determining the relative importance of each criterion with one another. Normalization of the criteria was applied to determine the priority of each criterion for the selected crop as suggested by Mu and Pereyra-Rojas, (2017). To determine the consistency in judgment of the PCM, consistency ratio tool was used in the pair-wise matrix judgment since the tool indicates the likelihood that the matrix judgments are reasonably consistent and are generated randomly. The acceptance level for the judgment is therefore presented as CR $\leq$ 0.10 (Saaty, 1977). The ratio is calculated using the equation below;

$CR = {}^{CI}/_{RI}$: Where CR= Consistency Ratio, CI = consistency index and RI = Random index (Table 3). Consistency index (CI) = $(\lambda - n)/(n-1)$ Where Lambda (λ) is the maximum Eigen value and n is numbers of criteria in the Pair-wise comparison.

Table 2: Saaty's Pair-wise comparison scale

Numeric value	Verbal Judgment
1	Equally important
3	Moderately more important
5	Strongly more important
7	Very strongly more important
9	Extremely important
Reciprocals	Values for Inverse Comparison

Source: Saaty (2012)

Table 3: Saaty's Pair-wise comparison scale

Order matrix	1	2	3	4	5	6	7	8	9	10
RI	0.0	0.0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty (2012)

RESULTS AND DISCUSSION

Priority of the selected Criteria

Result of the pair wise comparison priority for selected cereal crops are presented in Table 2 and the result revealed that, mean annual temperature has the highest contribution of 47.24%, 39.25% and 39.25% for rice, maize and sorghums respectively, while mean annual rainfall contributed 28.92%, 35.97% and 35.97% for rice, maize and sorghum respectively. These results clearly revealed that temperature and rainfall are the major factors considered in determining the growth and yield of crops in the area, as such high priority should be given to them in determining the suitability area for cultivation of the crops. Result of the PCM and priority also revealed a consistency ratio of 0.067, 0.054 and 0.070 for rice, maize and sorghum respectively which explained that there is consistency in pairwise comparison of the criteria based on the type of crop.

Table 2: Weight of the selected Criteria

	Weight (%)		
	Rice	**Maize**	**Sorghum**
Mean Temperature	47.24	39.25	39.25
Rainfall	28.92	35.97	35.97
Soil Texture	13.61	14.01	14.01
Soil pH	6.65	6.83	6.83
Slope	3.58	3.93	3.58

