LAND SUITABILITY CLASSIFICATION FOR SORGHUM (*Sorghum bicolor* L. *moench*) IN BUNKURE, KANO STATE, NIGERIA

BY

Mohammed AHMED
M.sc/SCIE/5259/2011-2012

DEPARTMENT OF GEOGRAPHY,
FACULTY OF SCIENCE
AHMADU BELLO UNIVERSITY, ZARIA, NIGERIA

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A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA. IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTERS DEGREE IN REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM

DEPARTMENT OF GEOGRAPHY, FACULTY OF SCIENCE
AHMADU BELLO UNIVERSITY, ZARIA, NIGERIA

SEPTEMBER, 2015

DECLARATION

I here do declare that the work in this thesis entitled "Land Suitability Analysis for Sorghum in Bunkure Kano State, Nigeria" was conducted by me, it has not been presented in the Department of Geography Ahmadu Bello University Zaria or anywhere for a degree. All quotation and source of information are duly acknowledged by means of references.

……………………………………. ………………………

Mohammed Ahmed Date

CERTIFICATION

This thesis *"Land Suitability Analysis for Sorghum in Bunkure Kano State, Nigeria"*, by Mohammed Ahmed meets the regulations governing the award of the degree of Masters of Science (GIS and Remote Sensing) of Ahmedu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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Dr. D. N. Jeb	Signature	Date
Member Supervisory Committee		
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DEDICATION

To my uncle Mallam Ahmed Usman and my mother Aisha Ikrama for whom owe everything I have in this life. Also to my lovely wife Fatima Sulaiman Muhammad for her kindness and support especially during undertaking this programme.

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ABSTRACT

The lack of sufficient and adequate information on soils characteristics is among the major limiting factors to agricultural development in Nigeria. The main aim of the study was to map out and generate soil database on the physicochemical characteristics for the cultivation of Sorghum (*Sorghum bicolour* (L.)) in Bunkure Local Government Area of Kano State. Fuzzy model and Multi Criteria Evaluation (MCE) were integrated for land evaluation. 51 soil samples from a grid map of the area at the depth of 0 - 30 cm were collected for this study. Spot 5 satellite image was used for the extraction of the landuse in the area. Digital Elevation Model (DEM) and some selected physicochemical parameters which includes; pH, Calcium, Magnesium, Organic carbon, Sodium, Nitrogen, Cations Exchange Capacity, Potassium, Electric Conductivity and Phosphorus were used for the purpose of this study. Soil characteristics map of the area combined with the soil physicochemical parameters were subsequently integrated in Arc GIS 10.1 (version) to generate the land suitability map for the selected crop. Analytical Hierarchy Process (AHP) was used in analyzing the weighting criteria for suitability class. The analysis shows that the area has been dominated by agricultural activities and the distribution of physicochemical parameters indicated that a pH value ranges from 2.90 - 9.66. The area is generally affected by low Sodium (Na) 0.01-0.23 and the moderate Nitrogen (N) and Cations Exchange Capacity (CEC) with 0.02-0.93 and 2.09-7.75 meq/100g respectively, moderately to high are Magnesium (Mg), Organic Carbon (OC), Sodium (Na), Calcium (Ca), Potassium (K), Electric Conductivity (EC) and Organic matter (OM) with 0.04-0.93ppm, 0-2ppm, 0.01-0.23ppm, 1.05-9.12ppm, 0.01-1.00 (cmol/kg) and 0.05-50.92(ds/m) respectively. The results for suitability analysis indicated that about 860.91 ha (8.6%) of land is highly suitable and 1712.15 ha (17.27%) of the area are moderately suitable. 2407.61 ha (24.29%) of the area was found to be marginally suitable while, 3568.67 ha (36.01%) of the land to be moderately suitable and 1361.88 ha (13.74%) to be unsuitable. It is concluded that the soil of the area is affected by salinity and low to moderate soil nutrients which can be controlled by proper management. The study recommended that there should be long time monitoring of the localized soils, proper use of fertilizer (organic and inorganic 50:50) by the farmers and further studies need to be carry out in the area on nutrient variability status using Multicriteria Evaluation (MCE) and Fuzzy logic.

CHAPTER ONE: INRODUCTION

1.1 BACKGROUND OF THE STUDY

Land suitability evaluation is classification of lands in terms of their suitability for a specific land use. According to Food and Agricultural Organization (FAO, 1976), suitability is a function of crop requirements and land characteristics. Suitability is a measure of how well the qualities of land unit match the requirements of a particular form of land use. The objective of land suitability and evaluation is the prediction of inherent capacity of the land units without deterioration (Elaalem, Comber and Fisher, 2001) or to minimize socioeconomic and environmental costs (De La Rosa, 2000; Neamatollahi *et al*., 2002). Physical land evaluation is a prerequisite for land-use planning, because it guides decisions on optimal use of land resources (Van Ranst, Tang, Groenemans, and Sinthurahat, 1996). In multi-criteria decision making which is utilized for determination of optimum land use type for an area, unequal importance of different land criteria is taken into consideration.

The FAO approach to land suitability evaluation classifies land according to a range from highly suitable to not suitable based on climate, terrain, soil properties and other land use related characteristics (FAO, 1976). This procedure starts by identifying relevant landuse types. The land use requirements are then matched with defined land conditions. The land conditions are described as dynamic regimes or land qualities, which are estimated from measured or estimated attributes, known as land characteristics (Melitz, 1986). FAO guidelines for land evaluation are widely accepted (FAO, 1983). The quality of land suitability assessment, and hence the reliability of landuse decisions, depend largely on the quality of the soil information used to derive them (FAO, 1976; Mermut and Eswaran, 2001; Bogaert and D’Or, 2002).

Those who use Geographical Information System (GIS) in agriculture recognize that the potential application of GIS in agriculture is large. However, the GIS user community in production agriculture is small compared to other business sectors. There is a lack of formal opportunities to share applications and innovations of GIS specifically focused on agriculture (Pierce and Clay, 2007). The Geographical Information System (GIS) offers a flexible and powerful tool as it can combine large volumes of different kinds of data into new datasets and display these new datasets in the form of informative and accessible thematic maps (Foote and Lynch, 1996; Marble *et al*., 1984). Different GIS software are capable of incorporating and manipulating a spatial data which will be used for decision making particularly the Agricultural sector.

In order to define the suitability of an area for a specific practice, several criteria need to be evaluated (Belka, 2005). Multi Criteria Decision Making (MCDM) or Multi Criteria Evaluation (MCE) has been developed to improve spatial decision making when a set of alternatives need to be evaluated on the basis of conflicting and incommensurate criteria. MCE is an effective tool for multiple criteria decision-making issues (Malczewski, 2006) and aims to investigate a number of choice possibilities in light of not only multiple criteria but also multiple objectives (Carver, 1991). Many of GIS-based land suitability analysis approaches are recently developed such as Boolean overlay and modeling for land suitability analysis.

Jidauna, Dabi and Dia (2012) shows that in the Sudano-Sahelian region of Nigeria Sorghum is the second stable and economic crop grown. Sorghum is the fifth most important cereal globally and the dietary staple of around 500 million people. It is an important food crop in many parts of Africa. Sorghum is tolerant, relative to other major cereal crops, to adverse growing conditions. It is efficient in photosynthesis and in water and nutrient use. Some earlymaturing sorghum cultivars require less than two months of rainfall to produce grain, and the species is genetically very diverse with preferred cultivars for different uses. Sorghum (*Sorghum bicolor* L. Moench) is one of the major cereals cultivated in Bunkure. Crop production like other form of agricultural practices in the area, is to a larger extent the most dominant form of agricultural productivity in the area. Thus, crop production is predominantly dependent on rainfed, with exceptional condition/cases where Ponds, Rivers and Dams are available, irrigation practices often occur closer to these surface sources of water.

In recent years, there has been increasing interest in the use of different application for analyzing soil information or perhaps land characteristics, capability, suitability and so on with multi-criterion decision analysis techniques for spatial planning and management and the use of the MCDA methods is still a new task in land suitability evaluation for agricultural crops (Elaalem, 2012).

1.2 STATEMENT OF THE RESEARCH PROBLEM

Land resource is gradually becoming scarce as increase in population places pressure on natural resources. As world population grows: an increase of food supply is urgently needed to meet those demands. According to FAO (2011) on the three decades of agriculture in the sub Saharan region, besides losing export market failed to increase the production of food calories per capital above 2100/day. However, all other major regions in the developing world improved, significantly (Alexandratos, 1995). It was projected that the region could not generate growth on the scale necessary for feeding its growing population and catch up with the predicted average for developing countries of 2730/day (Mortimore and Harris, 2003). Nevertheless, soil productivity depletion is often placed at the center of a nexus of population growth and agricultural decline (Cleaver and Schreiber, 1994; Breman 1998; White and Killick, 2001).

Furthermore, estimates were made by Stoorvogel, Smaling and Janssen (1993) in 38 sub Saharan countries. The result shows that most of the important soil nutrients were lost in the area and the loses were projected to increase the annual nutrient depletion. Also, the study of Henao and Banaante (1999) claimed that 86% of the sub Saharan African countries are losing soil (through erosion) not less than 60-100 kg/ha/year (World Bank, 2003). Furthermore, a direct link between soil nutrient depletion and food insecurity has been suggested by noting improvements for some major food crops (Gruhn, Goletti and Yudelman 2000).

Nigeria, having the largest population of any African country, rapid population growth, a high degree of dependence on agriculture at the household level and large area of low potential (sub humid and sub arid) rainfed farm land, is experiencing predominantly in nutrient depletion scenarios (Mortimore and Harris, 2003). Among many factors limiting agricultural development in Nigeria is the lack of sufficient information on soils and their characteristics (Adamu, 2012).

Inadequate information on soil has affected most of farming system and management. Ofor, Ibeawuchi and Oparaeke (2009) opined that sorghum has a high demand for nutrients compared to cereals like rice, millet and wheat. This crop require both the major nutrients (N, P and K) and the secondary nutrients (S, Mg, Ca, B, Fe, Cl, Cu etc.) in adequate amount to ensure good root establishment, vigorous and healthy growth and increased yields.

As such, there is need to identify the status of the land and the spatial distribution of this nutrient in the area. The elements form part of the essential elements needed for the growth and development of plant. Brady (1974) ascertained that plant growth maybe retarded because these elements are actually lacking in the soil, they become available too slowly, or they are not adequately balanced by other nutrients and most of these element are needed in relatively large amount.

Most of the studies conducted in Bunkure area concentrated on other crops like the study of Umar (2014) analysed the soil of Rugu rugu in Tudun wada of Kano State for suitability analysis for Arish Potato. Soil unit were used in the classification and the result shows that three areas were identified (soil units) and they are all moderately suitable with some management that has to do with water logging, erosion and low fertility. The study was limited to soil units in the mapping procedures, therefore the spatial distributions of the physicochemical properties were not analysed.

MARDITECH, (2011) analysed areas suitable for rice cultivation in some selected dam sites which includes Magaga, Watari and Tomas. The study showed potential areas are available for rice cultivation within.

Baffa (2012) studied the water requirement for irrigation on crops such as Sugar cane, Garden egg, Rice, Onion, Tomato, and Hot pepper using irrigation farming in Bunkure. The study also shows that yield (output) is low and the study concluded that salinity and other forms of land degradation are the major factors.

Tanko (2001) studied the effect of salinity and Foli (2012) characterized the soils of Bunkure, their finding shows poor drainage arising from the application of irrigated water in the area there by increasing the effect of salinity and low soil fertility status.

To the best knowledge of the researcher no study has been done on land suitability classification for Sorghum in Bunkure. Most of the studies carried out in the area were mostly on other crops.

The research is premise to answer the following questions:

(i) What are the major landuse/ land cover classes in the area?

(ii) What are the soil drainage, soil unit and slope characteristics in the area?

(iii) What are the levels of physical and chemical characteristics of soil in the area?

(iv) What is the spatial distribution of physical and chemical characteristics of soil in the area?

(v) What are the areas suitable for cultivation of Sorghum?

1.3 AIM AND OBJECTIVES

The main aim of the study was to classify the suitable land for the cultivation of sorghum (*Sorghum bicolor* L. *moench*) in Bunkure Local Government Area of Kano State.

The specific objectives were to:

i. identify the major landuse/land cover in the area

ii. classify the soil drainage, soil units and slope characteristics in the study area

iii. determine the levels of the physical and chemical properties which included pH, Calcium (Ca), Magnesium (Mg), Organic matter (OM), Organic Carbon (OC), Cation Exchange Capacity (CEC), Electric Conductivity (EC), Sodium (Na), Potassium (K), Nitrogen (N), Phosphorus (P)

iv. analyse the spatial distribution of physical and chemical parameters in the area

v. map out suitable areas for sorghum cultivation

1.4 SCOPE OF THE STUDY

The scope of the research covered part of Bunkur Local Government Area in Kano state with an area of 9911.22 hectares of land. The study analyse suitability classification for sorghum (*Sorghum bicolor* L. *moench*). For the purpose of this study, pH, EC, N, P, K, OM, CEC, Ca, Mg, Na and soil texture and slope were used for the analysis, Soil samples were collected at the beginning of the rainy season (April, 2014).

1.5 JUSTIFICATION OF THE STUDY

Inventory of land resource is a prerequisite for adequate utilisation and sustainable management of the natural resource base of any country. Accurate inventories become imperative for the assessment of available natural resources of a country (FAO, 1976). There is urgent need to optimize land use in the most practicable and logical ways to continue sustainable production while conserving fragile ecosystems (FAO, 1993). This study provides information on the Agricultural land, help in maintaining the promotion of compatible land uses and management practices in the area. In recent years thematic mapping has undergone some changes due to advances in geographic information science and remote sensing, especially in the soil studies.

This study also demonstrated the potentials of Remote Sensing and GIS in land suitability mapping at larger scale (local level) which can be applied to the medium and even the smaller scales (state and the country at large), it also provided a guide for the quantitative assessment of land for agriculture and have address the practical survey problem (especially the traditional survey method) that has been used for decades in the hope that this will enable a more consistent approach to land suitability evaluation (Grose, 1999).

CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discussed on the literature review which were break into sections, the sections include the concept and theories; Analytical Hierarchy Process (AHP); Multi Criteria Evaluation (MCE) technique; Fuzzy model and Suitability analysis. Each section was further subdivided into subheadings and relevant literatures were discussed under each.

2.2 CONCEPTUAL FRAME WORK

2.2.1 Land Suitability

It is useful for the purpose of this study to define what “Land suitability” means. A definition of this concept proposed by the Food and Agriculture Organization of the United Nations (FAO) is that land suitability is the fitness of a given type of land for a defined use. The land may be considered in its present condition or after improvements. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses. Land suitability analysis is a prerequisite to achieve optimum utilization of the available land resources for sustainable agricultural production. One of the most important and urgent problems in the study area is to improve agricultural land management and cropping patterns to increase the agricultural production with efficient use of land resources (Pareta and Jain, 2010). In general, a land area can be classified as “Suitable” or “Not Suitable” for a certain use. Suitable areas can be portioned in classes, which reflect the degree of suitability. The number of classes can vary, but it should be kept to the minimum necessary and should never exceed the number of five (Tinguely, 2012). The lowest number always represents the most suitable and the highest number the least suitable area. The FAO (1976) recommends three suitability classes with the following denominations:

i. Class S1: Highly suitable

ii. Class S2: Suitable

iii. Class S3: Moderately suitable

iv. Class S4: Marginally suitable

v. Not suitable

Tinguely (2012) explained that there can be a number of reasons why an area is classified as non-suitable. Among these reason are technical considerations (such as slope and soil fertility, etc.), environmental considerations (such potential damage of cultivation to biodiversity, aquifers, etc.), or economic considerations (investment costs and revenues).

Land evaluation models and suitability mapping can be used in a broad field of disciplines. However, most land evaluation methods are emphasizing the soil aspect (Tinguely, 2012). According to Rossiter's theoretical framework for land evaluation (1996), the reason for this is mainly because the FAO land evaluation methodology was initially developed by soil scientist. Rossiter (1996) in Tinguely, (2012) pointed out 3 different modeling approaches for land suitability evaluation. They are classified depending on how they take time and space into account:

Firstly, are the non-spatial models of single-area land suitability. In these models, the suitability of a single small and homogenous area on the earth's surface is determined. The influence from surrounding areas is neglected, and the geographic location is not taken into account. This type of analysis is only valid for a mapping unit consisting of several small areas, which share the same set of land characteristics. The evaluation units must be "small enough" and "homogeneous enough" for the objectives of the land evaluation, and must not exceed the precision of the natural resource inventory from which land characteristics are derived.

Secondly, are the spatial models of single-area land suitability. These models consider the suitability of an area for a certain land use that is dependent on its geographic position. Such models require GIS operations to implement them. In these operations, one computes a new value for each location as a function of existing data explicitly associated with that location, or as a function of its neighbourhood, or as a function of values associated with a zone containing the location.

Thirdly, are the models of multi-area suitability and the land allocation problem In evaluating a set of land mapping units that are to be planned together, for example, fields managed as part of the same farm or management parcels of a national park, there are often global constraints on the land use that apply to entire production or planning unit. There may be one overall goal, e.g. to maximize economic return over the entire project, or, more typically, multiple goals corresponding to the different land users or to a variety of societal objectives (Rossiter, 1996).

2.2.2 Sorghum (*Sorghum bicolour* L.)

Sorghum (*Sorghum bicolour* (L.) is the fifth most important cereal crop in the world after rice, wheat, maize and barley, and is the dietary staple of more than 500 million people in over 90 countries, primarily in the developing world (Sanjana, Patil, Nirmal and Gadakh, 2012). It is an indigenous crop to Africa, and though commercial needs and uses may change over time, sorghum will remain a basic staple food for many rural communities. It is adapted to semi arid areas receiving 400 to 800mm of rainfall annually by virtue of its heat and drought tolerance (Ouma and Akuja, 2013).

Nigeria is the largest sorghum producer in West Africa, accounting for about 71% of the total regional sorghum output (Ogbonna, 2011 and Ogbonna 1989). Nigeria's sorghum production also accounted for 35% of the African production in 2007 and the third largest world producer after the United States and India (FAOSTAT, 2012: FAO, 1995). Were as 90% of sorghum produced by United States and India is destined to animal feed, in Nigeria the crop is almost used completely as staple food, thus making Nigeria the world's leading country for food grain sorghum production (Gourichon, 2013).

Sorghum is one of the most important staple food crops in Nigeria. Its production surpasses all others crops (FMEST, 1984). In the Nigeria savannah zone, sorghum is grown on an estimated area of 4.5 million hectares with annual production output of about 6 million tons (NAERLS, 1997). The leaves and grains are also used for livestock feeds and the stalks for thatching houses and making fences. Sorghum is a very valuable industrial crop for brewing alcoholic and non-alcoholic drinks as well as in the baking and confectionery industry in Nigeria. According to National Research Council (NRC, 1996), sorghum has greater untapped potentials than any other crop. It even postulated that if the twentieth century was the century of wheat, rice and maize, then the twenty-first century could become the century of sorghum. Sorghum cover crops can also be used as livestock forage in a cropping system (Magdoff and Van Es, 2009). Sorghum-Sudangrass hybrids can produce up to 4,000-5,000 pounds of dry matter per acre (Clark, 2007).

This crop has extensive root systems that can penetrate up to 8 feet into the soil and extend more than 3 feet away from the stem (Shoemaker and Bransby, 2010). These aggressive root systems alleviate subsoil compaction. To encourage more significant root growth, sorghum stalks is cut at least once during the growing season when they reach 0.9 – 1.2 meters tall (Clark, 2007). Sorghum will grow in low fertility, moderately acidic and highly alkaline soils, but it is best adapted to fertile, well drained soils at a pH between 6.0–6.5. In addition it is not tolerant of frost, shade, or sustained flooding (Clark, 2007; FAO, 2012; Undersander, 2003).

2.2.3 Multi criteria evaluation (MCE) and analytical hierarchy process (AHP)

This approach helps in the Decision Making, however Multi-criteria decision making (MCDM) is primarily concerned with how to combine the information from several criteria to form a single index of evaluation (Chen, Yu and Khan, 2012).

Criterion weights are the weights assigned to the objective and attribute maps (Meng *et al*. 2011). Deriving weights for the selected map criteria (land characteristics map layers) is a fundamental requirement for applying the AHP method (Malczewski 1999, 2004). The determination of the particular criterion weight is therefore a crucial step in Multi-Criteria Decision (MCDM) Method. As previously discussed, the AHP is considered to be an adequate mathematical method for this step when analysing complex decisional problems (Saaty 1977, 1980, Malczewski 2004). It derives the weights by comparing the relative importance of the criteria in a pairwise manner. Through a pairwise comparison matrix, the AHP calculates the weighting for each criterion (wi) by taking the Eigenvector corresponding to the largest Eigenvalue of the matrix, and then normalising the sum of the components to unity.

2.3 THEORETICAL FRAMEWORK

2.3.1 Fuzzy Model

It is well known fact that many elements of land plot properties (soil, fertility of soil, microclimate, etc) have uncertainties. Uncertainty is inherent in decision-making processes, which involve data and model uncertainty. These range from measurement errors, to inherent variability, to instability, to conceptual ambiguity, to over-abstraction, or to simple ignorance of important factors (Tinguely, 2012).

An underlying philosophy of the fuzzy sets theory is to provide a strict mathematical framework, where the imprecise conceptual phenomena in decision making may be precisely and rigorously studied, in particular for knowledge management (Tinguely, 2012). The fuzzy sets theory includes fuzzy mathematics, fuzzy measures, fuzzy integrals, etc. Fuzzy logic is a minor aspect of the whole field of fuzzy mathematics. In classical sets theory, the membership of a set is defined as true or false, 1 or 0. Membership of a fuzzy set, however, is expressed on a continuous scale from 1 (full membership) to 0 (full non-membership).

In the GIS context, in decision making regarding land allocation, suitability is considered a fuzzy theory expressed as fuzzy set membership (Burrough *et al*. 1992, Hall *et al*. 1992). There are a variety of reasons why the application of fuzzy set membership in criteria standardization is highly appealing. First, it provides a very strong logic for the process of standardization. The process of criteria standardization can be seen as one of recasting values into a statement of set membership, the degree of membership in the final decision set. Compared with linear scaling, standardization using fuzzy set membership represents a specific relation between the criterion and decision set. This clearly opens the way for a broader family of set membership functions than that of linear rescaling. Second, the logic of fuzzy sets bridges a major gap between Boolean assessment and continuous scaling in weighted linear combination. Boolean overlay is a classical set problem and assumes a crisp boundary and certainty. By considering the process of criteria evaluation as one of fuzzy sets, the continuity and uncertainty in the relation between criteria and decision set are recognized. When set membership values are reduced to 0 and 1 (i.e. certainty), the set becomes crisp (a special case of fuzzy set) and the results will be identical to those of Boolean overlay (Jiang and Eastman 2000).

2.4 LITERATURE REVIEW

Elaalem (2012) compared two approaches to land suitability evaluations, Fuzzy MCDA and Boolean, to model the opportunities for sorghum production in the north-western region of Jeffara Plain, Libya. In this study a number of soil and landscape and climate criteria were identified and their weights specified as a result of discussions with local experts. The Fuzzy MCDA approach was found to be better than the Boolean approach. Boolean logic indicted that the study area has only four suitability classes (highly suitable, moderately suitable, marginally suitable and currently not suitable). In contrast, the results obtained by adopting the Fuzzy MCDA approach showed that the area of study has a greater degree of subdivision in land suitability classes for sorghum. The richer overall picture provides an alternative type of land suitability evaluation to Boolean approaches and allows subtle variations in land suitability to be explored.

A fuzzy membership functions (FMFs) was developed by Inakwu, Odeh and Crawford (2010) to determine soil suitability for multiple crops; determine the diversity of multiple suitability at each location using the Shannon's Index and equitability equation; and determine the overall versatility at the farm scale, and establish a new versatility equation by combining the previous versatility methodology with a diversity index. To understand the overall versatility of the study area suitability analysis was carried out for each of the several crops- canola, barley, field pea, Lucerne and wheat. The multiple suitability analysis demonstrated subtle differences in the trend or patterns of the individual crop mapped. The development of the improved versatility map, incorporating Shannon's index, yielded important information for management decisions.

The results indicate that the Northern and Southern paddocks of the study area exhibited higher versatility than the rest of the farm and would be highly suited for multiple crop rotations.

This study considers a GIS methodological framework based on fuzzy sets theory for land use management. Some principles of development of the GIS methodological framework are formulated. Applications of the GIS methodological framework are designed. In particular GIS knowledge management fuzzy models for analysis of soil commutative contamination by heavy metals, for the study of soil acidity, and for evaluation of soil conservation actions are obtained. On the basis of the fuzzy model, software oriented for use with MapInfo Professional GIS software, version 4.0 has been designed. By this, software values of integral index of multiple assessment of soil conservation action for selected land plots are calculated and mapped automatically. In particular from the analysis it follows that priority should be given to the land plot where the index of multiple assessment > 0.9. This approach was used for management of agrarian territories located in the suburbs of St. Petersburg. In particular, values of index of correlation between acidity of land plots and requirements of agricultural plants are calculated and mapped automatically. The result shows that only some plots of the second group offer favorable conditions for agricultural plants (plots where index of correlation > 0.9). Most of the territory is suitable for agricultural plants of the first group.

Mokarram, Rangzan, Moezzi and Baninemehc (2012) combined fuzzy and Analytical Hierarchy Process (AHP) in preparing land suitability evaluation maps for Wheat using Fuzzy classification in Shavur area, Khuzestan province. The results are compared to a Crisp classification using the standard FAO framework (parametric) for land evaluation which includes non-physical parameters as well. In the study, eight soil parameters, such as soil Texture, Wetness (ground water depth and hydromorphy), Cation Exchange Capacity (CEC) and

Exchangeable Sodium Percentage (ESP), Gypsum (%), CaCO3 (%), Topography, Soil depth and pH values were taken into consideration. AHP was used in analyzing the weight and the result classified 26% of the area as moderately suitable, 25% as marginally suitable and 49% as unsuitable. The results with the Fuzzy theory showed that 31% of the study area as highly suitable for growing wheat 29 % as moderately suitable, 19% as marginally suitable and 21% as unsuitable. This study was limited to non physical parameters targeting a single crop.

