Land Suitability Classification for Millet Production in Katsina State, Northwest, Nigeria

Sani Abdullahi, Roslan Ismail, Syaharudin Zaibon, Nordin Ahmad, Samaila Sani Noma

Abstract— **Land suitability is a function of soil characteristics and crop requirement. It involves the evaluation and grouping of specific areas of land in terms of their suitability for defined agricultural use. Factors such as soil characteristics, climatic condition, topography (terrain), rainfall, erosion etc. Henceforth, matching the land characteristics with the crop requirements provides suitability index in the form of ranks which are fundamental for sustainable agricultural practices. The main objective of the research was focused on GIS techniques for land suitability assessment and subsequently determine physical-chemical-climatic risk (to improve millet yield) in millet production for sustainable farming. This paper presents the land suitability for millet production in Katsina State (Nigeria). A total of fifty-five (55) soil samples were collected at the depth of 0-30cm, air-dried, gently crushed, and sieved through 2mm for soil physical-chemical analyses. Soil samples coordinates were marked with GPS Garmin 60csx and subjected to geospatial distribution analysis. Data collected for climatic (rainfall and temperature) condition and analyzed for soil physio-chemical characteristics were subjected to descriptive statistics (SAS v9.4). Soil properties distribution map were generated with ArcGIS v10.3 using Inverse Distance Weighted (IDW) techniques. The suitability for millet cultivation in Katsina from the climate and physical-chemical parameters indicates that annual rainfall (604-702mm), elevation (434.75-558.5◦), temperature (26.50-26.99◦C), drainage, erosion, soil depth (0-30cm), soil pH (6.4-6.7), organic carbon (OC, 1.67-2.22%) and organic matter (OM, 0.2-3.0%), and phosphorus (P, 4.40-10.23%) are noted within the acceptable suitability index values (for Class S1 to Class S3), that represent sustainable crop production. While, cation exchange capacity (CEC, 5-15 cmol(+)/kg), total nitrogen (TN, 0.5-5.0%), exchangeable acidity (EC,0.03-0.65ds/m) and effective sodium percentage (ESP, 1.06-1.53%) were noted below average value for crop production. Land suitability Class S1 (highly suitable) covers 1328.40ha which is about 21.19% of the study area. While land suitability Class S2 (moderately suitable) covers 1098ha (17.53% area). The land suitability Class S3 cover 1767ha (28.19% area). Besides that, Class N1 (potentially not suitable) covers about 851.33ha (13.58% area) and, finally Class N2 (potentially and actually not suitable) covers about 1223.08ha (19.51% area) with scores below average of millet requirement. Further, the Class N2 areas marked with rock outcrop and inherent low fertility. Studied area (Katsina) suitability class for crop production as follow: S3>S1>N2>S2>N1. This indicates that, land area under Class S3 (28.19%) requires moderate level of soil amendment to improve millet production. Whereas, Class S2 (17.53%), requires minimal level of soil amendment, whereas Class N1 and N2 with total land area of percentage of 30.09%, requires high input of soil amendment. Therefore, it can be stated that different land unit requires different level of input and land management to facilitate (improve) millet production in Katsina state for sustainable crop production.**