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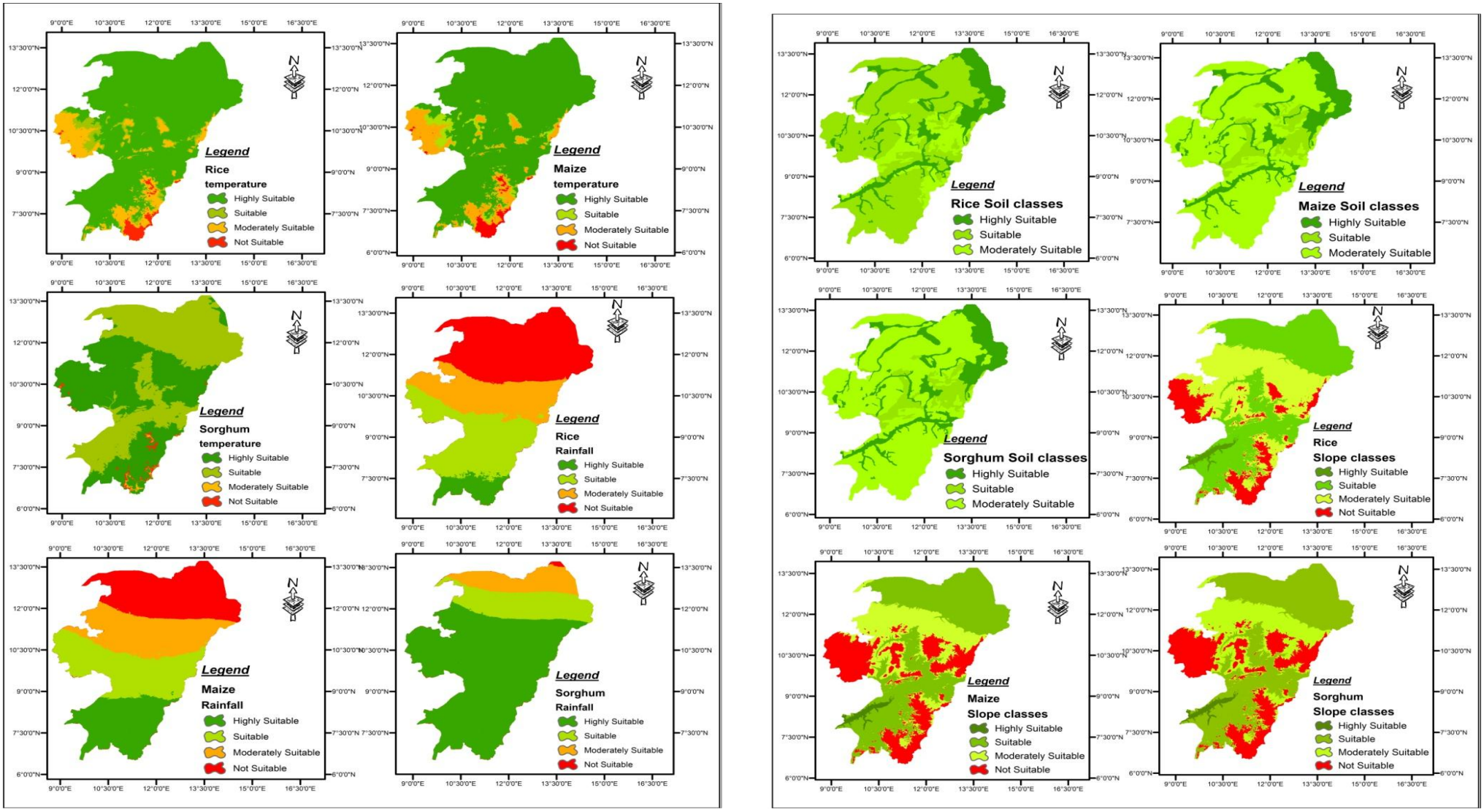

Figure 2: Criteria maps for temperature, rainfall, soil texture and slope

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Source: Authors' data analysis.

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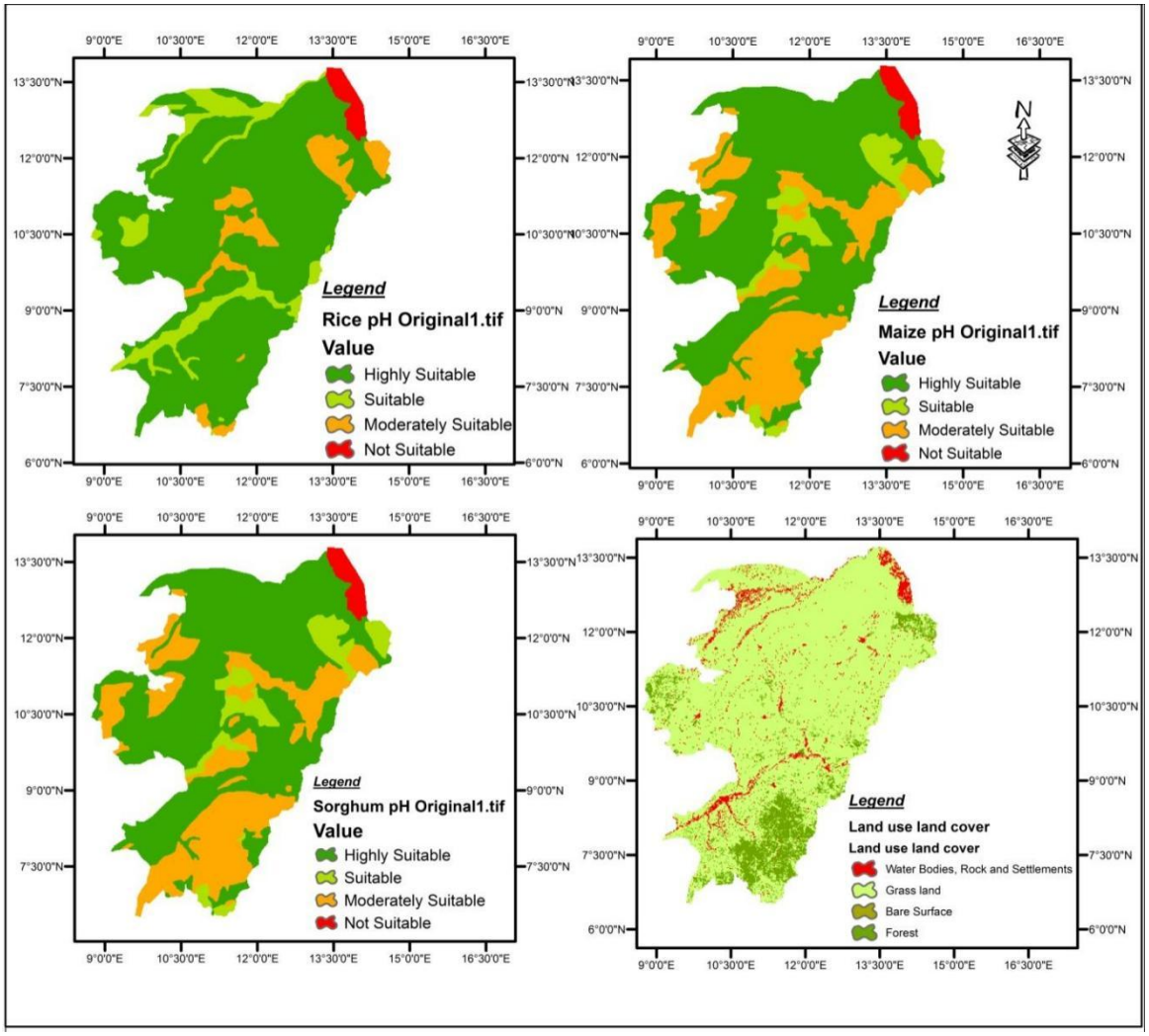