Mustafa, *et al* (2000) used Multi Criteria decision Making (MCDM) and Remote sensing in analyzing land suitability for different crops and for generating cropping pattern for the summer and winter seasons in Kheragarah *tehsil* of Agra. Different soil chemical parameters and physical parameters were evaluated for different crops. Results indicated that about 55 % of the land is highly suitable (S1) for sugarcane while 60%, 54% and 48 % of the area are moderately suitable (S2) for cultivating pearl millet, mustard and rice respectively. 50 % of the area is found to be marginally suitable (S3) for growing maize. This study concentrated on cereals. However, Sorghum was not included.

A study was carried out by Elaaleem (2012) modeled for land suitability for Sorghum cultivation using the Boolean Fuzzy (MCDA) in the north-western region of Jeffara Plain, Libya. The Fuzzy MCDA approach was found to be better than the Boolean approach. In this study, soil landscape and climate criteria were used. Similarly, Nisar, Ahamed and Gopal (2000) used Boolean and fuzzy methods which are designed to assign a pixel to a single class and no provision exist for assigning partial suitability to each of the appropriate suitability classes. Nine parameters were used in the study (eight of soil and one of topography). The results revealed that the maximum area is potentially suitable for growing ground nut. Land use of the area was not included because that will delineate the agricultural land.

Elaalem (2013) used both the Parametric and Fuzzy MCE approach for land suitability for the cultivation of Olive. Different factors were used in the study, these factors are: Soil (i.e. available water holding capacity; soil depth; infiltration rate; soil texture; soil salinity; soil reaction), climate, and erosion hazard and slope steepness which were all weighted. Factors affecting land suitability model for olive in north-west of Jeffara Plain region, Libya were defined based on previous studies for the study area and discussion with local experts (Sys, Van Ranst, Debaveye and Beernaert, 1993) The results of Fuzzy MCE showed that the majority of the study area is highly suitable for olive production, while the results obtained from the use the parametric method showed that most of the study area is moderately suitable for olive production. The Fuzzy MCE approach was found to be better than the parametric approach. The Fuzzy MCE approaches accommodate the continuous nature of many soil properties and produce more intuitive distributions of land suitabilities value for olive.

The study of Al-Mashreki *et al* (2011) presents a spatial modelling procedure for land suitability evaluation of rainfed sorghum crop using available biophysical information. Moreover, this study was undertaken to develop a physical land suitability method using GIS and remote sensing technologies in arid and semiarid ecosystems such as that of Ibb Governorate at Highland region of the southwestern Yemen. It aimed to provide a simple example of how GIS and remote sensing technologies can be applied to detect the types of potential land suitability of agriculture in the study area. In addition, it intended to design an information system for land resource assessment. Accordingly, this study reveals that the nearly 5 % of the study area is highly suitable, 25 % is moderately suitable, 31 % marginally suitable, 24 currently unsuitable as well as 15 % permanently not suitable for the production of sorghum.

Behnam, Dorri, Jaime and da Silva (2014) used different raster layers in analyzing the suitability for assessment of land suitability and the possibility and performance of a canola (Brassica napus L.) soybean (Glycine max L.) rotation in four basins of Golestan province, Iran, including climatic (precipitation, temperature), topographic (aspects and slope) and soil-related (texture, pH, EC) layers, were provided by interpolation, surface analysis and other related techniques in GIS. Overlaid layers were used to judge the capacity of agricultural lands to rotate a canola–soybean system in the study area, which included four important basins. Based on defined scenarios and pre-determined ecological requirements of the two studied crops, five suitability classes were detected and mapped. The results reveals that just 11.82% of total lands are very suitable to rotate soybean after canola while most agricultural lands in the study area fell into the moderate and low suitability classes. The consistency of results adopted from final overlaid maps with real statistics in the study region show that GIS as a systemic approach can play a vital role in saving time and reducing.

Da-chang *et al* (2011) employed artificial neural network (ANN) analysis to select factors and evaluate the relative importance of selected environment factors on wheat grain quality. The spatial models were developed and demonstrated their use in selecting the most suitable areas for the winter wheat cultivation. The strategy overcomes the non-accurate traditional statistical methods. Satellite images, toposheet, and ancillary data of the study area were used to find tillable land. These categories were formed by integrating the various layers with corresponding weights in geographical information system (GIS).

An integrated land suitability potential (LSP) index was computed considering the contribution of various parameters of land suitability. The study demonstrated that the tillable land could be categorized into spatially distributed agriculture potential zones based on soil nutrient and assembled weather factors using RS and GIS as not suitable, marginally suitable, moderately suitable, suitable, and highly suitable by adopting the logical criteria. The sort of land distribution map made by the factors with their weights showed more truthfulness. The analysis showed that most area in Beijing were more or less agriculturally suitable. However, about 3.9% (100.347 ha) of the area was rated as not suitable, a very large portion of the area (61.5%) comes under moderate to average, 16.1% rated marginally suitable, 27.2% (about 699.856 ha) of the area was rated as highly suitable.

Elsheikh *et al* (2013) used Model Builder approach for Agricultural land suitability evaluation for different types of crops in tropical and subtropical regions (e.g. mango, banana, papaya, citrus, and guava). A land suitability model was constructed using GIS capabilities and modeling functions. The Model was used to organize and integrate spatial processes to analyse the land suitability. The spatial geo-environmental factors (e.g. soil, climate, slope, erosion and flood hazard) were integrated into the GIS environment as information layers and overlaid to produce overall land suitability assessment for a particular land utilization type. The suitability analysis for geo-environmental factors is calculated in visual basic and integrated within the GIS Model Builder through linking of the two tables, considering matching in ID.

The overall suitability map was produced based on five layers of data: soil, slope, climate, flood and erosion. The weighted overlay process was used, and the weights generated from sensitivity analysis and variation of function, were applied to different thematic layers. The result of the analysis shows that high suitability class (S1) increased from 9% to 27% when the climate weighting was increased from 10% to 20%, respectively. The sensitivity analysis for the flood revealed that there was only a slight change in the highly suitable class when the flood weighting was varied for the erosion criterion, the results indicated that there were minor changes in the highly suitable class, but was less than the changes in the soil and slope criteria.

The results of the analysis indicated that 31% of the study area was identified as most suitable for mango (Class 1), 55% of the area as moderately suitable area (Class 2), 9% percent as marginally suitable (Class 3) and the remaining portion (5%) was not suitable for mango (Class 4 and Class 5).

Al-Mashreki (2011) determined the variation in the output caused by different input weights for four criteria namely climate, soil, slope, and erosion. So that sixteen weighting schemes were constructed, associated with the criterion map layers and run using the model's implementation in ArcGIS. The weighting schemes were applied for the selected crop (sorghum). The model finds the best path given the weights placed. By varying the weight, several different paths can be found. The results revealed that the slope is a very highly sensitive element in the suitability classification for sorghum crop, whereas the soil is a highly sensitive, the climate and erosion are moderately sensitive. This implies that each factor has to be given suitable weighting reflecting its importance for the suitability of sorghum in the study area.

Teshome *et al* (2013) used the Physical land suitability in Abobo area, western Ethiopia, following the FAO methodology for the determination of length of growing period and maximum limitation method for suitability classification. The result of the study revealed that the climate of the study area is moderately suitable (S2) for the considered varieties of cotton, maize and sorghum, whereas it is marginally suitable (S3) for upland rice. Considering soil and landscape suitability, the most limiting factors were soil depth, wetness, and soil fertility, mostly nitrogen. Based on the FAO model, the potential yields of cotton, maize, upland rice and sorghum were 2,645, 6,409, 4,774 and 4,194 kg ha-1, respectively. However, yield reductions of 7.32 to 12.09% and 6.01 to 11.16% were observed in simulated rain fed yield for maize and upland rice, respectively, as compared with their corresponding potential yields. The differences might mainly be induced due to water limitation, soils and landscape attributes, which suggests use of supplementary irrigation and soil management for optimum and sustainable production. All the limitations, except soil depth, can be improved so as to attain the potential suitability through improving and sustaining soil OM and practicing integrated soil fertility management.

In the study by Kihoro, Njoroge and Hunja (2013) in Kirinyaga, Embu and Mberee counties in Kenya, biophysical variables of soil, climate and topography were considered for suitability analysis to develop a suitability map for rice crop based on physical and climatic factors of production using a Multi-Criteria Evaluation (MCE) and GIS approach. All data were stored in ArcGIS 9.3 environment and the factor maps were generated. For MCE, Pairwise Comparison Matrix was applied and the suitable areas for rice crop were generated and graduated. The current land cover map of the area was developed from a scanned survey map of the rice growing areas. According to the present land cover map, the rice cultivated area was 13,369 ha. Finally, different layers were analysed like the land cover map with the suitability map to identify variances between the present and potential land use. The crop-land evaluation results of the present study showed that, 75% of total area currently being used was under highly suitable areas and 25% was under moderately suitable areas. The results showed that the potential area for rice growing is 86,364 ha and out of this only 12% is under rice cultivation. This research provided information at local level that could be used by farmers to select cropping patterns and suitability.

The study of Nurmiaty and Sumbangan (2013) employed land evaluation method in geographic information system (GIS) based on the FAO Framework for Land Evaluation. Land availability was assessed from overlaying information on land use (obtained from available land use map and SPOT XS image interpretation) and suitability classes based on the FAO

Framework, as well as administration boundary map. The results indicated that the S1 (highly suitable) class comprises a total area of approximately 34,468 ha, or about 24% from the total area. The limiting factors for S2 (moderately suitable) and S3 (marginally suitable) classes are slope and nutrient availability, but with the advanced management efforts (moderately input) such sub-classes can actually promote S3 class to S2 level. It was also found that from a total of 144,085 ha of the study area, potential maize development area (for intensification) covers approximately 24,716 ha (or 35.6%). Tanralili, Bantimurung, and Simbang sub-districts cover the largest suitable area, where no significant limiting factors exist. Surprisingly, potential development area for maize in Camba, Mallawa, and Tompobulu sub-districts denotes minus values. This implies the facts that maize cultivation is still practiced on the land that is ecologically not suitable, where steep slope is the dominant limiting factor.

Similarly, Pareta and Jain (2010) applied the Multi-Criteria Evaluation (MCE), Pairwise Comparison Matrix known as Analytical Hierarchy Process (AHP) for suitable areas for crop land using QuickBird (60 cm) of 16 April, 2010, and IRS-P6, Resourcesat-1 LISS-IV Mx (5.8m) 26 September, 2009 satellite image was classified using ERDAS Imagine 9.3 by means of supervised classification. The results showed that agricultural practiced, which prevailed in the study area didn't match with the potential suitability in the marginally suitable area. Thus, the average yield of the study area was substantially affected because of a significant proportion of crop land was under marginally suitable areas. The study concluded that it provided information at local level that could be used by farmers to select crop land, cropping patterns and suitability.

Mansor, Pormanafi, Mahmud and Pirasteh (2012) developed a model based on multi-agent genetic algorithm. The model was customized to accommodate the constraint set for the study area, namely the resource saving and environmental-friendly. The model was then applied to solve the practical multi-objective spatial optimization allocation problems of land use in the core region of Menderjan Basin in Iran. The first task was to study the dominant crops and economic suitability evaluation of land. Second task was to determine the fitness function for the genetic algorithms. The third objective was to optimize the land use map using economical benefits. The results has indicated that the proposed model has much better performance for solving complex multi-objective spatial optimization allocation problems and it is a promising method for generating land use alternatives for further consideration in spatial decision-making particularly in the Agricultural sector..

Fasina *et al* (2007) focuses on the some selected Cocoa soils of Ekiti State. Soils of were characterized, classified and evaluated for Cocoa production. The study revealed four major soil units located at four different sites (Aisegba, Ayedun, Ise and Ikoro). All the soils are well drained but concretional and gravelly in nature. Soil texture consists of sandy loam surface and clay loam/silt loam and clay in the subsurface. The soils are moderately acidic in reaction (6.16) and have low amounts of organic carbon (0.21-1.52%). The effective cation exchange capacities and percentage base saturations are low ranging from 0.70-1.51 meq/ 100 g of soil and 42.86-83.33%, respectively. The Aisegba and Ikoro soils classify as Tupic PIinthudult (Eutric Plinthosol-Ondo series) while Ayedun soils classify as Typic Udipsamment (Cambic Arenosol-Makun series and Ise soil was classified as Acrudoxic Plinthic Kandiudult (Eutric Plinthosol-Fagboseries). The major limitations of the soils are the gravelly Concretional nature of the soils, poor soil fertility and low rainfall distribution. On the basis of these limitations, all the soils have been classified as S3cfs (marginally suitable) for cocoa production.

A suitability analysis was carried out by Adesemuyi (2014) for Maize in Akure a humid zone of Southwestern Nigeria to evaluate the soil for a long term production of maize and to have a detailed soil data base for effective land use planning. Critical nutrient requirements for maize were collected from past research work and compared with data obtained from field survey. The suitability assessment result showed that although certain qualities or characteristics such as mean annual temperature, relative humidity, topography, and base saturation were optimum for maize cultivation, there was no highly suitable (S1) land for maize cultivation in the area. Some sections in area were moderately suitable (S2). While other sections were marginally suitable (S3), the sections occupying the depressions were currently non-suitable (N1) for maize production. In order to raise the productivity level of the land to optimum performance for maize production, the management techniques should enhance the nutrient and moisture holding capacity of the soil. Such techniques should include; continuous application of organic fertilizers/materials to the soil, improved efficiency of use of mineral fertilizers and use of low levels of chemical inputs, putting up appropriate drainage facilities in place to take care of the poorly drained area of the land while provision of irrigation facilities would make dry season.

Aondoakaa and Agbakwuru (2012) examined the suitability of the soil in Dobi, Gwagwalada Area Council, Federal Capital Territory (FCT), for rice cultivation. Soil samples were collected from the plot using systematic sampling procedure, at two standard depths of 0-15cm (top soil) and 16-30cm (sub soil). Standard procedures as applied to tropical soils were followed in analyzing the soil samples while the data obtained were statistically analysed. Results obtained were compared with the standard land quality requirements for rice cultivation in Southern Guinea Savannah. The soil parameters varied considerably but in general it was observed that, the high pH (6.73 for top soil and 6.74 for subsoil as against the normal range of 3.1-5.3) is not favourable for rice cultivation. The level of organic carbon (0.89 for topsoil and 0.81 for subsoil), total nitrogen (0.05 both for top and subsoil) available phosphorus (13.35 for topsoil and13.00 for subsoil) cation exchange capacity (7.14 for topsoil and 6.99 for subsoil) in the soil is favourable for cultivation of rice.

Furthermore, the calcium content (3.14 for topsoil and 3.01 for subsoil) in the soil is high which can be traced to the high soil pH which limits plant growth. Similarly, the magnesium level (2.06 for topsoil and 2.02 for subsoil) is high and as a base element, it limits rice yield. A parameter is considered high based on Olaleye, et al (2002)'s suitability evaluation for rice cultivation in Nigeria. The study recommended that for sustaining future agricultural productivity, there is need for detailed suitability assessment and land evaluation, also, a high dosage of NKP fertilizer application is encouraged and that salt free irrigation water can be applied to leach down the level of soil pH which will benefit both government and farmers for sustainable agricultural productivity.

Ande (2011) carried out study at Ilaju village in the derived savanna area of South Western Nigeria to evaluate the suitability of the soil for long term cassava production in order to extrapolate to similar soils in the region. Critical nutrient requirement for cassava were collected from past works. Soil survey was done within the area to collect soil samples which were analysed and compared with the critical nutrient levels. Three soil series were identified which are Apomu, Gbemi and Matako series. These were classified as Dystric arenosols, Plinthic Ferrasols and Dystric Fluvisols, respectively. The suitability evaluation shows that Dystric arenosols is moderately suitable due to its low nutrient with CEC of 3.92 cmol kg^{1}. The Plinthic Ferrasols is marginally suitable because of its high gravel content and shallow depth (39 cm). Dystric Fluvisols is not suitable due to its seasonal high water table and low CEC (3.48 cmol kg^{1}). Soil management recommendation includes use of organic fertilizer, mulching and leguminous cover cops to enhance soil quality.

Indiscriminate allocation of farm farmlands beyond efficient level affect farmers return, hence suitability and standard value of lands for cassava production for optimal use were investigated in the study of Ehirimi *et al* (2013) data were obtained using a multi-stage sampling technique, from a sample of 203 cassava farmers in the state and were analysed using descriptive statistics, land productivity ratio and econonometric tools. Most farmers are female of 55.7 6.8 years of age and post primary education status. Nutrient amendment is at the rate of 442.36 ± 102.73 Kg/Ha and at mean cost of N36401.77 ± 28575.84/Ha. The performance rate of 0.96 tons/person/Ha was obtained. The suitability index ranges from 0.139 to 0.908 with 46.3% cultivating on non-suitable land of 0.0-0.339 while only 20.7% cultivated on suitable lands of above 0.723 suitability indexes with a smaller mean area of 1.48Ha. The performance rate across these classes of land ranges from 0.44 tons/Ha/person to 2.11 tons/Ha/person for non-suitable land and suitable lands respectively. Suitable lands had the highest land productivity of 5.71 while moderate and non suitable lands had only 4.00 and 3.72 respectively, hence about 53.4% and only 7.5% increase in production is achieved as a piece of land is improved from non-suitable and moderately suiatble lands respectively to suitable land in the area. The MVP ranges from N302429.76/Ha for non-suitable lands to N718535.2/Ha for suitable lands. The study noted that suitable lands have higher opportunity cost than others for cassava production, hence recommends that opportunity cost of land must be based on higher MVP for optimal use.

A typical problem is faced in Nigeria, where agricultural lands are largely underutilized and mostly suffering from degradation leading to an unmitigated food security problem. Currently, food production growth rate in Nigeria remains unable to feed its fast growing population. This is largely attributed to the farm management practices on agricultural lands employed in crop production. A step in the right direction is to provide a central repository of data and knowledge where decision support on the best crop production practices to provide optimum yield in quality and quantity is made available in a view easily interpreted by the chief implementers, which in this case are the local farmers. This can be accomplished in part by building a system to provide soil suitability decision support.

The increasing world population, coupled with the growing pressure on the land resources, necessitates the application of technologies such as GIS to help in identifying the most suitable areas for a sustainable agricultural production for food supply according to the environmental potential. Selecting the best location for agricultural production is a complex process involving not only technical requirement, but also physical, economic, social, and environmental requirements that may result in conflicting objectives. Such complexities necessitate the simultaneous use of several decision support tools such as Geographic Information Systems (GIS) and Multi Criteria Decision Analysis (MCDA) using analytical hierarchy process (AHP). In this paper a model was developed to determine the suitability of the area for agricultural production using soils, slope, water bodies and geological maps of the area to support decisions making for sustainable agricultural production. This integration could benefit farmers and decision makers in agriculture planning. The central theme of this paper is to explain the process of developing a prototype GIS application to provide a system for supporting location decisions with respect to the implementation of agricultural planning. GIS was used based on a set of criteria derived from the spatial and environment aspect.

The study of Masoud (2013) seeks to determine the most suitable areas for inland valley rice cultivation using computer based models for selected sites (15km by 15km) in the Brong Ahafo Region (BAR) and Western Region (WR) of Ghana. The demand for rice (*Oryza sativa*) in Ghana is increasing at a rate of 11.8% from 939, 920 t in 2010. Though there has been some increase in production it does not match the increase in consumption. A sensitivity analysis was carried out by excluding the least contributing parameters and varying their weights to determine highly suitable areas. Finally, 12 most sensitive input parameters were identified from the original 22. These were used to model for five suitability classes (highly suitable, suitable, moderately suitable, marginally suitable and not suitable). The model results based on parameters having equal weights showed that 0.5% and 11.8% (BAR); and 1.4% and 21.4% (WR) of the area were highly suitable and suitable respectively. Using unequal weights, 0.8% and 7.6% (BAR); and 0.9% and 13.6% (WR) of the area were highly suitable and suitable, respectively. The study successfully mapped out suitable areas for rice cultivation using spatial models based on limited data set, which can be adopted for use elsewhere.

The study of Ogunwale, Olaniyan and Aduloju (2009) in University of Ilorin farmland, situated in the southern Guinea savanna zone of Nigeria, was evaluated for its suitability for the production of cowpea [*Vigna unguiculata* (L.) Walp.]. Potential and actual suitability indices were calculated from raw morphological and chemical data on five pedons. Climate was not a constraint to the production of cowpea in Ilorin and it's environ. Available phosphorus was a constraint in two of the five pedons studied. Aggregate potential suitability rating showed that Bolorunduro series was the most suitable for cowpea production, followed by Ilemona, Tanke and Badi series, respectively. Afon series is constrained by both drainage and texture factors.

Land Evaluation studies were carried out on two wetland soils (Ado-Ekiti and Kabba) in Nigeria by Babalola *et al* (2011). FAO Frame work and fertility capability classification (FCC) systems were used to evaluate the sites for rice production. The influence of two management practices (Local and Improved) on rice yield were evaluated on the field. Soil samples were collected under eight rice stands in each plot for regression analysis to determine the influence of individual soil properties on rice yield. An economic analysis was carried out to assess the more profitable site for rice production.

The wetland soil at Ado-Ekiti was classififed as Fluvaquept Endoaquept, while the Kabba wetland soil was classified as Typic Halaqeupt. The pedon at Kabba was classified as Lgh and that of Ado-Ekiti as Leghk using the FCC System, with cation Exchange capacity and K status accounting for differences between the two. Kabba sites was classified as presently not suitable (N1) for rice production and Ado-Ekiti as N2 because of limitations imposed by soil chemical properties. With proper soil fertility management, the potentials of these soils can increase to moderately suitable (S2), for rice production. Improved management system gave significantly higher yields than the local management (t=2.50). Stepwise regression of rice yield on soil properties revealed that Seventeen soil properties contributed to rice yield within the study areas with R2 values of 92.81% and 93.56% at Ado-Ekiti and Kabba respectively. Economic analysis of rice production in the two sites showed that the cost benefit ratio was positive at both sites but best return on investment was obtained from Kabba with gross margin of N532,775/ha**.**

The research of Mitra *et al* (2011) using land suitability evaluation (qualitative and economic classification) has been determined for tea in an area including 5000 ha in sloping lands of Guilan province in Iran. In the study area, eight soil series and three orders (Inceptisols, Entisols and Alfisols) were identified. The simple limitation method, the limitation method regarding number and intensity and the parametric methods including the Square root and the Storie methods were used for qualitative land suitability evaluation. Results of first and second methods showed similar marginally suitability classes (S3). According to these methods, the most important limiting factors were climate, topography and physical soil characteristics. Moreover, results of Storie method showed unsuitable condition for tea cultivation (N2), except one land unit, which had non-suitable but correctable conditions (N1). In addition, results of Square root method showed unsuitable condition for one and non-suitable conditions but correctable for six land units and just one land unit had marginally suitable land classes. Economic land suitability evaluation showed that four land units had marginally suitability, three land units had moderately suitability (S2), and only one of them had the highest class (S1) and the best gross benefits. Sloping area in Guilan used to be covered by forest, but regarding to the highly destruction of plant cover and deforestation in order to tea cultivation, an intensive erosion in the area is predict to happen in future.

Ali *et al* (2008) analysed five (5) different crops for suitability using Simple Limitation Method (SLM), the Limitation Method regarding Number and Intensity (LMNI) and the Parametric Methods (PM) such as the square-root and the Storie methods were used. The landscape, climate and soil and characteristics that influence suitability of the land for particular crops have been combined according to the adopted methodology. Economic factors were excluded and moderate level of management was assumed. The results of different methods show that the most important limiting factors are climate, pH, organic matter (OM), gravel, salinity and sodicity, taken either alone or in combination. For safflower, the cation exchange capacity (CEC) can be added to these factors. Evaluation by the SLM and LMNI methods result in similar suitability classes, which confirms previous findings by other researchers for the same crops. However, in many cases the use of parametric methods, especially the square-root method, turned to be more realistic in distinguishing separate suitability classes. This study not only compares different methods and their results but also evaluates the suitability of the study area for particular crops. According to the square-root method, the area can be recommended as marginally suitable for cultivation of wheat, barley, alfalfa and safflower and is expected to yield about 40–65% of optimal production.

Every activity is decision-based and requires serious processing if qualitative result is to be attained. However, in many cases, the choice is intuitive and thereafter hazardous with unpredictable consequences. On the other side, the operational research domain has produced many methods that could be adequately used in these situations. Using these methods will facilitate the decision making activity by considering specific Agric inputs situation. Many developing countries lack the means of maintaining high quality agricultural statistics collection. Consequently official statistics suffer from a lack of precision and reliability. One major contribution of the analytic hierarchy process (AHP) is its focus on overcoming these drawbacks (Magbagbeola Adetoso and Magbagbeola, 2012).

A 200 hectare parcel of land in Edo state of Nigeria was evaluated by Umweni and Ogunkunle (2014) for its suitability for rice cultivation, under three land utilization types (LUT) :(i) Rain-fed upland,(ii) Natural flood and (iii) Irrigated rice cultivation. Six soil mapping units were established and appropriate guidelines specific for each LUT was followed in establishing the suitability of the land for rice cultivation. The suitability of each soil for each of the different land utilization types was ranked relative to the other soils and the rankings were compared using the Spearman's ranking correlation coefficient. The results showed that Rain-fed upland rice can only be practiced in 40 hectares (19.5 %) of the area, at a marginal class of suitability, Irrigation can be practiced in at least 160 ha and Natural floods in 189 ha (94.5 %). With a correlation coefficient of 0.96 between Irrigated and Natural flood methods, it means that either of them can be practiced but because their seasons are different, one can be made to follow the other in practice Irrigation to follow Natural floods. .