Index Terms— **Land suitability, soil characteristics, climatic condition.**

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I. INTRODUCTION

Land is one of the most important natural resources, and maintaining it in good health, is very much needed for meeting out the increasing demand for food, fibre, fodder and fuel (Fadlalla & Elsheikh, 2016). The coupling of soil characterization, soil classification and soil mapping provides a powerful information for land users in field of agricultural sustainability (Sharu, M. B., Yakubu, M., Noma, S. S., & Tsafe, A. I, 2013). It assumes greater significance in present situation wherein the scope for further extension of cultivation is very limited (Tesfay, Biedemariam, & Hagazi, 2017a). It is necessary to select the judicious crops for cultivation according to the soil suitability, so that maximum profit may be achieved while maintaining the ecological sustainability (Öztürk, 2017). The crop land use planning involves making knowledgeable decisions about land use and the environment. Soil information is a vital component in the planning process, reflecting directly upon land-use suitability (Coleman & Galbraith 2000). The Land suitability is the process way or manner of assessing the suitability or ability of a given type of land facet for specific use (Bhandari, S., Jhadav, S. T., & Kumar, S, 2013). Land suitability classification process is the evaluation and grouping of specific areas of land in terms of their suitability for defined agricultural use (Bock *et al.*, 2018). Land suitability analysis is a prerequisite for sustainable agricultural practices. It involves evaluation of the factors like climate, elevation, as well as soil etc. Land suitability is a function of crop requirements and soil characteristics (Ahmed, 2015). Matching the land characteristics with the crop requirements provides suitability (Mathewos, M., Dananto, M., Erkossa, T., & Mulugeta, G. 2018). So, "suitability is a measure of how well the qualities of a land unit match the requirements of a particular form of land use" (FAO, 1976). Land suitability classification aims at evaluating and classifying land units on the basis of specific land and soil features and their limitations (Raju, 2015). Soil-site suitability studies provide information on the choice of crops to be grown on best suited soil units for maximizing the crop production per unit of land, labour and inputs (Zhang *et al*., 2015). The land suitability for a defined use and the impact of that use on the environment is determined by land conditions and land qualities (Tesfay, Biedemariam, & Hagazi, 2017b). The sustainable land use depends on soil resilience that is the balance between soil restorative and soil degradation processes (Kahsay, Haile, Gebresamuel, Mohammed, & Moral, 2018). Ecologically every factor of environment exerts directly or indirectly a specific effect on growth and development of the plants. However, it varies from habitat to habitat and determines the suitability of a plant to any particular environment (Ismail, 1991). Land management practices, which made up of unreasonable land use, has caused deterioration of soil quality, which may in turn resulting in soil structure degradation and organic matter loss which affect water, air and nutrient fluxes as well as plant growth (Hassan, P., Jusop, S., Ismail, R., Aris, A. Z., & Panhwar, Q. A. 2016). For planning and effective utilization of soil resources, the information relating to the soil-site characteristics for cultivation of crops is necessary (Leakey, *et al* 2006). In order to follow the principles of sustainable agriculture one has to grow the crops where they suit best and for which first and the foremost requirement is to carry out land suitability analysis (Ahamed *et al*. 2000). The natural resources like soil and water and associated climatic features deeply influence the cropping pattern and crop productivity in specified areas (Perveen, Nagasawa, Uddin, & Delowar, 2005). Each plant species requires definite soil and site conditions for its optimum growth. Since the availability of both water and plant nutrients is largely controlled by the physico-chemical properties and micro environment of the soils, therefore, the success and failure of cropping any plant species, in a particular area, is largely determined by these factors (Nanganoa et al., 2019)

II. Objectives

The main objective of the study was to carried out the land suitability analysis for millet in Katsina district based on FAO framework of land suitability classification using GIS and remote sensing.

A. Study area

Agriculturally, is found in the Sudan Savannah Zone of Nigeria, located on latitude 12° 27′ 16.00″ N to 12°59′ 26.95″N and longitude on 7″12′6.20″ E to 7°12′6.37″E. It falls in the Sudan Savannah zone, a climatic belt characterized by long dry seasons and short rainy season. Katsina central senatorial zone as the name implied, is a political entity located in the central part of Katsina state and the extremely north - western part of the state. It comprises of eleven local Government areas of Katsina, Kaita, Kurfi, Jibia, Batagarawa, Rimi, Batsari, Dutsin-ma, Safana, Danmusa, and Charanchi with land coverage of about 6, 269ha. It is relatively bounded by Funtua senatorial zone of the state to the South, Zamfara state to the west, Niger republic to the North, Kano and Jigawa states to the East. The zone has a total population of about 2, 667,000 in 2018 as projected from 2006 census figure based on growth rate of 3 %.