Figure 2: Soil pH and land use land cover maps

Source: Authors' data analysis.

Suitability Zones for Cultivation of Rice, Maize and Sorghums

Suitability map for cultivation of rice, maize and sorghum was produced based on the criterion map used. Result of the suitability map for cultivation of Rice is presented in Table 3 and figure 3 and the result revealed that the highly suitable zone for cultivation of rice covered 16.8% of the total land area and include areas in Taraba state around Takum, Donga, Wukari, Ibi, Bali, Gashaka, Ardo-Kola, karim and lau as also observed by Ezra *et al*., (2020). It also includes some places in Adamawa around Lamurde, Numan, Girei, Mayo-Belwa, Yola North and Yola South. Other places that are highly suitable are located along Gongola in Gombe and small area of the southern Bauchi State. All those places are highly suitable based on the fact that they have optimum temperature and rainfall amount that are essential for growth and yield of rice in the area. In addition, the places are characterized with soil textures which are alluvial in nature and have high water holding capacity which is suitable for rice growth and yield (Tripathi, 2011).

In the same vein, the zones are also characterized by clay content which has organic matter that is essential for crop development (Six, *et al.,* 2000). The slope nature of the area is also an added advantage for the development of the crop. The areas are located below the basement complex formation along rive Benue where the nutrient and other organic matter from the highlands are deposited which also support the growth of

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plant. The plain/flat surface which allows even distribution and efficient infiltration of water and nutrient for rice growth and yield is another factor that makes the area to be highly suitable for rice cultivation. Unlike the highly suitable areas, the moderately and not suitable places on the other hand are characterized by unfavorable temperature and rainfall, steep slope or depression that allows water runoff and nutrient leaching through the process of soil erosion from heavy rain and also leads to crop damage and low nutrient intake and high water infiltration (Mayumi *et al.,*, 2016 and Husson *et al.,*. 2001). In addition, the moderately and not suitable regions of the areas are those places that are difficult for rice cultivation because of the high undulation, scattered rock outcrops, water bodies, built-up area and hills which affect crop management practice negatively leading to poor growth and yield of crops (Worou *et al.,* 2012).

