LAND EVALUATION AND SUITABILITY ASSESSMENT FOR CROPS PRODUCED IN BUTUGURI AREA, BUTIAMA DISTRICT IN MARA REGION, TANZANIA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN SOIL SCIENCE AND LAND MANAGEMENT OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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ABSTRACT

Land evaluation was conducted in Butuguri area, Butiama District, Mara Region to assess land's suitability for cassava, maize and sorghum production. After reviewing literature and discussing with farmers and extension officers, five criteria for growing crops were selected which are: soil physical properties, soil chemical fertility, rainfall, temperature and topography. The Analytical Hierarchical Process was used to assign relative importance weights to the chosen criteria. Spatial information regarding the selected criteria were generated. Soil information was obtained by combining transects and free soil surveys after the preparation and confirmation of the base map. Climatic data were obtained from WorldClim and topographic data using Digital Elevation Map image (DEM). Seven soil units were mapped in Geographical Information System (GIS) after field and laboratory works. Soils were classified to four USDA soil orders: Inceptisols, Entisols, Alfisols and Mollisols. They were further classified to seven subgroups: Entic Haplustolls, Oxyaquic Haplustepts, Typic Kandiustalfs, Humic Dystrustepts, Typic Dystrustepts, Typic Ustipsamments and Vermic Ustorthents. In World Reference Base (WRB), soils were grouped into five Reference Soil Groups: Chernozems, Cambisols, Umburisols, Leptosols and Regosols and further classified into seven groups: Fractic Chernic Phaeozems (Colluvic, Novic), Ferralic Dolomitic Cambisols (Arenic, Aric), Cambic Acric Umbrisol (Arenic, Pachic), Skeletic Andic Cambisol (Aric, Ferric), Andic, Fragic Cambisol (Alcalic, Arenic), Gleyic Technic Leptosol (Arenic, Aric) and Brunic, Leptic Regosol (Arenic, Aric). Climate spatial information showed that the area has average temperature ranging between 21.1 ^{o}C and 22.2 ^{o}C, and annual rainfall ranging between 930 and 1160 mm. Topography spatial data showed the level, sloping to mountainous lands. The assigned weights indicated that soil's physical and chemical fertility were the most important attributes for growing cassava and sorghum, while rainfall was the most important factor for growing maize. The resulting suitability maps established indicated that soil physical and chemical properties were the most limiting for production of the three crops, although rainfall, temperature and topography were the least limiting.

DECLARATION

I, Zuwena Jackson, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work within the period of registration and that it has neither been submitted nor being concurrently submitted for a degree award in any other institution.

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(Supervisor)

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LIST OF ABBREVIATIONS AND SYMBOLS

AHP	Analytical Hierarchical Process
ALES	Automated Land Evaluation System
ALSE	Agricultural Land Suitability Evaluation
BPMSG	Business Performance Management Singapore
CEC	Cation Exchange Capacity
CR	Consistency Ratio
DEM	Digital Elevation Model
DPTA	Diethylenertiaminepentaacetic Acid
FAO	Food and Agriculture Organisation of the United Nations
FAOSTAT	Food and Agriculture Organisation Statistical Database
FESLM	Framework for Evaluation of Sustainable Land Management
GDP	Gross Domestic Product
GIS	Geographic Information System
IITA	International Institute of Tropical Agriculture
IUSS	International Union of Soil Sciences
KCl	Potassium Chloride
MCDM	Multi Criteria Decision Making
NBS	National Bureau of Statistics (Tanzania)
NFYDPT	National Development Plan of Tanzania
NSCA	National Sample Census of Agriculture
QGIS	Quantum Geographic Information System
RGS	Reference Soil Group
SOTER	Soil and Terrain Database
STRM	Shuttle Radar Topographic Mission
SUA	Sokoine University of Agriculture
USDA	United States Department of Agriculture
USGS	United States Geological Survey

WEMA	Water Efficient Maize for Africa
WRB	World Reference Base for Soil Resources

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information and Justification

Agriculture's ability to support growing populations has been a concern for generations and continues to be high on the global policy agenda (Rosegrant and Cline, 2003). Production of more food and fibre for feeding and clothing a growing population with a smaller labour force, production of more feedstock, contribution to overall development in the many agriculture-dependent developing countries, and adoption to more efficient and sustainable production methods to adapt to changing climate, are 21st Century's agricultural challenges (Food and Agriculture Organisation (FAO), 2009). Global population, the main challenge of agricultural development, is expected to reach 9 - 10 billion by the year 2050 and approximately 12 billion by 2100 (Smith, 2018). Although global food demand is expected to increase 60% by 2050, the rise will be much greater in Sub-Saharan Africa (SSA) as population will increase 2.5-fold by the year 2050 (Van Ittersum *et al.,* 2016).

Despise the high population (FAO, 2009), and expected 2.5-fold increase by 2050 (Van Ittersum *et al.,* 2016), SSA agricultural productivity is stagnant or declining because of land degradation driven by inappropriate land use caused by poverty (Lambina *et al.*, 2001). To alleviate poverty and sustain the growing population in SSA, sustainable management and utilization of steady land for the present and future generations should be considered (Smith, 2018). Through integrated long-term approach for rational utilization of the natural land resources and the elimination of current environmental and socio-economic problems, poverty alleviation will be achieved and population growth will be sustained. Intensive and sustainable use of agricultural and ecological systems such as water, soil, biodiversity and land will ensure production of food in Sub-Saharan Africa.

For this reasons, each country in SSA need to adapt the idea of land evaluation to overcome changing land use needs and pressure involving competing uses for the same land (FAO, 1976). Scientists working in land development have to interpret resource inventories for users and planners of land to achieve sustainability in agriculture (Rossiter, 1990). This can be done by making sure these groups know the suitability of land area for actual and expected uses. However, to evaluate suitability of land, somebody is supposed to have a good knowledge of soils and their production potential, through soil survey and soil survey interpretation (Verheye, 2009), which is lacking in many SSA countries Tanzania being one of them.

Undoubtedly, agricultural sector in Tanzania is faced with a multitude of problems which include low soil fertility and unsustainable agricultural practices leading to land degradation (Adamu, 2016). This has been highly contributed by continuous cultivation and cropping without any replenishment which affects soil physical and chemical properties (Butiama District Profile, 2013). A good data bank on soil physical and chemical properties and other ecological condition characteristics is a basic requirement to advise both current and potential land users on how to use the land in the best possible way (Msanya *et al.,* 2016).

Deckers *et al.* (2009) reported that soil survey retain fundamental geological concept as a major part of the information needed for land evaluation. Soils characterised in Tanzania by soil survey, produce information that provide baseline data for land evaluation (Samki, 1982; De Pauw, 1984). However, information obtained is inadequate with concentration only in a few selected high potential areas (Msanya *et al.,* 1991; Msanya and Magoggo, 1993; Kilasara *et al.,* 1994). The few existing soil resource inventories used small scale (1: 2 000 000) with high level of generalization, being based on rather few observations scattered over large areas (Msanya *et al.,* 2003) which were inadequate for land use planning at local levels (National Soil Service, 2006). Such vital information is mostly lacking for most parts of Tanzania including Mara Region where this study was conducted.

Although land evaluation and suitability assessment for rain-fed crops have been carried out in some parts of Tanzania giving areal distribution of soil information; farmers are not or are less involved in the process. It has also been noted that many land evaluation studies conducted (Kaaya *et al.,* 1994; Msanya *et al.*, 2001a, b ; Kimaro *et al.*, 2001; Msanya *et al.,* 2002; Kimaro *et al.,* 2003) put emphasis on soil information to produce suitability maps putting less consideration on other criteria or attributes such as climate, topography and other socio-economic attributes. The evaluation was done based on traditional land evaluation with empirical expert judgments putting less emphasis on computer based land evaluation which can be handled by Geographical Information Systems (GIS) database that can be utilized regardless of scale, at national, regional or farm level (De la Rosa and Van Diepen, 2002).

From the above observations, it seems important to pay attention on how soil, climate and topography singly or in association may have influence on land suitability for different land uses. Therefore, this study focused on evaluating land of Butuguri area for multiple crop suitability, using spatial bio-physical attributes of the area. The study involved farmers and extension staff in the area.

1.2 Objectives of the Study

1.2.1 Main objective

The main objective was:

To analyse the suitability of land for maize, cassava and sorghum in Butuguri area in Butiama District in Mara Region, following land evaluation.

1.2.2 Specific objectives

Specific objectives were to:

(i) Identify attributes/criteria important for growing cassava, maize and sorghum and rank them based on their importance for cassava, maize and sorghum production in Butuguri area.

(ii) Establish spatial distribution of the attributes/criteria important for growing cassava, maize and sorghum in the study area.

(iii) Produce suitability maps of the criteria important for growing cassava, maize and sorghum grown in Butuguri area.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Basic Definitions and Concepts in Land Use Planning

2.1.1 Land

Land is an area of the earth's terrestrial surface, including all attributes of the biosphere immediately above or below, the surface hydrology, near-surface sedimentary layers and groundwater reserve, living organism populations, the human settlement pattern and physical results of past and present human activity (FAO, 1995). Roser and Ritchie (2018) elaborated that only 71 % of earth's land surface is defined as habitable; the remaining 29 % comprises glaciers and barren land having thin soil, sand or rocks and deserts, dry salt flats, beaches, sand dunes, and exposed rocks. Land is the fundamental source of wealth and many civilizations in the earth (Rossiter, 1996). It is highly sought to a greater or lesser point for various current or future human activities (International Organisation of Supreme Audit Institution Working Group on Environmental Auditing (INTOSAI WGEA), 2013).

Correspondingly, humans use 51% of the global habitable area for agricultural production; the remaining 37 % is forested; 11 % as shrubbery; and only 1 % is utilised as urban infrastructure (Roser and Ritchie, 2018). Following all human uses of land; same land may have several uses or same land use can occur on several different parcels of land. There are different groups of people using land resources and the way one group uses, or wishes to use the land may vary from another group (Dell *et al*., 1986).

Moreover, agriculture is one of the ancient land uses discovered by man. More than three-quarters of agricultural land is used for the rearing of livestock through a combined use of grazing land and animal feed production whereas crop production has 23% (Roser and

Ritchie, 2018). However, the amount and quality of land available for agriculture is under pressure from the decisions and demands made by consumers, producers, and governments. Due to pressure of use, the total land area available for agricultural production is finite and the marginal cost of transforming agricultural land is high, creating a potential constraint to population growth (Lans *et al.,* 2014). Therefore, to spare land from crop production, yields need to increase at a faster rate outreaching population growth (Ritchie, 2017). This is not implausible as most countries though can manage to increase food production in decades, their efforts are offset by a growing population. Having considered that, planning of land use should be another consideration for using the available agricultural land.

2.1.2 Land use planning

The use of land in a rational and equitable way primarily for development requires land planning (Rossiter and Van Wambeke, 1989). Land use planning ought not to be based primarily on the needs and demands of the users but, rather, on the information of suitable land uses in order to achieve environmental sustainability (Nuga and Akinbola, 2015). FAO (1993) defined land use planning as "the assessment of land and water potential, alternative for land use and economic and social conditions in order to select and adopt the best land use options with the purpose of selecting and putting into practice those land use that will best meet the need of the people while safeguarding resources for the future". It has been elaborated by FAO experts that land uses are matched through a multiple goal analysis and assessment of the intrinsic value of the various environmental and natural resources of the land unit (FAO, 1995). The result is an indication of a preferred future land use, or a combined set of uses.

Correspondingly, Cox *et al.* (2013) found that food security depends on long-term land use planning to ensure the availability of sufficient fertile land, water quantity and quality is met. This can only be reached by safeguarding sustainable agricultural development that contributes to improving resource efficiency, strengthening resilience and securing social responsibility of agriculture and food systems in order to ensure food security and nutrition for all, now and in the future (The High Level Panel of Experts (HLPE), 2016).

Hence, for land use planning to be sustainable especially in need for land use change, there must be political will and ability to put plan into effect (FAO, 1993). This requires land use planning to be integrated approach by involving all stakeholders in the process of decision making on the future use of the land and the identification and evaluation of all biophysical and socio-economic attributes of land units (FAO, 1995). Considering that perspective, land use planning is having two spheres namely, the urban planning sphere and rural planning sphere. Expansion of settlement, industrial area, infrastructure (harbours, airports) and associated free land markets is vital in urban planning sphere. Rural planning sphere is mainly done for agriculture, rural land is divided on the basis of physical and biological characteristics for agricultural land use planning. This includes: climate, soils, terrain forms, land cover, and water resources. Soil characteristics in agricultural land use planning are used for evaluating potential and constraints of land.

Bacic *et al.* (2003) found that land users and planners were ignoring land evaluations as part of land use planning because the soil information obtained were of poor quality and low in relevance, or they did not contain crucial information necessary for the farmer taking decisions. Recently, agricultural land use planning has been successful due to efficient and relevant use of soil and other information obtained through land evaluation (Feizizadeh and Blaschke, 2013). Therefore, for agricultural planning to be sustainable, different land resource information need to be stored in data storage devise for national and international reference and so that they can be easily reached and exploited by many users (Chandran *et al.*, 2015).

2.2 Land Evaluation and Soil Survey

2.2.1 Land evaluation

In 2014, Adesemuyi defined land evaluation as "the prediction of land performance over time based on ability of the land to meet requirements of specific types of use and then using the prediction results to make decisions of land use" The prediction of land is done in term of expected benefits, constraints or environmental degradation from uses of a productive land (Rossiter, 1996). Changing land use needs and pressure involving competing uses for the same land are big drivers of land evaluation (FAO, 1976). Verheye (2009) reported that people started to make decisions on land and land use some 10 000 – 12 000 years ago when civilization changed from hunters and hazardous fruit pickers towards a more sedentary lifestyle. In that time land and land-related issues were directly related to agricultural or livestock production and assessment of the qualities of land remained a matter of local rural expertise. Land was considered as a natural free gift available to all members of a clan. As long as the population was small in number, the competition for land remained relatively small. From the moment when population increased, competition of use started to build up (Mhawish and Saba, 2016), opening the need for land evaluation.

Modern land evaluation practices grew out of agricultural land capability classification when FAO's Land and Water Development division (AGL) published the "Framework for Land Evaluation" in 1976 (FAO, 1976). Subsequently, FAO organised workshops leading to publication of guidelines for land evaluation in rain-fed agriculture (FAO, 1983), forestry (FAO, 1984) irrigated agriculture (FAO, 1985) and extensive grazing (FAO, 1991). With the great assistance of FAO framework and guidelines, land evaluations have been carried out for different purpose in different part of the world.

Although land evaluation involves the execution and interpretation of basic surveys of climate, soils, vegetation and other aspects of land in terms of the requirements of alternative forms of land use (FAO, 1976), it has remained pedocentric (Rossiter, 1996). This is due to the fact that many who worked on early surveys were pedologists who were skilled in the study of soils especially for agricultural land suitability (Soil Science Division Staff, 2017). Realising that soil formation is influenced by different factors, some soil scientists working as land evaluators have incorporated non-soil information into their evaluation. Agidew (2015) did suitability assessment of land for sorghum production using climatic data, topographic data and length of growing period as well as crop requirements. Olowojoba *et al.* (2016) included climate data such as rainfall and temperature, weather information such as sunshine hours together with soil information to evaluate land suitability for cassava production.

2.2.2 Land evaluation for rain-fed agriculture

Rain-fed agriculture is agriculture that is totally dependent on rainfall (Devendra, 2016). Rain-fed agriculture plays, and will continue to play, a significant role in global food production. Apart from 20% of global food production which depends on irrigation agriculture, 80% of agriculture depends on rainfall, making rain-fed agriculture contribute about 58% to the global food basket (Wani *et al.*, 2009). About 95% of the current population growth occurs in developing countries and a significant proportion of these people still depends on predominantly rain-fed agriculture for household income (Rockstrom *et al.*, 2003). Egeru (2012) found that in Africa, most countries derive over 50% employment from agriculture, mostly depending on rainfall. Agricultural production in Eastern Africa is mainly rain-fed although rainfall is highly variable and unreliable in many areas (Nakawuka *et al.*, 2018).