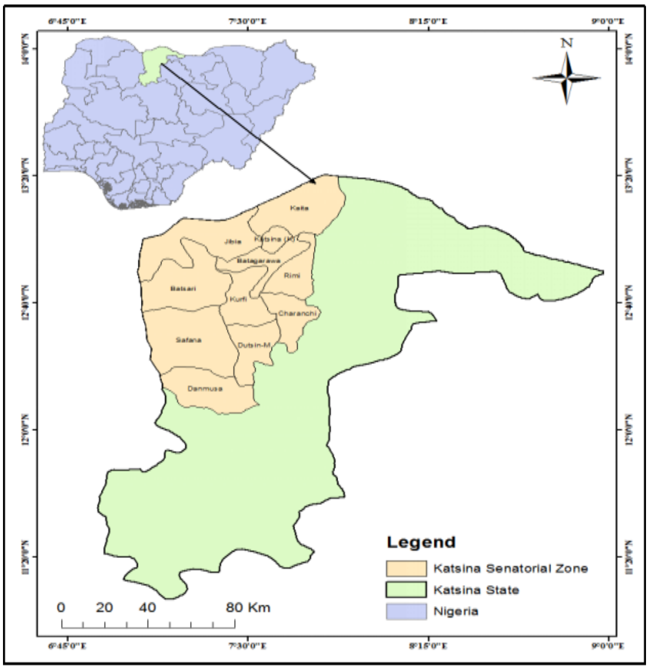


Figure 1 Map of study area

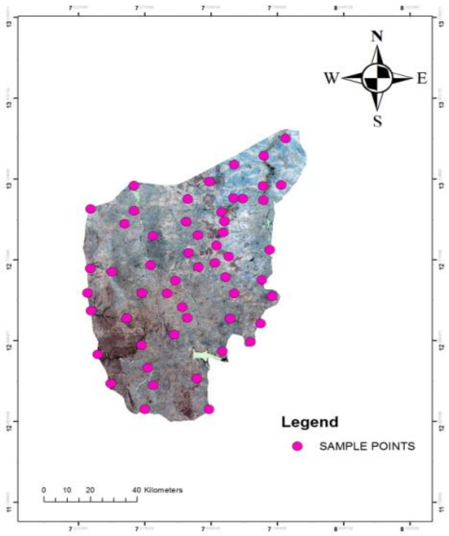


Figure 2 Map of sample points

B. Materials and method

For the suitability analysis 55 samples of soil (subsurface soil samples) were collected at the depth of 0-30cm in which it airs dried, gently crushed, and sieve through 2mm for routine analysis (Yusuf, 2011). The coordinates of each soil sample were taken for geospatial distribution analysis. The analysis of the data collected for both climatic elements such as rainfall and temperature, soil physical characteristics and chemical characteristics of soil was obtained through the use of descriptive statistics using SAS of 9.4 version software. The distribution map of each of the soil properties was generated in ArcGIS environment of 10.3 version using inverse distance weighted (IDW) techniques**.** The land qualities and characteristics used for suitability evaluation in this study were climate, topography and soil characteristics. In accordance with FAO (Jafazadeh, 2008). which consists of matching land characteristics against crop requirements and assigning a suitability rate for each land characteristic, land suitability evaluation for the major crops produced in the study area was carried out. The major crops in the study area (Perm millet). The selection of these crop was made based on its dominance (area coverage), preference and economic importance in the area. Climatic and land parameters were assigned to each factor affecting the suitability for crop. Land suitability requirement of millet were established using FAO (Kalogirou, 2002; Aaharaf 2011; Sharififar 2012).

At the reconnaissance survey, the analysis of the land units was executed in order to determine land suitability classification. The land suitability classification was falls in to five classes that indicate the degree of suitability. These classes are S1 (highly suitable), S2 (marginally suitable), S3 (moderately suitable), N1 (not suitable but, could be suitable under certain management practice), N2 (not suitable even under management practice). Based on the available data at reconnaissance level, climate, and land characteristics that were used as diagnostic criteria to determine land suitability classification made on the basis of land evaluation. For the evaluation of land resources by climate and land characteristics, the element of climate, land and soil properties under investigation are presented in (table 1)

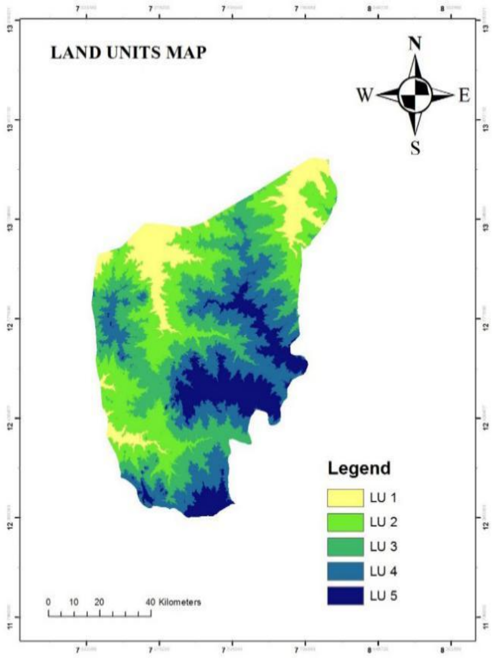


Figure 3 Land units

Table 1 Climate and land characteristics as parameters for land suitability

Land characteristic	symbol
Rainfall	c
Temperature	,,
Slope/Elevation	s
Texture	t
Soil depth	,,
CEC	f
pH	,,
OC	,,
OM	,,
TN	,,
P	,,
EC	,,
ESP	,,

Where c = climate limitation, s = slope limitation, t = soil limitation, and f = fertility limitation.
Source Field work (2019).