CHAPTER THREE: STUDY AREA AND METHODOLOGY

3.1 INTRODUCTION

This chapter discusses the study area and the methods used to source and analyse the data. The chapter is divided into sections: these are the study area which include the location size, extend, rainfall, topography, soils, climate, vegetation, and population. The methodology involves the reconnaissance survey, types and sources of data, AHP application, geo-referencing and digitizing of the maps, detailed field work, data integration and data analysis.

3.2 THE STUDY AREA

3.2.1 Location and Size

Bunkure LGA is located between Latitudes 11^o 34\` 02\`\`N to $11^o$ 46\` 05\`\`N of the Equator and between Longitudes 8^o 26\` 36\`\`E to $8^o$ 46\` 43\`\`E of the Prime Meridian. The study area comprises of fifteen wards (15) with an aerial extent of 9911.22 Km^2 and is bordered by Dawakin kudu and Kura LGAs to the North, Wudil and Garko LGA to the East while Kibiya to the South Western part of the study area (Baffa, 2012).

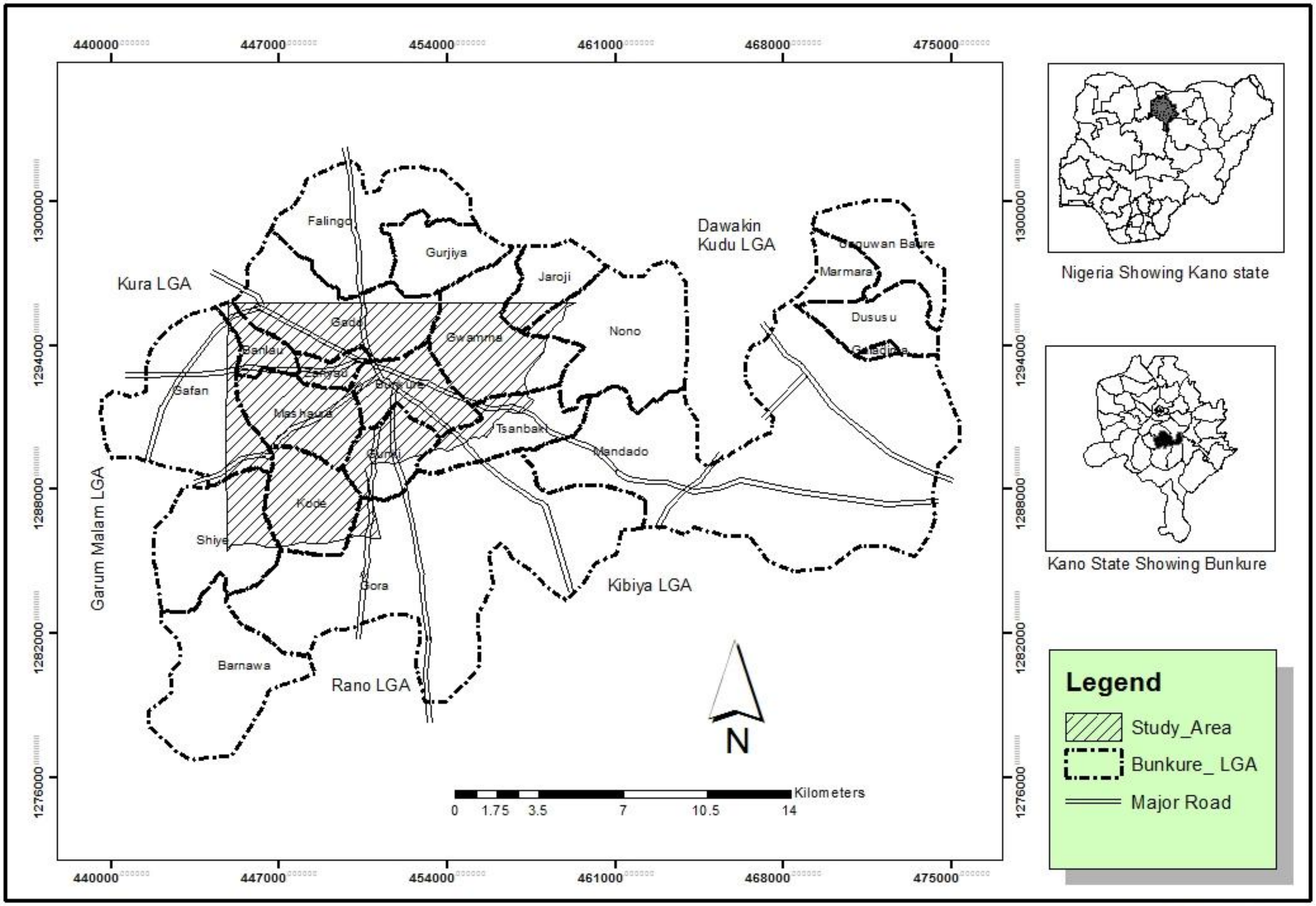

Figure 3.1: Bunkure Local Government and Study area

Source: Adopted from Min. of Lands Kano State

3.2.2 Climate

Kano Region experiences four distinct seasons, *Rani*, *Damina*, *Kaka* and *Bazara* closely associated with the movement of the ITD. The mean annual Rainfall is about 884mm varying greatly from the northern and southern parts of the Region. On the average, the wettest month is August where the highest number of rainstorms and sediment transport are recorded. The weather and climate of the area play a great role on the agricultural practices and are favourable to large scale cultivation of cereals, groundnuts, beans and vegetables. The socioeconomic activities of the people are also closely linked with the seasons, with crop production dominating during the wet season and off-farm activities (*ci rani*) dominating during the dry season while some engaged in irrigation activities (Maryam, Halima and Ummi, 2014).

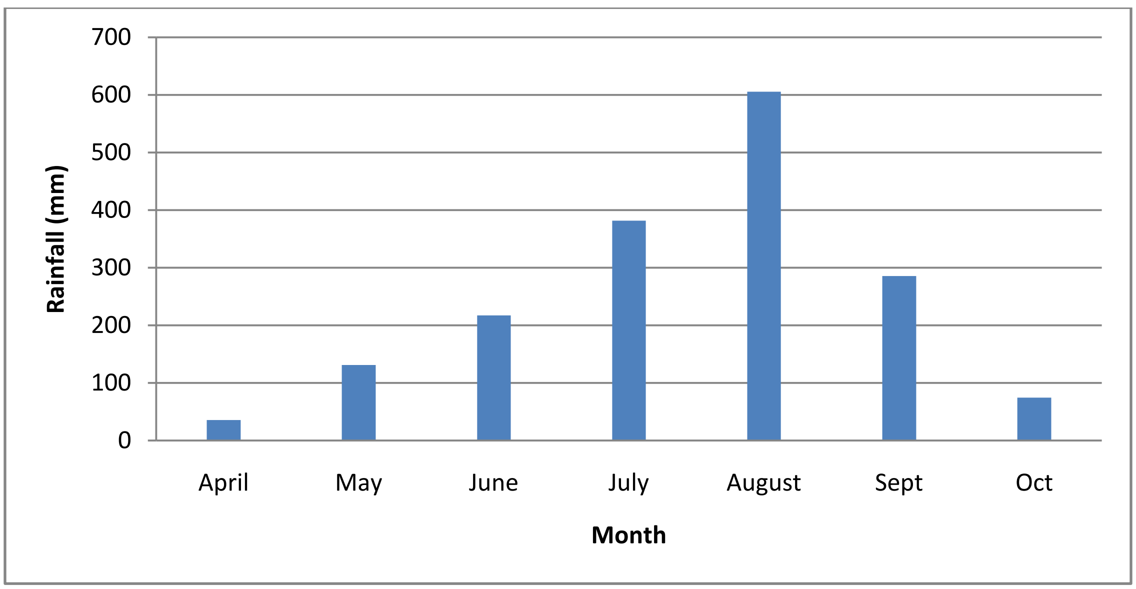

Figure 3.2: Mean Monthly Rainfall (mm) 1990-2010 in Kano State

Source: Adopted from Usman (2014)

Usman (2014) described the Rainfall in Kano Region as seasonal. Rainy season normally starts in May and ends in September. The dry season on the other hand, usually last from October till April (figure 3.2). Also, KNARDA (2001) noted that wet season start from April to October while the dry season commence from November and ends in March, with the rains starting from the southern part and the dry season starts from the northern part. The average rainfall ranged from 600mm per annum in the northern part of the zone to as high as1200mm per annum in the southern part of the zone. Mean annual temperature range from 26^{o}C - 32^{o}C, while the diurnal temperature ranges from an average daily maximum of 31.6 oC to an average daily minimum of 13.1^{o}C and relative humidity of 17% - 90% (Kowal and Knabe, 1972).

The interim report of MARDITECH (2011) and Buba (2000) affirmed that rainfall regime is characterized by two seasons, namely, the rainy season from May to October and the dry season from November to April. However, the average annual rainfall is less than 1000 mm. Annual rainfall tends to increase from north to south. In the extreme south it could reach 1200 mm per annum. Dugje, Kamara and. Ajeigbe (2009) found out that majority of the farmers in Bunkure (study area) planted sorghum and millet between late May and mid – June and that the Sorghum cultivation was ranked highest in some part of the area. Villages like Zangon- Buhari and Kalalawa have the highest record compared with other crops.

3.2.3. Topography

The Kano plain consists of the following morphologica1 units: an upland plain, two river terraces and wide channel beds, all sloping at angles less than 2 degrees. Others are inter-unit scarps sloping at angles steeper than 60 degrees and isolated residual hills ranging in height from 10m to 50m above the plains (Olofin, 2013). Consequently, the Netherlands Development

Company (NEDECO, 1974) has recognized the following landform units in the area: a storm channel (also called "floodplain") which is flanked by a low terrace which rises steeply from the channel, a high terrace separated from the low terrace by a steep wall, and an upland plain, also separated from the high terrace by a steep wall. Thus from the upland plain to the river channel, there are three steep units. 3 to 4 meters high and up to 60^{o} steep which encourage rapid runoff, in spite of the gentle slopes (1^{o} to 2^{o}) on the terraces.

3.2.4 Geology

Rocks of the basement complex underline over 70% of the Kano environment. The rock types in the area are older granites, met a sediments and older basement. The older basement is composed of migmatite, biotite gnciss, and blanded gneiss. Migmalite is composite gneiss produced by injection of granite magma in to schist host. Gneiss is metamorphosed granite and is granitic in composition while a biotite gneiss is a foliated crystalline rock with high biotite content. Banded gneiss has light and dark bands with a light fraction of quartz while the dark fraction or band consists of biotite, plagioclase and quartz minerals (Ahmed, 2006) composed of migmatite, biotite gnciss, and blanded gneiss. Migmalite is composite gneiss produced by injection of granite magma in to schist host. Gneiss is metamorphosed granite and is granitic in composition while a biotite gneiss is a foliated crystalline rock with high biotite content. Banded gneiss has light and dark bands with a light fraction of quartz while the dark fraction or band consists of biotite, plagioclase and quartz minerals (Ahmed, 2006).

The ancient metasedimentary rocks result from the weak metamorphism of sedimentary rock. Rock types include Phyllite which is derived from metamorphism of clayey sediments. It is intermediate in metamorphism between slate and schist. Quartzite metasediments results from cementation or fussion of quartz grains of sandstone. The geology of Bunkure has been dominated with carse porhyntiuc biotite and Biotite hornblende Granite which is under the Pan African Older Granite series within the Pericambrian to Cambrian Basement Complex (NGSA, 2006) (Figure 3.3).

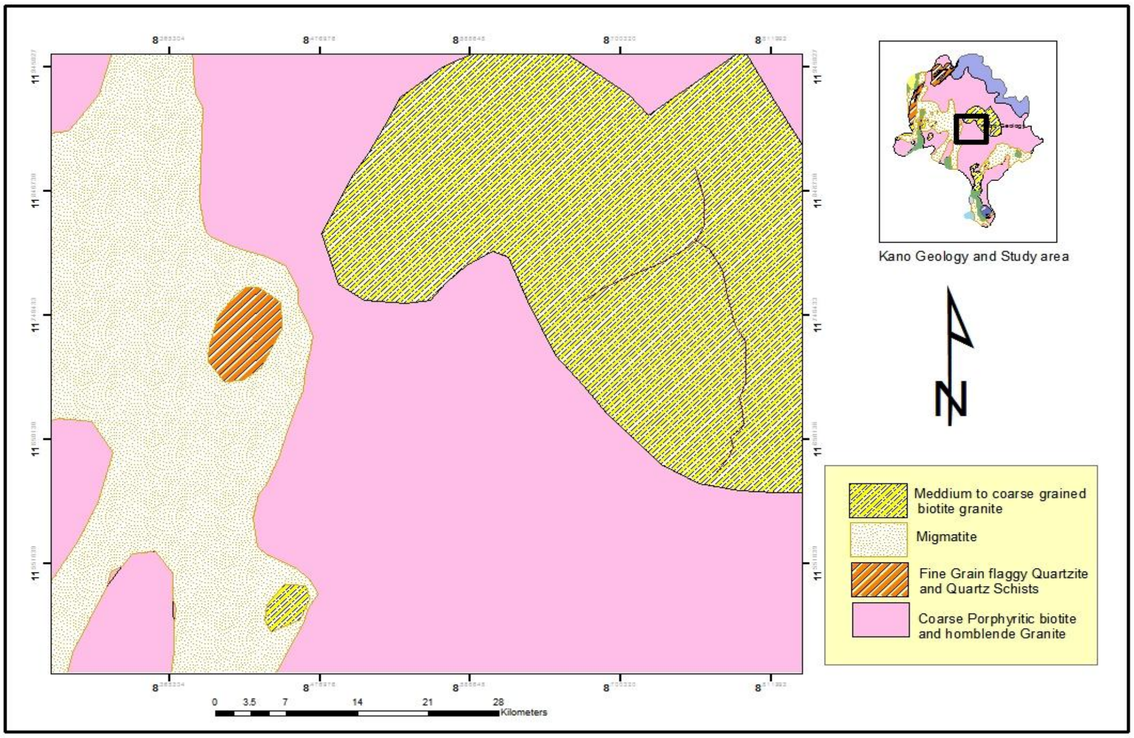

Figure 3.3: Geology of Bunkure

Source: Adopted from Nigerian Geological Survey Agency (2006)

3.2.5 Soil

Latosols are the dominant soils in the wind drift of Kano state. They are well-drained and brownish to reddish in colour. They are also deep except where iron pans are exposed or occur near the surface (Olofin, 1985). Hydromorphic soils tend to occur throughout the state where annual flooding occurs (*fadama*). These hydromorphic soils are darkgreyish in colour and have a high content of clay. On poorly drained sites one finds hydromorphic soils. These are in concave slope segments; the mineral soils exhibit no profile development. They are vertisol soils, which show deep and wide cracks in the dry season due to high content of clay (more than 30%) (Ahmed, 2006).

The agricultural potential of soils in the Kano Region is rated as low to marginal. The exceptions to this are the hydromorphic soils found in valley bottoms and flood plains of rivers (*fadama*) in the Region. The poor nutrient status of soils in the Region is largely responsible for this low agricultural potential. Efforts at raising the agricultural potential of the soils must aim at increasing their fertility levels. This could be achieved by the application of fertilizers (both organic and inorganic in a complementary manner) and soil management practices aimed at soil conservation (Esseit 2013)

The soil has appreciable reserves of weatherable minerals with moderately low CEC. Clay is mainly kaolinite but small amounts of illite may be present. Free iron oxides may form mottles and concretions. Differences from the dominant characteristics are attributed to other soil farming factors. For example, in the dry areas where there is appreciable amount of sand drift, there is developed what is known as the brown and reddish brown soils of semi arid areas.

However, because of the nature the soil in the area Kano was once a renowned groundnut producer. Millet, sorghum and cowpeas have also been grown for a long time. Crop-livestock integration has been practiced in forms that have been adapted to local conditions. Sunflower, soya beans and guinea corn are also produced while wheat production has been supported by irrigation. However, dependence on manual harvesting has led to much wastage and inefficiency. Further agricultural development will have to explore opportunities for mechanization. Already, large-scale production of tomato has induced the initiative to set up a processing factory with a capacity of 250 tons per day at Kadawa (MARDITECH, 2011). The soil of Bunkure according to

NEDECO (1974) as Hydromorphic soils with very pale brown sandy loam common fine Fe mottle, moist, friable consistence. While the profile were described as light gray sandy loam to sandy clay loam common medium Fe mottle, moist and firm consistence

3.2.6 Vegetation

The climatically defined vegetation types in Kano region are the northern Guinea savanna and Sudan savanna. Northern Guinea Savanna is an open woodland or bush land with grasses shorter than in the southern guinea where grasses are 1.5 to 3m tall. The Sudan Savanna has scattered trees in open grassland with grasses under 1.2 m tall (Ahmed, 2006). The vegetation has been largely cleared for cultivation to form cultivated parkland. Parkland has scattered protected trees at some distance apart in open cultivated land. Small trees and shrubs are more common on fallow land where regeneration may take place. About 75% of the land is cultivated parkland with average tree densities of less than 25 per hectare(Ahmed, 2006).

Within the two broad types of vegetation identified, there are pockets of other structural types. Thicket vegetation is found along large river channels and floodplains and it is described as impenetrable shrubby vegetation. Surviving savanna woodland is found as forest/game reserve such as the falgore reserve (370km^2). Here the trees and limited number of shrubs form a light canopy. Where the woodland reserve is degraded due to uncontrolled exploitation it changes into scrub vegetation or bush which is made of shrubs and herb and it is not closed. Gazetted grazing reserves may be grassland where trees and shrubs do not exist. The grazing reserve is degraded, through uncontrolled exploitation, when woody vegetation encroaches (Badamasi, 2014).

3.2.7 Population

The result of the 1991 census put the population of Kano at 5,725,116 and the results of the 2006 census further substantiated the earlier results whose tradition is to put Kano on top. The recent (2006) census results put the population of Kano state at 9,383,682. The population of Bunkure LGA shows that in 1991 with 122,856 (NPC, 1991) while in 2006 rose to 170,891 with the population density of 241.76 in 1991 and 336.28 in 2006 (NPC, 2006).

Subsistence and commercial agriculture is mostly practiced in the outlying districts of the state. Dugje, Kamara and. Ajeigbe (2009) found out that majority of the farmers in Bunkure planted millet, cowpeas, sorghum, maize and rice for local consumption while groundnuts and cotton are produced for export and industrial purposes. The Sorghum cultivation was ranked highest in the area. Other crops cultivated according to Baffa (2012) includes Watermelon, Sugar cane, Garden egg, Rice, Onion, Tomato, and Hot pepper the cultivation of these crops keep the people of the area busy for both dry and rainy seasons thus, they generate more income than other crops.

3.3 METHODOLOGY

3.3.1 Reconnaissance survey

A preliminary survey was carried out in the area. The purpose of the survey was for the researcher to be acquainted with the environment, and to help in the soil unit's identification using the soil characteristics map (base map).

3.3.2 Types of data

Data obtained include:

i. Soil Textural map

ii. Soil laboratory result

iii. Spot-5 of 2012 satellite image with 5 meter spatial resolution

iv. Digital elevation model (DEM) data from Shuttle Radar Topographic Mission (SRTM)

3.3.3 Sources of data

Both Primary and Secondary sources of data were used for this study. Soil samples were taken from the depth of 0 – 30 cm using a grid of 1500 m x 1500 (Figure 3.4). In order to facilitate the field work and to ensure the accuracy of the examination/sampling points, the points were uploaded on Global Positioning Systems (GPS) Garmin 76csx model and the soil examined and sampled according to MARDITECH (2011) Wollenhaupt *et al*., (1994); Rehm *et al*., (2001) and Umar (2011).

3.3.4 Detailed field work

3.3.4.1 Field survey and data collection

A grid cells were prepared on the base map for sampling. Fifty one (51) soil samples were identified to the distance of 1500 x 1500 meters and were collected in the field (Figure 3.4) using the USDA Soil Survey Manual (Soil Survey Staff, 1981). At each soil site, a GPS (Global Position Systems, Garmin 76csx model) reading was used in taking the coordinates. The field equipments and tools that were used in collecting the soil samples includes the soil auger, digital camera, Munsell color chart (USDA, 2009), 30 meters measuring tape and pH and EC kits.

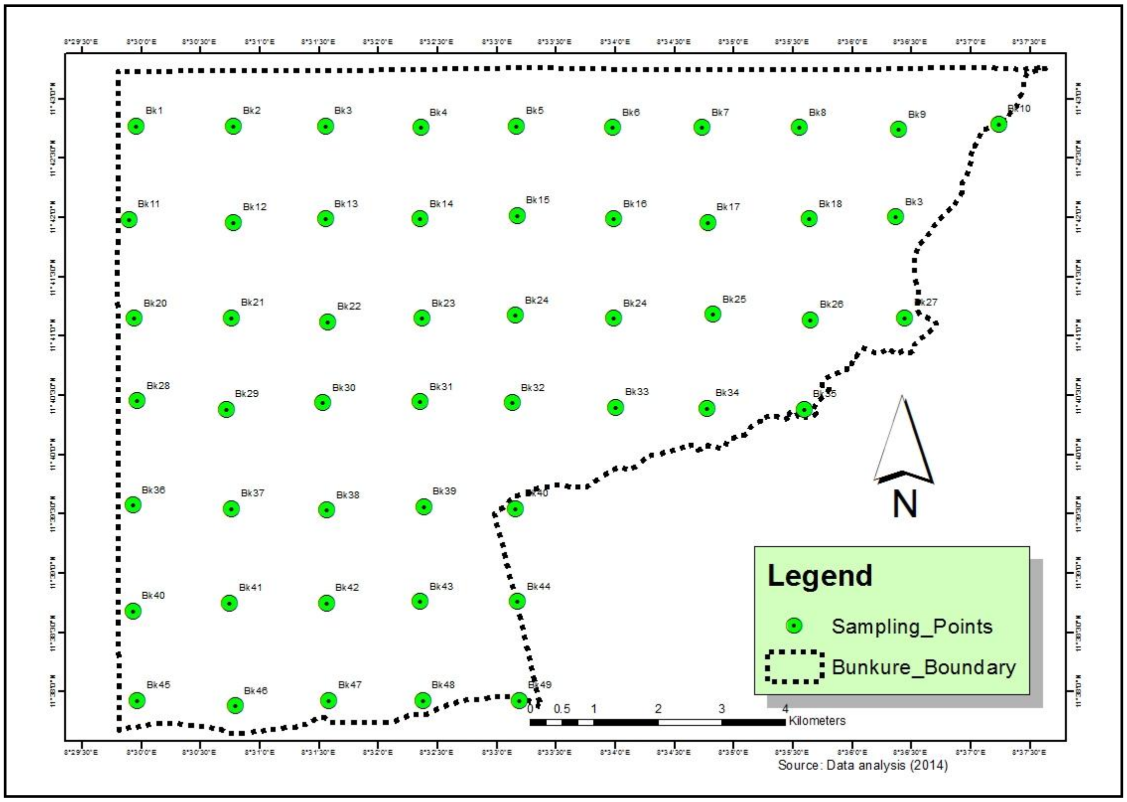

Figure 3.4: Sampling Points
Sources: Author's analysis (2014

Shuttle Radar Topographic Mission (SRTM) with the resolution of 90 meters were sourced (downloaded) from www.ftp//glcf/landsat. This was used in the creation and extraction of the Digital Elevation Model (DEM) (Figure 3.5) which were used for developing the slope map of the area.

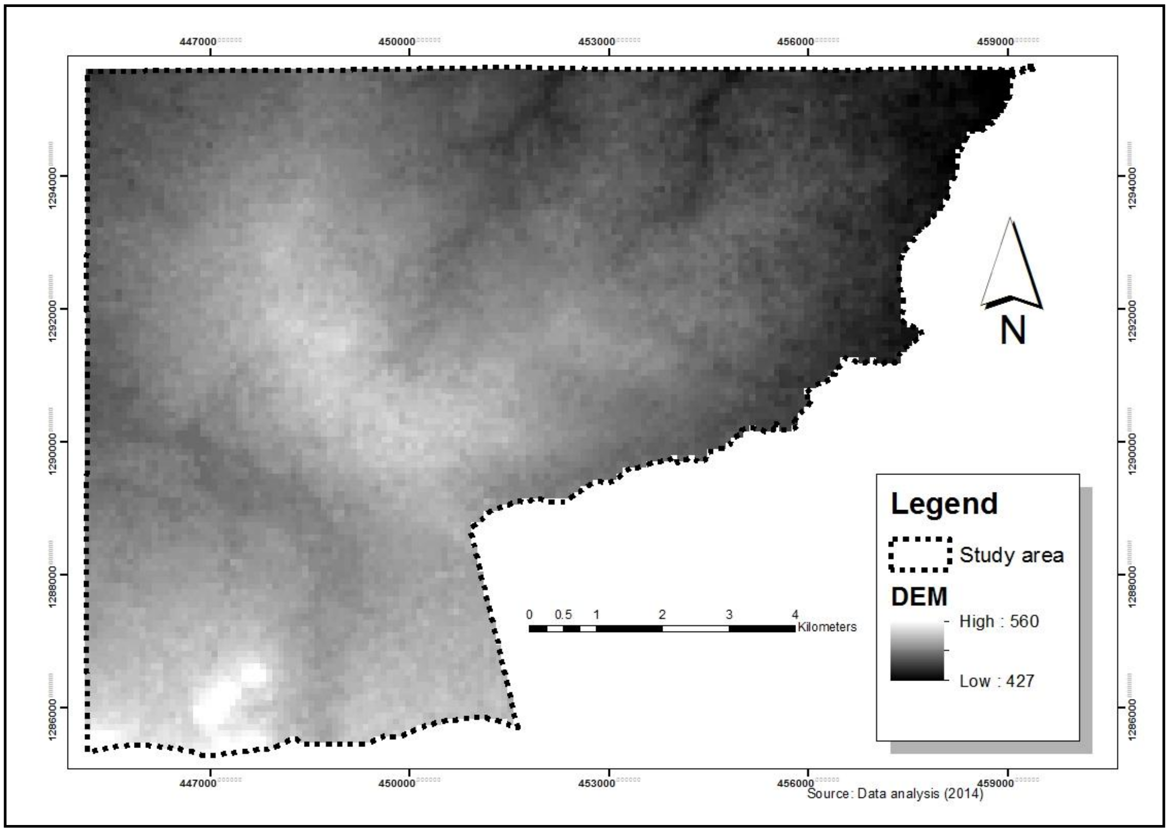

Figure 3.5: Digital Elevation Model (DEM) of the study area

Sources: Author's analysis (2014

The soil texture map of the area with the scale of 1:25,000 published in 1976 produced by Netherlands Development Company (NEDECO) was sourced from the Kano State Ministry of Agriculture. This was used in the extraction of the soil boundaries, soil drainage and soil units in the area.