In Tanzania, agriculture provides about 70% of employment, accounts for about 23% of Gross Domestic Product (GDP), 30 % of exports and 65% of inputs to the industrial sector

(National Five Year Development Plan Tanzania (NFYDPT), 2016). Despite its importance in the national economy, agriculture is very much affected by unreliable rainfall and periodic droughts (Tumbo *et al.,* 2017). Unfortunately, rain-fed agriculture is constrained by many problems, including moisture stress, soil erosion and crusting, nutrient deficiency, depletion and poor nutrient use efficiency and weed infestation; all these limit the yield potential of these lands (Baig *et al.,* 2013). Disease infestation is another problem facing rain-fed agriculture. Recently, Sub-Saharan Africa, especially East Africa, is having a fall armyworm (*Spodoptera Furgiperda*) crisis which has resulted into severe damage to more than 80 plant species, especially cereal crops such as maize and rice at all stages of growth and spreads very fast in the early stages and damage can lead to 100% crop loss (Mtaki, 2017). Heavy infestation of fall armyworm has been recently reported in Tanzania (FAO, 2018). Future climate change especially variability in the frequency and intensity of rainfall, temperature and evapotranspiration increase the risk in rain-fed crop production (Kassie *et al.,* 2014).

Following FAO guideline for rain-fed agriculture (FAO, 1983), land evaluation for agricultural crop productions especially in rain-fed agriculture, has been carried out in different parts of the world. Gameda and Dumenski (1995) assessed the sustainability of two land-use systems (rain-fed cereals and livestock) in the Canadian Prairies using the Framework for Evaluation of Sustainable Land Management (FESLM). They found that the conservation-based land-use system was more sustainable than the conventional one.

In Africa, land evaluation for rain-fed agriculture has been carried out in different countries putting into account agricultural great potential to support economic growth and reduce poverty and hunger across the continent. Land evaluation for Agriculture has been done in South Africa by Ghebremeskel (2003) evaluating the suitability of land for rain-fed agriculture using soil, topography and climatic data. He used the FAO method of suitability rating using both expert's knowledge as well as GIS information such as Digital Elevation Map (DEM). He came with suitability results for different crops as well as limitations for crop production in specific areas. Other land evaluation studies include that done in Nigeria by Olowojoba *et al.* (2016) assessing land suitability and evaluation for the production of cassava using geo technology. Geographical Information System used to bring bio-physical factors such as rainfall, temperature, sunshine hours, soil, soil slope, elevation and geology together to ascertain the most suitable area for cassava production in the area. The most suitable areas were highlighted for large scale cassava production for industries and prospective investors.

It is important to note however, that in East Africa, land evaluation and suitability assessment for rain-fed agriculture was done in the Western part of Kenya by Wandahwa and Van Ranst (1996). They assessed the qualitative suitability for pyrethrum cultivation using expert knowledge and GIS consisting of a collection of computer programs that act upon a geographical database. They came up with climatic and land suitability maps accounting for soil suitability and limitation of soil in the area for production of a specific crop. The study done in Kenya seems to be primitive compared to that done in Rwanda by Verdoodt and Van Ranst (2003) which used spatial data to evaluate the land. However, the study in Rwanda covered the whole country, relying on a small scale 1:250 000 covering land suitability classification for all the crops grown in at country. In Uganda land suitability evaluation was done for cash and food crops by Nuwategeka *et al.* (2014). The study involved Acholi ethnic group of northern Uganda, coming up with land suitability evaluation results for different crops indicating different soil types (management units) following indigenous knowledge.

In Tanzania, part from the country study of soil and physiography (De Paw, 1984) and the soil and terrain study (Eschweiler, 1998) at a scale of 1: 2 000 000; few studies on agricultural land evaluation have been carried out. Such studies include land evaluation done in Morogoro and Zanzibar (Hettige, 1990, Msanya *et al.*, 2001a; Kimaro *et al*., 2001). In Zanzibar, evaluation and suitability of land was done for various agricultural crops and other uses, to produce maps showing basic data required for planning purposes. However, the applicability of this study results are questionable (Hettige, 1990).

Evidently, in Morogoro Region, land inventory was done in Morogoro Urban aiming at providing data at semi-detailed exploratory scale of 1:50 000 for land planners, conservationists, agriculturists and other users. The small scale used made it fall into limited application in detailed planning for sustainable exploitation and conservation of the soil and land resources opening room for detailed studies (Msanya *et al*., 2001a). Another study relating to this was done in rural part of Morogoro (Kimaro *et al.*, 2003) and another one done in Kilosa District (Kimaro *et al.*, 2001). A study done at Sokoine University of Agriculture (SUA) aimed at assessing the suitability of soil for some crops under rain-fed conditions aimed at benefiting farmers within the University (Kaaya *et al*., 1994). Another study done in Kilosa was economic land evaluation assessment revising the potential of large-scale Jatropha oil production in Tanzania. This study focused on covering economic land evaluation (Segerstedt and Bobert, 2013). The studies done were based on traditional land evaluation with empirical expert judgments and little involvement of local people. All the studies were done to some parts of the country, covering some areas of interest regarding the objective of each study and the research data obtained could not provide detailed land evaluation information of the whole country and, sometimes, even of the locality in which it was done.

In Kilombero District of Morogoro Region, a study by Massawe (2015) focused on digital soil mapping and GIS-based land evaluation for rice suitability in Kilombero valley, which provided information on suitability of land for rice production. Geographical information obtained in this study can be easily acquired and retrieved but it relied on a single crop giving farmers very little chance to exploit the land for other uses.

In Butiama District, specifically Butuguri area, no detailed land evaluation and suitability assessment has been done at large scale to cover the area considering agricultural crops grown and other land resource uses. This opened room for large scale land evaluation that would involve indigenous people to make it applicable and highly sustainable.

2.2.3 Soil in land evaluation

2.2.3.1 Soil

Soil can be defined as "the entire surficial earthy layer which is inhabited by plant roots limited by the depth at which roots are found" (Sibirtsev, 1900). In Soil Taxonomy (Soil Survey Staff, 2017) soil is defined as "a natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that is distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment". In this definition of soil, soil depth was not considered but natural bodies included all genetically related parts of the soil that is either capable of supporting plants or has horizons or layers that are the result of the pedogenic processes.

Modern concept defines soil as "a natural three-dimensional body at the Earth's surface capable of supporting plants and has properties resulting from the effects of climate and living matter acting on earthy parent material, as conditioned by relief and by the passage of time" (Lindbo *et al.*, 2012). Soil is composed of physical, chemical, gas; soluble and insoluble, and organic as well as inorganic substances. There are ions and compound such as salts, acids, bases, minerals and rock fragments (Osman, 2012). Since the soil-forming factors are responsible for the genetic development of soil profiles; the relationships between landscapes, landforms, and soils are used to understand the predictable patterns of natural soil bodies in the landscape by a method known as soil survey (Soil Science Division Staff, 2017).

2.2.3.2 Soil physical properties

Soil physical properties are the properties that depend on the history of soil formation and can be substantially modified by human intervention such as agricultural practice (Delgado and Gomez, 2016). Important physical properties of soil include colour, texture, structure, porosity, density, consistency, temperature and air (Osman, 2012). These properties affect air and water movement in the soil, thus affecting crop production (McCauley *et al.*, 2005).

2.2.3.3 Soil chemical properties

Because the soil is a chemical entity, all the materials making soil are chemical substances (Osman, 2012). Soil chemical properties are formed as a result of chemical weathering. The particles are also called colloids; they are very active chemically because of having ion exchange properties and other important indices of soil, chemical environment such as pH and redox potential (Eh).

Soil chemical properties directly affect production of runoff and erosion processes and how these properties may interact with time can result into conditions which further affect the interaction between soil and rainfall (Lal, 1998). Some soil chemical properties are not easily altered. This includes: composition of soil solution and exchange phase, pH, redox potential (Eh) and organic matter contents. Other chemical properties of soil such as mineralogy and charge density of clays are altered easily and are important in determining the physical properties of soil such as aggregation, water holding capacity, density and porosity.

2.2.4 Soil survey

The Soil Science Division Staff (2017) defined soil survey as "the method which describes the characteristics of the soils in a given area, classifies the soils according to a standard system of taxonomy, plots the boundaries of the soils on a map, stores soil property information in an organized database, and makes predictions about the suitability and limitations of each soil for multiple uses as well as their likely response to management systems". Soil survey involves the background study of the area, ground-truthing of collected geo-referenced information such as aerial or remote sensing data, in-depth soil profile study and soil sampling, extrapolation and boundary verification, laboratory analysis and data crunching, map production, interpretation and reporting (Deckers *et al.*, 2009). A soil map consists of much individual delineations showing the location and extent of different soils. The collections of all delineations that have the same symbol on the map are called map unit. Each map unit is named for one or more soils or non-soil areas. In early time soil surveys were done by geologists who thought of soils as mainly the weathering products of geologic formations because they were the only ones who were skilled in the field methods and scientific correlation needed for the study of soils. Later on other features were obtained which refined the information but retained fundamentally geological concepts.

Soil survey is used for evaluating the quality of different mapping units for specific types of land use; it provides only part of the information needed for land evaluation (Deckers *et al.,* 2009). Soil survey is done together with land utilization types determining land use requirements by observing favourable and unfavourable land properties to each kind of use, as well as erosion and soil degradation hazards (FAO, 1985). Survey results are used for production of mapping units, where land quality and characteristics for suitability assessment are measured or estimated.

In Tanzania, a database of soil and terrain (SOTER) has been surveyed at a scale of 1:2 000 000 (Eschweiler, 1998). The main source of SOTER database was the early work of De Pauw (1984) who produced a soil and physiography map and reported it as soils, physiography and agro-ecological zones of Tanzania and it served as a basis for delineation of SOTER units and displaying the land units. The scale used was very small resulting into a reduced number of attributes and generalization of information. The type soil survey carried out was exploratory and it was for the whole country which made it less specific especially for small areas.

Apart from SOTER work and early work of De Pauw, regional surveys were done in some regions at a scale of 1:100 000 to 1:500 000 for resource inventories aiming at studying suitability of land for relevant land use in sustainable way in Kilimanjaro, Mbeya, Tabora, Tanga and Rukwa. Detailed soil surveys at a scale of 1:5000 to 1:10 000 have been done under project covering small areas farms, estates, irrigation schemes and village areas to solve project design and development and production constraints (Msanya *et al.,* 2002). However, the results aimed at meeting project designed objectives.

2.3 Soil Suitability Evaluation.

To optimise the use of soil resources and external inputs such as fertilizers, suitability assessment of land is very crucial. Soil suitability is the degree of appropriateness of land for a certain use and it can be assessed for present conditions or after improvements (Ritung *et al*., 2007). According to Ande (2011), soil suitability assessment for agriculture is meant "to evaluate the ability of a piece of land to provide optimal ecological requirements of a certain crop while, at the same time, managing limiting factors to suit crop requirement and to improve productivity". Soil suitability assessment for crop production rate the quality of land resources base on specific measurable features such as pH, rainfall, altitude and temperature and match the rated land quality with crop requirements (National Soil Service, 2006). It is the first step in agriculture for sustainable crop production as it is the guide for land utilization in a sustainable way (Nuga and Akinbola, 2015). Thus, soil suitability assessment consists of characterisation of soil, topography and vegetation data with the aim of comparing land characteristics with crop requirements (Hongmei *et al*., 2006).

Because there are already established land uses in different areas, assessing the suitability of the soil for a crop is necessary to predict land performance of the expected future, constraints and environmental problem from current productive use of land (Rossiter, 1996). This opens room for addressing issues related to productivity, suitability and potential degradation which may be due to current management practices of land use (Olaniyi *et al*., 2015).

2.3.1 Use of spatial data for assessing soil suitability

Geographic Information Systems are capable of managing large amounts of spatially related information, providing the ability to integrate multiple layers of information and to derive additional information (Dai *et al.*, 2001). Initially, Automated Land Evaluation System (ALES) was used to evaluate land before starting using or integrating spatial data. Automated Land Evaluation System is a computer program that allows land evaluators to build an expert system to evaluate land in accordance with the FAO's framework of land evaluation (FAO, 1976). Automated Land Evaluation System itself is a framework within which evaluators build their own models; it does not by itself contain any knowledge but provides a reasoning mechanism and constrains for the evaluator to express inferences using this mechanism and build their own expert systems (Rossiter, 1990). Expert's judgment plays an important role in the ALES framework (Rossiter, 1996).

ALES has no map inputs and assumes that all properties of the same mapping unit are the same, forgetting that map units are natural units defined by soil, climate, geomorphic and physiographic natural resources. These made it to require inputs from GIS (Rossiter and Van Wambeke, 1993). Following the need to map different attributes for land evaluation and suitability assessment, many authors have been integrating GIS in the expert knowledge system framework (Wandahwa and van Ranst, 1996; Bydekerke *et al.,* 1998; Cools *et al.,* 2003). GIS is used as the platform in managing, combining and displaying the criterion data and also as a tool for producing new data, especially by utilising spatial analysis functions (Store and Kangas, 2001). In 2013, Elsheikh and his colleagues did some modification to ALES by introducing Agricultural Land Suitability Evaluation (ALSE) for crop production using GIS (Elsheikh *et al.,* 2013). The process required specialized geo-environmental information and the expertise of a computer scientist to analyse and interpret the information. Agricultural Land Suitability Evaluation can assess land suitability for different types of crops in tropical and sub-tropical regions.

2.3.2 Multi-criteria suitability assessment using AHP

To assess land especially for crop production number of criteria have to be considered (FAO, 1976). Multi-criteria evaluation or Multi Criteria Decision Making (MCDM) is one of the approaches needed. Multi Criteria Decision Making is a decision analysis approach for sustainability (Proops and Safonov, 2004). It aims at improving decision making when a set of alternatives need to be evaluated on the basis of conflicting and incommensurate criteria (Mustafa *et al.,* 2011). However, it is understood that there is no certain standard concerning the criteria to be taken into consideration when assessing land suitability potential for agriculture and that the criteria used in similar studies are usually those that are accessible (Akinci *et al.,* 2013). Multi Criteria Decision Making requires some effort, but it greatly increases the chance of making a good decision by standardising, weighing and combining criteria during evaluation (Store and Kangas, 2001). However, this transparent decision making method is rarely used in developing countries due to poor awareness of its applicability in land evaluation (Maddahi *et al.,* 2014).

One of the most popular MCDM methods is the Analytic Hierarchy Process (AHP). Analytic Hierarchy Process is a decision making method under situation of uncertainty and with a number of factors compared (Saaty, 1980). Analytic Hierarchy Process is very intuitive, easy to use and understandable and thus beats most of the other MCDM methods that have a solid mathematical background but are so complex that they can be used only by scientists and qualified decision analysts. Also it is superior to many other weighting methods because it can deal with inconsistent judgments by providing a measure of inconsistency (Massawe, 2015). This method combines quantitative and qualitative analyses; quantitative analysis is used to express subjective judgment and experience of people (Huang *et al*., 2007) while quantitative analysis process subjective judgment of people mathematically to give an index on a sliding scale (De la Rosa and Van Diepen, 2002). Analytic Hierarchy Process can be integrated into GIS software to access suitability of agricultural land to different crops (Mustafa *et al.,* 2011; Akinci *et al.,* 2013; Maddahi *et al.*, 2014; Massawe, 2015).

In suitability assessment of land for agriculture, different scholars have used AHP during their MCDM. Mustafa *et al.* (2011) did suitability assessment of soil physical and chemical properties for different crops using winter and summer criteria in Kheragarahtehsil of Agra in India. They found different suitability of crops for the two seasons. Akinci *et al.* (2013) did agricultural land use suitability analysis using the GIS and AHP technique in Yusufeli district of Artvincity (Turkey). Land suitability assessment was done by comparing different parameters such as soil depth, slope, aspect, elevation, erosion degree and other soil properties. Maddahi *et al.* (2014) analysed land suitability with respect to potential for rice cultivation using multi criteria evaluation approach using AHP in Mazandaran province in Iran. For rice suitability in the area, soil physical and chemical properties, climate, topography, irrigation water, availability and market were considered and found to affect rice productivity. In 2015, Massawe did a study on land evaluation for rice suitability analysis in Kilombero Valley, Tanzania, using multi-criteria such as soil chemical fertility, soil physical properties, topography, accessibility and distance to market. Realizing the importance of sustainability in land evaluation and suitability assessment, farmers and extension officers were involved in the process.