The evaluation was done base on the parametric approach to defined the degree in limitation of diagnostic criteria and the subsequent process of obtaining the land suitability rating percent by dividing value of parameter over higher range of parameter (Udo *et al* 2012). Algebraically the formula to obtained land suitability can be express as

$$Si = \frac{value\ of\ parameter}{high\ range\ of\ parameter} * 100 \qquad \text{…………………equation 3}$$

Where Si = suitability index

In the process of obtaining the suitability index the parametric approach by the division process (mean of parameter over high range of suitability classification) multiply by percentage was used to define the level of limitation expressed as percentage (Udo *et al* 2012). The evaluation of these was done based on a relative limitation scale, rating and land suitability classes (table 1) and the evaluation of the properties for land suitability classification is presented in a scheme of which the frame is given (table 2).

Table 2 Limitation category, rating and suitability classes

Limitation	**Rating**	**Land suitability class**
Highly suitable	100-85	S1
Moderately suitable	85-60	S2
Marginally suitable	60-40	S3
Actually not suitable But potentially suitable	40-25	NI
Actually and potentially unsuitable	25-0	N2

Source Sys (1993).

The land units were evaluated according to the criteria of (table 2). The following definition of suitability classification for each land unit in (table 3) can be applied in order to obtained the land suitability classes.

Table 3 Framework of a land suitability table

Parameters	**Range in the degree of limitation**					
	0	**1**	**2**	**3**	**4**	**5**
	S1	**S1**	**S2**	**S3**	**N1**	**N2**
	100	**95**	**85**	**60**	**45**	**25**
PPT						
Temp.						
Slope						
Soil depth						
CEC						
pH						
OC						
OM						
TN						
P						
EC						
ESP						
Texture						

Source Sys (1993).

The land suitability classification of land unit for each crop and the approach toward determining the land indices was acquired from rating of land properties of the combination of land suitability requirement for each crop (table 5) and framework of FAO land suitability (table 4).

Table 4 Suitability classes for land index

Limitation	Rating	Land suitability class
0 : No	100-85	S1
1 : Slight	85-60	S2
2 : Moderate	60-40	S3
3 : Severe	40-25	NI
4 : Very severe	25-0	N2

Source Sys (1993).

III. Results and Discussion

According to Sys (1993) the determination land suitability classification based on FAO framework of land suitability classification (1976), involves the compare of land characteristics with crop requirements. The climate and soil requirement of millet are shown in (table 6). Equally important the range of climate and soil requirements of millet production is also reveals in the same table. Therefore, the potentialities of climatic characteristics and soil for millet cultivation in the study area is in table 5 and table 6 respectively for comparing the individual scores of parameters for determination of soil requirement. However, the climate elements in the study area are at optimum level as it matched with the millet requirements.

Table 5 Suitability classes for Millet: Climate and physio-chemical requirement

Parameters	H S	M S	MG S	N1	N2
PPT	450-500	500-600	600-800	200-250	<200
Temp.	26.70-26.99	26.40-26.69	26.20-26.39	26.10-20.19	-
Elevation	400-434,95	435.95-469.3	469.3-514.95	514.95-530.5	530.5-558.5
Soil depth	21-30	20-Nov	0-10	<10	-
CEC	15-Nov	10-Jun	0-5	-	-
pH	6.5-6.0, 6.5-7.0	6.0-5.6, 7.0-7.6	5.6-5.4, 7.6-8.0	5.4-5.2, 8.0-8.2	8.2-14
OC	1.6-3.0	1.5-0.8	1.0-0.2	-	-
OM	3.0-5.0	1.7-3.0	1.0-1.7	0.5-1	-
TN	0.5-0.1	0.25-0.50	0.15-0.25	0.05-0.15	<0.05
P	25-30	18-25	17-Nov	10-May	0-5
EC	0-2	4-Feb	8-Apr	16-Aug	16-25
ESP	0-10	25-Oct	25-35	35-45	>45
Texture	Si,CL,L,SC,Si	SL, SCL	LS,Lfs	Cm,SiCm,LcS,F	Cs