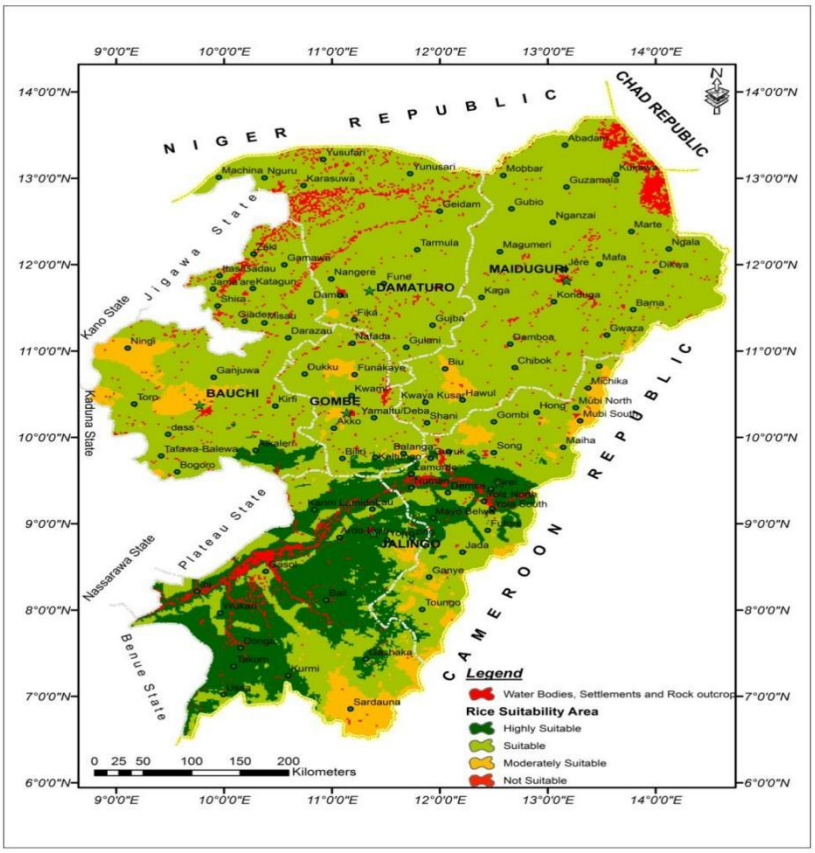

Figure 3: Suitability Map for Rice Cultivation

Source: Extracted by Authors

Result of the suitability map for the cultivation of Maize (Figure 4) in the area covered an area of 41,410.58km^2 (Table 3) which represents 14.78% of the total land area in the region. The result showed that over 30% of Taraba State which include Takum, Donga, Wukari, Ibi, Bali and Gasol are highly suitable for Maize cultivation. It also includes places around Numan, Demsa, Yola North, Yola South and Girei which are located along river Benue in Adamawa State and some small place in southeastern part of Yamaltu Deba in Gombe State. All those places are highly suitable based on the fact that they have optimum temperature and rainfall of 20-26^{o}C and >1200mm respectively (CSR/FAO, 1983). In addition, soil texture of the area is characterized with sandy clay loam which has high water holding capacity that supports the growth and yield of the crop. In addition, the nature of slope allows deposition of nutrient transported from the highlands.