2.3.2.1 Use of soil for suitability assessment

One of the most important factors affecting the land suitability classification for cultivation is soil properties (Maddahi *et al.,* 2014). In assessing suitability of land for crop production, soil is a primary factor to be considered. Soil is highly considered in land evaluation because the FAO land evaluation methodology was developed by soil scientists whose experience had been in agricultural land suitability classification (Rossiter, 1996). Still, soil survey is the primarily traditional base for land evaluation (Al-Mashreki *et al.,* 2011).

Soil physical characteristics, biological and soil chemical properties are measured when assessing soil suitability depending on the researcher's interest. Wang (1994) used internal soil characteristics such as temperature, moisture, aeration, natural fertility, depth, texture and salinity to assess suitability. In different studies, soil parameters such as soil fertility, texture, depth, pH and drainage were used to map the study area (Feizizadeh and Blaschke, 2013; Sarkar *et al.,* 2014; Massawe, 2015). Soil parameters such as texture, drainage, depth, colour and surface stones were used to survey the soil and assess its suitability for sorghum production (Al-Mashreki *et al.*, 2011; Agidew, 2015) whereas Adesemuyi (2014) used soil survey data to assess suitability of land for maize production and Maddahi *et al.* (2014) used soil survey data to assess it is suitability for growing rice. Mustafa *et al.* (2011) used remote sensed and soil survey data to perform an integrated analysis in the GIS environment to assess suitability of land for different crops in winter and summer seasons.

2.3.2.2 Use of topography for suitability assessment

Topography affects soil formation singly or in combination with rainfall and drainage (Verheye, 2009). It determines the amount of water that percolates in soil and, thus, adds to dissolution, leaching and migration of elements. It also stimulates erosion of profile in the uplands and upper slope while create accumulation of water and soil in the lowlands. It’s one of the factors important for determining suitability of land for different land use especially crop production. In some studies, topography was used to acquire information using GIS because GIS offers a flexible and powerful tool than conventional data processing systems, as it provides a means of taking large volumes of data of different kinds (Al-Mashreki *et al.*, 2011).

Evidently, topography is a very important criterion for some crops especially rice. In his study, Massawe (2015) found that topography influenced the duration and amount of flooding in rice fields. In another study, topography was found to be very important especially for irrigated rice (Maddahi *et al.*, 2014). In a study done in the Eastern Plateau Region in India, topography was found to delineate watershed (Sarkar *et al.*, 2014). Agidew (2015) used topographic data of South Wollo Zone of Ethiopia to describe soil degradation when relief was affected by human activities, especially agriculture, as where

Adesemuyi (2014) used topography to check its contribution for maize suitability in South-Western Nigeria.

2.3.2.3 Use of climate for assessing suitability

The requirement of crops and the qualities of land are determined by measuring different physiographic characteristics including rainfall and temperature (Wang, 1994). Temperature and rainfall are important climatic variables required by crops in different seasons in different parts of the world (Mustafa *et al.*, 2011). These variables are either used singly or in combination depending on their importance to the specific study. However, in many tropical parts of the world, rainfall has been considered as an important criterion for assessing suitability because is the only source of water for rain-fed agriculture, hence its distribution and dependability plays a significant role in optimizing crop production (Wang, 1994; Adesemuyi, 2014; Maddahi *et al.*, 2014; Sarkar *et al.*, 2014; Agidew, 2015).

Maddahi *et al.* (2014) assessed contribution of temperature following its influence in growing cycle of rice such as developing stage and ripping stage. In some studies temperature and rainfall were jointly considered for assessing suitability of land because these climate variables played a significant rule in crop production in different seasons, winter and summer (Al-Mashreki *et al.*, 2011; Mustafa *et al.*, 2011; Feizizadeh and Blaschke, 2013). It was also found that rainfall and temperature were used to map areas using GIS platform to ascertain the most suitable area for production of different crops (Sarkar *et al.*, 2014; Olowojoba *et al.*, 2016). Other elements of weather have been rarely considered in assessing suitability. Relative humidity was considered due to its effect in harvesting stage of rice (Maddahi *et al.*, 2014; Massawe, 2015).

2.3.2.4 Involving farmers in assessing suitability

Cools *et al.* (2003) reported that from the past, farmers have been doing indigenous land evaluation but due to technological change new systems have to be adapted. Unfortunately, resource professionals use methods of high cost for conventional land evaluation at detailed scales required for land use planning at community level. They also reported that scientific community use methods for land evaluation that often perform poorly when it comes to predicting land productivity at local level. It is because their approach is largely deductive to farmers who have few reference points to guide their decisions in adapting new technology. Suitability assessment has to be carried out in such a way that local needs and conditions are reflected well in the final decisions (Prakash, 2003). Therefore, improved understanding of local variations in land characteristics within the farmers' environment that will allow a more efficient assessment of farming systems constraints and opportunities need to be considered.

2.4 Land Use Requirement for Crop Production

Land use requirements are explained in terms of land quality to determine the suitability of a particular land unit for particular land utilization type (FAO, 1983). Land use requirement relates to: physiological requirement of crops, management for the land utilization type and conservation requirements in which land utilization type must be operated in sustained basis (FAO, 1993).

Land use requirements are determined by factor rating which is a set of values indicating suitability of land for specific land use. Factor rating is done using five classes, namely: highly suitable, moderate suitable, marginally suitable, currently not suitable and permanently not suitable (FAO, 1983). Contrary to suitability assessment classified by FAO, in Butuguri area suitability assessment was done focusing on crop requirement using GIS tools.

2.4.1 Cassava production requirements

Cassava (*Manihot esculenta*) is a starchy root crop cultivated mainly in the tropic and sub-tropic regions of the world over a wide range of environmental and soil conditions (Richardson, 2011). Although Latin America remains to be a leading producer, Africa and Asia have managed to commercialise, trade and consume cassava in many ways than in Latin America (Food and Agriculture Organisation Statistics (FAOSTAT), 2015). Cassava is the most important source of dietary calories in the tropics after rice and maize (FAO, 2013). Cassava plays an increasingly important food security role especially in areas which have poor soil nutrient condition and or are prone to drought, because it is drought tolerant and it is able to grow with limited input where most other crops would fail completely (Howeler, 2012; Forsythe *et al.*, 2016).

Cassava is grown in 30^{o} North altitudes and 30^{o} South latitudes under very broad climatic and edaphic conditions even with poor nutrient supply (Lozano, 1986). Cassava grows best in all regions near the equator, at elevations below 1500 m (Kouakou *et al.,* 2016). Although cassava can withstand periods of drought, it is very sensitive to soil water deficit during the first three months after planting (FAO, 2013). Water stress at any time in that early period reduces significantly the growth of roots and shoots, and impairs subsequent development of the storage roots. Rainfall between 1000 to 1500 mm per year and temperature of between 23 and 25 ^{o}C is needed by cassava on planting (Kouakou *et al.*, 2016). Once established, cassava can grow in areas that receive just 400 mm of average annual rainfall. But higher yields have been obtained with much higher levels of water supply (FAO, 2013). With the exception of heavy (clayey), stony or saturated soils, it can grow in all soil types; it prefers light, well-drained, deep soils that are rich in organic matter. Cassava is tolerant to high levels of aluminium and manganese in the soil, but does not thrive well in extremely sandy and salt affected soil. It favours sunny locations and grows in high temperatures in tropical and subtropical regions (Hauser *et al.*, 2014; Kouakou *et al.,* 2016).

While human population growth rates of many African countries continue to be highest in the world, in spite of its pre-eminence in overall production, Africa has lower average cassava yields (10.9 tonnes per hectare) than both South America (13.2 tonnes per hectare) and Asia (19.7 tonnes per hectare) (FAOSTAT, 2015). Therefore there is an urgent need to match growing population with expeditious increases in cassava production.

Tanzania is one among the leading producer countries of cassava in Africa (FAO, 2005). It is the second largest producer of cassava in East Africa after Uganda with average yields of 5.5 tonnes per hectare (FAOSTAT, 2015). Major cassava producing areas include the coastal strip along the Indian Ocean, around lakes Victoria and Tanganyika and along the shores of Lake Nyasa (Mkamilo and Jeremiah, 2005; Bennett *et al.,* 2012). According to Bennett *et al.* (2012) more than 80 per cent of Tanzania's cassava production is used as human food and per capita consumption supporting the livelihood of 37% of farmers in rural areas. The remaining is used to feed livestock, make starch, or is exported (Kapinga and Jeremiah, 2015). Cassava production reached its peak some years ago but recently production has been declining due to disease infestation and fertility decline (National Bureau of Statistics (National Bureau of Statistics (NBS), 2018).

Butiama District, where Butuguri is located, produces cassava as one of its major staple food crops (Mara Regional Profile, 2003). From 1997 to 2003 the area under cassava production was 58 692 ha for Mara Region, Musoma District, which included Butiama before the latter became a fully-fledged district had 13 758 ha under cassava cultivation and the average production was 28 938 tonnes (Mara Regional Profile, 2003). Butuguri is the major producer of cassava which is the staple food in Butiama District (Butiama District Profile, 2013).

2.4.2 Maize production requirements

Maize (*Zea mays*) originates in the Andean region of Central America (Valdivia *et al.*, 2017). It is one of the most important cereals both for human and animal consumption and is grown for grain and forage. The crop is grown in climates ranging from temperate to tropical during the period when mean daily temperatures are above 15 °C and frost-free. Adaptability of varieties in different climates varies widely (FAO, 2014).

Tanzania is a major maize producer in Sub-Saharan Africa (Suleiman and Kurt, 2015). In the last five decades, Tanzania has ranked among the top 25 maize producing countries in the world (Barreiro-Hurle, 2012). Maize is primary staple crop in both urban and rural areas in Tanzania (Minot, 2010; Suleiman and Kurt, 2015). It's grown in all the agro-ecological zones in the country (NBS, 2007). Over two million hectares of maize are planted per year with average yields of between 1.2 – 1.6 tonnes per hectare and accounts for 31% of the total food production and constitutes more than 75% of the cereal consumption in the country (Water Efficient Maize for Africa (WEMA), 2010). For all the maize growing regions in Tanzania; it is mostly rain-fed with low inputs use especially synthetic fertilizers (Rowhani *et al.*, 2011).

From 1997 to 2003 the area under maize production was 45 418 ha for Mara region, Musoma District which included Butiama previously having area of 5866 ha and the average production was 8983 tonnes (Mara Region Profile, 2003). Butuguri produces maize as one of major staple food (Butiama District Profile, 2013).

2.4.3 Sorghum production requirements

Sorghum (*Sorghum bicolor* (L.) Monech) is an important staple food for the world's poorest and food insecure people in arid and semiarid tropics (Hariprasanna and Patil, 2015). It is known to be cultivated as food grain in Africa and Asia (Chapke *et al.*, 2011). Sorghum is also a source of feed, fodder and biofuel apart from food (Hariprasanna and

Patil, 2015). It is a short-day C4 plant; thrive well in areas of moisture deficit, high ambient and soil temperatures and where other crops would normally fail, hence grown by resource poor small scale farmers for their subsistence (Christiansen, 2006).

Sorghum is mainly cultivated in drier areas, especially on deep, well drained soils as it develops extensive root system. Sorghum is mainly grown on low potential, shallow soils with high clay content, which usually are not suitable for the production of maize (Christiansen, 2006). Sorghum usually grows poorly on sandy soils, except where heavy textured subsoil is present. Sorghum is more tolerant of alkaline salts than other grain crops and can therefore be successfully cultivated on soils with a pH (KCl) between 5.5 and 8.5. It can better tolerate short periods of water logging compared to maize. Soils with a clay percentage of between 10 % and 30 % are optimal for sorghum production.

A medium to good and fairly stable rainfall pattern during the growing season of about 400 to 800 mm per year is suitable for sorghum production. Sorghum is a warm-weather crop, which requires high temperatures for good germination and growth with frost-free period of approximately 120 to 140 days. The minimum temperature for germination varies from 7 to 10 ºC. At a temperature of 15 ºC, 80 % of seed germinate within 10 to 12 days. The best time to plant sorghum is when there is sufficient water in the soil and the soil temperature is 15 ºC or higher at a depth of 10 cm. Temperature plays an important role in growth and development after germination. A temperature of 27 to 30 ºC is required for optimum growth and development but low temperature to 21 ºC has no dramatic effect on growth and yield. Exceptionally high temperatures cause a decrease in yield. Flower initiation and the development of flower primordia are delayed with increased day and night temperatures (Department of Agriculture, Forestry and Fisheries (DAFF), 2010).

Sorghum is grown mostly in an annual rainfall range of 300 to 750 mm. It is grown in areas which are too dry for maize. Early drought stops growth before floral initiation and the plant remains vegetative while late drought stops leaf development but not floral initiation. The crop has a relatively deep rooting system that can extract water from low sources (DAFF, 2010).

In Tanzania, about 43% of the national sorghum production is done in the drier central regions of Singida and Dodoma, as well as around Lake Victoria, including Mwanza, Shinyanga and Mara regions. All regions together generate around 350 000 tonnes of sorghum each year (Rohwani *et al.,* 2011). The results of the 2002 - 03 National Sample Census of Agriculture indicated that just 17% of sorghum output is marketed, the remaining is used for human consumption and in the brewing of traditional beers. It is considered as an inferior food in the sense that per capita consumption is higher in rural areas and among low-income households (NBS, 2007). Food and Agriculture Organisation Statistics (2009) suggest that international trade in sorghum is practically non-existent. Yet, sorghum is highly considered for future food security following climate change (Reincke *et al.,* 2018).

Moreover, sorghum is among of the cereal crops that were planted in both seasons (long and short) during 2014/2015 agriculture year in Tanzania. The area planted with sorghum was 781 025 ha of which 187 415 ha were planted during the short rainy season and 593 610 ha in the long rainy season. Nationwide, the production of sorghum was 531 206 tonnes. Mara Region had the highest production of sorghum (62 674 tonnes) during short rainy season compared to other regions. For the case of the long rainy season, the highest production was in Dodoma Region (81,573 tonnes) (NBS, 2016). Butuguri area in Butiama District produces sorghum as one of major staple food (Butiama District Profile, 2013).

2.5 Sustainability of Land Evaluation

Sustainability of land evaluation cannot be reached without involving local people as local people are the ones who utilise the land. Unfortunately, land evaluation and suitability assessment results are not taken back to local expert for sustainable implementation making land evaluation unsustainable. Therefore we need people whose opinions must be taken into account during decision-making process in land evaluation (Feizizadeh and Blaschke, 2013). This can be done by having a framework that can be used for collaborative evaluation.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3. 1 Description of the Study Site

3.1.1 Location

The study was conducted in Butuguri area located in Butiama District in Mara Region covering Busegwe and Butuguri Wards (Fig. 1). The study covered 108.5 km^2, occupying the area lying between 598 530 and 610 754 m Northings and 980 8624 to 980 9316 m Eastings (zone 36^o S of Universal Transverse Mercator). The area borders Butiama Ward on the south part, Muriaza Ward on the east part, Buruma Ward on the west part and Bukabwa Ward in the north part.