Table 6 Climate and soil requirements range for Millets

Nutrients	Rating
Rainfall	200-800mm
Temperature	26.10-26.99◦C
Elevation	434,75-558.5◦
Soil depth	10-30cm
CEC	5-15 cmol/kg^{-1}
pH	6.0-7.6
OC	0.2-3.0%

OM	0.5-5.0%
TN	0.05-0.1%
P	0.5-30ppm
Ec	0-25ds/m
ESP	0-45%

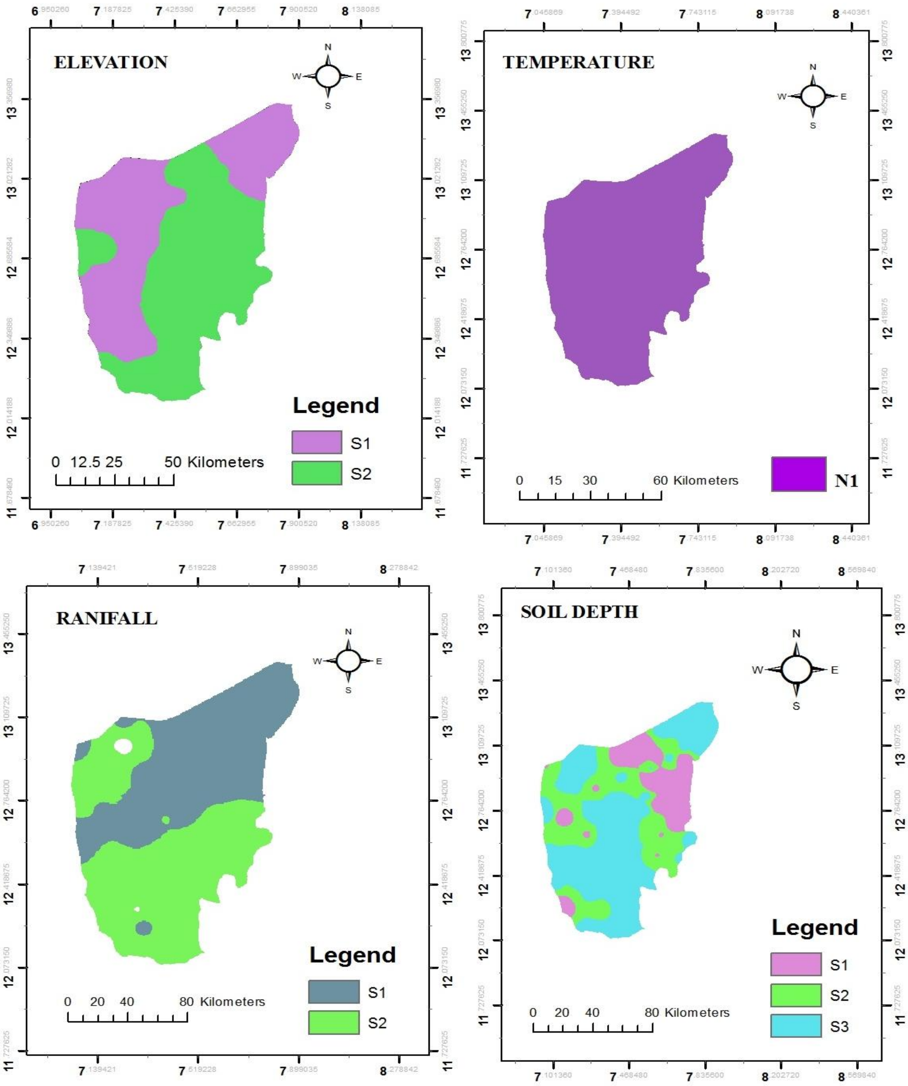
Source: Sys (1993)

Table 7 Millet Suitability Rating and Matching Requirements
Source: Adopted from Ajayi *et al* (1998)

Parameter	Rating	LU 1	LU 2	LU 3	LU 4	LU 5
Rainfall	200-800	678.92	604	605.04	704.34	702.43
Temperature	26.10-26.99	26.79	26.8	26.69	26.71	26.66
Elevation	434.75-558.5	434.95	469	514.95	530.5	558.5
Soil depth	30-Oct	25.35	25	17.5	21.4	22.3
CEC	15-May	6.11	5.8	7	5.85	7.17
PH	6.0-7.6	6.8	6.5	6.7	6.3	6.4
OC	0.2-3.0	2.22	1.67	1.91	1.94	2.09
OM	0.5-5.0	3.45	2.96	3.28	3.35	3.62
TN	0.05-0.5	0.1	0.1	0.14	0.14	0.13
P	30-May	6.04	4.4	8.48	10.23	6.02
EC	0-25	0.03	0.03	0.04	0.04	0.04
ESP	0-45	1.53	1.83	1.06	1.26	1.42