Spot-5 satellite imagery with a 5 meter resolution for 2012 was sourced from the Archive of the National Remote Sensing Center (NRSC), Kano. This was already rectified and corrected and was used for land unit identification and landuse classification of the area. Also, data and related information for the suitability of the selected crops were sourced from literatures.

3.4 DATA ANALYSIS

The data analyses were divided into two parts: these are the laboratory and GIS based analysis.

3.4.1 Laboratory Analysis

The samples were taken to the Standard laboratory (Department of Geography Bayero University Kano) air dried and gently crushed with porcelain pestle and mortar; and then passed through a 2mm sieve to remove coarse fragments. The fine earth samples (<2mm soil portion) collected were analysed. Particle size distribution was determined using hydrometer method (Gee and Bauder, 1986). Sand, silt and clay was determined by dispersing the soil samples in 5% calgon (sodium hexametaphosphate) solution. The dispersed samples were shaken on a reciprocating shaker after which particle size distribution was determined with the aid of Bouyoucous hydrometer at progressive time intervals. The textural classes were determined with the aid of USDA textural triangle.

The soil pH was determined both in water and 0.01M $CaCl_2$ solution, using a soil to solution ratio of 1:2.5 (IITA, 1979). On equilibration, pH was reading with a glass electrode on a Pye- Unicam model 290mk pH meter. Delta pH (dpH) values were determined. The Walkley – Black (1934) wet digestion method were used to determine the organic carbon content of the soil samples. Total nitrogen was determined using the macro – kjedhal method. Soil available phosphorus was determined using the Bray I method calorimetrically. Electrical Conductivity of the saturated paste extract of 1:2.5 soils to water ration were determine using a rheostat, Wheat-stone bridge model at 25^0C (Bower and Wilcox, 1965).

Exchangeable Ca, mg, Na and K were extracted with 1m ammonium acetate (1M NH_4OAc) solution buffered at pH 7.0 as described by Anderson and Ingram (1998). Potassium and Salinity in the extract were read on a GallenKamp flame Analyzer. The extracts were diluted two times with the addition of 2ml of 6.5% lanthanuv cm chloride solution to prevent ionic interference before Ca and Mg was read. The Ca and Mg were read on a pye unicam model SP 192 atomic absorption spectrophotometer (AAS) at 423 and 285nm wavelength respectively. The sum of Ca, Mg, Na, and K gave total exchangeable bases.

The soils were leached with 1m KCl solution. Exchange acidity (Al+H) in the 1m KCl extract was determined by titration with 0.1m sodium hydroxide solution as described by Anderson and Ingram (1998). Cation Exchange Capacity (CEC) of the soil were determine with 1m NH_4OAc (1m ammonium acetate), buffered at pH 7.0 (Chapman 1965, Rhodes, 1982). The excess acetate was removed by repeated washing with alcohol. The absorbed ammonium ions were displace with 10% sodium chloride (pH 2.5) and determined by the Kjeldahl procedure (Soil Survey Staff, 1972).

3.4.2 Data processing and GIS analysis

This part focused on the analysis towards achieving the objectives.

3.4.2.1 Major landuse /land cover in the area

For the identification of the agricultural landuse, Spot-5 satellite images were digitized using “on-screen” in the Arc GIS 10.1 environment. Different land classes were identified in the area which includes agricultural land, built up areas, vegetation, water body and wetland. This analysis was performed according to Nuhu and Ahmed (2013).

3.4.2.2 Soil drainage, soil units and slope characteristics in the study area

The soil textural map were scanned and imported into Arc GIS10.1, then geo-referenced by using four (4) Ground Control Points (GCP) that were read from UTM. For registration process (image geo-referencing), some modifications were made during the geo-referencing for the selected control points in order to minimize the error during digitization. The map was projected to WGS 1984 using Minna datum, UTM zone 32. The soil drainage was extracted from the map using “on screen digitization” query and overlay from the scanned map were performed. The shape files of the soil drainage and soil units were converted to raster format 5 meters resolution; in this case the resolution of the satellite was adopted. The soil unit was also extracted from the map with the combination of the satellite image (Spot-5). The slope of the area were determined using Digital Elevation Model (DEM) which were extracted from Shuttle Rader Topographic Mission (SRTM) data. The slope was reclassified by converting the values (slope angles) into percentage and also adopting the satellite image resolution (5 meters).

3.4.2.3 Level of physical and chemical parameters in the study area

The soil physical and chemical properties were subjected to statistical analysis using simple correlation. Statistical Package for Social Sciences (SPSS) was used to analyse the levels and their relationship between the soil parameters. The analysis was conducted according to Gomez and Gomez (1984) who revealed the magnitudes and direction of relationship between soil parameters. Tables were used in presenting the result of the analysis in mean, minimum and maximum and standard deviation also, matrix were presented for the correlation presenting the significant levels.

3.4.2.4 Distribution of physical and chemical parameters in the study area

The laboratory results were entered into the Microsoft Excel with their respective coordinates (Latitude and Longitude) and transformed (imported) into GIS environment in order to analyse the spatial distribution of the selected parameters in the area. Different thematic maps (layers) were generated for each of the parameters using Inverse Distance Weighted (IDW) interpolation in the Arc GIS 10.1 software.

The IDW interprets spatial autocorrelation in a literal fashion. A surface created with IDW will not exceed the known value range or pass through any of the sample points. IDW is a good interpolator for phenomena whose distribution is strongly correlated with distance. One potential advantage of IDW is that it gives you explicit control over the influence of distance, an advantage over Spline or Kriging methods (Mustafa *et al,* 2011). Each parameter were reclassified and converted into raster format.

3.4.2.5 Suitable areas for the cultivation of Sorghum.

The Multi-Criteria Evaluation (MCE) technique was performed using Fuzzy model by Saaty, (1980). All layers/themes produced in objective i, ii and iii were transformed into raster format (see figure 3.10.2.1). Weighting of all the criteria were performed by ranking the relative importance of criteria (Table 3.1), subcriteria and suitability classes, the procedure involved many steps:

Table 3.1: Explanation of the intensity Scale

Scale	Degree of Preference
1	Equal importance
3	Moderate importance of one factor over another
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values

Sources: Saaty and Vargas (1991).

The first step is using Weighted Linear Combination (WLC) which is the most common technique used to create suitability map. Weight is used to develop a set of relative weights for a group of factors in a Multicriteria Evaluation (MCE). The weights are developed by providing a series of Pair-wise comparisons of the relative importance of factors to the suitability of pixels for the activity being evaluated.

The second stage is the generation of a hierarchy structures according to Malczewski (1999) the relationship between the objectives and their attributes has a hierarchy structure. The pair-wise comparison matrix PWCM is a rating of the relative importance of the two factors regarding the suitability of the cropland. For determining the relative importance/weight of criteria, sub criteria and suitability classes, the PWCM was applied using a scale with values from 9 to 1/9 introduced by Saaty, (1980). A rating of 9 indicates that in relation to the column factor, the row factor is more important. On the other hand, a rating of 1/9 indicates that relative to the column factor, the row factor is less important. In cases where the column and row factors are equally important, they have a rating value of 1 (Saaty, 1980).

The rating of the suitability classes of sub criteria were used in land suitability analysis, a map represents each evaluation criteria with ordinal values (S1, S2, S3 and N1) indicating the degree of suitability with respect to a sub criterion, based on sorghum requirement (see Table 3.2) (Sehgal, 1999). These classes have to be rated, how important is the class S1 with respect to a particular sub criterion to contribute for the final goal. This process is called the standardization which yields the normalized score for each suitability class (Table 3.1).

Table 3.2: Soil-site suitability criteria for sorghum

Land Use requirement	Highly suitable	Moderately suitable	Marginally suitable	Not Suitable
Soil Nutrient	(S1)	(S2)	(S3)	(N)
pH	6.0-8.0	5.5-5.9 & 8.1-8.5	< 5.5 & 8.6-9.0	< 9.0
N (%)	> 1.0	0.50-1.0	0.1-0.5	< 0.1
P (ppm)	> 8.0	5-7	4-5	< 4.0
K (cmol/kg)	> 0.40	0.20-0.40	0.15-0.20	< 0.15
Ca (ppm)	> 10.0	8.0-10.0	4.0-8.0	< 4.0
Mg (ppm)	> 4.0	2-4	0.5-2.0	< 0.50
Na (ppm)	0.01-0.03	0.03-0.05	0.05-0.10	> 0.10
OC (%)	0.50-0.75	0.50-0.20	< 0.20	-
OM (%)	> 5	5-3	3-1	< 1
CEC(cmol/kg)	30-20	20-10	< 10	-
Soil Texture	c. cl, sicl, sc	1 ,sil, sic, scl	sl, ls	S
Land Quality				
Slope (%)	0-4	3-8	8-16	> 16
Soil condition	Deep soil	Deep soil	Moderately deep	Shallow soil
Soil drainage	Well drained	Well Drained	Moderately drained	Poorly drained
Soil toxicity				
EC(ds/m)	2-4	4-8	8-10	> 10

Note: clay-c, clay loam-cl, silt clay loam-sicl, silt clay-sc, loam-l, silt loam-sl, silt clay-sic, silt loam-sl, Loam sand-ls, sand-s.

Source: FAO (1979), Metson (1961), USDA (1993), Bungham, (1962), MAFF (1967) and Van Diepen, Van Keulen, Wolf and Berkhout, (1991).

Other criterion used in this study includes land uses and other physical parameters i.e soil unit, soil drainage etc. It should be noted that for preventing bias through criteria weighting the Consistency Ratio were used. As a rule of thumb, a CR value of 10% (0.1) or less is considered as acceptable according to Mustafa *et al,* (2011)

$CI = (\lambda - n) / (n - 1)$ .... (1)

$CR = CI / RI$ ....(2)

Where: λ: The average of consistency vector

CI: Consistency Index

CR: Consistency Ratio

RI: Random Index

n: The numbers of criteria or sub-criteria in each pairwise comparison matrix (appendix II). The final suitability classes were analysed using Weighted Sum Overlay in the Arc GIS environment by combining all raster layers produced using Model builder (figure 3.6) to produce the final suitability map.

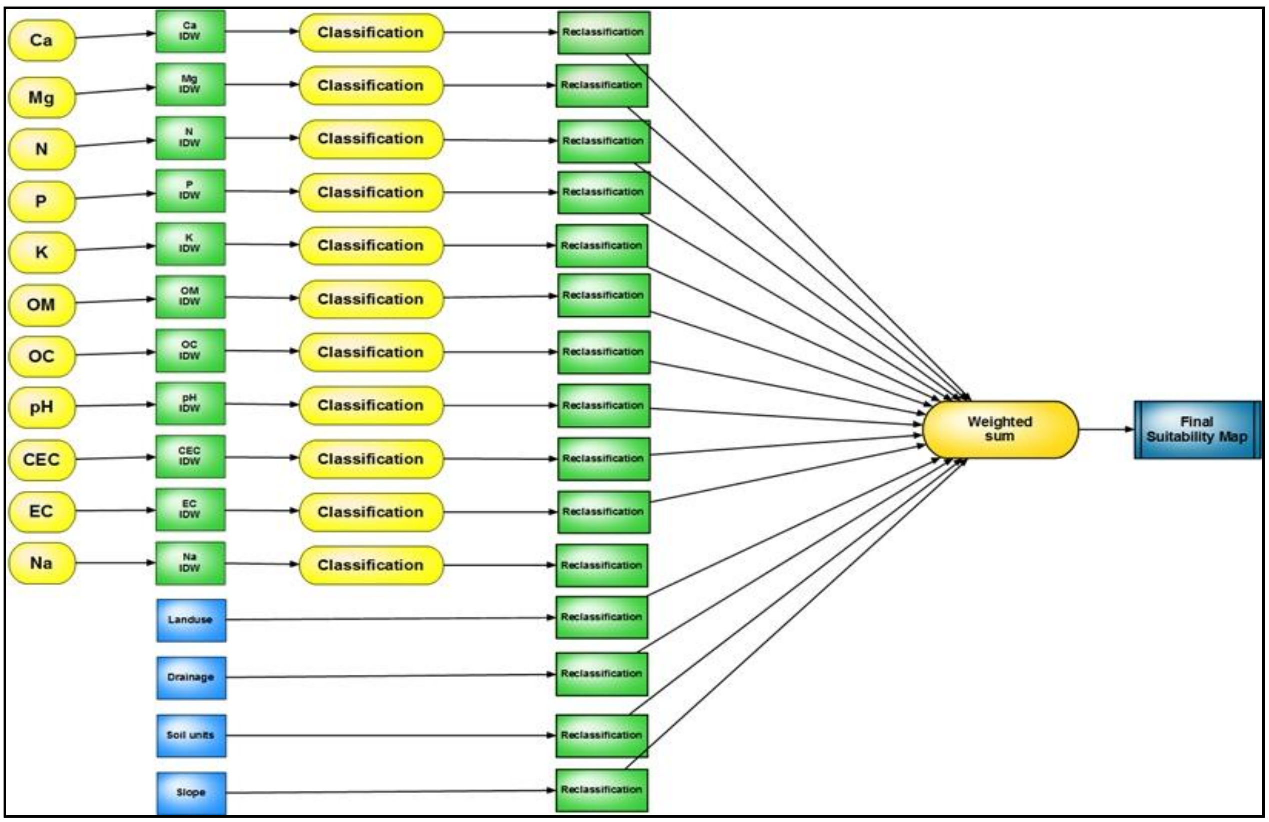

Figure 3.6: Model Builder
Source: Author’s analysis (2014)

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter has been divided into four (4) sub headings which include the landuse and land cover, soil drainage, soil unit and slope characteristics with their explanations.

4.2 LANDUSE AND LAND COVER CLASSES IN BUNKURE

In delineating the boundaries of suitable land for crop cultivation, land use characteristics should be included as part of the factors that could be used. On the other hand land classification is an important factor for land suitability mapping.

The result of the analysis for landuse and land cover shows that eight classes were identified (Figure 4.1) these include: Badland which occupies 9.70% (961.80 ha) of the total land of 9911.22 ha, most of this area are affected by erosion. The vegetation covering 133, 25 ha (1.34%) which are mostly cultural trees situated at the western part of the town (Bunkure). Bare soil covering 4.35% (431.58 ha) of land in the area, and this area are generally covered with lateritic materials and animal track known as *Burtali*. The cultivated land occupying 76.40% (7571.96 ha) of land this are farmlands (rain fed and irrigated) and it was the dominant landuse in the area which shows an indication that the dominant activity in the area is farming.

The rock outcrop occupying 0.73% (71.96 ha) of the area which area scattered but is more to the southern part of the area, while Wetland with 3.77% (332.34 ha) of land this are mostly swampy or marshy areas. The built-up areas with 3.77% (373.67 ha) of the land this includes the major town of Bunkure and other surrounding villages while the water body with 0.35% (34.66 ha) which is the least among the classes of the classified landuse in the area (Table 4.1).

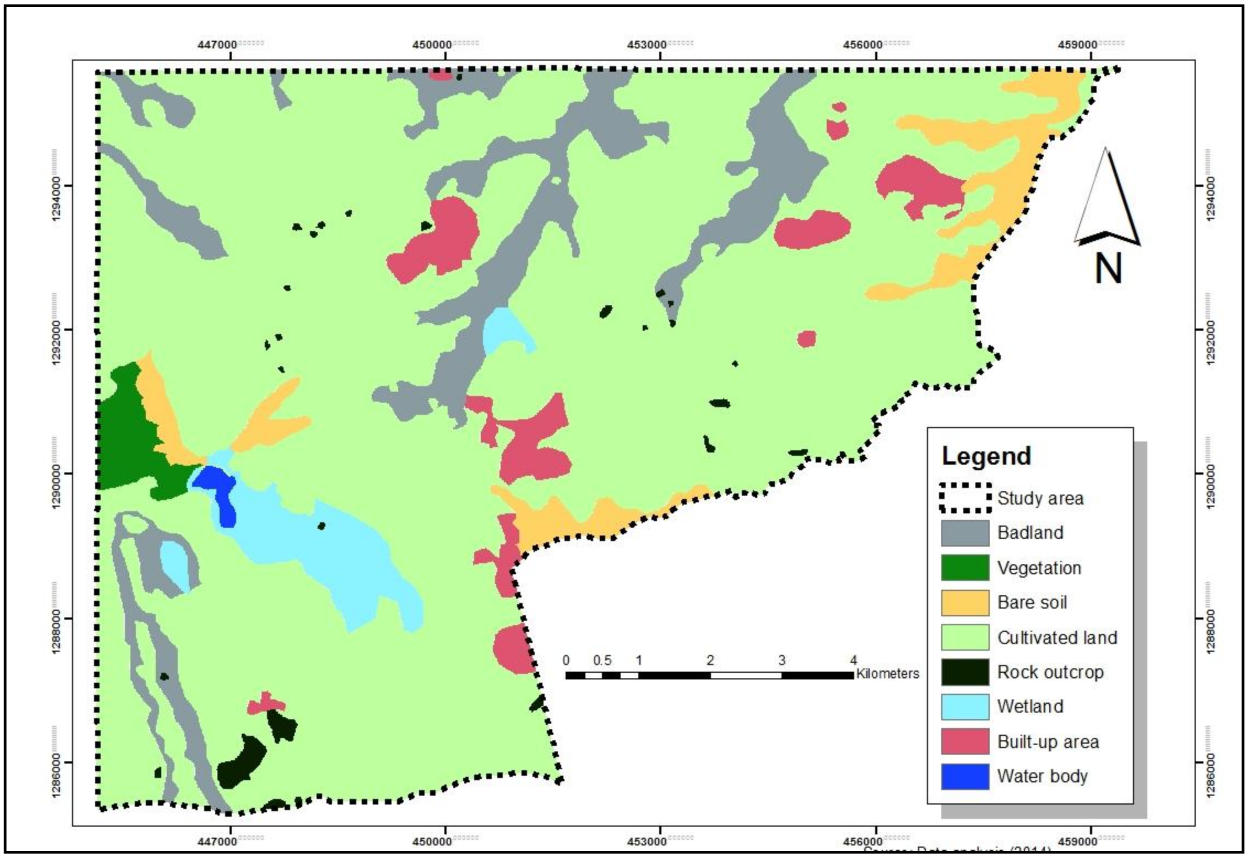

Figure 4.1: Landuse classification in Bunkure
Source: Author's analysis (2014)

Table 4.1: Landuse classification

Landuses	Area (ha)	%
Badland	961.80	9.70
Vegetation	133.25	1.34
Bare soil	431.58	4.35
Cultivated Land	7571.96	76.40
Rock outcrop	71.96	0.73
Wetland	332.34	3.35
Built-up-area	373.67	3.77
Water_Body	34.66	0.35
Total	**9911.22**	**100**

Source: Author's analysis (2014)

4.3 SOIL DRAINAGE, SOIL UNITS AND SLOPE CHARACTERISTICS

The soil drainage map was characterized into three (3) categories these include: well drained, moderately drained and poorly drained. The soil of the area is dominated by well drained soil with about 85.31% of the land. Normally, the well drained soil according to Corbett and Tatler (1970) is having a coarse texture soil with small available water capacity and only saturated during and just after heavy rain. Surplus of water is removed very rapidly. While moderately drained with 11.22% of land in the area. The upper 90 cm saturation for short period after heavy rainfall but no horizon within 50cm remained saturated for more than one month in the year Tatler (1970), and the poorly drained with 3.46% of the land in the area, in this case the soil has been characterized by the saturation to be at least half a year in the upper 50 cm but in the upper 25 cm is unsaturated during most of the year growing season and also the horizon is dominated by peaty surface.

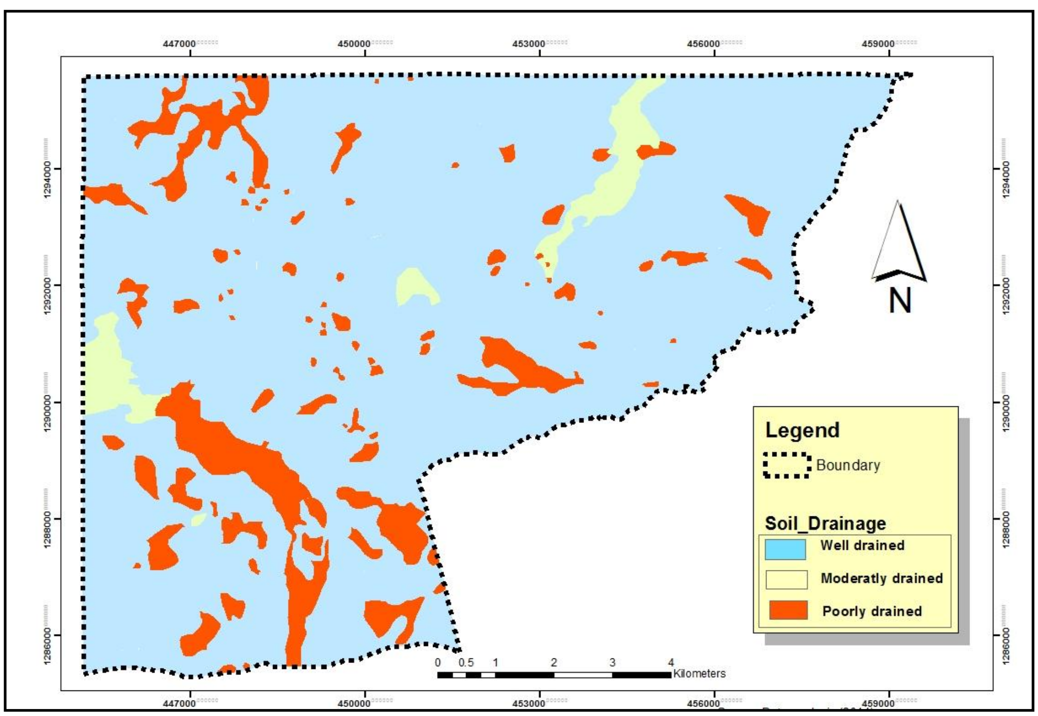

Figure 4.2: Soil Drainage
Source: Author’s analysis (2014)

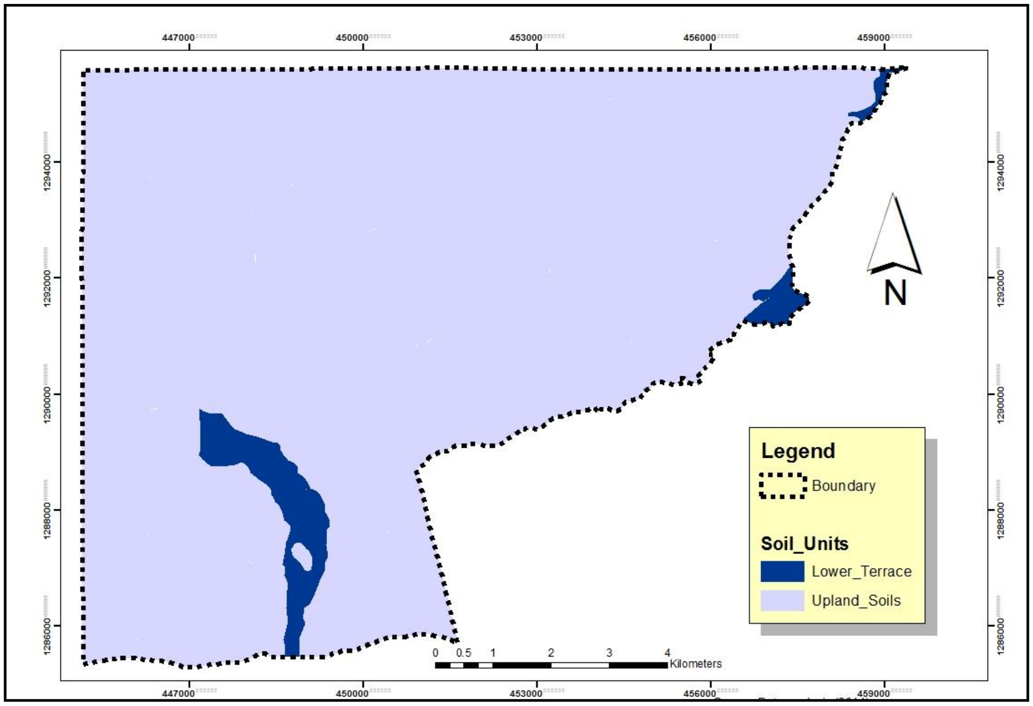

Figure 4.3: Soil Units
Source: Author's analysis (2014)

The soil unit in the area were categorized into two (2) these are upper and lower terrace. The upper terrace is mostly areas with relatively flat terrain where rain fed were practice and is within the range of 450 to 500 meters above mean sea level, this area covering about 90% of the land. While the lower terrace is areas below 400 where mostly irrigation activities were carried out during dry season and these areas are subjected to poorly drain in nature.

The extraction of slope map was performed using Digital Elevation Model (DEM). The slope was classified into different classes ranging from flat to undulating terrain. The classification shown that the area is relatively flat because the dominant surface is from 0 – 3 followed by 5 – 8, 8 – 10 and greater than 10%. The southern part of Figure 4.4 is an indication of hilly areas which is not suitable for cultivation, Steven (1998) emphasized on some factors that affect cultivation due to erosion, these include climate, soil erodibility, surface roughness, field length, slope length and steepness, cropping practices, and conservation practices.