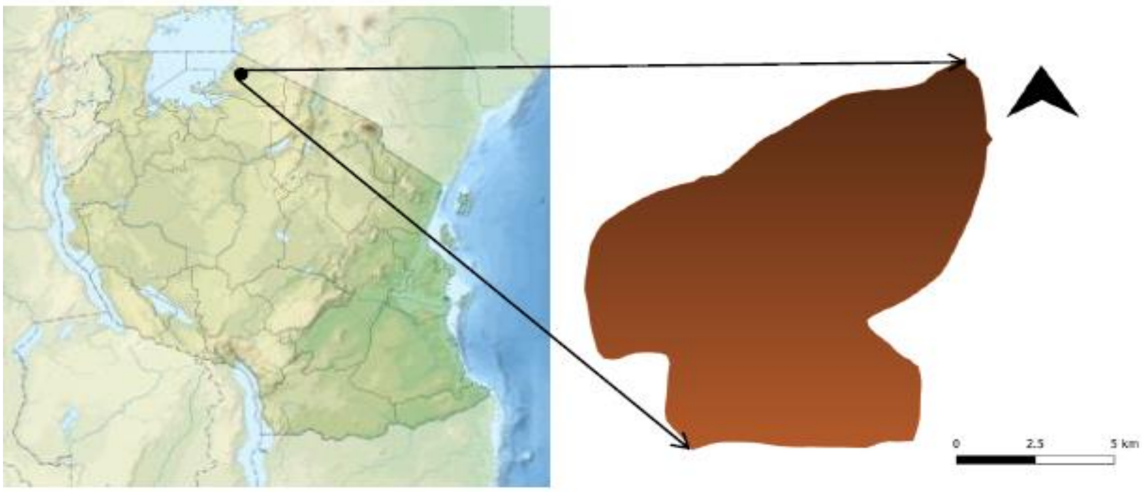

Figure 1: Study area

Climate

Butuguri area receives both short and long rains in which the average annual rainfall ranges between 600 to 1200 mm (Butiama District Profile, 2013). Short rains last from September to January and long rains last from March to May. Its altitude is about 1200 – 1600 metres above sea level (m.a.s.l.). The average annual temperature is 21^{o}C (Mara Region Profile, 2003).

3.1.2 Soil

The area is characterized by black cotton soils (Mbuga) on the lowlands and Sandy loam soils on the highlands. Most of the land is covered by sandy soils which are affected severely by erosion. Soil erosion is accelerated by overgrazing and deforestation, which are caused by human development activities and shifting cultivation.

3.1.3 Population

Butuguri area is comprised of two wards, Butuguri and Busegwe Wards. According to the 2012 population census (National Bureau of Statistics (NBS), 2016a), Butuguri Ward had 9006 inhabitants, 4302 being male and 4704 women. The Ward has an annual growth rate of 2.5% and a population density of 147 inhabitants per square kilometre. Busegwe Ward had 5319 inhabitants of whom 2554 were male and 2765 women. Busegwe has a population density of 112 inhabitants per square kilometre (NBS, 2016a).

3.1.4 Vegetation

Much of the natural vegetation in Butuguri area is characterized by grass and scattered woodlands together with bushes and shrubs. Butuguri is one of the areas in the district with lowest forest cover. In the area, woodlands located on hills are heavily exploited and highly degraded. There are occurrences of natural and man-made forests in some of protected area. Man-made forests are privately owned. Other natural vegetation can only be seen in protected hill areas. Natural vegetation also occurs in areas abandoned by farmers where natural regeneration takes place (Butiama District Profile, 2013). Most people are dependent on firewood and/or charcoal as fuel for food preparation. This means that an enormous amount of wood is cut for energy purposes (Arhem and Freden, 2014). Invasive plant species such as devil weeds (*Chromolaena odorata)* and lantana (*Lantana camara)* are also present in the area.

3.1.5 Socio-economic profile

The majority of people in the area involve themselves in the agricultural sector, which includes crop cultivation and livestock husbandry. The major crops grown in the area are grains, root crops and vegetables. These include maize, sorghum, beans, cassava, sweet potatoes and rice. Cotton is the cash crop grown in the area. Cassava is the staple food crop in the area followed by sorghum. Maize has been cultivated in recent years as an alternative staple food crop due to disease infestation in cassava. Crop productivity of the area is low due to infertile sandy soils and unreliable rainfall patterns resulting in long periods of drought and crop failures. Few people engage themselves in mining activities and local businesses. The largest ethnic group of Butuguri is Zanaki with few numbers of Kuria and Jita.

3.2 Methodology

3.2.1 Pre-field work

Generation of base map

Base map preparation was done using existing geological and topographic maps, together with landform features derived from digital elevation model. Geological map of Kiabakari drawn at a scale of 1:125 000 (Geological Survey Department, 1961) and topographic map of Nyankanga drawn using a scale of 1:50 000 (Survey and Mapping Division, 1976) were used. The maps were georeferenced in QGIS software to access the true location of the study area (Quantum Geographical Information System (QGIS) Development Team, 2014). Area boundaries were extracted from Tanzania ward boundary shape files created by Humanitarian Data Exchange (HDX) (2012) then clipped using QGIS to extract Butuguri from Tanzania. The 1 arc (approximately 30 m spatial resolution) Shuttle Radar Topography Mission (SRTM) terrain model (United States Geological Survey (USGS), 2000) was used to generate and visualize differences in elevation and other land form features using QGIS. The visualization aided in deciding where to capture soil variability related to landform features such as elevation and slope gradient.

3.2.2 Field work

3.2.2.1 Confirmation of base map

Initially, the base map was prepared through desktop work using remote sensing materials and existing geological and topographic maps. Confirmation of the base map to ascertain soils, landform and land use features was done by free survey. Changes on the base map were incorporated to reflect features as seen on the ground.

3.2.2.2 Identification of important criteria for growing cassava, maize and sorghum in the area

To get information about criteria important for growing cassava, maize and sorghum in the area, literature review and opinion from local extension officers and farmers of the area were consulted. Local extension officers assigned in the area were involved, while six farmers were randomly selected from the area. After discussing the important criteria for growing crops in the area we came up with common agreement that soil, climate and topography are important criteria for crop production. The three staple crops in the area were considered; they included cassava, maize and sorghum.

3.2.2.3 Ranking of identified criteria for growing crops in Butuguri area

The ranking was done using a theory of measurement of relative intangible criteria known as Analytical Hierarchical Process (AHP) in which a scale of priorities is derived using pair-wise preference matrix by comparing criteria to each other (Saaty, 2014). Farmers and extension officers were the domain experts in this activity. Using a fundamental scale or AHP preference scale 1 to 9 (Table 1), farmers and extension officers translated the verbal judgment to numerical value and formed the paired comparison matrices.

Table 1: AHP preferences scale

APH scale of importance for comparison pair	Numeric rating	Reciprocal decimal
Extremely importance	9	1/9(0.111)
Very strong to extremely	8	1/8(0.125)
Very strong importance	7	1/7(0.143)
Strong to very strong	6	1/6(0.167)
Strong importance	5	1/5(0.200)
Moderately to strong	4	1/4 (0.250)
Moderate importance	3	1/3(0.333)
Equal to moderately	2	1/2(0.500)
Equal importance	1	1 (1.000)

Source: Alexander (2012)

Through guidance from researcher, farmers and extension officers categorized five criteria which were soil physical properties, soil chemical fertility, topography, temperature and rainfall into hierarchies. Criteria importance or priority was scaled by the number of levels in the hierarchy in which most important criteria come first estimating probabilities of best-case followed by moderate important or intermediate-case one and lastly by least important criteria as worst-case. Revisions of the preference matrices were done for all pair wise comparisons showing inconsistent judgment when Consistent Ratio (CR) was above 10%. Ranking and weighing was firstly done separately by farmers and extension officers then it was jointly done. Independent ranking aimed at making them familiar with the exercise before joint ranking.

3.2.2.4 Field characterisation of soils

Soil survey of the area was done by assessment of soil properties (Dent and Young, 1981). This was achieved by describing, classifying, mapping and interpreting natural three-dimensional bodies of soil on the area (Soil Science Division Staff, 2017). The base map prepared in earlier stage was used to guide the exercise. Each mapping unit was characterized by a representative pedon. More observations were made available for some map units by composite soil sampling due to variations within the unit. This was done by comparing profile topsoils laboratory results to those of composite samples.

From each mapping unit a representative soil profile pit was established to study the dominant soil. Seven soil profiles were established. Soil profiles were dug to a limiting layer and described according to standard guidelines for soil description (FAO, 2006). In most cases it was possible to dig soil profile down to 120 cm depth except for mountainous and water logged profiles, in which the depth was less than 80 cm deep. Soil profile morphological characteristics studied in the field included soil colour, moisture condition, texture, consistence, structure, porosity, effective depth, presence or absence of clay cutans, mottles, concretions and type of primary minerals and rock fragment.

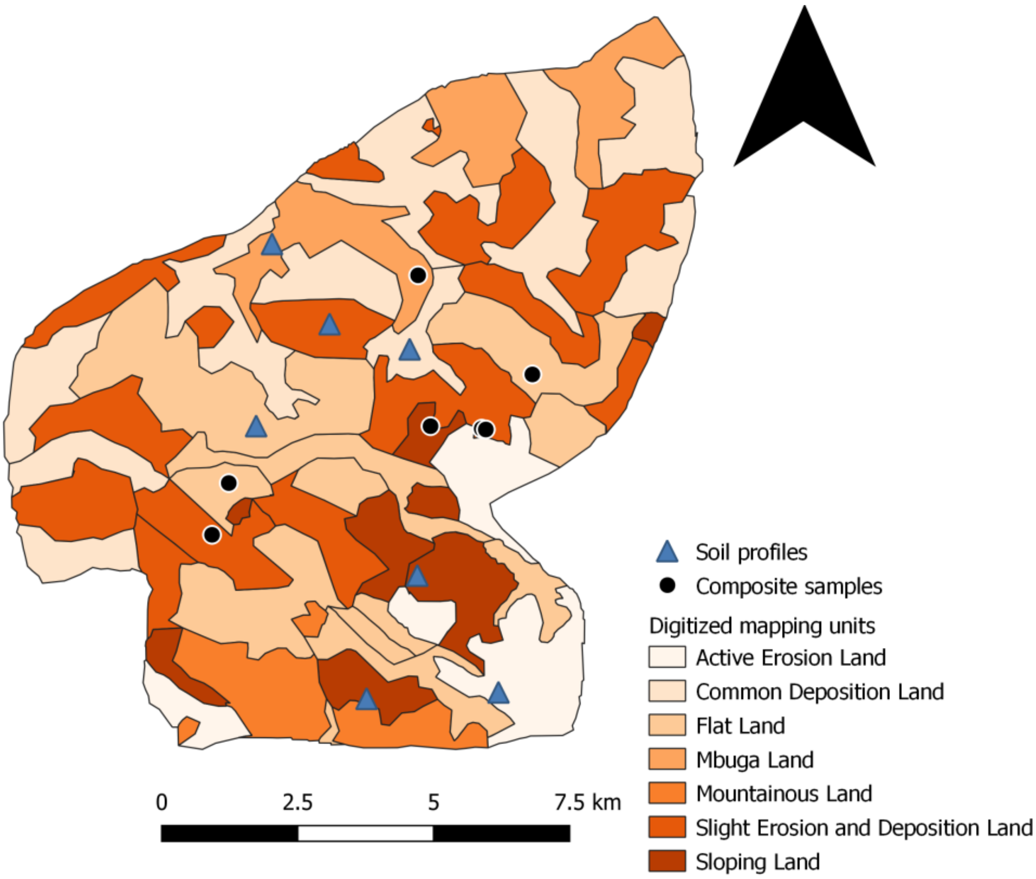

Figure 2: Digitized mapping units with location of representative profile pedons and composite soil points

Soil colour was determined using Munsell Soil Colour Charts (Munsell Soil Colour Charts, 2009). Geo-referencing was done using a portable Global Position System (GPS) receiver (eTrex Garmin). Sampling locations were chosen according to the judgment of the soil surveyor based on experience about the relation between landscape and soil representativeness.

Bulk soil samples were taken from the identified horizons in each soil profile. From each soil horizon, 1 kg soil sample was collected for laboratory analysis. Additional composite samples were collected using a zigzag method from each mapping unit to supplement soil profiled data. Figure 2 above, shows the digitized mapping units, profile establishment points and soil composite sampling points.

3.2.3 Post-field work

3.2.3.1 Creation of spatial information of the attributes important for growing cassava maize and sorghum

Spatial information recorded includes soil related spatial information, climate related information and topography related information. Soil related spatial information were obtained by mapping of soil units obtained through the soil survey process as previously described under the Soil Survey section.

Climate-related spatial information was obtained from WorldClim-Global Climate Data (Fick and Hijmans, 2017) for mapping spatial climate data of the area with a 30 arc-second resolution grid (1 km resolution). From WorldClim version 2, two bioclimatic variables were downloaded, which included mean annual temperature and annual precipitation. They were the average for the years 1970 - 2000. Each download was a "zip" file containing 12 GeoTiff (.tif) files, one for each month of the variables. The shape files were in Geographic Coordinate System (GCS) (World Geodetic System (WGS), 1984). Using QGIS Butuguri boundary map was overlaid on the WorldClim shape-files to query regions within its boundary (Olusina and Odumade, 2012). Mean annual temperature and annual precipitation for whole site were obtained. Topography related spatial data were obtained by downloading Shuttle Radar Topographic Mission-Digital Elevation Model image (SRTM-DEM) of 30 metre spatial resolution on global coverage product from United States Geological Survey (USGS) archives (USGS, 2000). The original SRTM DEM was used to produce elevation map for the study area using QGIS software. Every cell in the output raster had elevation value. From the map, clear boundaries showing difference in elevation were seen.

3.2.3.2 Laboratory soil analysis

The soil samples were air-dried and sieved through a 2 mm sieve. Both physical characteristics and chemical properties were determined. Particle size analysis was done by the Bouyoucos hydrometer method (Gee and Or, 2002). Soil pH was determined in water and 0.01N $CaCl_2$ solution at a ratio of 1:2.5 soil: water and soil: $CaCl_2$ using the glass electrode pH meter (Thomas, 1996). Electric conductivity (EC) was determined using a conductivity meter in a 1:2.5 soil-water suspension following the method by Rhoades (1982). Total nitrogen in the soil samples was determined by the macro-Kjeldahl digestion method (Bremner and Mulvaney, 1982). Organic carbon was determined by the Walkley and Black wet oxidation method (Nelson and Sommers, 1982); percentage organic matter was calculated by multiplying the value for organic carbon by the "Van Bermenalen factor" of 1.724, which is based on the assumption that soil organic matter contains 58 % Carbon (Allison, 1965). Available phosphorus was extracted using the Bray-1 method for samples with pH less than 7.4 (Bray and Kurtz, 1945) but for soil with pH above 7.4 available phosphorus extractions was done using Olsen's method then determined spectrometerically (Sparks, 1996; Olsen, 2018). The CEC and exchangeable bases were extracted by saturating soils with neutral 1M NH_4OAc and the absorbed NH_4^+ was displaced by K^+ using 1M KCl and then determined by Kjeldahl distillation method for the estimation of CEC of the soil (Thomas, 1982). Exchangeable bases ($Ca^{2+,}$ Mg^{2+} K^+ and Na^+) were extracted with 1 N neutral ammonium acetate solution (pH 7) then $Ca^{2+}$and

Mg^{2+} were measured using an atomic absorption spectrophotometer, while K^+ and Na^+ were measured by the flame photometer method (Thomas, 1982). Micronutrients, including Zinc (Zn), Manganese (Mn), Iron (Fe) and Copper (Cu), were extracted by using DPTA extraction method then quantified by X-ray diffraction (Lindsay and Novell, 1978).

3.2.3.3 Soil classification

Using field and laboratory data, the soils were classified to 2-qualifiers of the World Reference Base (IUSS Working Group WRB, 2015), and to the subgroup level of the USDA Soil Taxonomy (Soil Survey Staff, 2014).

3.2.3.4 Suitability classification

In classifying suitability for each criterion, reclassification was done in order to have a common scale since the attributes were originally measured using different scales and dimension ranges (Marinoni and Hoppe, 2006). Soil pH was used as the basis for creating the common scale, since soil pH determines crops growth and development (Islam *et al.*, 1980). Soil suitability classes were established based on pH and class numbers were made (Table 2). The total numbers of classes were 7 from “very low” to “very high”. Soils which had high pH values obtained the highest class value, while those with lowest pH value obtained lowest class value. The medium number implies the highest suitability of the criterion. This is due to the fact that the pH was optimum for plant growth.