Table 8 Suitability scores and classification for millet

Parameter	LU 1	LU 2	LU 3	LU 4	LU 5
Rainfall	S2 (84)	S2 (76)	S2 (76)	S1 (88)	S1 (87)
Temperature	S1 (99)	S1 (99)	S1 (98)	S1 (99)	S1 (98)
Elevation	S2 (78)	S2 (84)	S1 (92)	S1 (94)	S1 (100)
Soil depth	S1 (85)	S2 (83)	S3 (58)	S2 (71)	S2 (74)
CEC	S3 (41)	N1 (37)	S3 (47)	N1 (39)	S3 (48)
PH	S1 (89)	S1 (86)	S1 (88)	S2 (83)	S2 (84)
OC	S2 (74)	S3 (56)	S2 (64)	S2 (65)	S2 (70)
OM	S2 (69)	S3 (59)	S2 (66)	S2 (67)	S2 (72)
TN	N2 (20)	N1 (20)	N1 (28)	N1 (28)	N1 (26)
P	N2 (20)	N2 (15)	N1 (28)	N1 (34)	N2 (20)
EC	S1 (0.12)	S1 (0.12)	S1 (0.16)	S1 (0.2)	S1 (0.2)
ESP	S1 (3)	S1 (4)	S1 (2)	S1 (3)	S1 (3)



Source: Sys (1993)

Figure: 4 Suitability of physical properties for millet production

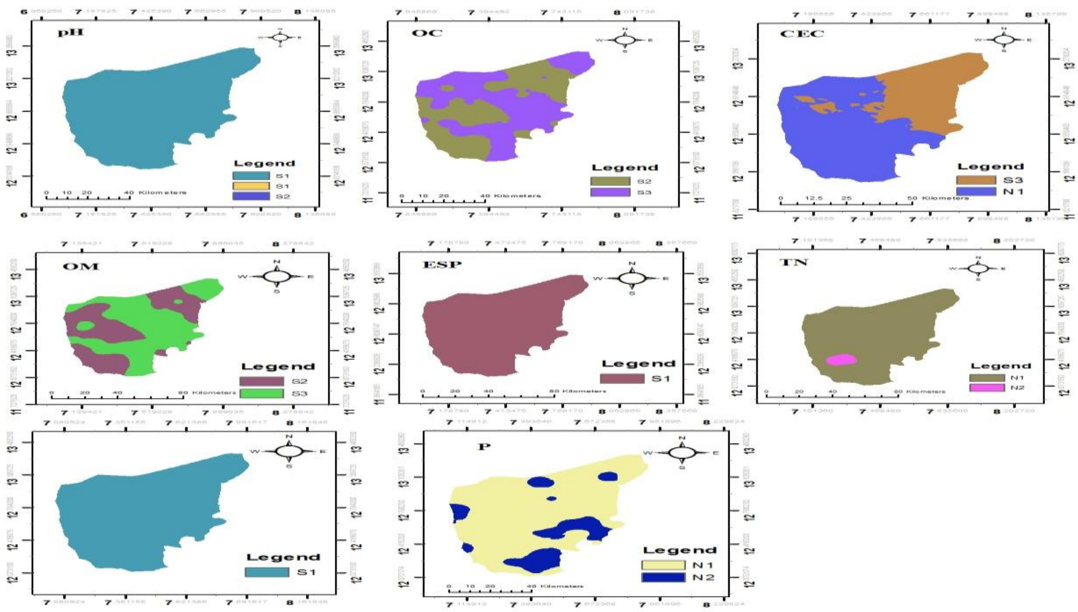


Figure: 5 Suitability of chemical properties for millet production

IV. SUITABILITY CRITERIA FOR MILLET

The weighted factor was evaluated by pair wise comparison matrix (Chen, 2012) based on land characteristics. After organizing the issue as a chain of command utilizing the Eigenvector. The criteria weight for physical and chemical parameters were performed in combination with the other factors like the slope and soil depth, slope and climate, soil depth and temperature. Geo-processing model were employed to perform the grouping of command to make physical and chemical suitability maps which were created within the Fuzzy and AHP model for all the parameters, however the Model Builder was used in combining all the layers to generate the final suitability maps. The suitability for each chemical and physical parameter was generated individually and classified in figure (4 and 5).