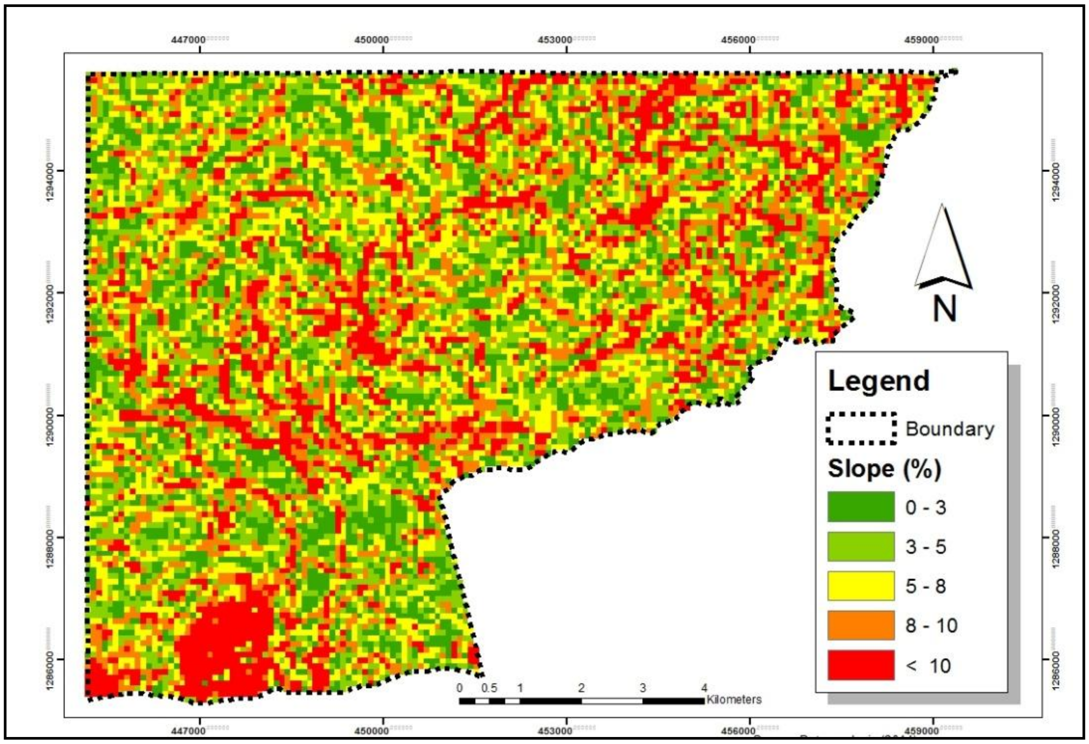

Figure 4.4: Slope (%)
Source: Author's analysis (2014)

4.4 LEVELS OF THE PHYSICAL AND CHEMICAL PROPERTIES

Table 4.1 showing sand fraction generally dominated the soils, with Sandy Loam as the general textural class. The findings of Malgwi *et al.* (2000) and Voncir *et al*. (2008) shows that sorting of soil materials by biological activities, clay eluviation or surface erosion or combination of these pedological processes are the result of the dominance of sand in the Northern Nigerian soils. Also, lower clay content of the surface soil is a characteristic that has been observed for most soils on Basement complex in Nigeria (Esu, 1987). Clay eluviation from the soil surface is common along the area due to negative and significant correlation coefficient -0.892** (Appendix 3) observed between clay and sand content.

While, Ca dominated the exchange complexes of the soils. It has been reported that Ca usually dominates the exchange sites of most soils with Mg, K, NH_3 and Na having lower concentrations (Enloe *et al*., 2006). This study shows a negative correlation which indicated that there is an inverse relationship with a correlation coefficient of r = -0.32 observed between calcium content and CEC (Appendix 3). The correlation between OC with clay is showing r = -0.154 (Appendix 3) which is an indication of a sharp decrease in organic carbon may be attributed to immobilization of organic matter by clay in the horizons in forms of organo-clay-complexes (Mortland, 1970).

Magnesium has a positive relationship with calcium (0.21) which is insignificant. Potassium and sand particles also are showing a positive correlation (insignificant) this is attributed to low content in the study area (see table 4.1 and Appendix 3). However, sodium having a significant correlation with calcium (0.360**) and magnesium (0.514**) which shows that the correlation is significant at 99%. Ca and Mg having values range between 1.02 – 9.21ppm and 0.04 – 1.23ppm (table 4.1) is an indication of low in Ca and moderate in Mg.

Electrical conductivity with values ranging from 0.02 to 51.4 (ds/m) (Table 4.1) showing a negative correlation with Ca, Mg, K, and Na (see appendix III), thus, on the bases of saturation extract values of 0 to 2 ds/m are safe for all crops; yield of very sensitive crops are affected between 2 to 4 dS/m; many crops are affected between 4 and 8dS/m; while only tolerance crops grow well above that level (Richards, 1954)

While the pH (soil reaction) is showing a positive correlation with Ca (r = 0.172) and magnesium with a positive and significant correlation of 95% (r = 0.286*). This result is indicating relationship between the two elements with the pH ranging between 2.9 – 9.96. Organic carbon showing a positive correlation with Mg, K, Na and pH but with Ca having 95%

of significant correlation (r = 0.302*). Organic matter and organic carbon are having a significant correlation (r = 1.000**) (appendix 3). This is an indication which shows that they all contributed the same in the soils of the area.

Nitrogen is showing a negative (inverse) correlation with sodium (Na) which is significant with (r = -0.483**). Table 4.2 showing low in N. The lower Nitrogen content of this element could be as the result of intensive irrigation in some of the places in the area and lower organic matter. Paz-Gonzalez et al. (2000) reported that fertilizer application did not change total N or inorganic content of soils under intensive irrigation. While, Jaiyeoba (2003) found that total nitrogen content of the topsoil was greater in 3-year cultivated soil compared to 20-year. Also, Kilic, Kilic and Kocyigit (2012) lamented that total N content of the cultivated fields decreased over the time in spite of fertilizer additions.

The result of Phosphorus indicated a positive correlation with most of the soil parameters in the study which is insignificant, this includes Mg, K, OC, OM, while with pH is showing a significant correlation of 95% (r = 0.306*) and P is values is between 0.05 – 3.58. Cations exchange capacity in the area is showing a significant correlation of 99% with EC (r = 0.448**) with a very strong correlation and this is also the same with N (r = 0.421**), where the EC is ranging between 0.02 – 51.40 ds/m, this automatically indicated a saline soils.

Table 4.2: Levels of the physical and chemical properties

	N Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic	Std. Deviation Statistic
Sand	51	56	79	72.27	6.25
Silt	51	7	22	12.71	3.86
Clay	51	11	26	14.87	3.27
Ca (ppm)	51	1.02	9.21	3.27	2.27
Mg (ppm)	51	0.04	1.23	0.66	0.34
K (cmol/kg)	51	0.01	1.01	0.2	0.25
Na (ppm)	51	0.01	0.23	0.09	0.06
EC (ds/m)	51	0.02	51.4	7.92	8.72
pH	51	2.9	9.96	6.03	1.5
OC (%)	51	0.01	0 .55	0.22	0.13
OM (%)	51	0.02	0.94	0.38	0.22
N (%)	51	0.02	0.96	0.31	0.32
P (ppm)	51	0	7.8	3.23	1.99

Source: Author's analysis (2014)

4.5 SPATIAL DISTRIBUTION OF PHYSICOCHEMICAL PARAMETERS

The distribution of the soil elements would help in the identification of their concentration. Inverse Distance Weighted (IDW) model were used for the analysis. The distribution of the parameters using different ranges values or ratings from lower values to the higher values shows that the distribution of pH (Figure 4.5b K) with value of 2.90 – 4.67 is extremely acidic (USDA, 1993) possibly toxic to some crop and is likely to have excess of some trace elements like Zn and Fe, from the analysis this occurred to a small portion of the study area especially the irrigated areas. While values that ranges from 4.67 – 6.43 which is extremely to slightly acidic dominated the area for about 65% and this is within the expectable values for most of the cereal crop. Values within 6.43 – 8.20 are slightly acidic, neutral and moderately alkaline have occurred to mostly areas that have high water retention capacity and poorly drained in the area and this is likely to have a decreasing availability of some trace elements. The pH of 8.20 – 9.66 are moderately to very strong alkaline soils though, is occupying a smaller portion in the area and in this case there is likely to Ca and Mg unavailable and may be toxic to most crops as stated by Truog (1948).

The Phosphorus (P) in figure 4.4I shows that the values are within 0.05 – 2.71, 2.71 – 3.10 and 3.10 – 3.58 in the area which indicated a low value and this is mostly needed for cereal crops (Cook, 1979). The range of 7.75 is moderate which occupied part of the northern and southern tips in the study area and is good for cultivation of Tomato and Cotton. While, Organic Carbon (OC) in the area were classified according to Metson (1961) as value less than 2 in OC is said to be very low and this is an indication of the whole area to having a very low organic carbon.

The analysis of the expendable sodium (Na) in figure 4.5b J shows that the whole values ranging from 0.01 to 0.23 is within the very low threshold as it's indicated by Richards (1954) which shows that values between 2 – 3 may be more suitable criterion for distinguishing sodic soils, therefore the whole area under study is dominated with very low Na, this element may be utilized by some plant as a partial substitute for Potassium (K) (MAFF, 1967).

Figure 4.4a C showing the distribution of Nitrogen (N) with value ranging from 0.02% – 0.22% low to very low according to Metson (1961). The value between 0.22 – 0.50% is within the medium range, while the value of 0.96% is very high for N, the result of the analysis indicated that the area is concentrated in the medium range. The higher value in the area is likely as the result of soil management (the use of animal dung).

Magnesium (Mg) is one of the exchangeable bases that are needed in the soil for plant development. The analysis shows that values ranging from 0.04 – 0.34 in figure 4.4F is within the low values stated by MAFF (1967) while the range of 0.34 – 0.5 is within the medium and greater than 0.5 is high. Therefore, the dominant range is within 0.63 – 0.93 this is an indication that the area is suitable for most of the cereal crops.

The availability of calcium (Ca) varies from soil to soil, however Ca deficiency as a plant nutrient occurring in soil of low pH values of 5.5 or less (London, 1988). From the analysis in figure 4.4A shows that value ranges between 1.05 – 9.12 ppm which is an indication that the distribution of Ca is very low in the area and Ca deficiencies are reported for some leguminous crop at value < 120 ppm (Meredith, 1965) and cotton is known to have a high Ca requirement.

The CEC measurements are commonly made as part of the overall assessment of the potential fertility of a soil (London1991) the analysis indicated the range of values from 2.09 to 7.75 meq/100g from low to medium with an the mean value of 7.25 there is concentration of this elements at the middle of the study area (figure 4.4B). The FAO (1979a) CEC value in the top 30 cm of soil for satisfactory favourable lower value than those should be highlighted in land suitability classification. Any CEC of < 4 meq/100g soil indicate a degree of infertility normally unsuitable for agriculture although rice is tolerance of slightly lower value.

The classification of EC in the area was classified by FAO-Unesco (1973) and Schofied (1942) which stated that the critical value for saline soils should be within 0 – 2 salinity are negligible excepted for most sensitive plant. The result indicated that the range is within 0.05 to 50.92 with the mean value of 7.93. Values from 4.63 – 8.22 are slightly saline, yield of many crops restricted while 8 – 15 moderately saline only tolerant crops yield satisfactorily and greater than 15 is strongly saline. In this case tolerant crop yield satisfactorily. The result of the distribution indicates that the whole area is affected with salinity with the concentration at the western part of the area (figure 4.4D).

The result of Potassium (K) in figure 4.4E the area ranging from 0.01 – 1.00 (cmol/kg) with the mean value of 0.20 which has been stated by Young and Brown (1962), Thomas (1966), Metson (1961) and MAFF (1967) to be medium and it concentrated at the central part of the study area.

Organic Matter (OM) is within the range of 0.02% - 1.6% with a mean value of 0.38% (figure 4.5G) from very low to low, however the distribution of OM in the area is mostly within the low even though, some areas may have a very low values also some crops may adopt to little OM. Most soil fertility experts that higher amounts of soil organic matter are related to increased productivity because of its contribution to water holding capacity, improved soil structure, and supply of nutrients (Steven, 1998). And London, (1991) reported that the Organic Matter (OM) of the soils can be classified into different categories, these are: low for soil with organic matter less than 1.5%, medium for soil with OM between 3.1% - 4.5%, high for soils with OM greater than 4.5%. The very high category is used peats and mucks with OM greater than 19%.

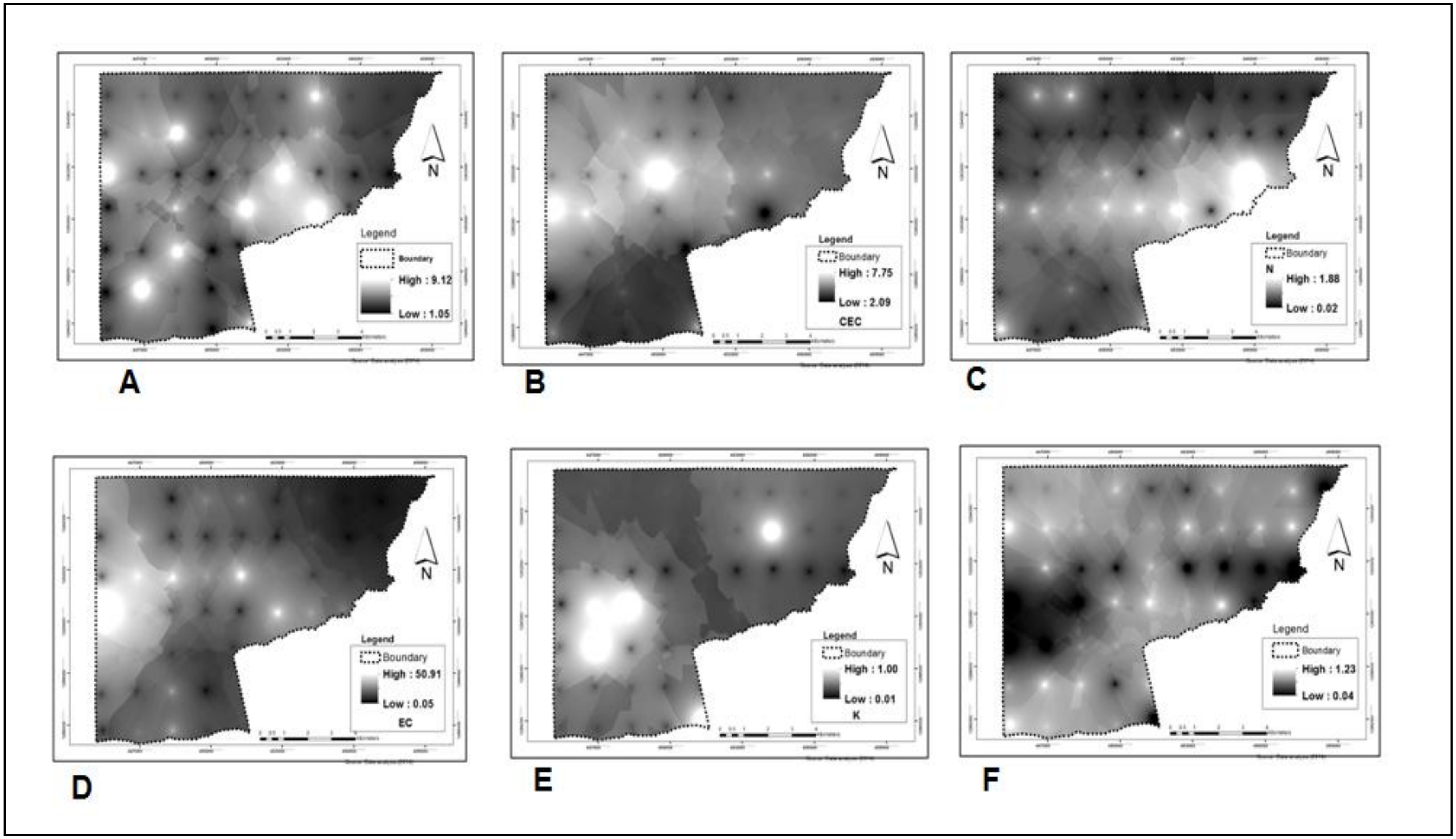

Figure 4.5a: Spatial Distribution of Soil Physical and Chemical Parameters
Sources: Author's analysis (2014)

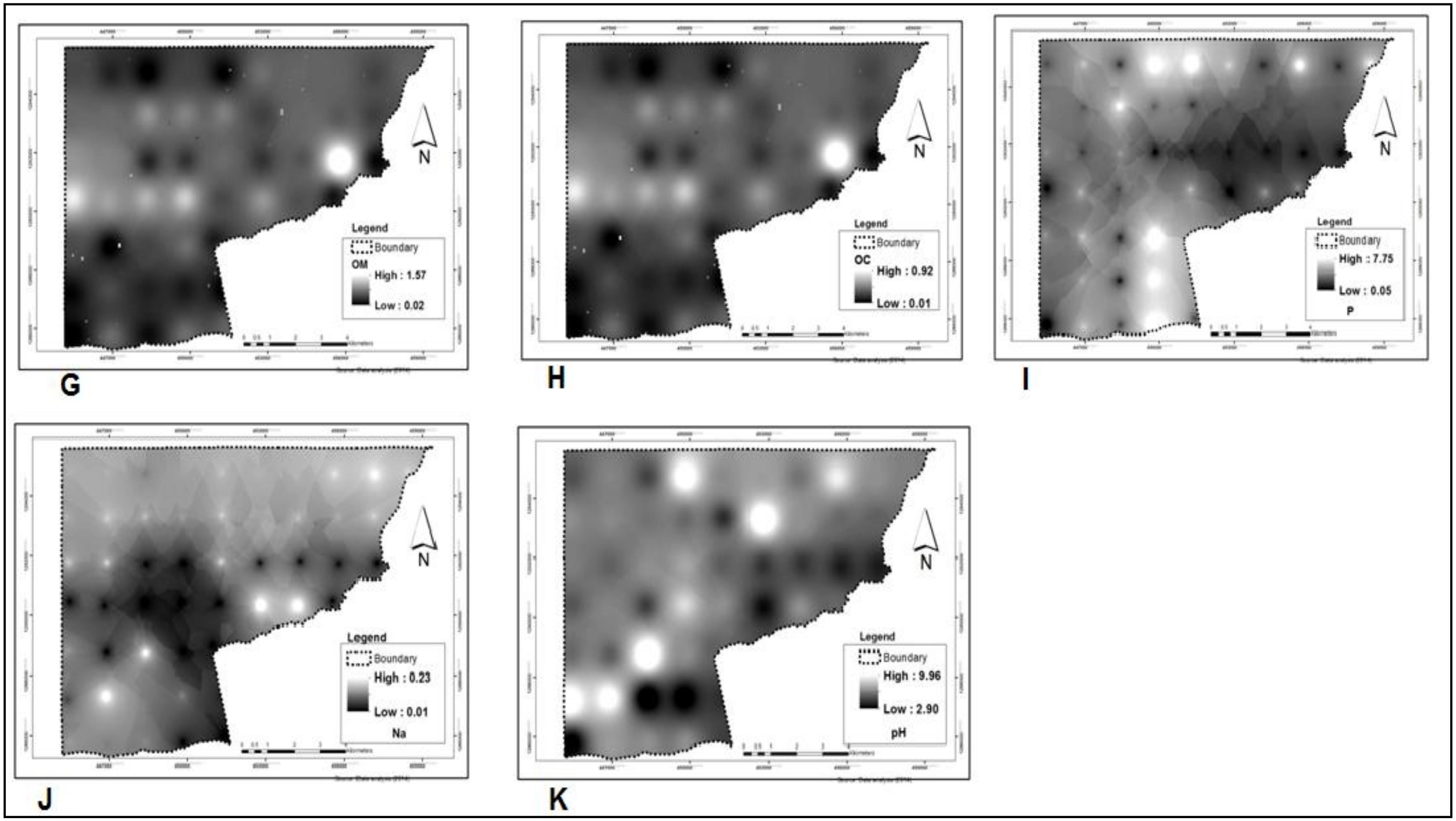

Figure 4.5b: Spatial Distribution of Soil Physical and Chemical Parameters

Sources: Author's analysis (2014

4.6 SUITABILITY CRITERIA FOR SORGHUM

The weighted factor was estimated by pair wise comparison matrix (Saaty 1980) based on land characteristics. After structuring the problem as a hierarchy using the Eigenvector. The criteria weight for physicochemical parameters were performed together with the other factors like the slope and land uses.

Geo-processing model were used to execute the sequence of command to generate physical suitability maps which were developed in the Fuzzy and AHP model for all the parameters or factors, while the Model Builder was used in combining all the layers to generate the final suitability map. The suitability for each chemical and physical parameter was generated individually and classified in Table 4.5 while the Analytical Hierarchy Process (AHP) was presented in appendix II.

The analysis for pH showing in figure 4.5aC and table 3.4a that the most suitable area is (S1) 52.83% (5236.26 ha) While the moderately suitable (S2) 26.28% (2604.86 ha), marginally suitable (S3) 20.20% (2001.00 ha) and not suitable (N) with 0.69% (68.40 ha) More than 50% is within the suitable class for sorghum, however pH value is strongly related to BS-% within a soil testing class, and can be used as an indicator or index of certain chemical reactions occurring in the soil. At very low pH, solubility of Al, Mn and Zn increase, and can become toxic to sensitive plants. At high pH values, the solubility of Mn, and to a lesser extent Zn and Cu, can become so low that sorghum are unable to obtain adequate supplies from the soil. The acceptable pH range varies for each soil class.

The analysis for Organic Matter (OM) in figure 4.5a E shows that the area for moderately suitable (S2) having 0.20% (19.61 ha) marginally suitable (S3) with 33.39% (3309.08 ha) and area not suitable (N) for sorghum shows that 66.41% (6582.53 ha). Soil organic matter (OM) according to London (1988) is distinguished by its high moisture retention, low plasticity, low cohesion, and the dark color it imparts to the soil. These in turn lead to the favorable physical properties such as high water holding capacity, more stable structure, improved tilth, and more rapid water infiltration associated with mineral soils having significant organic matter content.

The electrical conductivity (EC) is an indicator for determination of saline soils, the analysis in figure 10I shows that the suitability (S1) for sorghum having 1506.34 ha (15.20%), moderately suitable (S2) 42.97% (4259.10 ha), while the marginally suitable with (S3) 16.12% (1597.48 ha) and areas that are not suitable with (N) 25.71% (2548.30 ha).

The CEC affects the way a soil should be managed for sorghum cultivation. For example, a soil with a low CEC (less than 5 meq/100g) generally has a low clay and organic matter content, has a low water holding capacity, requires more frequent lime and fertilizer additions, and is subject to leaching and such soils will have lower yield potential than soils with higher CEC under the same level of management, but high productivity can be maintained by intensive management (Steven, 1998). The CEC values ranging within the marginally suitable (S3) with 100% (9911.22 ha) (Figure 4.5aB) this indicated that the whole area is marginally suitable for sorghum.

Nitrogen (N) is the element most frequently lacking for optimum sorghum production. Nitrogen recommendations will vary with expected yield, soil texture, and cropping sequence (Grain Sorghum Production, 1998). The analysis for total Nitrogen (N) in figure 4.6bH and table 4.3a shows that the suitable area with (S1) 0.68% (67.12 ha) moderately suitable (S2) 13.51% (1339.35 ha) marginally suitable (S3) 85.60% (8483.68 ha) and not suitable (N) with total area of 0.21% (21.07 ha).

The suitability for magnesium (Mg) for sorghum requirement (Figure 4.5a J) shows that the area is generally affected by deficiency in Mg. In cereal crops, Mg deficiency symptoms include interveinal chlorosis on the lower leaves. Leaf edges may also show a thin hint of red or purple (London 1988). On broad-leaved crops, the lower leaves of Mg deficient plants may initially show interveinal chlorosis and become purplish-red with green veins. Because, the result indicated that marginally suitable (S3) with 11.69% (1158.96 ha) and not suitable (N) with 88.31% (8752.26 ha).

Potassium (K) is also relatively weak in the area the analysis indicated that the suitable area (S1) for sorghum in figure 4.5a K is occupying 5.25% (520 ha) of the area while moderately suitable (S2) 34.47% (3416.47 ha) marginally suitable (S3) 35.93% (3560.97 ha) and unsuitable (N) 24.35% (2413.76 ha).

Calcium (Ca) deficiency results in poorly developed root systems and relatively little fruit of poor quality. Foliage symptoms are extremely variable. Since Ca is immobile in the plant, affected plants may display malformed young leaves and abnormal terminal growth. Calcium is not readily leached from the soil, although levels may be quite low in sandy surface soils. Deficiencies rarely occur in crops other than peanuts, potatoes and vegetables subject to blossom end rot as stated by London (1988). In this study Ca shows that the area is dominated by low to very low values particularly for sorghum cultivation. The suitable area shows that (figure 4.5a A) (S1) 0.01% (0.86 ha), marginally suitable (S3) with 15.51% (1536.74 ha) (and unsuitable areas with (N) 84.49% (8373.62 ha).

The analysis of total sodium (Na) shows that suitable area (S1) with 0.36% (35.28 ha) moderately suitable (S2) with 6.54% (647.89 ha) while marginally suitable (S3) having the area of 44.45% (4405.46 ha) and the area that is not suitable with 48.66% (4822.59 ha).

The suitability Phosphorus (P) in the area having more of the land that is within the threshold for sorghum cultivation. This is an indication of having the suitable land (S1) with 87.07% (8630.16 ha) and the moderately suitable (S2) with 11.39% (1128.53 ha) while marginally suitable with 1.52% (150.89 ha) and areas with not suitable (N) within 0.02% (1.64 ha) Therefore, the area contained high amount of Phosphorus (P). This is unique among the anions, it has low mobility and availability in soils. It is difficult to manage because it reacts so strongly with both solution and solid phases of the soil. As a result, mobility through the soil is extremely limited in all but organic soils or white bleached sands with extremely low CEC's. Concentrations in soil solution range from less than 0.1 to around 5 ppm. Most crops respond to P additions when soil solution levels are less than 0.1 to 0.2 ppm (London, 1988).