Table 2: Reclassified soil pH in the study area (modified from Soil Science Division Staff (2017))

pH range	Class term	Meaning	Class value
3.5–4.4	Extremely acid	Very low	1
4.5–5.0	Very strongly acid	Low	2
5.1–5.5	Strongly acid	Low – medium	3
5.6–6.0	Moderately acid	Medium	4
6.1–6.5	Slightly acid	Medium – high	5
6.6–7.3	Neutral	High	6
7.4–7.8	Slightly alkaline	Very high	7

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Important Requirements for Growing of Cassava, Maize and Sorghum

The requirements identified through literature review and focused group discussions with the local experts (farmers and extension officers) were as shown in section 4.1.1 to 4.1.3.

4.1.1 Soil

The soil characteristics of the area were subdivided and considered in terms of soil physical properties and soil chemical fertility.

4.1.1.1 Soil physical properties

In this study, soil physical properties were represented by soil texture and soil colour. The soils in this area were well drained in highland all the time but poorly drained in low land especially during the rainy season. This was due to elevation difference which influenced erosion on highlands and deposition in lowland (Klingebiel *et al*., 1988). Soil texture was selected because of its influence on growing all three crops. Farmers grow cassava on high land and not on low land because cassava prefers light sandy soil which is on highland and not heavy clayey or saturated soil which is mostly found in the lowland (Hauser *et al.*, 2014).

Maize can grow in broader soil textural ranges including clay loam, sandy loam, sandy clay and sandy clay loam (Kochhar,1986) although the supply of water to plants is usually greater in soil of moderately fine texture than in that of coarse texture (FAO, 1985). Farmers in the area grow maize both on highland with sandy soil and low land with clayey soils but mostly on lowland. In some parts of the world, sorghum is mainly grown on low potential, shallow soils with high clay content, which usually are not suitable for the production of maize (DAFF, 2010). But in Butuguri area sorghum is grown in well-drained sandy soil, same field used to grow cassava and maize.

Soil colour was considered to be an important attribute for growing the three crops. It is one of the attributes used locally by farmers to determine soil fertility status of soil hence selection of the crop to be grown in a particular piece of land. Brown to reddish brown coloured soil seems not to be preferred for growing all the three crops. Even though maize seems to be having poor production in soils with this colour, farmers still grow it in those soils due to scarcity of cropping land. Black cotton soil (mbuga) is preferably used to grow maize especially during the short rainy season.

4.1.1.2 Soil chemical fertility

In this study, the attributes which were included in soil chemical fertility criteria were macronutrients and micronutrients although farmers only knew low and high soil fertility in reference to crop production. Farmers were aware of low fertility in the area and they attributed it to continuous cultivation (Agidew, 2015). Although farmers admitted that this attribute is very important for growing cassava, maize and sorghum, still farmers do not put any effort on its improvement. There is nutrient mining as farmers grow cassava, sorghum and maize (nutrient heavy feeders) without any replenishment, making soil less fertile.

This is very common in Africa as many farmers have completely eliminated fallow periods and are not compensating for nutrient losses by adopting soil fertility management techniques, such as cover crops, nutrient recycling and manure application (FAO, 2013). Sandy soils which are common in the area have a low capacity to retain nutrients and have low soil water holding capacity (Yanai *et al.*, 2005), but still cassava can yield well, giving hope farmer to continue planting without adding organic or inorganic fertilizers as is commonly done in Africa (FAO, 2013).

Farmers of Butuguri area admitted that, during off season they use their field to graze cattle but they consider returning manure from livestock in the farms worthless especially for food crops. Some farmers use farm yard manure and inorganic fertilizers for growing vegetables because of its fast return of money. However, many farmers in the area cannot afford industrial fertilizers resulting into poor productivity especially for cassava, maize and sorghum.

4.1.2 Climate

The climatic factor was subdivided into two parts: rainfall and temperature.

4.1.2.1 Rainfall

Rainfall is the important factor for soil formation and for growing all the three crops, namely: maize, cassava and sorghum in the area. Farmers in the area depend on both short and long rains, and the area receives moderate annual rainfall ranging from 600 mm to 1200 mm (Butiama District Profile, 2013). In the area short rains are currently unreliable and unevenly distributed due to climate change.

Cassava is mostly planted in September to get best the harvest. September is the period for the start of short rains in the area. Rainfall between 1000 to 1500 mm per year is needed by cassava during planting, once established; cassava can grow in areas that receive just 400 mm of average annual rainfall (FAO, 2013; Kouakou *et al.*, 2016; Olowajoba *et al*., 2016). Therefore, rainfall present in the area was suitable for cassava production. Maize for short rains is grown in October and November. For long rains, maize is grown between

February and March. According to IITA (1982) rainfall amount required for planting maize is 480 to 800 mm. Hence rainfall amount in the area was suitable for maize production. However, short and unreliable rains commonly present in the area limit maize production.

Short rains sorghum is grown between August and September to get good harvest while for long rains sorghum is planted in March. Though sorghum does not need a lot of moisture to grow (Christiansen, 2006), an annual rainfall range of 300 to 750 mm is needed for good harvest (DAFF, 2010). In the area, rainfall is important to moisten the soil which is sandy in nature. Sorghum is grown in the early time of the rainy season when there is good moisture in the soil. When there is rainfall delay many farmers do not grow sorghum at all as they cannot get good harvest due to early drought which stops growth before floral initiation.

In this area food production is much dependent on short rains because there are excessive long rains. Too much rainfall during the long rainy season saturates the soil, resulting into poor production of crops (Morales-Olmedo *et al.*, 2015). When water saturates the field, it fills the micropores resulting into poor aeration hence yellowing of crops especially maize grown in lowland area with black cotton soil. Also, when water logging occurs in fields, farmers are unable to weed hence poor production of crops.

4.1.2.2 Temperature

Annual temperature of the area ranges between 18 ^{o}C and 22 ^{o}C. The reason for choosing this factor is because of its importance on the physiological growth of all the three crops. According to Hollinger and Angel (2009), maize and sorghum can grow well at temperatures between 15 to 27 °C while temperature of between 23 and 25 ^{o}C is needed by cassava (Kouakou *et al.,* 2016). Hence, the temperature of this area was considered suitable for maize and sorghum production as well as for cassava production (FAO, 2013; Olowajoba *et al*., 2016).

In the area, temperature affects crop growth mostly during the rainy season. When there is too much rain, soil temperature cools down, slowing down physiological activities and can cause stem rot in cassava (FAO, 2013). But when temperature is too high sorghum cannot be grown in the area as excessive temperature activates evapotranspiration causing soil to lose moisture excessively hence affect germination (Hatfield and Prueger, 2015).

4.1.3 Topography

Following guideline for profile description (FAO, 2006), topography of the area had three major landforms which included: level, sloping to mountains landforms. Topography was considered by farmers and extension officers to be moderately important for growing cassava, maize and sorghum because it has a strong influence on soil characteristics. Due to difference in elevation, nutrients move from sloping land to level land causing soil erosion and nutrient mining on native point and deposition to destination point (Schoonover *et al.,* 2015). In the area, soils seems to be nutrient deprivative on the upper slope while the lower slopes they seems to be rich in nutrients; this was highly indicated by soil colour and texture. Slope has influence on water and nutrient movement as well as soil formation affecting growth and yield of cassava, maize and sorghum (Munoz, 2014). Steep soils are susceptible to accelerated erosion and generally have a shallower ‘A’ horizon and overall less development.

4.2 Ranking of Criteria

The ranking results are explained below crop-wise. The results are based on joint ranking exercise using AHP method by a group of farmers and extension officers of Butuguri area.

4.2.1 Cassava

The decision matrix suggested jointly by the farmers and local extension officers for cassava is shown on Table 3. When performing the pair-wise comparisons CR for this matrix was less than 10%, thus the weights were taken since there was consistent judgement.

Table 3: Cassava suitability analysis criteria preference matrix

	Soil physical properties	Soil chemical fertility	rainfall	Temperature	Topography
Soil physical properties	1	1	1	3	2
Soil chemical fertility	1	1	2	7	3
Rainfall	1	0.5	1	4	6
Temperature	0.33	0.14	0.25	1	1
Topography	0.5	0.33	0.17	1	1

The values of Table 3 reflect the domination of soil physical properties, soil chemical fertility and rainfall criteria over temperature and topography in cassava production.

Values of 1, 2 and 0.5 in first three rows of Table 3, tell us that criteria like soil physical properties, soil chemical fertility and rainfall are regarded to be equally or moderately important to each other but were much more important than temperature and topography as they scored high value of 3, 4, 6 and 7 in pair-wise matrix to temperature and topography as seen in first, second and third rows of the last two columns of Table 3.

The criteria weights calculated from the decision matrix and their respective rankings are shown on Table 4. Results for cassava by joint group of farmers and local extension officers shows that chemical fertility was ranked highest by scoring 34.9% followed by soil physical properties 27.3% and rainfall 23.2%. Topography and temperature received the lowest priority by scoring 8.1% and 6.5% respectively.

Table 4: Criteria weights and ranks for cassava suitability analysis

Criteria	Weight	Rank
Soil chemical fertility	34.9%	1
Soil physical properties	27.3%	2
Rainfall	23.2%	3
Topography	8.1%	4
Temperature	6.5%	5

The criteria weights and their respective rankings showed that soil chemical fertility received highest percentage as both famers and extension officers agreed that soil chemical fertility is a very important requirement to be considered when growing cassava. This case was raised as a result of some trials done in the area by the International Institute of Tropical Agriculture (IITA) which showed that plots with fertilizers resulted into better production compared to control plots. Soil physical properties were ranked second, revealing its importance in growing cassava. Soil texture was very important in growing cassava as cassava prefers sandy soils. This texture also allowed easy growth, extension and harvesting of cassava roots (Ande, 2011).

According to priority made rainfall was ranked third as one of the important criteria for growing cassava. This came due to the fact that although cassava can withstand periods of drought, it is very sensitive to soil water deficit during the first three months after planting (FAO, 2013). Farmers and extension officers together agreed that cassava prefers high amount of rainfall at planting than during other stages of growth. Rainfall was also considered important due to texture of soil in the area which is sandy in nature. Temperature was given the lowest weight as the temperature of the area did not affect crop growth.

Considering topography, farmers and extension officers considered this attribute as important for growing cassava due to the fact that the area had highlands which have good texture for cassava production and lowland which do not support cassava production due to poor infiltration resulting from high clay amount resulting from deposited soil emanating from erosion in highlands (Klingebiel *et al*., 1988).

4.2.2 Maize

The decision matrix suggested jointly by farmers and local extension officers is shown on Table 5. When performing the pair-wise comparisons CR for this matrix was less than 10%, thus the weights were taken since there was consistent judgement.

Table 5: Maize suitability analysis criteria preference matrix

	Soil physical properties	Soil chemical fertility	Rainfall	Temperature	Topography
Soil physical properties	1	0.5	0.5	6	2
Soil chemical fertility	2	1	1	9	7
Rainfall	2	1	1	6	7
Temperature	0.17	0.11	0.17	1	2
Topography	0.5	0.14	0.14	0.5	1

The values of Table 5 reflect the domination of soil physical properties, soil chemical fertility and rainfall criteria over temperature and topography in maize production. Values of 0.5, 1 and 2 in the first three rows of Table 5 show that criteria like soil physical properties, soil chemical fertility and rainfall are regarded to be equally or moderately important to each other but were much more important to temperature and topography as they scored high value of 6, 7 and 9 when compared to temperature and topography in pair wise preference matrix as seen in the first, second and third rows of the last two columns of Table 5.

The criteria weights calculated from the decision matrix and their respective ranking jointly by farmers and extension are shown on Table 6.

Table 6: Criteria weights and ranks for maize suitability analysis

Criteria	Weight	Rank
Rainfall	41.3%	1
Soil chemical fertility	32.6%	2
Soil physical properties	17.2%	3
Temperature	5%	4
Topography	4%	5

Results for maize by farmers and extension officers shows that rainfall was ranked highest by scoring 41.3% followed by soil chemical fertility 32.6% and soil physical properties 17.2%. Temperature and topography received the lowest priority by scoring 5.0% and 4.0% respectively.

Rainfall received the highest weight in joint group ranking which came as a result of emphasis given to this criterion. The importance of rainfall came on considering the total crop failure or poor yields experienced by both extension officers and farmers when there is no or little amount of rainfall. This was highly contributed by the sandy soil texture of the area as it stores less moisture (Jalota *et al.*, 2010). Water is highly needed by crops during the planting period (IITA, 1982).

Soil chemical fertility was ranked as the second most important criterion for growing maize as it has important parameters which support the growth and productivity of maize. The criterion importance of this came due to it is limiting nature in maize production which came as a result of continuous cultivation of the land without adding inputs for fertilizing the land and sandy soils which have a low potential to retain nutrients (Chikuvire *et al.,* 2007). Soil physical properties followed in ranking of the factors, indicating that they were important in growing maize. Both farmers and extension considered it important for growing maize. Soil texture strongly determines water holding capacity of soil (Li *et al.*, 2013). Farmers and extension officers mentioned that soil texture of the area affected maize production as it does not retain water and nutrient. Temperature and topography was considered as less important ranking, as they had less influence in maize production in the area.

4.2.3 Sorghum

The decision matrix suggested jointly by the farmers and local extension officers for sorghum is shown on Table 7. When performing the pair-wise comparisons CR for this matrix was less than 10%, thus the weights were taken since there was consistent judgement.

Table 7: Sorghum suitability analysis criteria preference matrix

	Soil physical properties	Soil chemical fertility	Rainfall	Temperature	Topography
Soil physical properties	1	0.5	0.25	6	4
Soil chemical fertility	2	1	1	6	8
Rainfall	4	1	1	9	7
Temperature	0.17	0.17	0.11	1	2
Topography	0.25	0.13	0.14	0.5	1

The values of Table 7 reflect the domination of soil physical properties, soil chemical fertility and rainfall criteria over temperature and topography in sorghum production.

Values of 0.25, 0.5, 1 and 2 in first three rows of Table 7 shows that the factors like soil physical properties, soil chemical fertility and rainfall are regarded to be equally or moderately important to each other but were much more important to temperature and topography as they scored high value of 4, 6, 7, 8 and 9 when compared to temperature and topography in the pair wise preference matrix of the last two columns in Table 7.

The criteria weights calculated from the decision matrix and their respective rankings are shown on Table 8. Jointly, farmers and local extension officers ranked soil chemical fertility as highest criterion for growing sorghum by giving it 36.9% weight; followed by soil rainfall 33.8% and soil physical properties 18.6%. Temperature and topography received the least priority by scoring 5.5% and 5.2% respectively.

Table 8: Criteria weights and ranks for sorghum suitability analysis

Criteria	Weight	Rank
Soil chemical fertility	36.9%	1
Rainfall	33.8%	2
Soil physical properties	18.6%	3
Temperature	5.5%	4
Topography	5.2%	5

Soil chemical fertility was considered as the most important attribute for growing sorghum. The ranking was made considering how wide the criterion supported sorghum production. This is because sorghum is more tolerant of alkaline soils than other grain crops (DAFF, 2010). Rainfall was the second criterion to receive high weight considering how it suitably supports sorghum production. A medium to good and fairly stable rainfall pattern during the growing season is suitable for sorghum production (FAO, 2013). Considering soil physical properties, farmers and extension officers named it as one of the important criterion for sorghum production. This is due to the argument made considering the criterion negatively affects sorghum production in the area. Sorghum mainly grown on low potential, shallow soils with high clay content but it grows poorly on sandy soil, which is common in the area (DAFF, 2010). Temperature and topography received the lowest score because they affected sorghum production to a lesser extent in the area.

4.3 The Soils of Butuguri Area

The soils of Butuguri area were studied as guided by the developed base map from which representative soil profiles were excavated and composite soil samples were collected. The map indicating the soil-mapping units is shown on Fig. 3. Soil types and their salient characteristics are described below.