Temperature is a primary factor affecting the rate of plant growth and development and each plant species has a required specific temperature range for optimum production (Hatfield and Prueger, 2015). To temperature requirement of millet cultivation, the whole study area scored (S1) highly suitable 100% (6269ha) figure 3, and 4. respectively. Rainfall is one of the important factor affecting the limiting physiological process and ecological adoptability of plant species in any region (Huang and Zhang, 2016). In terms of rainfall suitability for millet cultivation in the study area all land units are found within the average level. However, (S1) highly suitable occupied 35.65% (1399ha) and (S2) moderately suitable recorded 64.35% (2525ha). Elevation is one of the major determination of the rate and magnitude of erosion of an area and equally important is among the factors used in this research in order to determine the suitability for millet. From the reclassification based on millet requirement the area is divided in (S1) highly suitable 45.96% (3121ha) and (S2) moderately suitable with 54.04% (3669ha) figure 3. Soil depth is another important factor under investigation for suitability analysis of a particular crop. In this research the depth of soil for millet cultivation was classified in to (S1) highly suitable 17.23% (779ha), (S2) moderately suitable 14.84% (671ha) and (S3) marginally suitable 67.92% (3070ha) respectively figure 3. The pH is a process of measuring soil acidity and alkalinity that gives an indication of the activities of hydrogen ion (H^+) and hydroxyl ion (OH^-) in a water solution (Murphy and Hazelton, 2007). The pH characterizes the chemical environment of the soil and may be used as a guide to suitability (Murphy and Hazelton, 2007). The spatial analysis of this research classified the study area on millet production in to (S1) highly suitable 43.23% (43.23ha) and (S2) moderately suitable 56.77% (56.77ha) respectively figure 4. The analysis of organic matter showed in figure 4, depict that the area of (S2) moderately suitable for millet cultivation covered 58.56% (2342ha) which

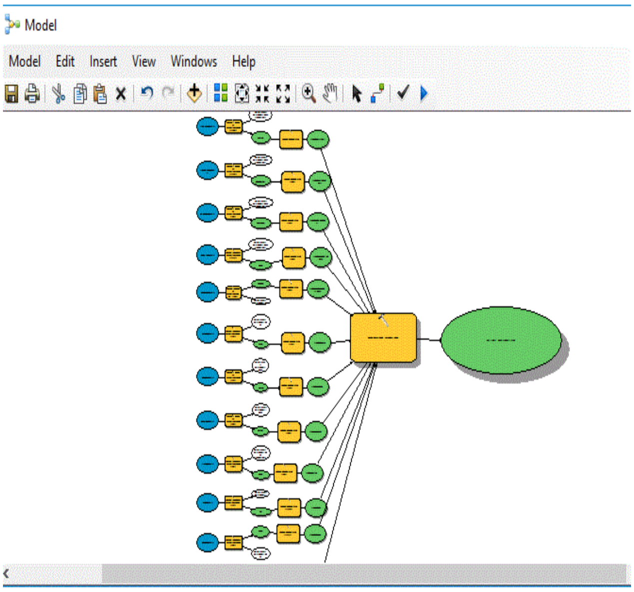


Figure: 5 Model builder for millet Suitability

is more half of the study area and (S3) marginally suitable covered 41.44% (1657ha). The analysis of organic carbon in figure 5 shows that the study area is divided in to (S2) moderately suitable 59.69% (2242ha) and (S3) marginally suitable for millet cultivation 40.31% (1314ha) figure 4. The Ec is an equally indicator of determination of saline soils, the analysis in figure 4.24 shows that the whole area found in (N2) potentially and actually not suitable for the production of millet. The spatial distribution of CEC for millet suitability in study area is falls into two (S3) marginally suitable 43.60% (2992ha) and (N1) potentially not suitable with 56.40% (3870ha) figure 4. The analysis of TN in figure 5 shows that (N1) potentially not suitable for millet cultivation covered 96.70% (8376ha) and (N2) potentially and actually not suitable covered 3.30 (287ha). Phosphorus is also relatively weak in the study area, for millet suitability the analysis indicated that (N1) potentially not suitable occupied 86.28% (5706ha) and (N2) potentially and actually not suitable for millet cultivation covered 13.72% (907ha) of the total study area figure 5. The ESP is an equally indicator of determination of saline soils, the analysis in figure 4, shows that the whole area found in (N2) potentially and actually not suitable for the production of millet 100% (6269ha).