The physical parameter in the area were also analysed for sorghum suitability classes and the result shows (Figure 4.5a L) the agricultural land is the most suitable area for the cultivation. The result indicated that the suitable (S1) area from the land use category is within 79.90% (7919.47 ha) followed by moderately suitable (S2) with 15.41% (1526.95 ha) marginally suitable (S3) 0.25% (24.76 ha) and not suitable within 4.44% (440.04 ha).

Soil texture is one of the determinants of the potentiality of a soil to hold nutrients and most of the physical characteristics of the soil depend upon texture class because is the relative proportions of the various size groups of individual soil grains in a mass of soil. In this study the suitability for Sorghum was determined and about four different classes of soil texture were identified in the area, this includes sandy clay loam, sandy loam, clay loam and complex soils (the combination of two different soils) and all were tested for suitability, the result shows that (figure 4.5a L) areas with suitable texture with (S1) 0.31% 30.26 ha while moderately suitable

(S2) 72.27% (7162.99 ha) (and the area occupied by marginally suitable (S3) within 19.27% 1910.16 ha the area that is not suitable (N) with 8.15% (807.81 ha)

The result of the soil drainage in the area shows that three classes of soil drainage were identified and analyzed these includes well drained, moderately and poorly drained soils, the suitable areas (S1) for sorghum is within 85.32% (8455.91 ha) while moderately suitable (S2) with 11.22% (1112.19 ha) and not suitable (N) with 3.46% (343.12 ha) (figure 4.5a M).

Slope of an area determines the rate of erosion of an area and is one of the factors used in this study for determination of suitable areas for sorghum. Classification has been made from DEM for the suitability classes. Four classes were identified ranging from 0 – 4%, 4 – 8%, 8 – 10% and greater than 10%. The result shows that suitable area (S1) with 41.65% (4128.27 ha) while moderately suitable (S2) within 25% (2498.63 ha) marginally suitable (S3) 23.82% (2360.83 ha) and area that is not suitable (N) with 9.32% (923.49 ha). The result of this analysis in figure 4.5a N indicated that the southern part of the area is affected by badland topography and erosion.

Soil depth is another important factors used for suitability analysis for the cultivation of a particular crop. In this study the soil depth were classified into deep, moderately deep and shallow soils and the result indicated that the suitable area (Figure 4.6c and Table 4.3b) (S1) for sorghum with 53.92% (5344.37 ha) while for moderately suitable (S2) with 35.24% (3492.37 ha) and the area for not suitable (N) to be 10.84% (1074.45 ha). The soil unit were categorized as upper and lower terrace which were tested for the suitability for sorghum and found out that the suitable area (S1) with 96.23% (9537.45 ha) while for moderately suitable (S2) with 3.71% (373.77 ha).

Table 4.3a: Suitability classes for Sorghum in the study area

Suitability classes	Na Area (ha)	Na (%)	OC Area (ha)	OC (%)	EC Area (ha)	EC (%)	K Area (ha)	K (%)	pH Area (ha)	pH (%)	N Area (ha)	N (%)
Suitable **(S1)**	35.28	0.36	1934.66	19.52	1506.34	15.2	520.02	5.25	5236.26	52.83	67.12	0.68
Moderately suitable **(S2)**	647.89	6.54	1666.28	16.81	4259.1	42.97	3416.47	34.47	2604.86	26.28	1339.35	13.51
Marginally suitable **(S3)**	4405.46	44.45	6127.23	61.82	1597.48	16.12	3560.97	35.93	2001.7	20.2	8483.68	85.6
Not suitable **(N)**	4822.59	48.66	183.05	1.85	2548.3	25.71	2413.76	24.35	68.4	0.69	21.07	0.21
Total	**9911.22**	**100**	**9911.22**	**100**	**9911.22**	**100**	**9911.22**	**100**	**9911.22**	**100**	**9911.22**	**100**

Suitability classes	P Area (ha)	P (%)	Mg Area (ha)	Mg (%)	CEC Area (ha)	CEC (%)	Soil Texture Area (ha)	Soil Texture (%)	OM Area (ha)	OM (%)	Ca Area (ha)	Ca (%)
Suitable **(S1)**	8630.16	87.07	0.00	0.00	0.00	0.00	30.26	0.31	0.00	0.00	0.00	0.00
Moderately suitable **(S2)**	1128.53	11.39	0.00	0.00	0.00	0.00	7162.99	72.27	19.61	0.20	0.86	0.01
Marginally suitable **(S3)**	150.89	1.52	1158.96	11.69	9911	100	1910.16	19.27	3309.08	33.39	1536.74	15.51
Not suitable **(N)**	1.64	0.02	8752.26	88.31	0.00	0.00	807.81	8.15	6582.53	66.41	8373.62	84.49
Total	**9911.22**	**100**	**9911.22**	**100**	**9911.22**	**100**	**9911.22**	**100**	**9911.22**	**100**	**9911.22**	**100**

Sources: Author's analysis (2014)

Table 4.3b: Suitability classes for Sorghum in the study area

Suitability classes	Land use Area (ha)	Land use (%)	Slope Area (ha)	Slope (%)	Soil Drainage Area (ha)	Soil Drainage (%)	Soil Depth Area (ha)	Soil Units Area (ha)	Soil Units (%)
Suitable **(S1)**	7919.47	79.90	4128.27	41.65	8455.91	85.32	5344.37	9537.45	96.23
Moderatly suitable **(S2)**	1526.95	15.41	2498.63	25.21	1112.19	11.22	3492.4	373.77	3.77
Marginally suitable **(S3)**	24.76	0.25	2360.83	23.82	0.00	0.00	0.00	0.00	0.00
Not suitable **(N)**	440.04	4.44	923.49	9.32	343.12	3.46	1074.45	0.00	0.00
Total	**9911.22**	**100**	**9911.22**	**100**	**9911.22**	**100**	**9911.22**	**9911.22**	**100**

Sources: Author's analysis (2014)

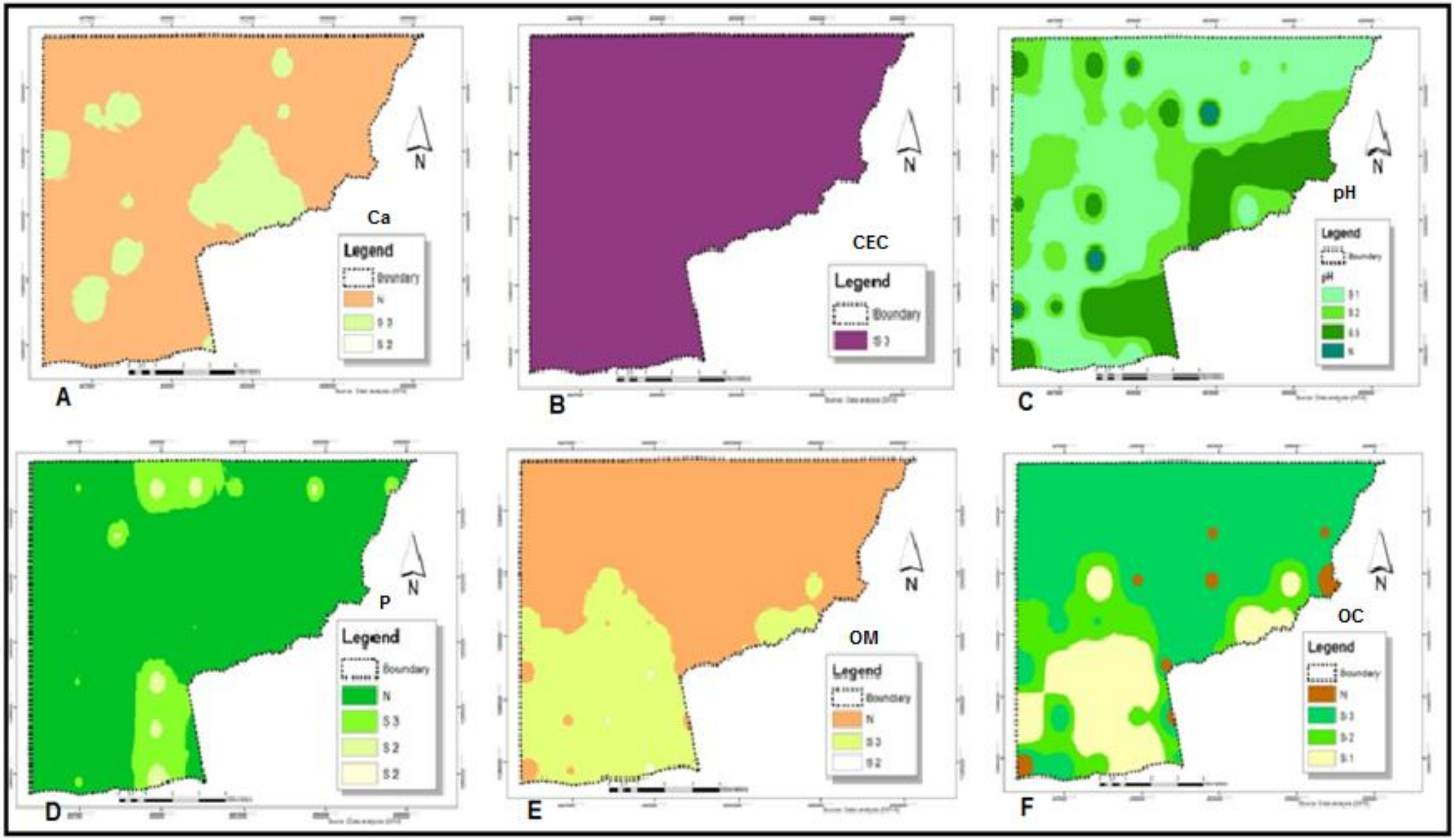

Figure 4.6a: Suitability for Physical and Chemical Parameters for Sorghum

Sources: Author's analysis (2014)

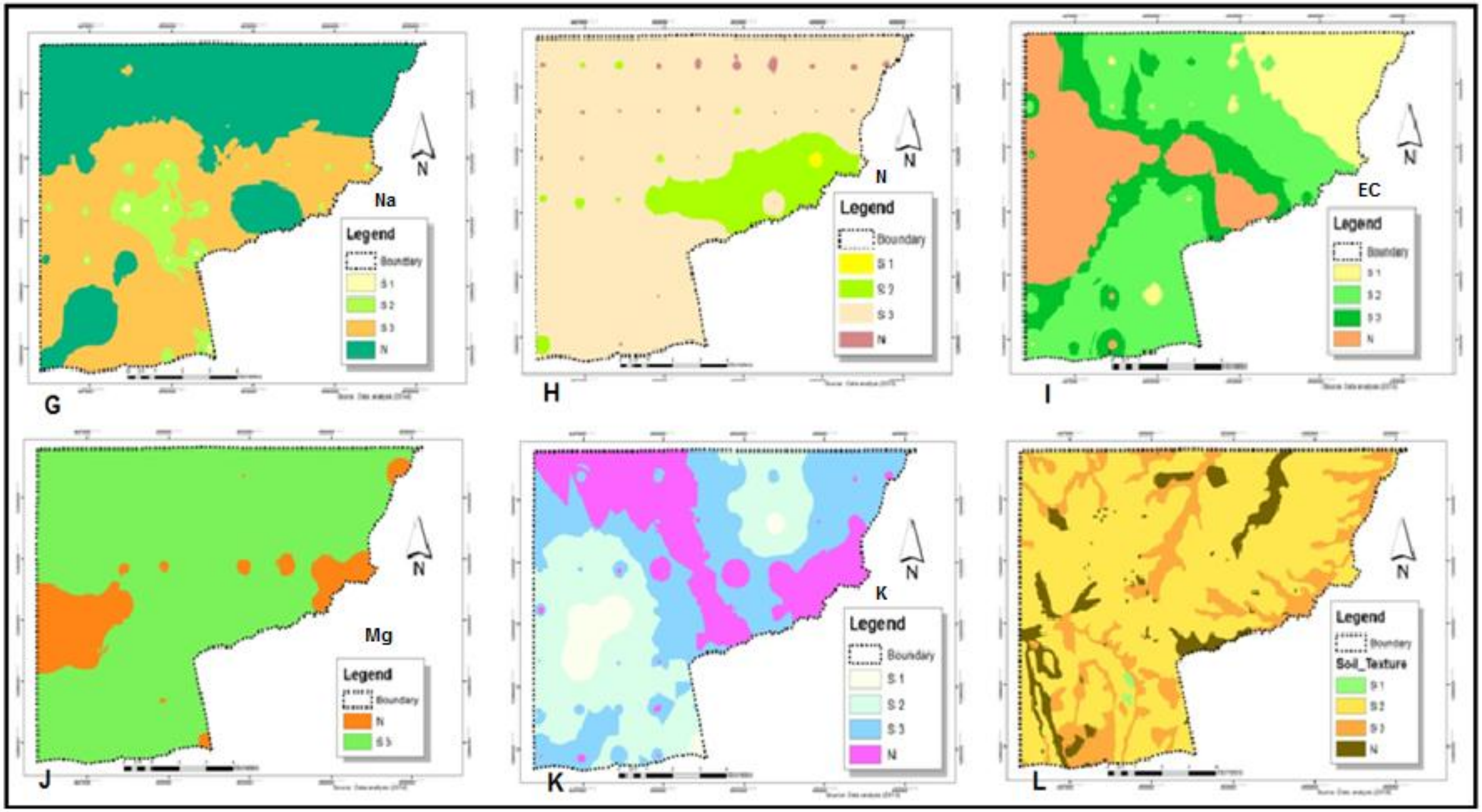

Figure 4.6b: Suitability for Physical and Chemical Parameters for Sorghum

Sources: Author's analysis (2014)

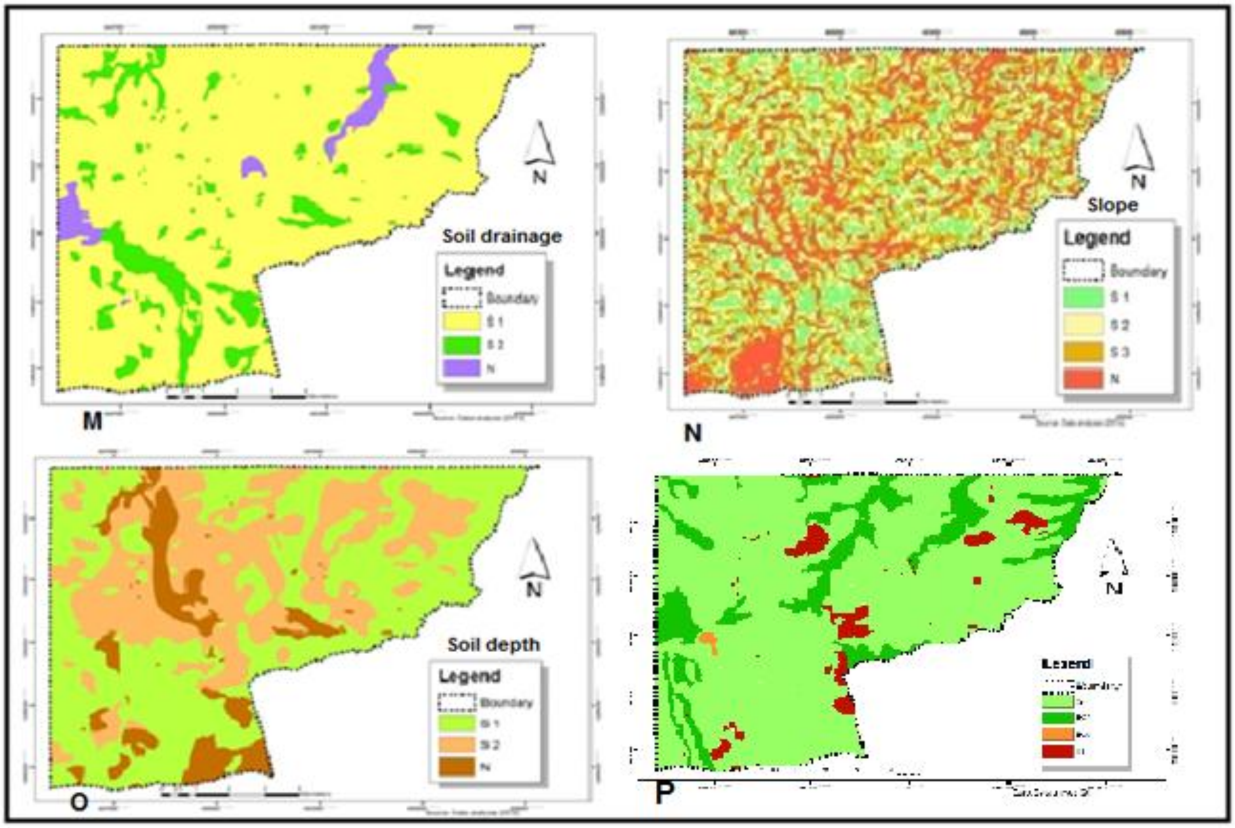

Figure 4.6c: Suitability for Physical and Chemical Parameters for Sorghum

Sources: Author's analysis (2014)

Note: A= Calcium (Ca), B = Cation Exchange Capacity (CEC), C = pH, D = Phosphorus (P), E = Organic Matter (OM), F = Organic Carbon (OC), G = Sodium (Na), H = Nitrogen (N), I = Electrical Conductivity (EC), J = Magnesium (Mg), K = Potassium (K), L = Soil texture, M = Soil drainage, N = slope (%) and O = Soil depth and P = Land use.

4.7 COMBINED LAYERS (THEMES) FOR SORGHUM SUITABILITY

The pairwise comparison matrix (Appendix II) for all the criteria of sorghum cultivation, were weighted of the alternatives, the final rate were calculated the final suitability map. Model Builder shown in figure 3.6 was used in combining the thematic layers produced in figure 4.6a, 4.6b and 4.6c (Soil and physical parameters) from the AHP and Fuzzy analysis were performed in the weighted overlay operations using the spatial analyst tool.

The result of the analysis in figure 4.7 shows that the highly suitable area that meet up with all the requirement is within (**S1)** 8.69% (860.91 ha). This area possesses the qualities that is requires (most suitable) to cultivate sorghum. According to NEDECO (1974) is Hydromorphic in nature it mostly consist of silt and some combination of loamy soils, clayey and sand that developed within the terraces which is good for cereal crops. Even though, the area is a very small portion within the land, in this case the area is having minor limitations that will not significantly reduce production and will not raise input above an acceptable.

While, the suitable area **(S2)** (Figure 4.7) with 17.27%. (1712.15 ha). This land imposes constraints which can be overcome by little investment. The area is affected by low levels of plant nutrients especially low organic matter (OM), high electrical conductivity (EC) and little erosion. Perennial crops are thus more suitable for this area crops (USDA, 1999). Moderately shallow soil depth, making agriculture possible only with little management, minimum tillage and careful erosion control. The limitations will reduce productivity or benefits, and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciatable inferior to that expected on (S1) class I land.

The moderately suitable (**S3**) with 24.29% (2407.61 ha) this area is falling within the irrigated field in the study area which is affected by salinity, poorly drained and low nutrients. However, the land is having limitations which, in aggregate are severe for sustained application of given use and will so reduce productivity or benefit or increase required input, that this expenditure will be only moderately justified.

Marginally suitable **(S4)** having the area with 36.01% (3568.67 ha) but the area is affected by severely erosion, shallow soils, very low organic matter and slopping topography. It is dominated by an undifferentiated texture there by making the soil to be sandy. However, the land having limitations which may be surmountable in time, but which cannot be corrected with existing knowledge at currently acceptable cost; the limitation are too severe as to preclude successful sustained use of the land is the given manner.

The area not suitable **(N)** (Figure 4.7) for sorghum cultivation is 13.74% (1361.88 ha) (Figure 4.7), this area is generally affected by badland topography, rock outcrop, complex texture and very poor nutrient others include built-up areas and water bodies which are generally not for cultivation. Land having limitations which appear so severe as to preclude any possibilities of successful sustained use of the land to the given manner.

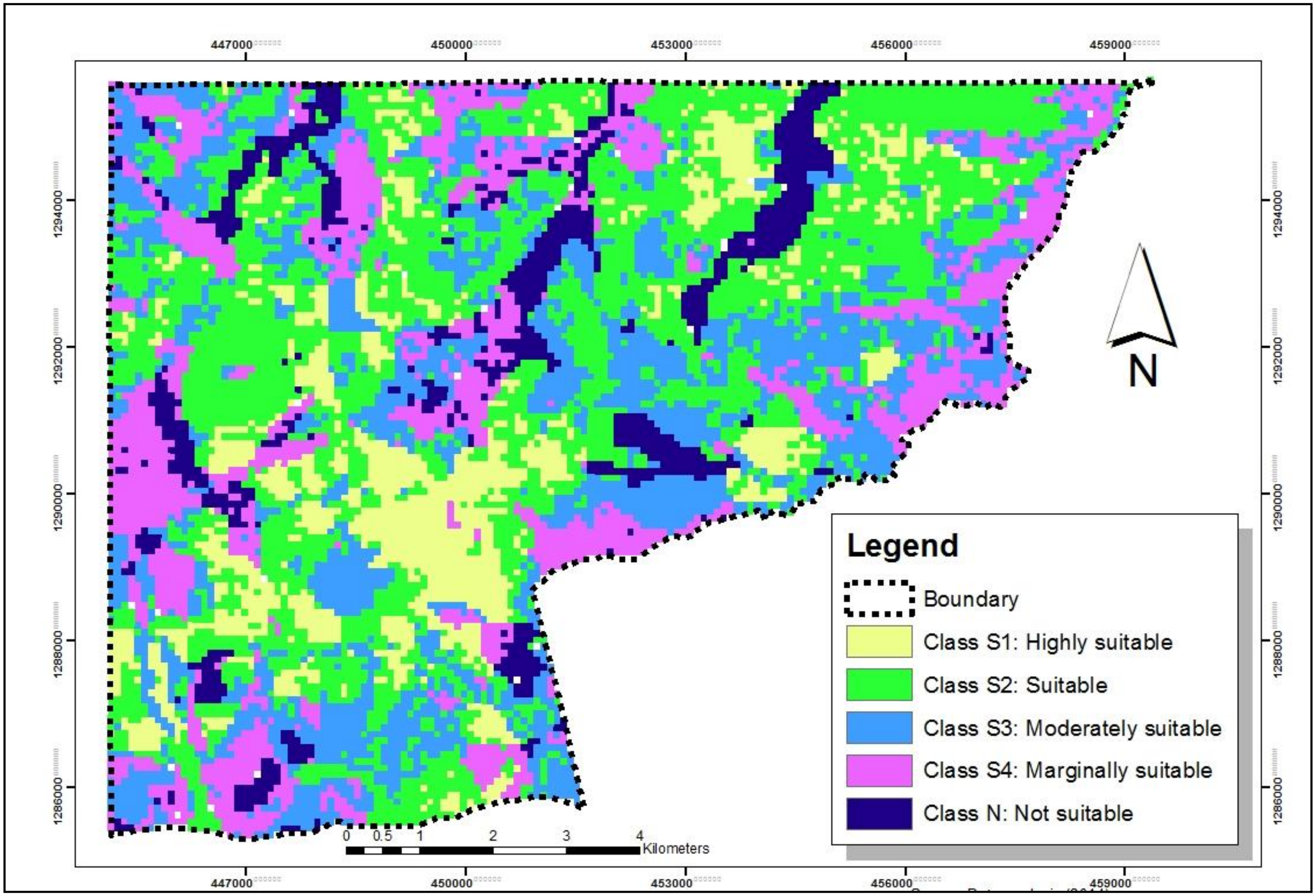

Figure 4.7: Suitability map for Sorghum
Sources: Author's analysis (2014)

CHAPTER FIVE: SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 SUMMARY OF FINDINGS

This research demonstrated the applications of GIS and spatial analysis through selection of the criteria which were weighted through Multi Criteria Evaluation. AHP and Fuzzy logic were used in facilitating the challenges of delineating the suitable areas for sorghum cultivation.

From the classified land use of the area, it shows that cultivated land dominated the area with 76.40% and the land is well drained. The more favourable area for cultivation is upper terrace among the soil unit in the area with more than 90% of the land. The terrain is relatively flat unless to some extend the southern part of the area where the slope is greater than 10%.

The spatial distribution of the physiochemical parameters shows that the area is highly acidic with pH < 4 unless to some cases were patches of values of pH with 9 were experienced. Organic matter (OM) and organic carbon (OC) are ranging from low to medium. The distribution of sodium (Na) and nitrogen (N) from their mean shows low to moderate (0.09 ppm and 0.31%) respectively. Magnesium (Mg) and CEC are within the moderate threshold while calcium (Ca) is low and the whole area is affected with salinity.

The suitability for sorghum cultivation from the parameters shows that pH, Phosphorus (P), soil drainage, slope, soil unit and soil depth are within acceptable suitable range while, those falling within moderate to marginal are OM, CEC, N and K. And Ca is low when comparing with sorghum requirement.

The final analysis shows that 8.69% of the area is highly suitable covering of the land, while 17.27% is suitable and 24.29% is moderately suitable, marginally suitable with 36.01% and lastly area not suitable is with 13.74%.

5.2 CONCLUSION

The research made the following conclusion

1 That most part of the study area is under cultivation and that farming contributed to the food production and income generation in the area.

2 Sand fraction generally dominated the soil with Sandy Loam as the general textural class. The soils are well drained, relatively flat, very few rock outcrops, Most of the nutrients in the soils are within the threshold levels and that is what makes the soils of the area to be of high agricultural potentials.

3 The soil of the area has comply with the USDA (1951) which shows the soil of the area is sand still forms a large proportion (> 50%) but there is clay (15%) to allow the soil so cohere and mould fairly easily when mist without being sticky.

4 That the soil of the area is affected with salinity and some of the essential elements needed in the soils like Ca and most micronutrients are lacking in the soils. The pH of the area is generally acidic and hence toxic to must crops

5 The area is moderate to marginally suitable for sorghum cultivation and the crop thrives well due its drought resistance that makes it suitable for areas erratic rainfall and aridity.