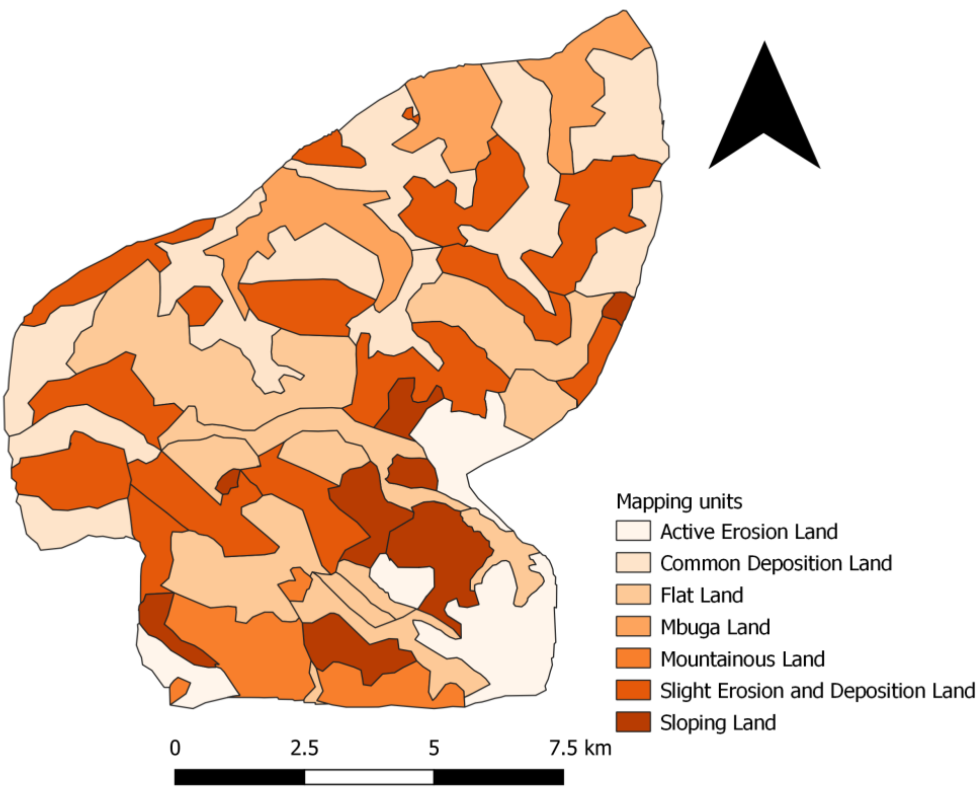

Figure 3: Land mapping units of Butuguri area

4.3.1 Soil physical properties

Selected soil physical properties of mapping units of Butuguri area are shown in Tables 9 and 10 for topsoils and subsoils, respectively. The profiles studied show a number of shared physical properties, including high rock fragment content in subsoils and a textural class ranging from sandy loam to sandy clay loam. The major part of the area has soils which were very deep over 150 cm. In exception of mbuga land area soils were

Table 9: Topsoils physical properties of Butuguri area

Profile Number	Mapping unit	Depth (cm)	Soil colour	Structure size	% sand	% silt	% clay	Textural class
KSM-P1	MBL	145	Black	fine	75.04	13.28	11.68	sandy loam

KMY-P2	CDL	120	Dark brown	medium	81.04	7.28	11.68	sandy loam
KMV-P3	SEDL	184	Dark brown	medium	83.04	5.28	11.68	loamy sand
BTG-P4	FL	133	Dark brown	medium	80.04	6.28	13.68	sandy loam
BSG-P5	SL	190	Dark brown	fine	80.04	4.28	11.68	loamy sand
KGR-P6	ASL	160	Dark brown	fine	85.04	5.28	9.68	loamy sand
NMK-P7	ML	74	Dark reddish brown	medium	64.04	6.28	24.68	sandy clay loam

Table 10: Subsoils physical properties of Butuguri area

Profile Number	Mapping unit	Depth (cm)	Soil colour	Structure size	% sand	% silt	% clay	Textural class
KSM-P1	MBL	145	Very dark gray	coarse	52.04	11.28	36.68	sandy clay
KMY-P2	CDL	120	Strong brown	medium	79.04	6.28	14.68	sandy loam
KMV-P3	SEDL	184	Yellowish red	coarse	69.04	6.28	24.68	sandy clay loam
BTG-P4	FL	133	Strong brown	coarse	70.04	6.28	23.68	sandy clay loam
BSG-P5	SL	190	Yellowish red	medium	72.04	5.28	22.68	sandy clay loam
KGR-P6	ASL	160	Very dark grayish brown	medium	82.04	7.28	10.68	loamy sandy
NMK-P7	ML	74	Dark Brown	fine	70.04	3.28	26.68	sandy clay loam

Key:

MBL-Mbuga Land

CDL -Common Deposition Land

SEDL -Slight Erosion and Deposition Land

FL-Flat Land

SL-Sloping Land

ASL-Active Erosion Land

ML-Mountainous Land

Somewhat excessively drained, commonly dark brown having loamy sand or sandy loam texture on the topsoils. Subsoils were having strong brown to yellowish red colour having medium to fine granular, angular to subangular structure with sandy loam to sandy clay loam texture.

The Mbuga Land had deep soil (145 cm), well drained, sandy loam with black colour, having fine sized granular and subangular structure on the topsoils. Subsoils were dark grey to very dark grey, sandy loamy to sandy clay loam, having medium granular, angular to subangular structure on depth between 25 and 53 cm and wedge structure between 53-

65 cm deep . The lowest part of Mbuga Land soil profile (92-145 cm) had dark grey soil with a sandy clay texture with medium granular structure size.

Topsoils were formed as a result of alluvial and colluvial deposits resulted from erosion on the sloping land in the area. This could be explained by plain landform characterized by straight slope with 0.5 to 1 % slope gradient, soil colour and soil texture of topsoils were very different from that of subsoils as well as lacked erosion evidence.

Common Deposition Land had very deep soils, somewhat excessively drained soils formed from in situ weathered materials of granite parent materials. The slope type was straight, positioned on the upper slope with slight erosion and deposition. Topsoils were thick (28 cm), dark brown, medium sized granular structure and abundant fine pores with sandy loam texture. Subsoils (28 - 104 cm) were strong brown, medium sized granular structure; abundant to coarse pores with sandy loam texture same as that of topsoils. The lowest soils were having yellowish soil colour, massive structure, common few pores and abundant medium weathered materials.

Slight Erosion and Deposition Land and Flat Land had deep to very deep soils, somewhat excessively drained, dark brown to yellowish red soil colour having loamy sand to sandy clay loam texture. Soils were formed from in situ weathered granite rocks. Topsoils were deep (32 and 37 cm), dark brown with medium sized granular structure characterized by loamy sand and sandy loamy textural class. Subsoils were deep, having medium size of granular soil structure, with sandy clay loam textural class.

Sloping to Active Erosion Land areas had soils, which were very deep, somewhat excessively drained, dark brown to yellowish red with loamy sandy and sandy clay loam textural class. Topsoils were deep (26 and 30 cm), dark brown, with fine sized granular structure with loamy sand texture. Subsoils were deep, very dark greyish brown to yellowish red colour, medium sized angular and subangular blocky structure, sandy clay loam and loamy sand texture with weathered primary minerals.

Mountainous Land was found having moderately deep soil, somewhat excessively drained, dark reddish brown to dark brown coloured soil with sandy clay loam texture. Topsoils were shallow (16 cm), dark reddish brown, medium size of granular structure. Subsoils were shallow, dark brown, fine sized granular structure. The area had evidence of by slight rill erosion but no deposition.

4.3.2 Soil chemical properties

4.3.2.1 Macronutrients

Table 11 presents soil chemical properties of the area. Soils of the area were generally acidic with pH ranging from 5.14 - 6.00 (very strong acid-medium acid) in topsoils and 4.37 – 7.5 (Very strong acid-neutral) in subsoils (Msanya *et al.*, 2001b). Acidic soils could be due to loss of basic cations (Ellis and Foth, 1996).

Table 11: Soil chemical properties (macronutrients)

	pH in ($CaCl_2$)		**Electric conductivity (dS/m)**		**Bray/Olsen P (mg/Kg)**		**Organic carbon (%)**		**Total N (%)**		**CEC (Cmol(+)/kg)**	
Mapping unit	Topsoils	Subsoils	Topsoils	Subsoils	Topsoils	Subsoils	Topsoils	Subsoils	Topsoils	Subsoils	Topsoils	Subsoils
ML	6	7.5	0.06	0.08	10.8	1.99	2.79	0.23	0.15	0.05	16.4	15.8
CDL	5.97	5.00	0.06	0.05	5.71	7.51	1.41	0.35	0.11	0.05	10.6	8.6
SEDL	5.32	4.52	0.05	0.05	6.71	6.54	0.68	0.36	0.07	0.07	9.4	9.5
FL	5.44	4.84	0.05	0.05	3.10	1.94	0.78	0.49	0.08	0.09	8.8	9.7
SL	5.14	4.37	0.05	0.04	2.05	2.14	0.53	0.41	0.11	0.09	7.8	9.8
AEL	5.21	4.44	0.05	0.04	0.75	1.23	0.29	0.32	0.09	0.06	5.8	7.36
ML	5.5	4.67	0.06	0.05	0.99	4.48	1.63	0.82	0.15	0.07	14.4	12.1

Key:

ML-Mbuga Land CDL-Common Deposition Land

SEDL-Slight Erosion and Deposition Land | FL-Flat Land

SL-Sloping Land | AEL-Active Erosion Land

ML-Mountainous Land

General evaluation of some chemical properties value was according to compiled values made by Msanya *et al.* (2001b). Electric conductivity of soils of the area was generally low ranging from 0.04 dS/m to 0.06 dS/m in both topsoils and subsoils which indicate that the area did not have salinity problem (Rhoades *et al.*, 1999). Available P was ranging from 0.75 to 10.8 mg/kg of soil in topsoils and 1.23 to 7.51 mg/kg of soil in subsoils. This indicates that available P in the area was medium to low due to low soil pH which increased the ability of soil to fix phosphorus by aluminium and iron (Price, 2006). The area was having very low to medium CEC ranging from 5.8 to 16.4 cmol (+) kg^{-1} in topsoils which could be attributed by low organic carbon (OC), low clay mineralogy and low soil pH (Ellis and Foth, 1996). In subsoils CEC was low to medium ranging from 7.36 to15.8 cmol (+) kg^{-1} this could be due to deposited basic cations leached from topsoils (Ellis and Foth, 1996). However, CEC tended to decrease as the elevation increased clearly showing the influence of erosion and deposition to soil chemical properties (Badia *et al.*, 2016).

In the area, soil organic C and total N decreased with increasing altitude but was high at the highest elevation which could be contributed by forest having decomposed plant materials (humus) (Badia *et al.*, 2016). The area was observed to have very low to low total N ranging from 0.07 to 0.15 % in topsoils and 0.05 - 0.09 % in subsoils, which could be due to poor supply of plant nutrients and poor recycling of plant and animal residues (Uwitonze *et al.*, 2016). Sandy soil texture also reduced amount of total N in soil as a result of leaching (Price, 2006).

Organic Carbon (OC) was medium to high at 1.41%, 1.63% and 2.79% on topsoils of Common Deposition Land, Mountainous Land, and Mbuga Lands, respectively; but it was very low to low in the rest of the area and subsoils of all soils had OC value ranging from 0.23 to 0.82%. Rainfall and temperature of the area could have speeded up decomposition of organic matter resulting in low OC in soil (Price, 2006).

In Mbuga Land, the pH ranged from slightly acid to strong alkaline, with value ranging from 6 - 7.5 (Table 11). Alkaline pH can be due to high levels of exchangeable calcium on the topsoils and calcium and sodium in subsoils which can be due to presence of exposed parent material (calcium carbonate), neutral pH is due to neutralizing capacity of calcium released from weathering of carbonate in the absence of effective leaching and recycling of other basic cations which balances influence of biological activities, acidity inputs from precipitation and other factors (Ellis and Foth, 1996). The soils had low electric conductivity (EC) ranging from 0.06 to 0.08 dSm^{-1} which indicate that the area was not having salinity problems (Rhoades *et al.*, 1999). Available phosphorus (Bray and Kurtz) was medium as a result of soil pH while Olsen was low due to phosphorus fixation by calcium due to high pH (Price, 2006). Organic carbon was high in topsoils and very low on subsoils while total N was low in topsoils and very low in subsoils (Msanya *et al.*, 2001b). Cation Exchange Capacity (CEC) levels were medium in topsoils (16.40 cmol (+) kg^{-1} of soil and some horizons of subsoils but it was high in subsoils 28.6 cmol (+) kg^{-1}) of soil this could be due to exchangeable basic cations in subsoils (Price, 2006).

Table 11 shows that Common Deposition land had pH of 5.79 in topsoils and 5.0 in subsoils with very low electric conductivity ranging from 0.06 in topsoils and 0.05 dSm^{-1} in subsoils hence soil was not saline (Rhoades *et al.*, 1999). Bray and Kurtz I P value was low with value of 5.71 and 7.51 mg/kg of soil in topsoils and subsoils respectively this could be attributed to P fixation (Price, 2006). Organic carbon was high in topsoils and low on subsoils while total nitrogen was generally low. The area was having medium CEC level in topsoils 16.60 cmol (+) kg^{-1} this could be due to presence of some exchangeable basic cations. Low CEC in subsoils that was 8.6 cmol (+) $kg-^{1}$ could be attributed by low exchangeable basic cations.

Slight Erosion and Deposition Land, Flat Land, Sloping Land and Active Erosion Land were having acidic soils with pH ranging from 5.44 to 5.21 in topsoils and 4.52 to 4.44 in subsoils probably due to low exchangeable cations (Ellis and Foth, 1996). The areas were having very low EC ranging from 0.05 in topsoils and 0.04 - 0.05 dSm^{-1} in subsoils indicating low salinity in the area (Rhoades *et al.,* 1999). The available P (Bray and Kurtz I) was low in both topsoils and subsoils this could be caused by P-fixation due to low pH values. Organic carbon was medium to very low in topsoils and very low in subsoils while total N was low to very low in topsoils but very low in subsoils this could be due to farming practices in the area that do not add nutrient inputs significantly lower concentrations organic matter in soil and total nitrogen (Diallo *et al.,* 2016). These areas were having low to very low CEC both in topsoils and subsoils, 7.36 to 9.8 cmol (+) kg^{-1} topsoils 7.4 to10 cmol (+) kg^{-1} in subsoils.

Mountainous Lands were having acidic soils with pH of 5.50 in topsoils and 4.67 in subsoils with low EC of 0.06 0.04 dSm^{-1} in topsoils and 0.04 dSm^{-1} in subsoils (Table 11). This indicated that the area was not having salinity problem (Rhoades *et al.,* 1999). The available P (Bray and Kurtz I) was very low in both topsoils and subsoils this could be due to P-fixation accelerated by low pH values. Organic carbon was medium in topsoils but very low in subsoils (1.63 and 0.82%) respectively, while total N was low topsoils and very low in subsoils. The areas were having medium CEC in top and low CEC in subsoils

(14.40 cmol (+) kg^{-1} in topsoils and 12.1 cmol (+) kg^{-1} in subsoils). Medium CEC could be attributed by exchangeable basic cations in subsoils of this pedon (Price, 2006).

4.4.2.2 Micronutrients

The levels of DTPA extractable Fe, Zn, Mn and Cu are shown on Table 12. Extractable Mn and Fe values of the study area were generally higher than the critical values established (Siva *et al.*, 2017). Extractable Zn and Cu were generally lower than critical values except for a few soils.