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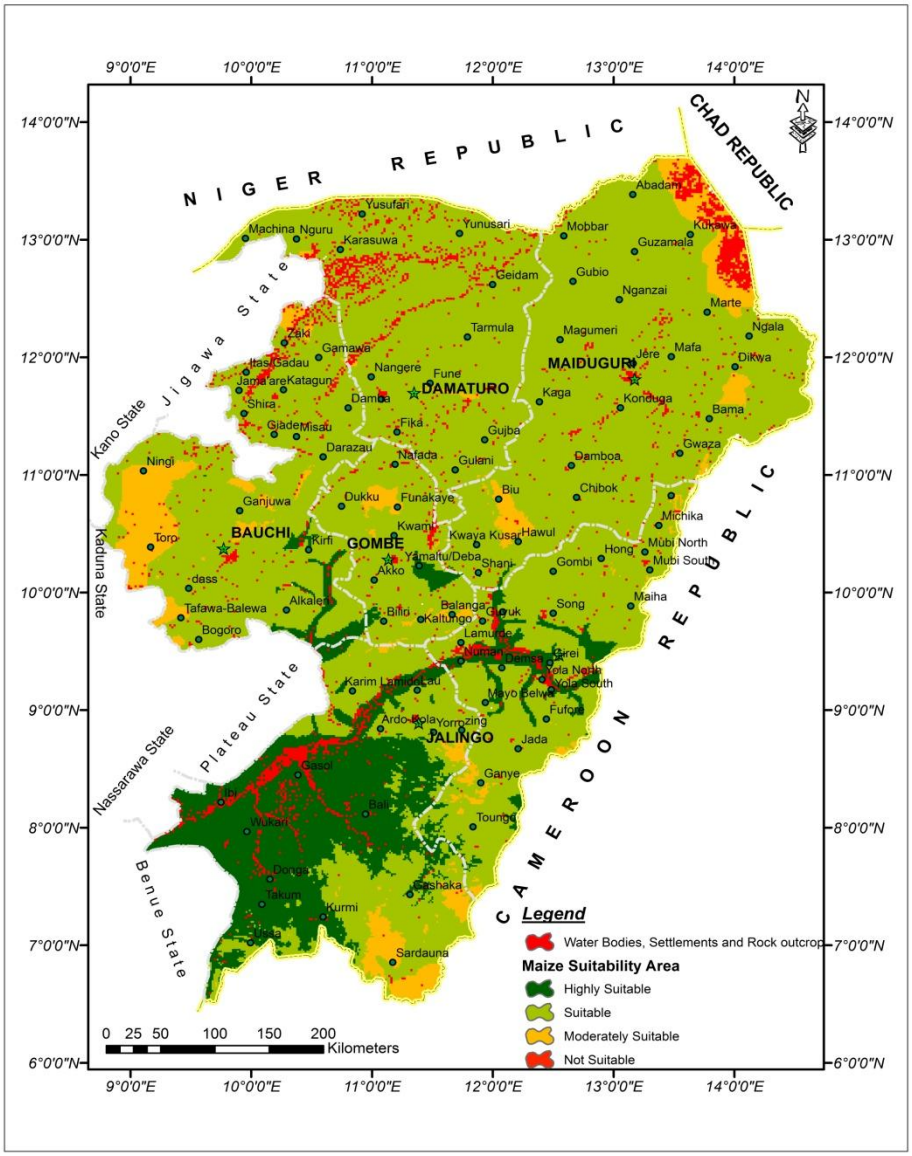

Figure 4: Suitability Map for Maize Cultivation

Source: Extracted by Authors

Suitability map for cultivation of Sorghum is presented in Table 3. The result revealed that the highly suitable zone for cultivation of sorghum covered a total land area of 107,891.25km^2 (38.52%) and includes places such as Guyuk, Mayo-Belwa, Toungo, Fufore, Girei, Gombi, Hong, Maiha, Mubi North, Mubi South, Michika and Madagali in northern Adamawa state, Biu, Hawul, Gwaza, Bama, Kaga and Chibok in Borno, Nafada, Akko, Dukku, Funakaye, and Biliri in Gombe, Alkaleri, Bogoro, Toro, Tafawa-Balewa, Das, Kirfi, Darazau, Damba and Misau in Bauchi State, Nangare and Fika in Yobe State. All those places are highly suitable based on the fact they have optimum temperature and rainfall amount that is essential for the growth and yield of sorghum in the area. In addition, the zones have soil texture with high nutrient content that is sufficient for the development of the crop. The slope area is relatively flat/plain which allows for equal distribution of water and nutrient that support the growth and yield of sorghum in the area.

Following all the results presented above, it is clear that sorghum has the largest land area that is highly suitable for it cultivation, which is based on the fact that the crop has high resistance to drought and other climatic

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changes compared to other crops such as rice and maize as also documented by Salah *et al*., (2020).

Table 3: Suitability area for the cultivation of the selected cereal crops

	Highly Suitable		Suitable		Moderately Suitable		Not Suitable		Total Area	
	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
Rice	47,152.75	16.83	214,025.08	76.41	17,240.40	6.16	1,685.70	0.60	280,103.93	100
Maize	41,410.58	14.78	216,806.52	77.40	20,204.09	7.21	1,682.74	0.60	280,103.93	100
Sorghum	107,891.25	38.52	167,281.48	59.72	3,162.23	1.13	1,768.97	0.63	280,103.93	100