5.3 RECOMMENDATIONS

The study made the following recommendations

1 The farmers in the area should provide a device of changing the water that goes into their cultivated areas to avoid water logging that causes salinity.

2 Fertilizer application should be complimented with animal dung (50:50) to avoid soil pollution.

3 Policy makers should encourage mix-cropping especially the leguminous species in the area to enhance soil fertility.

4 Long term soil monitoring sites should be established using a localize soil map by the government using regular soil samples and management aspect which should be taken and stored in Database. With such data, temporal changes in soil fertility can be monitored.

5 The study recommends for further studies in combining Fuzzy-AHP, Multicriteria Evaluation and Semiviriogramme for fertility variability in the area.

References

Adamu G. K. (2014). An Assessment of The Surface Characteristics and Potentials of Fadama Soils in The Reaches of Two Major Streams in Kano State, Nigeria. Unpublished PhD. Theses submitted to the Department of Geography Bayero University Kano.

Adekunle Y., B. Ekaba O, Fagbemi, O, Obuke, E. Alao, J. and Maitanmi, O. (2013). Framework Model for a Soil Suitability Decision Support System for Crop Production in Nigeria. *American Journal of Engineering Research.* Vol. 02, Issue-06, 09-13

Adesemuyi, E.A (2014). Suitability assessment of soils for maize (zea mays) production in a humid tropical area of south-western Nigeria. *International Journal of Advanced Research* Vol. 2, Issue 2, 538-546

Ahmed, K. (2008). The Physical Environment of Kano State, *www.kanostate.net/physicalenvironment.html.* Accessed February 2009

Ahmed, K.(1995),Some constraints to crop production and rehabilitation in North-Western Kano State, *Journal of Social and Management Studies,* Vol. 2, Bayero University, Kano.

Alexandratos, N. (Ed), (1995). World Agriculture: Towards 2010. An FAO study. FAO/Wiley, Rome/Chichester.

Ali A. J., Parisa A., Mohamed R. N. and Siamak S. (2008). Land Suitability Evaluation of Bilverdy Research Station For Wheat, Barley, Alfalfa, Maize and Safflower. *Soil & Water Res., 3,* (Special Issue 1): S81–S88

Al-Mashreki M. H., Juhari M., Abd Rahim S., Md. Desa K., Lihan T. and Haiden R. (2011). GIS-Based Sensitivity Analysis of Multi-Criteria Weights For Land Suitability Evaluation of Sorghum Crop in the Ibb Governorate, Republic of Yemen. *J. Basic. Appl. Sci. Res.*, 1(9)1102-1111

Ande O.T. (2011). Soil Suitability Evaluation and Management for Cassava Production in the Derived Savanna Area of Southwestern Nigeria. *International Journal of Soil Science,* 6: 142-149.

Anderson, J. S. and Ingram, J.I.S. (1998). Tropical Soil Biology and Fertlity. A Handbook of Methods. 2nd Edition. Information Press, U.K. Pp. 221.

Aondoakaa, S.C. And Agbakwuru, P.C. (2012) An assessment of land suitability for rice cultivation in Dobi, Gwagwalada area council, FCT Nigeria. *Ethiopian Journal of Environmental Studies and Management* Vol. 5 no.4 (Suppl.1).

Babalola TS, Oso T, Fasina AS and Godonu K (2011) Land evaluation studies of two wetland soils in Nigeria. *International Research Journal of Agricultural Science and Soil Science* Vol. 1(6) pp. 193-204

Badamasi M. M., (2014) Vegetation and Forestry In A.I Tanko and S.B. Mumale (Eds.) *Kano Environment, Society and Development*. London and Abuja, Adonis and Abbey Publishers

Baffa M. A. (2012) Problems of Crop Water Requirement on Irrigation Plots at Bunkure LGA. Kano State. An Unpulished Bsc. Thesis submitted to the Department of Geography Bayero University Kano, Nigeria

Behnam K. Mohammad A. D and Jaime A. T da Silva (2014) Assessment of land suitability and the possibility and performance of a canola (*Brassica napus* L.) – soybean (*Glycine max* L.) rotation in four basins of Golestan province, Iran. Egyptian Journal of Remote sensing and Space science DOI: 10.1016/j.ejrs.2013.12.001

Belka, K.M. (2005). Multicriteria analysis and GIS application in the selection of sustainable motorway corridor. Master's thesis submitted to linkopings University Institution for datavetenskap.

Bogaert, P. and D'Or, D. (2002). Estimating Soil Properties from Thematic Soil Maps, the Bayesian Maximum Entropy Approach. *Soil Sci. Soc. Am. J*., 66: 1492-1500.

Brandy, N. C. (1974), Organic matter of mineral soils. In: Buckman, H. O. and Brady N. C. ed. *The nature and properties of soils*. Macmillan Publishing Co., New York, p. 137-163.

Breman H., (1998) Amelioration de la fatilite des sols en Afrique de I'Ouest: contraintes es perspectives. In Renard, G., Neef, A., Becker, K., Von Oppen, M. (Eds.), *Soil Fertility Management in West African Land Use Systems*. Margraf Verlag, Weikersheim, pp. 7-20.

Buba, L. F (2000) Spatio Temporal rainfall and temperature variation in Northern Nigeria. An Unpublished PhD thesis Submitted to the Geography Department Bayero University Kano, Nigeria

Bungham A (1962) Chemical Test for Available Phosphorus. Soil Science 94, 87-95.

Burrough, P. A., Macmillan, R. A., and Van Deursen, W., (1992) Fuzzy classification methods for determining suitability from soil profile observation and topography. *Journal of soil science,* 43, 193-210.

Carver, S.J., (1991). Integrating multi-criteria evaluation with geographical information systems. *International Journal of Geographical Information System*, 5: 321-339.

Chapman H.D. (1965). Cation Exchange Capacity. In :Black C.A (ed). Methods of Soil Analysis. Part 2. *American Society of Agronomy*, Madison. Pp. 1149-1178

Chen Y., Yu J. and Khan S. (2012) Spatial sensitivity analysis of multi-criteria weights in GIS based land suitability evaluation. *Environmental Modelling & Software* Vol.25, 1582-1591

Clark A. (2007) Managing Cover crops Profitable 3rd (ed) National SARE Outrech Handbook series Book 9. Natl. Agric, Lab, Bertsville MD.

Cleaver K.M., and Schreiber, G. A., (1994) Reversing the spiral: the Population Agriculture and Environment Nexus in sub-Saharan Africa. The World Bank Washington DC

Cook R. J. (1979). Influence of crops besides wheat on Gaeumannmyces graminis and take-all decline. (Abstr.) Phytopathology 69:914

Dave F. (2008) Developing Zone Soil Sampling Maps. NDSU Extension Soil Specialist SF-1176-2 (Revised) www.ag.ndsu.edu

David W (1998), Fertilizer Requirements. Grain Sorghum Production Handbook Extension State Leader, Agronomy Program

De La Rosa, D., (2000). Micro LEIS Conceptual Framework: Instituto de Recursos Naturalesy Agrobiologia, CSIC, Sevilla, Spain, 267, p. 212.

Dugje, I. Y. Kamara A. Y and. Ajeigbe H (2009) Biophysical Characterisation of Crop Fields in Sudan Savanna Zone of North Western Nigeria: Kano-Katsina-Maradi Pilot Learning Site Sudan Savanna Agro-Ecological Zone Innovation Platform. Sub Saharan Challenge Programme for Integrated Agricultural Research for Development. *International Institute of Tropical Agriculture* (IITA, *Research to Nourish Africa*)

Ehirim, N. C., Okere, R. A, S. Onyeagocha, U. O. M.Y Rahji, T.T. Awoyemi B.I. Oluwatayo and K.K. Salman (2013) Econometric analysis of suitability and marginal value productivity of farmlands for cassava production in Imo State, Nigeria *Academic Journals* Vol. 5(11), 450-456

Elaalem E, A. Comber, and P. Fisher, (2001) "A Comparison of Fuzzy AHP and Ideal Point Methods for Evaluating Land Suitability*", Transactions in GIS*, vol.15, 329- 346,

Elaalem M. (2012) Land Suitability Evaluation for Sorghum Based on Boolean and Fuzzy Multi-Criteria Decision Analysis Methods *International Journal of Environmental Science and Development*, Vol. 3, No. 4.

Elaalem M. (2013) A Comparison of Parametric and Fuzzy Multi-Criteria Methods for Evaluating Land Suitability for Olive in Jeffara Plain of Libya. *www.sciencedirect.com* APCBEE Procedia 5 405 – 409

Elsheikh R., Abdul R. B. Shariff M., Amiri F., Noordin B. Ahmad S. K. B, Soom M. A. M(2013) Agriculture Land Suitability Evaluator (ALSE): A decision and planning support tool for tropical and subtropical crops. *Computers and Electronics in Agriculture journal* www.elsevier.com/locate/com 93 98-110

Esseit U. E. (2013) Soils Geography of Kano region. Tanko and Mumale S, B. (Eds) Kano *Environment, Society and Development*. London and Abuja, Adonis and Abbey Publishers

FAO (1976) A framework for land evaluation, 1th ed., Food and Agricultural Organization of the United Nations., Rome, FAO, 1-187.

FAO (1979) Soil Survey Investigation for Irrigation. Soil Bull No. 42 FAO Rome

FAO (1993). *Guidelines for Land Use Planning*. FAO Development Series No. 1, FAO, Rome, Italy.

FAO (1995). Sorghum and millets in human nutrition. ISSN 1014-3181, p.184.

FAO (2012) The State of Food Insecurity in the World 2012. Economic growth is necessary but not sufficient to accelerate reduction of hunger and malnutrition. Rome.

FAO/Unesco. (1973) Irrigation, Drainage and Salinity. An International Sourcebook. Paris, Unesco/Hutchinson (Publishers), London. 510.

FAOSTAT (Food and Agriculture Organization/Statistics (2012) Trade data base, Production data base http://faostat.fao.org. Accessed 01/02/12013

FMEST, Federal Ministry of Education, Science and Technology (1984). Sorghum: Science and Technology Briefing.

Foli (2012) Qualitative and quantitative diagnosis of macro and micronutrient deficiencies in soils across three agro-ecological environments of northern Nigeria using the double-pot technique MSc internship report Plant Production Systems group Course code: PPS-70424 Wageningen University. From http://www.n2africa.org

Foote K., M. Lynch (1996) Geographic Information Systems as an Integrating Technology: Context, Concepts and Definition University of Texas, Austin, Texas, USA

Gee G. W. and J. W. Bauder. (1986): Particle size analysis. In 'Methods of soil analysis, Part 1'.Vol. 9.(Ed. A. Klute) pp. 91–100.*American Society of Agronomy*: Madison,WI.

Gomez, K.A. and A.A. Gomez, 1984. Statistical procedure for agricultural research, 2nd Ed. John Wiley and Sons, Inc., New York, USA. 680p.

Gourichon H., (2013). Analysis of incentives and disincentives for sorghum in Nigeria. Technical notes series, MAFAP, FAO, Rome.

Grose C.J. (Ed) (1999), Land Capability Handbook. Guidelines for the Classification of Agricultural Land in Tasmania. Second Edition, Department of Primary Industries, Water and Environment, Tasmania, Australia

Gruhn, P., Goletti, F., and Yudelman, M., (2000). Integrated Nutrient Management, Soil Fertility, and Sustainable Agriculture: Current Issues and Future Challenges, Agriculture and the Environment Discussion Paper 32. *International Food Policy Research Institute*, Washington.

Hall., G. B., Wang. F. and Subaryono (1992)) Comparison of Boolean and Fuzzy classification method in Land Suitability analysis by using Geographic Information System. *Environment and Planning*, 24, 497-516.

Henao, J. and Banaante, C., (1999) Estimating Rates of Nutrient Depletion in Soils of Agricultural Lands of Africa, International Fertilizer Development Center, Mussel Shoals, AL.

IITA. (1979). *Selected methods for soil and plant analysis*. International Institute of Tropical Agriculture. Manual series No. 1 pp 70.

Inakwu O.A. Odeh and Mark C. (2010) Soil suitability and crop versatility assessment using fuzzy analysis at a farfv m scale. World Congress of Soil Science, Soil Solutions for a Changing World 1 - 6 August, Brisbane, Australia. 19th Symposium http://www.iuss.org

Jaiyeoba, I. A., (2003) Changes in soil properties due to continuous cultivation in Nigerian semiarid savannah. *Soil & Tillage Research*, 70: 91-98

Jiang H. and Eastman J. R. (2000) Application of fuzzy measures in multi-criteria evaluation in GIS *int. j. geographical information science,* vol. 14, (2) 173 – 184

Jidauna, G. G., Dabi, D. D. and Dia, R.Z (2012)The effect of climate change on agricultural activities in selected settlements in the Sudano-Sahelian Region of Nigeria. Archives of Applied Science Research, 4 (1):703-713

John S., Antonia M., and Randy K. (2004) Take Good Soil Sample to help make good decision. Iowa State Univ. File code Agronomy 8-5

Kilic K., S. Kilic and R. Kocyigit (2012) Assessment of spatial variability of soil properties In areas under different land use *Bulgarian Journal of Agricultural Science,* Vol. 18 (No 5), 722-732

KNARDA (Kano Agricultural and Rural Development Authority) (2001). Development Area Statistics.

Kowal, J. M. and Knabe, D. T. (1972). An Agroclimatological atlas of Northern States of Nigeria with Explanatory Notes. ABU Press, Zaria. Nigeria.

London J. R. (1988). Toward a standard field assessment of soil texture for mineral soils. Soil survey and land Evaluation 8 (3) 161-165

London J.R. (1991). Booker Tropical Soils Manual. John Willey and Sons Inc. New York

MAAF, (1967). Soil Pottassium and Magnesium. Tech Bull 14. HMSO

Magbagbeola, J.A.O, Adetoso, J.A and Magbagbeola, E.O (2012). Use of Multicriteria Decision-making (MDM) Process to Solving Agricultural Inputs problem in Oriade Local Government Area, Osun State, Nigeria. *Journal of Emerging Trends in Economics and Management Sciences* 3 (1): 99-102.

Magdoff F and Van Es H. (2009) Building Soil for better crops, sustainable soil management. *Sustatinable Agric*. Publ. Waldorf, MD.

Mahler, R.L. and T.A. Tindall (1990) Soil sampling. . Univ. Idaho Coop. Ext. Bull. 704 (revised)

Malczewski, J. (1999). GIS and multicriteria decision analysis. Wiley & Sons Inc., New York, USA.

Malczewski, J. (2006). GIS-based multicriteria analysis: a survey of the literature. *International Journal of Geographic Information Science,* 20: 703–726.

Malczewski, J., (2004). GIS-based land-use suitability analysis: a critical overview. *Progress in Planning* 62 (1), 3e65.

Malgwi, W.B., Ojanuga, A.G., Chude, V.O., Kparmwang, T. and Raji, B.A (2000). Morphological and Physical Properties of Some Soil at Samaru, Zaria, Nigeria. Nigerian Journal of Soil Research 1:58 – 64.

Mansor S. B, Pormanafi S, Mahmud A. R. B. and Pirasteh S (2012). Optimization of Land use Suitability for Agriculture Using Integrated Geospatial Model and Genetic Algorithms ISPRS Annals of The Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume I-2, Congress, 25 August – 01 September, Melbourne, Australia

Marble D.H., H.W. Calkins, and D.J. Pequet (1984). Basic Readings in Geographic Information Systems SPAD System Limited, Williamsville, NY

MARDITECH (2011). Development of a GIS-Based Soil Suitability Classification for Rice Production in Kano State, Nigeria, Unpublished Interim Report submitted to the Kano State Government, MARDITECH, Kualar Lumpur, Malaysia

Maryam L, Halima A. Idris and Ummi K. Mohammed (2014). Weather and Climate. In A.I Tanko and S.B. Mumale (Eds.) *Kano Environment, Society and Development*. London and Abuja, Adonis and Abbey Publishers

Masoud J., Agyare W. A., Forkuor G., Namara R. and Ofori E. , (2013). Modeling Inland Valley Suitability For Rice Cultivation. VOL. 8, NO. 1 ISSN 1819-6608 ARPN *Journal of Engineering and Applied Sciences* Asian Research Publishing Network (ARPN). All rights reserved. www.arpnjournals.com

Melitz, P.J. (1986). The Sufficiency Concept in Land Evaluation. *Soil Surv. Land Eval.*, 6(1): 9-19.

Meng Y, Malczewski J. and Boroushaki S. (2011) A GIS-Based Multicriteria Decision Analysis Approach for Mapping Accessibility Patterns of Housing Development Sites: A Case Study in Canmore, Alberta *Journal of Geographic Information System*, 3, 50-61

Meredith, W.R.(1987) "Final Report of the Cotton Foundation Yield and Productivity Study. " Proc. Beltwide CottonRes. Conf., 33-37.

Mermut, A. R. and Eswaran, H. (2001). Some Major Developments in Soil Science since the Mid-1960s. *Geoderma*, 100: 403-426.

Metson A.J (1961) Method of Chemical analysis for soil survey samples. New Zealand DSIR. Soil Bur Bull Govt. Printer, Wellington New Zealand.

Mitra D., Mehdi N., Mojtaba R., Mehdi A. and Ali A. (2011) Qualitative and Economic Land Suitability Evaluation for Tea (*Camellia sinensis* L.) In Sloping Area of Guilan, Iran. *J. Biol. Environ*. 5(15), 135-146 135

Mokarram M., Rangzan K , Moezzi A and Baninemehc J. (2012) Land suitability evaluation for wheat cultivation by fuzzy theory approaches as compared with parametric method. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. 38, Part II

Mortimore M. and Harris F. (2003) Do small farmers' achieve contradict the nutrient depletion scenarios for Africa? Land use policy 22 43-56 *Elsevier*

Mortland, M.M. (1970). Clay organic matter complexes and interactions. In Brady, NC. (ed) advance Agronomy 22;75-117.

Mustafa A.A, Man Singh, R. N Sahoo, Nayan Ahmed, Manoj Khanna, A. Sarangi and A. K. Mishra (2011) Land Suitability Analysis for Different Crops: A Multi Criteria Decision Making Approach using Remote Sensing and GIS. *Researcher*, 2011; 3 (12) http://www.sciencepub.net/researcher

NAERLS, National Agricultural Extension Research and Liaison Services (1997). Prospects and Problems of the 1997 Cropping Season, NAERLS/APMUE, Kaduna, Nigeria.

Neamatollahi, M. Bannayan, M.R. Jahansuz, P. Struik, A.R. Farid (2002) Agro-eco logical zoning for wh eat (*Triticumaestivum*), sugar beet (*Beta vulgaris*) and corn (*Zea mays*) on the Mashhad plain, Khorasan Razavi province Egypt. J. Remote Sensing Space Sci., 15 pp. 99–112

NEDECO, (Netherlands Dev. Company) (1974). Kano River Irrigation Project (KRIP) Main Report. Part VIII. Ministry of Agriculture and Natural Resources, Kano, Nigeria.

Nigerian Geological Survey Agency (NGSA) (2006) Geological map of Kano State

Nisar T.R Ahamed, K. and Gopal Rao, J.S.R. (2000) Murthy GIS-based fuzzy membership model for crop-land suitability analysis Agricultural Systems 63. 75:95 www.elsevier.com/locate/agsy

Njoroge J B., and Hunja M. (2013). Suitability analysis for rice growing sites using a multicriteria evaluation and GIS approach in great Mwea region, Kenya. *Springerplus*. Vol. 2: 265.

NPC (2006) National Population Commission

NRC National Research Council (1996). Lost Crops of Africa; Volume 1 Grains, Washington D.C., National Academic of Sciences.

Nuhu Z and Ahmed M (2013) Agricultural Landuse in Sub-urban Lafia of Nasarawa State, Nigeria. Part-ii: Social Sciences and Humanities ISSN-l: 2223-9553, ISSN: 2223-9944 Vol. 4 no. 4

Nurmiaty and Sumbangan B. (2013) Spatial Based Assessment of Land Suitability and Availability for Maize (*Zea mays* L.) Development in Maros Region, South Sulawesi, Indonesia. *Open Journal of Soil Science*, Vol. 3, 244-251

Ofor, M.O I.I Ibeawuchi and A.M.Oparaeke (2009) Crop Protection Problems in Production of Maize and Guinea Corn in Northern Guinea Savanna of Nigeria and Control Measures Nature and Science;7(11)

Ogbonna A. T. (1981) Proc. Int. Symposium on Sorghum Grain Quality ICRISAT Pantanchan 45 – 54

Ogbonna A. T. (2011). *Current Developments in Malting and Brewing Trials with Sorghum in Nigeria: a review*

Ogunwale J. A,. Olaniyan J. O and. Aduloju M.O (2009) Suitability evaluation of the University of Ilorin farmland for cowpea. *Crop Res.* 37 (1, 2 & 3): 34-39

Olofin E. A. (1985). Human Responses to the Natural environment in the Kano Region. In: Barkindo, A. A. (ed). Kano and its Neighbours. ABU Press, Zaria.

Olofin E. A. (2014) Location, Relief and Landforms. In A.I Tanko and S.B. Mumale (Eds.) *Kano Environment, Society and Development*. London and Abuja, Adonis and Abbey Publishers

Umar, G. (2011) Assessment of the Fertility Status of some Irrigated Fluvisols in Northern Guinea Savannah of Nigeria. Volume 6 (1); Savannah Journal of Agriculture ISSN 1597 9377 Faculty of Agriculture, Bayero University

Ouma J. P., and Akuja T. E. (2013) Agronomic and morphological performance of sorghum (sorghum bicolour l.) for the dry highlands of Kenya *J. Appl. Biosci* 4720

Pareta K and C. K. Jain Land Suitability Analysis for Agricultural Crops using Multi-Criteria Decision Making and GIS Approach (2010) http://agropedia.iitk.ac.in/sites/default/files/Land%20Suitability%20Analysis%20for%20Agricultural%20Crops.pdf

Paz-Gonzalez, A., S. R. Vieira and Ma .T. Taboada Castro, (2000). The effect of cultivation on the spatial variability of selected properties of an umbric horizon. *Geoderma*, 97: 273-292.

Pierce, F.J., Clay, D., (2007). GIS Applications in Agriculture, CRC Press, Boca Raton, p. 224. *R*

Rehm, G.W., A.P. Mallarino, K. Reid, D. Franzen, and J. Lamb. (2001). Soil sampling for variable-rate fertilizer and lime application. North Central Multistate Report 348 - NCR-13 Committee. Minnesota Agricultural Experiment Station Bull. 608-2001. Univ. of Minnesota, St. Paul., MN.

Rhoades, J.D. (1982). Cation exchange capacity. In Page, A.L., Miller, R.H. and Keeney, D.R. (eds). *Methods of Soil Analysis.* Part 2 Agron 9. Madison WI. PP 149-157.

Richards, L. A. (1954). Diagnosis and improvement of saline and alkali soils. USDA Agric. Handb. 60. U. S. Gov. Print. Office, Washington, DC

Rossiter, D.G., (1996). A theoretical framework for land evaluation. *Geoderma* 72, 165–190.

Saaty, T.L. (1980). The analytic hierarchy process: McGraw Hill International., New York.

Saaty, T.L., (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology* 15, 231 281.

Saaty,T.L.,Vargas,L.G.(1991) Prediction, Projection and Forecasting. Dordrecht, Kluwer Academic

Sanjana Reddy P, Patil j. V., Nirmal S. V. and Gadakh S. R. (2012) Improving post-rainy season sorghum Productivity in medium soils: does Ideotype breeding hold a clue? *Current science, vol. 102, no. 6, 25 Research Communications*

Sehgal, J. (1999). Pedology: Concept and Applications. Kalyani publishers.Lodhiana, India.

Shoemaker CE and Brandy DI (2010). The role of sorghum as a bioenergy Feed stock. In: Brauk, R., Karlen D. and Johnson (ed) editors sustainable alternative fuel feed stork opportunities, challenges and roadmaps for six US. Region, Proceedings of the sustainable feedstock for advance Biofuels Workshop, Atlanta, GA 28 – 30 September.

Soil Survey Staff. (1972). Soil Taxonomy. U.S. Dept. Agric. Handbook 436. U.S. Govt. Printing Office, Washington D.C

Soil Survey Staff. (1981). Keys to Soil Taxonomy, 8th edition. USDA Natural Resource Conservation Service, U.S. Government Printing Office, Washington DC.

Steven C., (1998) Managers/Management of soil erosion. In: Management Practices for Maintaining soil Productivity in the douglas-firregion (Ed) Sam D. Angima and Thomas A. Terry. In Best. Oregon State University. Extension service

Stoorvogel, J., Smaling, E., and Janssen, B., (1993). Calculating soil nutrient balances in Africa at different scales: I. Supra-national scale, *Fertile. Res*., 35, 227 – 235

Sys, C., Van Ranst, E., Debaveye, J. and Beernaert, F. (1993) *Land evaluation, Part 3: Crop requirements.* Agricultural Publications 7. General Administration for Development Cooperation, Brussels.

Tanko A.I. (2001), Some Physical and Chemical Changes in Soils, and their Agricultural Implications under large-scale Irrigation in Kano Region, Northern Nigeria, Proceedings of Faculty Seminar Series Vol 1, *Faculty of Social and Management Sciences*, Bayero University Kano pp 247-269.

Tatler, W. and Corbett, W.M., (1970) Soils in Norfolk III. Sheet TG31 (Horning), Soil Survey Record 42 , (Soil Survey of England and Wales, Harpenden)

Teshome Y., Kibret T, Gebrekidan H and Beyene S. (2013) Physical Land Suitability Evaluation for Rainfed Production of Cotton, Maize, Upland Rice and Sorghum in Abobo Area,western Ethiopia *American Journal of Research Communication* 1(10): 296-318www.usa-journals.com ISSN: 2325-4076.