Table 12: Soil chemical properties (micronutrients)

Mapping unit	(Extractable Mn (mg/kg)		Extractable Zn (mg/kg)		Extractable Fe (mg/kg)		Extractable Cu (mg/kg)	
	Topsoils	Subsoils	Topsoils	Subsoils	Topsoils	Subsoils	Topsoils	Subsoils
MBL	45.67	22.33	1.03	0.30	61.88	11.72	0.26	0.38
CDL	26.16	21.42	0.63	0.44	35.31	44.54	0.2	0.35
SEDL	23.11	23.24	1.39	0.41	24.38	15.52	0.2	0.17
FL	44.45	9.17	0.50	0.53	22.19	14.57	0.2	0.29
SL	31.65	21.5	0.29	0.28	27.81	29.00	0.39	0.64
ASL	19.45	33.48	0.08	0.07	28.75	45.88	0.92	0.54
ML	52.38	24.94	0.11	0.08	45.63	28.60	2.11	0.66

Key:

MBL-Mbuga Land CDL-Common Deposition Land

SEDL-Slight Erosion and Deposition Land FL-Flat Land

SL-Sloping Land ASL-Active Erosion Land

ML-Mountainous Land

The levels of all micronutrients in the topsoils were higher than those in subsoils, which could be attributed to the soil parent material. In Mbuga Land high level of Mn could be due to high pH and Ca levels observed while low Zn could be because of low soil pH (Mitchell and Adams, 1994). High amount of Mn and Fe could be due to weathering of parent materials (Khageshwar *et al.*, 2015).

4.3.3 Soil composite samples

Composite sample results in Table 13 and 14 were used to supplement profile data in the area.

Table 13: Soil chemical properties of composite samples (macronutrients)

Mapping unit	pH ($CaCl_2$)	Electric conductivity (dS/m)	Bray P (mg/kg)	Organic carbon (%)	Total N (%)	CEC (cmol(+)/kg)
MBL	5.21	0.05	1.74	0.99	0.11	1.98
CDL	5.46	0.06	2.36	0.39	0.12	0.78
SEDL	4.93	0.05	1.43	0.65	0.07	1.29
FL	5.62	0.06	1.55	1.95	0.14	3.90
FL	5.56	0.06	4.91	0.19	0.06	0.39
SL	4.71	0.05	2.05	0.40	0.04	0.80
ASL	5.77	0.06	3.54	0.88	0.09	1.76
ASL	5.13	0.05	1.30	0.52	0.05	1.04

Table 14: Soil chemical properties of composite samples (micronutrients)

Mapping Unit	mg/kg Mn	mg/kg Zn	mg/kg Fe	mg/kg Cu
MBL	30.43	0.55	101.56	1.25
CDL	9.09	0.05	24.69	1.64
SEDL	21.89	0.32	46.25	1.91
FL1	213.35	2.66	60.94	2.83
FL2	25.55	0.05	24.69	1.58
SL	29.21	0.03	23.13	1.45
ASL1	46.89	0.16	37.19	1.97
ASL2	38.96	0.08	30.63	0.92

Key:

MBL-Mbuga Land CDL-Common Deposition Land

SEDL-Slight Erosion and Deposition Land FL-Flat Land

SL-Sloping Land ASL-Active Erosion Land

Although composite sample was taken to supplement profile data, most of the chemical properties of composite soil samples were different from those of topsoils in soil profiles established on the same soil-mapping unit. Composite soils obtained had lower values compared to topsoils of soil profiles this could be due to the fact that composite samples were admixture of different subsamples while from soil profiles only topsoils were taken.

The highest pH of topsoils from profiles was 6 while that of composite was 5.77. The lowest Soil pH of topsoils from profiles was 5.14 while that of composite was 4.71. The highest extractable P value of topsoils from profiles was 10.8 while that of composite was 4.91. The lowest extractable P value of topsoils from profiles was 0.75 mg/kg while that of composite soils was 1.30 mg/kg. The highest OC value of topsoils from profiles was 2.79 % while that of composite soils was 1.95 %. The lowest OC value of topsoils from profiles was 0.29 % while that of composite soils was 0.19 %. The highest total N value of topsoils from profiles was 0.15 % while that of composite was 0.11 %. The lowest total N value of topsoils from profiles was 0.07 % while that of composite was 0.04 %. The highest CEC value of topsoils from profiles was 16.4 cmol (+) kg^{-1} while that of composite soils was 1.98 cmol (+) kg^{-1}. The lowest CEC value of topsoils from profiles was 5.8 cmol (+) kg^{-1} while that of composite samples was 0.39 cmol (+) kg^{-1}. However electric conductivity of composite samples and that of soil pedons (Table 11 and 13) and micronutrient values of composite samples and that of soil pedons were more or less the similar in all soil mapping units (Table 12 and 14).

4.3.4 Dominant soil types

Distribution of soil orders (USDA Soil Taxonomy) in the study area is shown on Fig. 4.

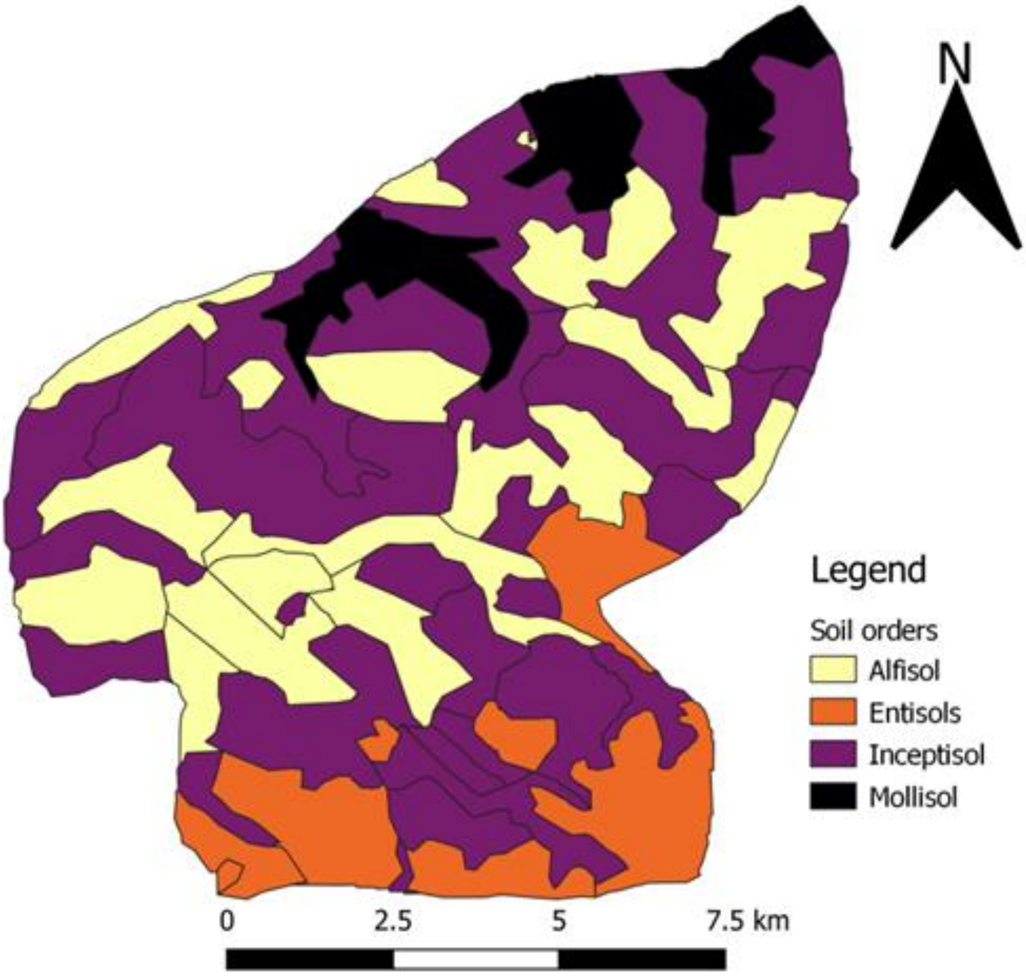

Figure 4: Soil orders of Butuguri area

The soils of Butuguri area fall into 4 USDA Soil Taxonomy orders: Inceptisols, Entisols, Alfisols and Mollisols (Table 15).

Table 15: Classification of soils of Butuguri to Subgroup level of USDA Soil Taxonomy

USDA Soil Taxonomy 2014				
Profile No.	**Order**	**Suborder**	**Great group**	**Subgroup**
KSM-P1	Mollisols	Ustolls	Haplustolls	Entic Haplustolls
KMY-P2	Inceptisols	Ustepts	Haplustepts	Oxyaquic Haplustepts
KMV-P3	Alfisols	Ustalfs	Haplustalfs	Typic Kandiustalfs
BTG-P4	Inceptisols	Ustepts	Dystrustepts	Humic Dystrustepts
BSG-P5	Inceptisols	Ustepts	Dystrustepts	Typic Dystrustepts
KGR-P6	Entisols	Psamments	Ustipsamments	Typic Ustipsamments
NMK-P7	Entisols	Orthents	Ustorthents	Vermic Ustorthents

Inceptisols and Entisols were the dominant soil orders, represented by 5 out of 7 classified pedons. One pedon was classified as Alfisols and the last as Mollisols. In the World Reference Base for Soil Resources soil Legend, these soils were grouped into 5 Reference Soil Groups: Chernozems, Cambisols, Umburisols, Leptosols and Regosols as shown in Table 16.

Table 16: Classification of soils of Butuguri area to tier 2 according to the World Reference Base for Soil Resources [IUSS Working Group WRB (2015)]

Profile No.	Reference Soil Group (RGS)- TIER 1	Principal Qualifiers	Supplementary Qualifiers	TIER 2 name
KSM-P1	Chernozems	Chernic Fractic	Colluvic, Densic, Novic	Fractic Chernic Phaeozems (Colluvic, Novic)
KMY-P2	Cambisols	Ferralic, Dolomitic	Arenic, Aric	Ferralic Dolomitic Cambisol (Arenic, Aric)
KMV-P3	Umbrisols	Acric, Cambic	Arenic, Pachic	Cambic Acric Umbrisol (Arenic, Pachic)
BTG-P4	Cambisols	Andic, Skeletic	Aric, Ferric	Skeletic Andic Cambisol (Aric, Ferric)
BSG-P5	Cambisols	Fragic, Andic	Arenic, Aric	Andic, Fragic Cambisol (Alcalic, Arenic)
KGR-P6	Leptosols	Technic Gleyic	Arenic, Aric	Gleyic Technic Leptosol (Arenic, Aric)
NMK-P7	Regosols	Leptic, Brunic	Arenic, Aric	Brunic, Leptic Regosol (Arenic, Aric)

Cambisols were the dominant Reference Soil Groups (RGS) in the area having 3 pedons representing sloping land of the area. The remaining soil groups such as Chernozems, Umbrisols, Leptosols and Regosols each was represented by a single pedon.

In subgroups of USDA Soil Taxonomy and Qualifiers of WRB, different formative elements were obtained. Formative elements ‘Typic’ connotative for USDA soils that are typical or modal of particular great group. Other formative elements included ‘Entic’, connotative for common sandy particle size, ‘Oxyaquic’ for seasonal saturation, ‘Humic’ for soil with colour value of 3 or less when moist and a colour value of 5 or less when dry and ‘Vermic’ for mollic epipedon with termite burrows. The principal qualifier ‘Skeletic’ was connotative of WRB surface soils with dried coarse fragment. The common supplementary qualifiers are ‘Aric’ connotative for soil being ploughed to a depth greater than 20 cm and ‘Arenic’ connotative of soils having a textural class of sand or loamy sand in a layer ≥ 30 cm thick.

Soils found in Mbuga Land were classified as Mollisols in USDA (Soil Survey Staff, 2014) and Chernozems in WRB (IUSS Working Group WRB, 2015), indicating presence of thick, dark soils with high base saturation and high organic carbon. They were further classified to Entic Haplustolls due to some free carbonates in horizons. These Mbuga Lands of study area were receiving water and eroded soil materials from upland, making them fertile, hence able to support different crops. The crops grown in this area included maize, sorghum and vegetables.

Soils in Common Deposition Land were classified as Inceptisols in USDA (Soil Survey Staff, 2014) soil taxonomy and Cambisols in WRB (IUSS Working Group WRB, 2015), as they had Cambic horizons in the subsurface horizons. These soils are weakly developed mineral soils in unconsolidated materials rich in coarse fragments. In USDA, these soils were further classified into the Oxyaquic Haplustepts subgroup as they were saturated with water for 30 or more cumulative days especially in the long rainy season. This soil was suitable for growing maize, sorghum and vegetables. It was also used for grazing.

The soils of Slight Erosion and Deposition Land were classified as Alfisols in USDA Soil Taxonomy (Soil Survey Staff, 2014) and Umbrisols in WRB (IUSS Working Group

WRB, 2015). These Alfisols in USDA were due to diffuse horizon boundaries while Umbrisols in WBS were due to presence of Cambic horizon. They were further classified to Typic Kandiustalfs in USDA Cambic Acric Umbrisol (Arenic, Pachic) in WRB.

Soils on Flat Land and those of Sloping Land were classified as Inceptisols in USDA Soil Taxonomy and Cambisols in WRB. These were moderately developed soils showing transformation of parent material which is evident from structure formation. They were further classified to Humic Dystrustepts and Typic Dystrustepts in USDA Soil Taxonomy while in WRB they were classified as Skeletic Andic Cambisol (Aric, Ferric) and Andic, Fragic Cambisol (Alcalic, Arenic), respectively. Though the soil was less fertile, it was used intensively for agriculture especially crop production.

Soils of Active Erosion Land and those of Mountainous Land were classified as Entisols in USDA Soil Taxonomy but one was classified as Leptosols and another as Regosols in the WRB. They were young soils but one was further classified in to Typic Ustipsamments in USDA or Gleyic Technic Leptosol (Arenic, Aric) in WRB and another as Vermic Ustorthents subgroups (USDA) or Brunic, Leptic Regosol (Arenic, Aric) in WRB. Regosols were very weakly developed mineral soils in unconsolidated materials that did not have a mollic or umbric horizon, not very rich in coarse fragments, were not sandy, with no fluvic materials and were very thin but Leptosols were weakly developed mineral soils in unconsolidated materials that did not have a mollic or umbric horizon and were not very thin.

4.4 Spatial Distribution of the Attributes Important for Growing Cassava, Maize and Sorghum

4.4.1 Soil data spatial distribution

Figures 5 to 6 show soil physical properties spatial distribution in the study area. The results show that the area had variation in soil chemical properties while soil physical properties were less variable.