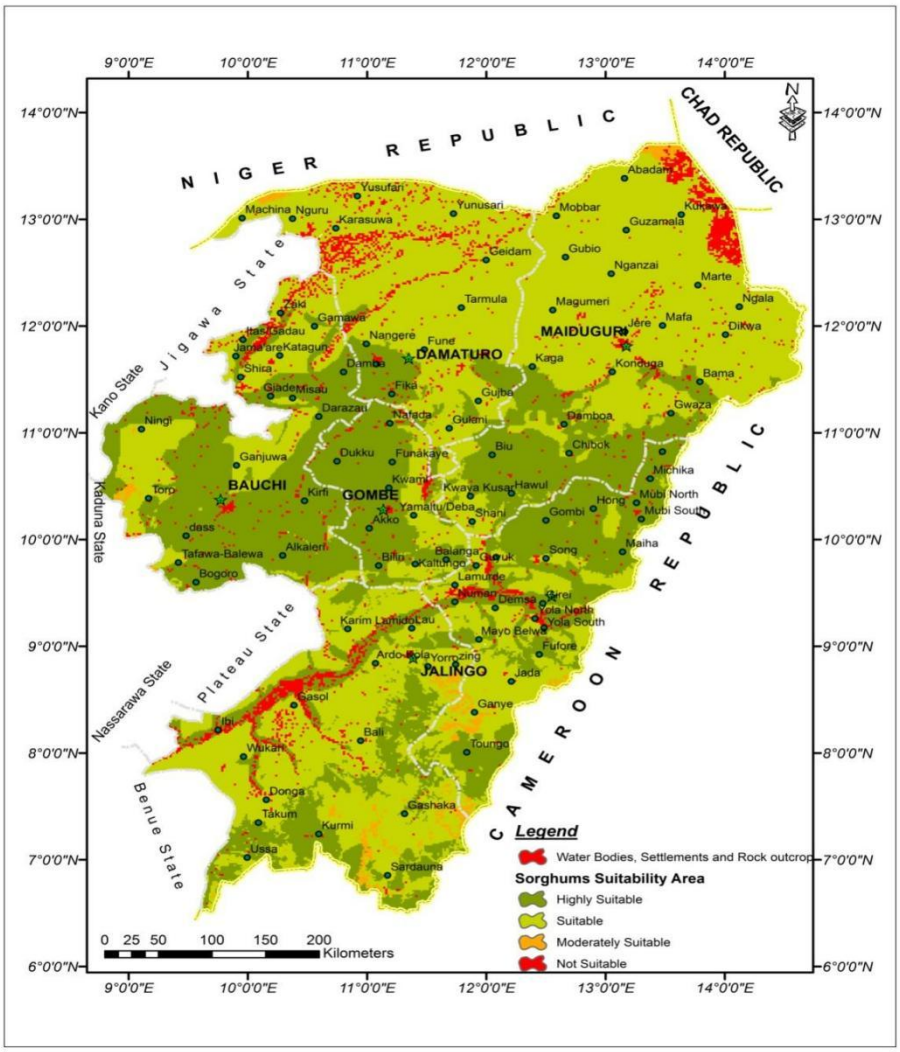

Figure 5: Sorghum Suitability Map

Source: Extracted by Authors

CONCLUSION

It was concluded based on the findings of this study, that the highly suitable places for cultivation of rice covered a smaller percentage of the northeastern Nigeria and are mostly located along the major rivers around Takum, Donga, Wukari, Ibi, Bali, Gashaka, Ardo-Kola, karim and lau. It also includes places in Adamawa around Lamurde, Numan, Demsa, Girei, Yola North and Yola South. It was also concluded that the suitably places for the cultivation of Maize in the area covered a small area of 14.78% of the total land area in the region and are mostly located in southern part of Taraba State. Unlike rice and maize suitability zone, the suitability zone for the

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cultivation sorghum covered a large portion of the region and are located in the central part of the area. It is therefore concluded that cultivation of sorghum is preferable in the region following the fact that it has the highest land area that is highly suitable.

Recommendations

1. Cultivation of Rice, Maize and Sorghum is recommended in zones that are highly suitable in the region.
2. Agricultural Extension services should be strengthened especially in dissemination of latest information on places that are highly suitable for crop cultivation in the region.
3. The application of GIS and Multi-Criteria Evaluation (MCE) using AHP provide a guide map for decision makers considering crop substitution in order to achieve better agricultural production. As such, integration of the tool is recommended in agro research.
4. For further study, there is a need for integration of more factors like agricultural input and socio-economic factors that influence the sustainable use of the land.

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