V. COMBINED THEMATIC MAPS FOR MILLET SUITABILITY

The pairwise matrix comparison for all the factors under investigation of millet cultivation were overlay weighted of the alternatives, from which the final rate were calculated the final suitability map for millet production. Model builder showed in figure 5 were used in the combining of the thematic layers produced in figure 4 and 5 from the AHP analysis performed in the weighted overlay processes.

Table 10 Suitability rating of millet on climate and soil properties

Parameter	LU 1	LU 2	LU 3	LU 4	LU 5
Rainfall	S	S	S	VS	VS

Temperature	VS	VS	VS	VS	VS
Elevation	S	S	VS	VS	VS
Soil depth	VS	S	LS	S	S
CEC	LS	NS	LS	NS	LS
PH	VS	VS	VS	S	S
OC	S	LS	S	S	S
OM	S	LS	S	S	S
TN	VNS	VNS	NS	NS	NS
P	VNS	VNS	NS	NS	VNS
EC	VNS	VNS	VNS	VNS	VNS
ESP	VNS	VNS	VNS	VNS	VNS

Source Udo et at (2012)

Where VS= very suitable, S= suitable, LS= low suitable, NS= not suitable, VNS= very not suitable.

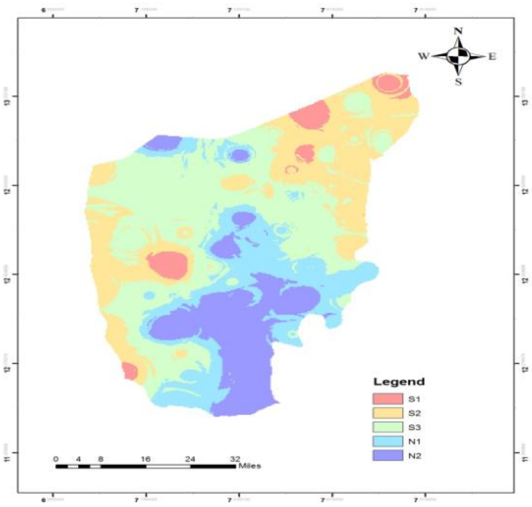


Figure 6. The map of land suitability for millet

Table 11 Millet suitability classes

Suitability classes	**Area in ha**	**% of area covered**
S1	1328.40	21.19
S2	1098.95	17.53
S3	1767.23	28.19
N1	851.33	13.58
N2	1223.08	19.51

The land suitability classes for millet are showed in figure 6 and table 11. As it has been found the cultivation of millet in Katsina North, land suitability class S1 (highly suitable) cover 1328.40ha which is about 21.19% of the study area. The areas which cover the average of the soil suitability S1 are parts of Dankama, karangi, Illela, Duru as well as Karangi. This portion possess the qualities that are required for millet production. While land suitability S2 (moderately suitable) cover1098ha which is about 17.53% of the total study area. The spread of S2 above the study area average are found in the area of Kaita, Kurabau, Kabobi, Jibia and Angawa respectively. The land suitability class S3 cover 1767.ha which is about 28.19% of total area, this class S3 are traced in Gimi, Dagawa and Zobe. The N1 (potentially not suitable) class is cover about 851.33ha which take the portion of 13.58%, found in areas of Tashar Baba, Makera and Salihawa. While the last suitability class N2 (potentially and actually not suitable) is cover about 1223.08ha which is about 19.51% this are areas that scored below average of millet requirement and are traced in areas around Tudu, Wurma and Fakuwa. This land (N2) is affected generally by poor scenery, rock outcrop, complex texture as well as infertile soil.

VI. Conclusion

No doubt measuring and monitoring the spatial variability of climate, and physio – chemical characteristics of soil is very important for agricultural land use, checking soil degradation and other related land use activities. The production of soil thematic maps in modern agriculture become very important as it helps in determining the spatial distribution of soil limitations and the ways of controlling it. It would also help in reducing the amount of farm inputs been added to the soil as way of supplements in order not to over exhaust the soil which can lead to pollution thereby degrading the land. and physio – chemical characteristics of soil but also for nonagricultural development. The study does not only show the land suitability classes for agricultural land use but also for nonagricultural development. There is also emphasize of avoiding using nonagricultural land for agricultural use. The land suitability classification of Katsina can be used at a regional or local level for making decision on land improvement and farm consolidation for developing land use plans and for preparing equitable land assessment.

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