Tinguely U. (2012) Suitability Mapping for *Jatropha curcas* Production in Kenya - A Spatial Modelling Approach. An Msc Theses submitted to Institute of Geography, Department of Integrative Geography Faculty of Natural Sciences University of Bern, Switzerland.

Truog E. (1948) Lime in relation to availability of plant nutrients. Soil Sci. 65: 1-7

Umar I. A. (2014) Land Suitability Evaluation for Cultivation of Arish Potato Under Faadama Irrigation Management in Rugu rugu of Tudun Wada Local Govt. of Kano State. An Unpublished Msc Theses submitted to Geography Department Bayero University Kano

Umar, G. (2011) Assessment of the Fertility Status of some Irrigated Fluvisols in Northern Guinea Savannah of Nigeria. Volume 6 (1); Savannah Journal of Agriculture ISSN 1597 9377 Faculty of Agriculture, Bayero University

Umweni, A. S. and Ogunkunle, A.O (2014) Comparison of the suitability of a 200 ha land for rice cultivation by three 'native' techniques in Southern Nigeria. *Journal of Agriculture and Veterinary Science* Vol. 7, Issue 2 Ver. I, PP 91-101.

Understander D. (2003) Sorghums Sudangrass and Sorghum Sudan Hybrid Univ. of Wisconsin Focus on Forage 5:5, Madison http://www.uwexedu/CES/crop/uwforage/sorghumsFOF.htm.

USDA (1993), U.S Dept. of Agriculture. Soil Survey Manual

USDA (1994). Natural Resources Conservation Service, *State Soil Geographic (STATSGO) Database - Data Use Information*. Misc. Publication No. 1492. National Soil Survey Center, Lincoln, NE.

USDA (2009), Natural Resources Conservation Service. Planting And managing switch grass as a biomass energy crop. Plant Materials Program. (http://plant materials.nrcs.usda.gov/pubs/NPMtechnotes/ npmptn3-13079.pdf). Accessed 12/08/ 2014

USDA (1951). Soil Conservation Service. Soil Survey Staff. Soil Survey Manual. U.S. Dept. of Agric. Handb. 18. U.S. Govt. Print. Off. Washington, DC. 503 pp., illus.

Usman A (2014) Rainfall variability in Kano region. Unpublished Msc. Theses submitted to the Department of Geography Bayero University Kano, Nigeria

Van Diepen C.A, Van Keulen H., Wolf J., and Berkhout J.A.A (1991) Land Evaluation from Intuition to Quantification. In BA. Stewart (ed) *Advance in Social Science* Springer New York 139-204 pp.

Van Ranst E., H.Tang, S. Groenemans, and S. Sinthurahat (1996), "Application of fuzzy logic to land suitability for rubber production in peninsular Thailand". *Geoderma*, vol.1, pp. 1-19

Voncir, N., S. Mustapha. V.A Tenebe, A.L. Kumo and S. Kushwaha (2008). Content and profile distribution of extract Zinc (Zn) and some physiological properties of soil along a toposequence at Bauchi, Northern Guinea Savannah of Nigeria International Journal of soil science 3:62-68

Walkley, A. and Black, A. (1934). An examination of Degtjareff Method of Determining Soil Organic Matter and a proposed modification of the chromic acid titration method. Soil Science 37: 29-38.

White, H. and Killick, T., (2001) African Poverty at the Millennium. The World Bank, Washington DC.

Wollenhaupt, N.C., R.P. Wolkowski, and M.K. Clayton. (1994) Mapping soil test phosphorus and potassium for variable-rate fertilizer application. *J. Prod. Agric*. 7:441-448.

World Bank, (2003) Sustainable development in a dynamic world. Transforming institutions, growth, and quality of life. World Development Report. The World Bank, Washington, DC.

www.ftp//glcf/landsat

Young, A. and P. Brown. (1962). The Physical environment of Northern Nyasaland. Govt. Printer, Zomba, Malawi.

APPENDICES

Appendix 1: Soil physical and chemical parameters

S/N	Sand	silt	Clay	Texture	Soil_Sampl	Ca (ppm)	Mg (ppm)	K (cmol/kg)	Na (ppm)	EC (ds/m)	pH	OC (%)	OM (%)	N (%)	P (ppm)	CEC (cmol/kg)
1	72	13	14	SaL	Bk1	2.37	0.61	0.15	0.12	12.4	5.3	0.21	0.36	0.03	2.3	3.34
2	76	9	14	SaL	Bk2	3.07	0.68	0.16	0.12	8	6.2	0.11	0.19	0.65	4.5	4.02
3	78	9	12	SaL	Bk3	2.6	0.78	0.14	0.09	0.1	5.1	0.01	0.02	0.74	1.7	3.7
4	78	9	12	SaL	Bk4	2.27	0.9	0.16	0.11	10	9.1	0.2	0.34	0.02	7.1	3.44
5	72	15	13	SaL	Bk5	2.33	0.48	0.16	0.13	9.6	6.3	0.03	0.05	0.03	7.6	3.1
6	76	11	13	SaL	Bk6	2.33	0.43	0.16	0.12	2	6.6	0.31	0.53	0.03	4.7	3.04
7	72	15	13	SaL	Bk7	6.44	0.85	0.15	0.12	5	5.9	0.29	0.5	0.03	1.7	3.56
8	78	7	15	SaL	Bk8	2.48	0.72	0.17	0.15	1.19	8.1	0.28	0.48	0.02	6.7	3.51
9	72	13	15	SaL	Bk9	2.2	0.92	0.14	0.18	0.02	6.4	0.2	0.34	0.02	1.7	3.41
10	70	13	16	SaL	Bk10	2.23	0.2	0.14	0.14	2.01	6.1	0.28	0.48	0.02	5.5	3.43
11	68	13	18	SaL	Bk11	2.44	1.23	0.14	0.12	3.01	6.4	0.29	0.5	0.03	3.3	3.93
12	76	11	12	SaL	Bk12	2.34	0.94	0.13	0.12	0.22	5.7	0.25	0.43	0.02	2.6	3.52
13	74	14	12	SaL	Bk13	2.16	1.05	0.13	0.14	1.33	5.6	0.19	0.32	0.02	2.5	3.82
14	76	11	12	SaL	Bk14	4.58	0.82	1.01	0.13	6	6.4	0.29	0.5	0.02	2.3	3.68
15	72	12	16	SaL	Bk15	2.42	1	0.16	0.11	0.33	9.96	0.19	0.32	0.71	2.5	3.69
16	78	8	14	SaL	Bk16	2.8	0.87	0.15	0.15	24	5.5	0.3	0.51	0.03	1.4	4.05
17	78	8	14	SaL	Bk17	2.33	0.76	0.16	0.11	2	5.7	0.36	0.62	0.03	2.6	3.36
18	56	18	26	SaCl	Bk18	2.26	0.78	0.13	0.14	3	4.7	0.35	0.6	0.03	1.8	3.39
19	62	20	18	SaL	Bk19	8.27	0.83	0.15	0.13	2.11	5.9	0.4	0.68	0.03	6.2	4.39
20	78	9	13	SaL	Bk20	4.41	0.95	0.15	0.14	15.7	6.3	0.3	0.51	0.03	2.5	3.65
21	78	9	13	SaL	Bk21	8.79	0.64	0.15	0.14	5.01	6.1	0.4	0.68	0.03	3.5	3.73
22	76	9	15	SaL	Bk22	2.28	0.96	0.15	0.15	19.22	5.6	0.36	0.62	0.03	2	3.53
23	78	10	12	SaL	Bk23	1.5	0.35	0.07	0.01	21.9	6.4	0.12	0.21	0.46	3.8	3.8
24	70	13	17	SaL	Bk24	1.13	0.28	0.02	0.01	12.47	6.8	0.16	0.27	0.63	0.7	7.8

25	56	20	24	SaCl	Bk25	7.21	0.14	0.02	0.02	9.09	4.8	0.16	0.27	0.56	1.4	4.4
26	62	22	16	SaCl	Bk26	2	0.19	0.01	0.02	3.39	4.8	0.24	0.41	0.53	1.4	4.5
27	62	20	18	SaL	Bk27	1.5	0.21	0.02	0.02	4.13	4.4	0.22	0.38	0.9	1.1	3.7
28	58	20	22	SaCl	Bk28	1.46	0.05	0.01	0.01	3.59	4.4	0.04	0.07	0.53	1.1	3.5
29	78	10	12	SaL	Bk29	1.3	0.05	0.03	0.02	51.4	5.4	0.14	0.24	0.67	0.7	6.5
30	78	10	12	SaL	Bk30	2.96	0.42	0.61	0.02	14.68	6.2	0.44	0.75	0.7	4.2	5
31	78	10	12	SaL	Bk31	5.21	0.14	1	0.01	5.91	5	0.48	0.82	0.53	2.1	4.2
32	76	10	14	SaL	Bk32	2.26	0.94	0.16	0.01	3.6	7.7	0.55	0.94	0.78	3.4	3.33
33	70	16	14	SaL	Bk33	8.27	1.05	0.15	0.01	1	6.4	0.21	0.36	0.83	4.4	4.01
34	78	10	12	SaL	Bk34	4.41	0.82	0.17	0.23	21.19	4.1	0.41	0.7	0.95	0.7	4.21
35	79	9	12	SaL	Bk35	8.09	1.1	0.14	0.22	12.47	6.4	0.23	0.39	0.04	3.7	2.07
36	79	9	12	SaL	Bk36	2.28	0.37	0.14	0.02	9.71	5.7	0.08	0.14	0.96	3.5	3.81
37	73	13	14	SaL	Bk37	1.5	0.76	0.14	0.01	3.29	5.6	0.1	0.17	0.35	3.8	2.31
38	69	13	18	SaL	Bk38	1.13	0.78	0.11	0.02	4.13	6.4	0.31	0.53	0.28	7.8	3.11
39	73	13	14	SaL	Bk39	7.21	0.73	0.13	0.2	3.59	9.9 6	0.2	0.34	0.14	1.4	3.29
40	69	13	18	SaL	Bk40	2	0.15	1.01	0.01	11.21	5.5	0.01	0.02	0.19	4.5	3.45
41	62	22	16	SaL	Bk41	1.5	0.04	0.16	0.11	14.68	5.7	0.22	0.38	0.21	3.7	4.02
42	68	10	22	SaL	Bk42	1.46	0.96	0.15	0.04	5.91	4.7	0.02	0.03	0.05	3.5	3
43	75	13	12	SaL	Bk43	1.3	0.35	0.1	0.1	0.11	3.3	0.09	0.15	0.05	6.5	3.12
44	68	16	16	SaL	Bk44	2.96	0.94	0.15	0.09	12.29	2.9	0.11	0.19	0.42	1	3.52
45	70	14	16	SaL	Bk45	9.21	1.05	0.13	0.21	3.45	8.9	0.22	0.38	0.3	4	3.07
46	68	14	18	SaL	Bk46	1.02	0.82	0.14	0.06	4.02	9.2	0.04	0.07	0.14	3.1	2.23
47	70	16	14	SaL	Bk47	2.21	1.1	0.14	0.11	2.23	3.6	0.02	0.03	0.84	0	3.9
48	76	10	14	SaL	Bk48	3.21	0.87	0.12	0.09	9.12	6.6	0.3	0.51	0.1	4.6	3.05
49	70	16	14	SaL	Bk49	2.91	0.76	0.14	0.1	13.5	6.4	0.06	0.1	0.04	2.1	3.01
50	78	11	11	SaL	Bk50	1.13	0.78	0.11	0.02	4.13	6.4	0.31	0.53	0.28	7.8	3.11
51	79	9	12	SaL	Bk51	5.21	0.14	1	0.01	5.91	5	0.28	0.48	0.53	2.1	4.2

Source: Data analysis (2014)

Appendix 2: Pearson's correlation matrix for various soil physical parameters

	Sand	silt	Clay	Ca	Mg	K	Na	EC	pH	OC	OM	N	P	CEC
Sand	1													
silt	-.901**	1												
Clay	-.862**	.562**	1											
Ca	.023	.030	-.068	1										
Mg	.216	-.270	-.110	.214	1									
K	.255	-.246	-.206	.145	-.218	1								
Na	.171	-.164	-.153	.360**	.514**	-.176	1							
EC	.238	-.210	-.191	-.114	-.263	-.028	-.066	1						
pH	.215	-.256	-.118	.172	.286*	-.054	.215	-.136	1					
OC	.219	-.218	-.154	.302*	.123	.192	.169	-.025	.115	1				
OM	.219	-.218	-.154	.300*	.121	.193	.168	-.024	.115	1.000**	1			
N	-.023	.095	-.051	-.049	-.268	-.002	-.483**	.145	-.187	-.091	-.090	1		
P	.177	-.172	-.145	-.050	.053	.006	-.026	-.242	.306*	.074	.074	-.336*	1	
CEC	-.032	.060	-.006	-.049	-.399**	.030	-.292*	.448**	-.149	.102	.101	.421**	-.352*	1

**. Correlation is significant at the 0.01 level (2-tailed). Source: Data analysis (2014)

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix 3: Pairwise Comparison Matrix for sorghum.

a Potassium (K)

Matrix		0 - 0.15 1	0.15 - 0.20 2	0.20 - 0.40 3	< 0.40 4	0 5	0 6	0 7	0 8	0 9	0 10	normalized principal Eigenvector
0 - 0.15	1	1	1/4	1/4	1/7	-	-	-	-	-	-	5.2%
0.15 - 0.20	2	4	1	1/4	1/7	-	-	-	-	-	-	10.5%
0.20 - 0.40	3	4	4	1	1/4	-	-	-	-	-	-	23.4%
< 0.40	4	7	7	4	1	-	-	-	-	-	-	60.9%
0	5	-	-	-	-	1	-	-	-	-	-	0.0%
0	6	-	-	-	-	-	1	-	-	-	-	0.0%
0	7	-	-	-	-	-	-	1	-	-	-	0.0%
0	8	-	-	-	-	-	-	-	1	-	-	0.0%
0	9	-	-	-	-	-	-	-	-	1	-	0.0%
0	10	-	-	-	-	-	-	-	-	-	1	0.0%

b Slope

Matrix		0 - 4 1	4 - 8 2	8 - 10 3	< 10 4	0 5	0 6	0 7	0 8	0 9	0 10	normalized principal Eigenvector
0 - 4	1	1	1	1/4	1/9	-	-	-	-	-	-	6.3%
4 - 8	2	1	1	1/4	1/8	-	-	-	-	-	-	6.6%
8 - 10	3	4	4	1	1/4	-	-	-	-	-	-	22.2%
< 10	4	9	8	4	1	-	-	-	-	-	-	64.9%
0	5	-	-	-	-	1	-	-	-	-	-	0.0%
0	6	-	-	-	-	-	1	-	-	-	-	0.0%
0	7	-	-	-	-	-	-	1	-	-	-	0.0%
0	8	-	-	-	-	-	-	-	1	-	-	0.0%
0	9	-	-	-	-	-	-	-	-	1	-	0.0%
0	10	-	-	-	-	-	-	-	-	-	1	0.0%

c Phosphorus (P)

Matrix		0 - 0.15 1	0.15 - 0.20 2	0.20 - 0.40 3	< 0.40 4	0 5	0 6	0 7	0 8	0 9	0 10	normalized principal Eigenvector
0 - 0.15	1	1	1/4	1/4	1/7	-	-	-	-	-	-	5.2%
0.15 - 0.20	2	4	1	1/4	1/7	-	-	-	-	-	-	10.5%
0.20 - 0.40	3	4	4	1	1/4	-	-	-	-	-	-	23.4%
< 0.40	4	7	7	4	1	-	-	-	-	-	-	60.9%
0	5	-	-	-	-	1	-	-	-	-	-	0.0%
0	6	-	-	-	-	-	1	-	-	-	-	0.0%
0	7	-	-	-	-	-	-	1	-	-	-	0.0%
0	8	-	-	-	-	-	-	-	1	-	-	0.0%
0	9	-	-	-	-	-	-	-	-	1	-	0.0%
0	10	-	-	-	-	-	-	-	-	-	1	0.0%

d CEC

Matrix		0 - 1.0 1	1.0 - 3.0 2	< 3.0 3	0 4	0 5	0 6	0 7	0 8	0 9	0 10	normalized principal Eigenvector
0 - 1.0	1	1	1	1/3	-	-	-	-	-	-	-	20.0%
1.0 - 3.0	2	1	1	1/3	-	-	-	-	-	-	-	20.0%
< 3.0	3	3	3	1	-	-	-	-	-	-	-	60.0%
0	4	-	-	-	1	-	-	-	-	-	-	0.0%
0	5	-	-	-	-	1	-	-	-	-	-	0.0%
0	6	-	-	-	-	-	1	-	-	-	-	0.0%
0	7	-	-	-	-	-	-	1	-	-	-	0.0%
0	8	-	-	-	-	-	-	-	1	-	-	0.0%
0	9	-	-	-	-	-	-	-	-	1	-	0.0%
0	10	-	-	-	-	-	-	-	-	-	1	0.0%

e. Magnesium {Mg)

Matrix		0 - 3 1	3 - 8 2	8 - 10 3	< 10 4	0 5	0 6	0 7	0 8	0 9	0 10	normalized principal Eigenvector
0 - 3	1	1	4	2	8	-	-	-	-	-	-	52.2%
3 - 8	2	1/4	1	2	9	-	-	-	-	-	-	25.8%
8 - 10	3	1/2	1/2	1	5	-	-	-	-	-	-	18.0%
< 10	4	1/8	1/9	1/5	1	-	-	-	-	-	-	4.0%
0	5	-	-	-	-	1	-	-	-	-	-	0.0%
0	6	-	-	-	-	-	1	-	-	-	-	0.0%
0	7	-	-	-	-	-	-	1	-	-	-	0.0%
0	8	-	-	-	-	-	-	-	1	-	-	0.0%
0	9	-	-	-	-	-	-	-	-	1	-	0.0%
0	10	-	-	-	-	-	-	-	-	-	1	0.0%

f. pH

Matrix		6 - 8 1	5.5 - 6 2	8.1 - 8.5 3	8.5 - 9 4	0 - 5.5 5	< 9 6	0 7	0 8	0 9	0 10	normalized principal Eigenvector
6 - 8	1	1	5	4	7	7	9	-	-	-	-	50.2%
5.5 - 6	2	1/5	1	1	4	4	6	-	-	-	-	17.0%
8.1 - 8.5	3	1/4	1	1	5	5	7	-	-	-	-	19.5%
8.5 - 9	4	1/7	1/4	1/5	1	1	2	-	-	-	-	5.1%
0 - 5.5	5	0	0	0	1	1	2	-	-	-	-	5.1%
< 9	6	0	0	0	1	1	1	-	-	-	-	3.1%
0	7	-	-	-	-	-	-	1	-	-	-	0.0%
0	8	-	-	-	-	-	-	-	1	-	-	0.0%
0	9	-	-	-	-	-	-	-	-	1	-	0.0%
0	10	-	-	-	-	-	-	-	-	-	1	0.0%

g. Organic Carbon (OC)

Matrix		0 - 0.20 1	0.20 - 0.50 2	0.50 - 0.75 3	< 0.75 4	0 5	0 6	0 7	0 8	0 9	0 10	normalized principal Eigenvector
0 - 0.20	1	1	1/4	1/4	1/9	-	-	-	-	-	-	4.8%
0.20 - 0.50	2	4	1	1	1/5	-	-	-	-	-	-	15.5%
0.50 - 0.75	3	4	1	1	1/5	-	-	-	-	-	-	15.5%
< 0.75	4	9	5	5	1	-	-	-	-	-	-	64.3%
0	5	-	-	-	-	1	-	-	-	-	-	0.0%
0	6	-	-	-	-	-	1	-	-	-	-	0.0%
0	7	-	-	-	-	-	-	1	-	-	-	0.0%
0	8	-	-	-	-	-	-	-	1	-	-	0.0%
0	9	-	-	-	-	-	-	-	-	1	-	0.0%
0	10	-	-	-	-	-	-	-	-	-	1	0.0%

h. Electric conductivity (EC)

Matrix		2 - 4 1	4 - 8 2	8 - 10 3	< 10 4	0 5	0 6	0 7	0 8	0 9	0 10	normalized principal Eigenvector
2 - 4	1	1	4	6	9	-	-	-	-	-	-	61.6%
4 - 8	2	1/4	1	2	7	-	-	-	-	-	-	21.2%
8 - 10	3	1/6	1/2	1	6	-	-	-	-	-	-	13.4%
< 10	4	1/9	1/7	1/6	1	-	-	-	-	-	-	3.7%
0	5	-	-	-	-	1	-	-	-	-	-	0.0%
0	6	-	-	-	-	-	1	-	-	-	-	0.0%
0	7	-	-	-	-	-	-	1	-	-	-	0.0%
0	8	-	-	-	-	-	-	-	1	-	-	0.0%
0	9	-	-	-	-	-	-	-	-	1	-	0.0%
0	10	-	-	-	-	-	-	-	-	-	1	0.0%

i. Soil Draidage

Matrix		Well drained 1	Moderatly drained 2	Poorly drained 3	0 4	0 5	0 6	0 7	0 8	0 9	0 10	normalized principal Eigenvector
Well drained	1	1	4	9	-	-	-	-	-	-	-	70.9%
Moderatly drained	2	1/4	1	5	-	-	-	-	-	-	-	23.1%
Poorly drained	3	1/9	1/5	1	-	-	-	-	-	-	-	6.0%
0	4	-	-	-	1	-	-	-	-	-	-	0.0%
0	5	-	-	-	-	1	-	-	-	-	-	0.0%
0	6	-	-	-	-	-	1	-	-	-	-	0.0%
0	7	-	-	-	-	-	-	1	-	-	-	0.0%
0	8	-	-	-	-	-	-	-	1	-	-	0.0%
0	9	-	-	-	-	-	-	-	-	1	-	0.0%
0	10	-	-	-	-	-	-	-	-	-	1	0.0%

j. Sodium (Na)

Matrix		0 - 0.03 1	0.03 - 0.05 2	0.05 - 0.10 3	< 1.0 4	0 5	0 6	0 7	0 8	0 9	0 10	normalized principal Eigenvector
0 - 0.03	1	1	2	2	9	-	-	-	-	-	-	44.3%
0.03 - 0.05	2	1/2	1	4	8	-	-	-	-	-	-	36.5%
0.05 - 0.10	3	1/2	1/4	1	4	-	-	-	-	-	-	15.1%
< 1.0	4	1/9	1/8	1/4	1	-	-	-	-	-	-	4.2%
0	5	-	-	-	-	1	-	-	-	-	-	0.0%
0	6	-	-	-	-	-	1	-	-	-	-	0.0%
0	7	-	-	-	-	-	-	1	-	-	-	0.0%
0	8	-	-	-	-	-	-	-	1	-	-	0.0%
0	9	-	-	-	-	-	-	-	-	1	-	0.0%
0	10	-	-	-	-	-	-	-	-	-	1	0.0%

k. Soil characteristics

Matrix		Sandy clay 1	Sandy clay loam 2	Complex soil 3	Undiffrentiated texture 4	Badland 5	Rock outcrop 6	Loamy sand 7	0 8	0 9	0 10	normalized principal Eigenvector
Sandy clay	1	1	1	7	7	8	9	4	-	-	-	33.2%
Sandy clay loam	2	1	1	5	8	7	9	5	-	-	-	33.3%
Complex soil	3	1/7	1/5	1	3	5	7	1/4	-	-	-	8.2%
Undiffrentiated texture	4	1/7	1/8	1/3	1	1	4	1/8	-	-	-	3.6%
Badland	5	1/8	1/7	1/5	1	1	2	1/7	-	-	-	3.0%
Rock outcrop	6	1/9	1/9	1/7	1/4	1/2	1	1/7	-	-	-	2.0%
Loamy sand	7	1/4	1/5	4	8	7	7	1	-	-	-	16.6%
0	8	-	-	-	-	-	-	-	1	-	-	0.0%
0	9	-	-	-	-	-	-	-	-	1	-	0.0%
0	10	-	-	-	-	-	-	-	-	-	1	0.0%

l. Land uses

Matrix		Cultivated land 1	Wetland 2	Baresoil 3	Vegetation 4	Badland 5	Water body 6	Buit-up are 7	Rock outcrop 8	0 9	0 10	normalized principal Eigenvector
Cultivated land	1	1	2	8	3	8	9	9	9	-	-	38.1%
Wetland	2	1/2	1	2	2	7	8	8	9	-	-	21.2%
Baresoil	3	1/8	1/2	1	1/2	7	7	9	9	-	-	14.0%
Vegetation	4	1/3	1/2	2	1	4	8	8	8	-	-	15.7%
Badland	5	1/8	1/7	1/7	1/4	1	1	3	6	-	-	4.4%
Water body	6	1/9	1/8	1/7	1/8	1	1	1	1	-	-	2.5%
Buit-up are	7	1/9	1/8	1/9	1/8	1/3	1	1	1	-	-	2.1%
Rock outcrop	8	1/9	1/9	1/9	1/8	1/6	1	1	1	-	-	2.0%
0	9	-	-	-	-	-	-	-	-	1	-	0.0%
0	10	-	-	-	-	-	-	-	-	-	1	0.0%

m. Soil Depth

Matrix		Deep soil 1	Moderatly deep soil 2	Shallow soil 3	0 4	0 5	0 6	0 7	0 8	0 9	0 10	normalized principal Eigenvector
Deep soil	1	1	4	7	-	-	-	-	-	-	-	69.6%
Moderatly deep soil	2	1/4	1	4	-	-	-	-	-	-	-	22.9%
Shallow soil	3	1/7	1/4	1	-	-	-	-	-	-	-	7.5%
0	4	-	-	-	1	-	-	-	-	-	-	0.0%
0	5	-	-	-	-	1	-	-	-	-	-	0.0%
0	6	-	-	-	-	-	1	-	-	-	-	0.0%
0	7	-	-	-	-	-	-	1	-	-	-	0.0%
0	8	-	-	-	-	-	-	-	1	-	-	0.0%
0	9	-	-	-	-	-	-	-	-	1	-	0.0%
0	10	-	-	-	-	-	-	-	-	-	1	0.0%