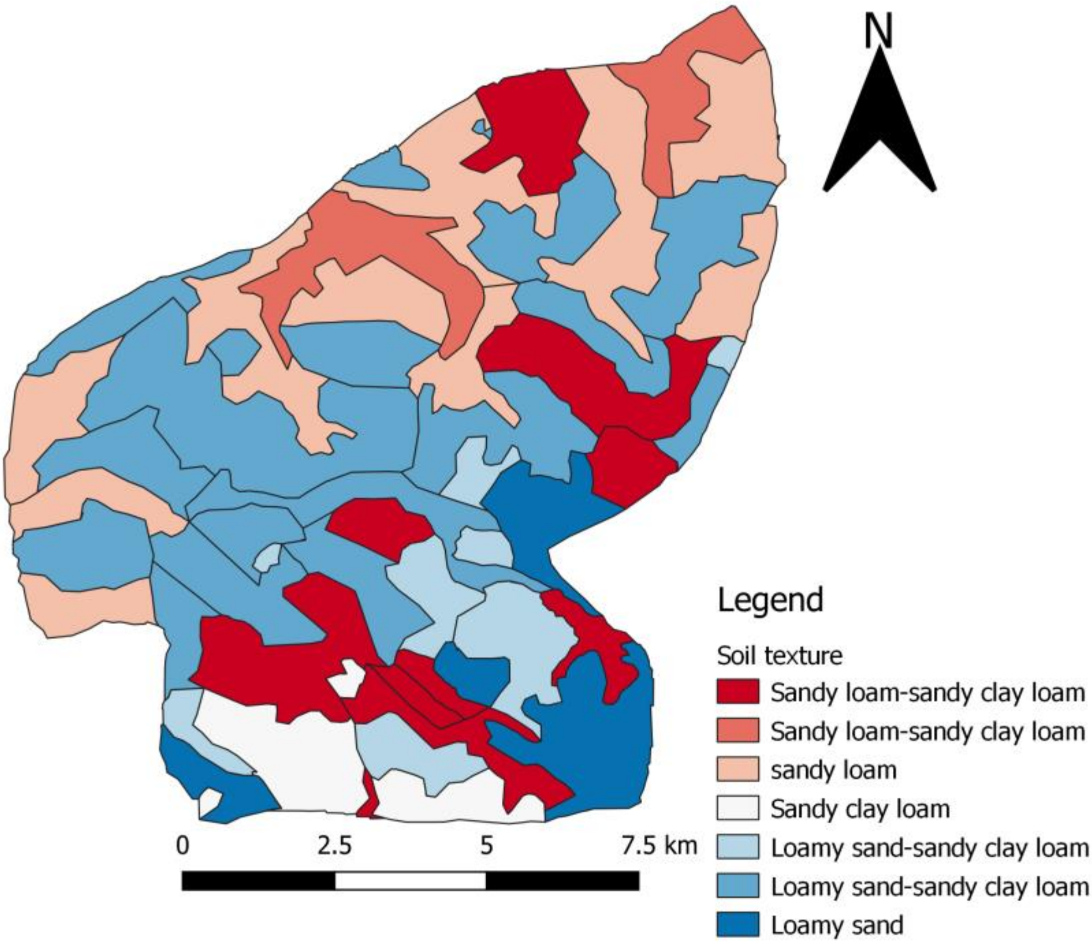

Figure 5: Spatial distribution of soil texture

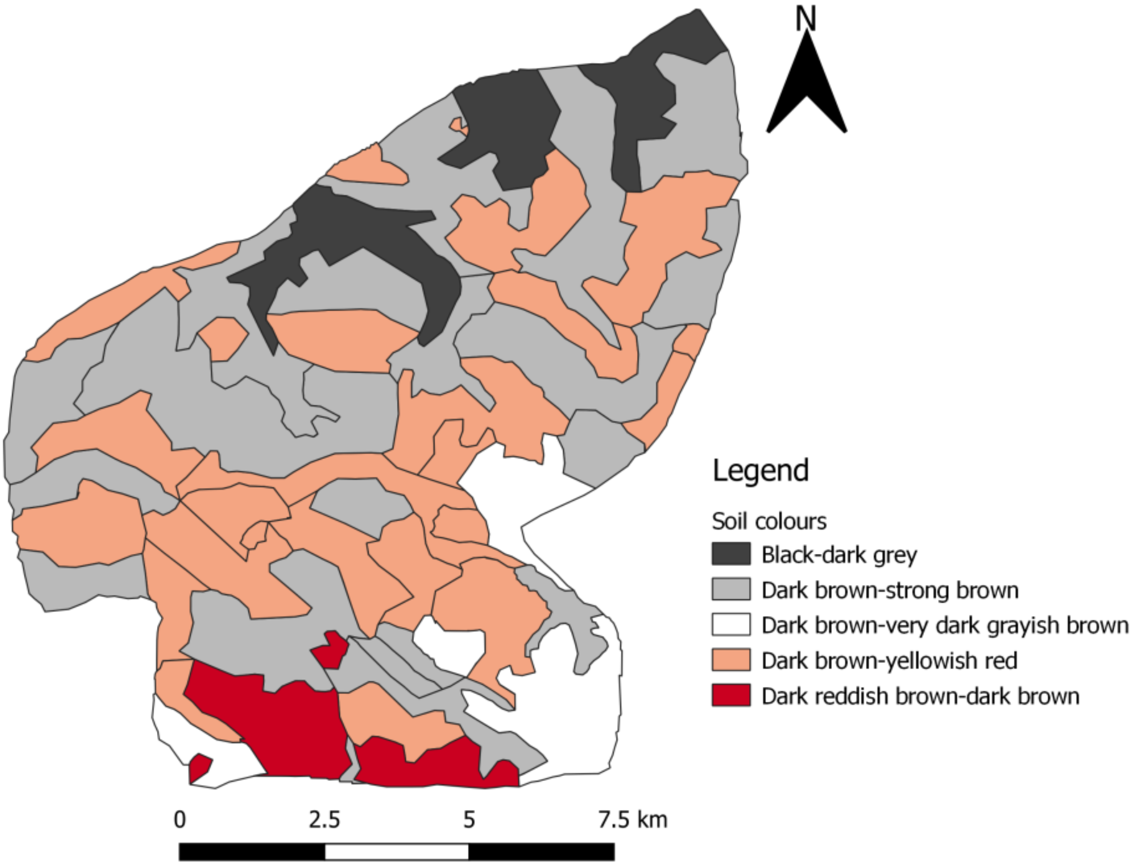

Figure 6: Spatial distribution of soil colour

Although soil physical properties in the map show less variability, these properties highly affected crop productivity in the area. The common texture of soil in the area was sandy loam and sandy clay loam. These textures of soil did not support good production of many crops and vegetation in general because they cannot store enough water and nutrients for plant growth due to high infiltration rate although cassava can strive well in this texture of soil. The common soil colour seen in the map was dark brown to yellowish red with very few areas having black soil. Dark brown and yellowish red reveal the fact that soils were less fertile hence less productive for major crops in the area because soil colour correlates well with the amount of soil organic carbon and total nitrogen (Moritsuka *et al*., 2014), the latter were low in the area. Black soils (mbuga) in the area were good for production of maize and sorghum.

Variability in soil pH and CEC had effect in production of crops grown in the area as shown in Fig. 7 and 8.

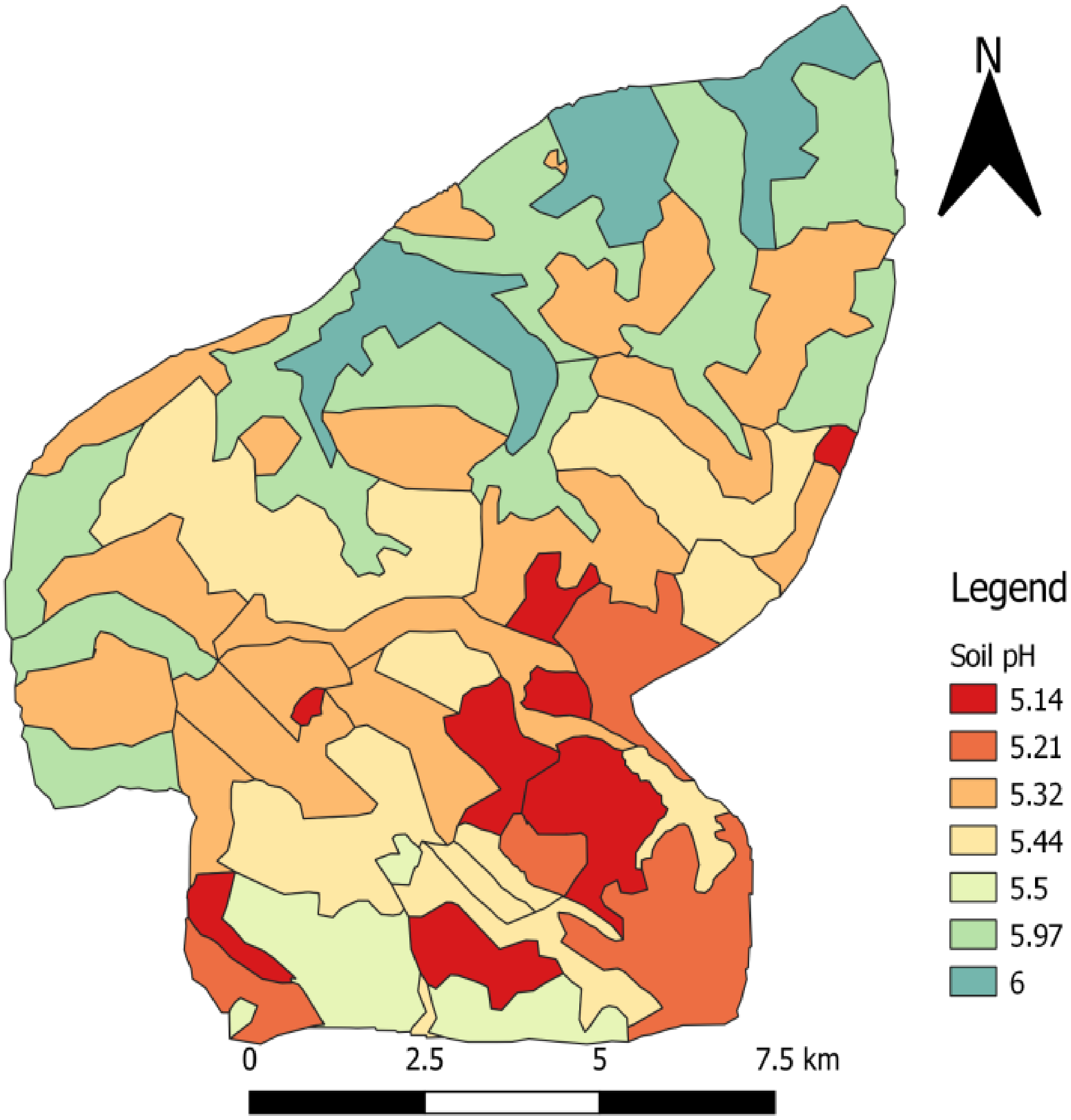

Figure 7: Spatial distribution of soil pH

Area with low pH and low CEC were less productive compared to area with high soil pH and CEC as soils with high CEC have the ability to hold more cations, making them sufficient in calcium, magnesium and other cations, which increase soil fertility (Afretuei, 2016).

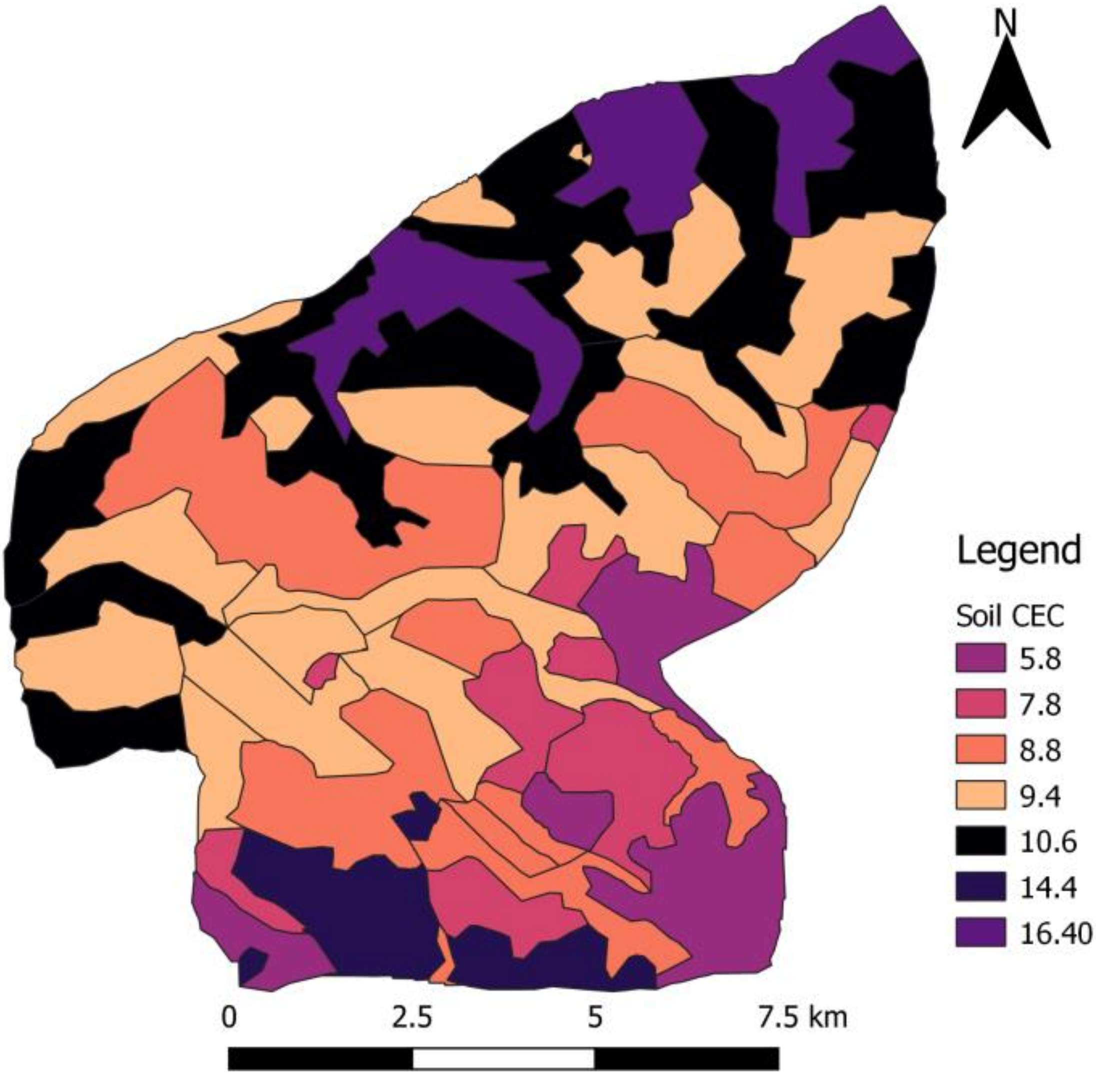

Figure 8: Spatial distribution of soil CEC

4.4.2 Climate data spatial distribution

Figure 9 present average temperature data of Butuguri area. It indicated that the area is having average temperature range of 21.1 ^{o}C to 22.2 ^{o}C. Northern part of the area has average temperature of 22.2 ^{o}C annually; the western part has average temperature of 21.9^{o}C annually, eastern part of the area has average temperature for of 21.5 ^{o}C annually while the southern part of the area has average temperature of 21.1 ^{o}C annually. Only two temperature value and large size of pixels because of poor resolution (1 km by 1 km) which occurred because of downscaling world data to cover a small area. Figure 9 present average rainfall data of Butuguri area. Rainfall data depicts that the area had rainfall amounts between 930 and 1160 mm. Rainfall map was showing large size of pixels and few data because of poor resolution (1 km by 1 km) which occurred because of downscaling world data to cover a small area.

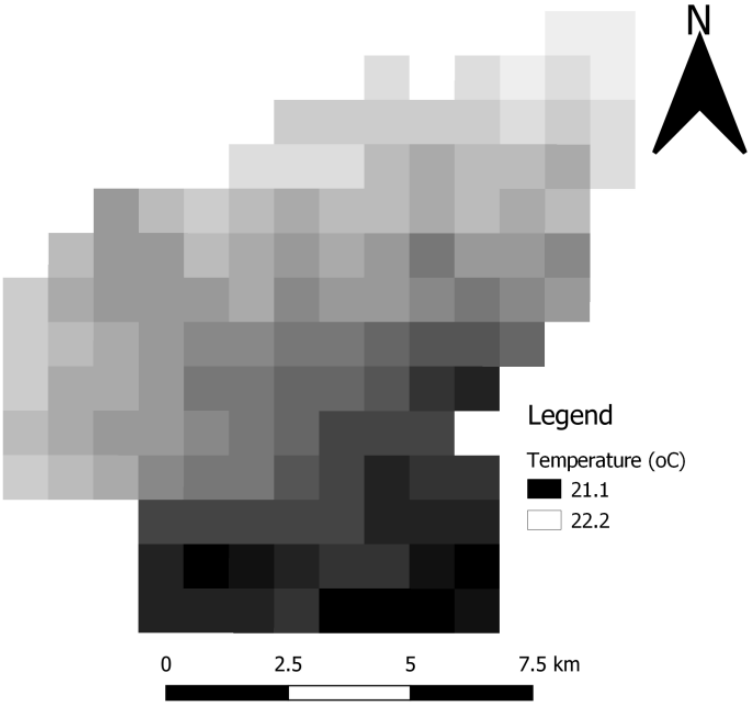

Figure 9: Temperature data of Butuguri area (Source: WorldClim data)

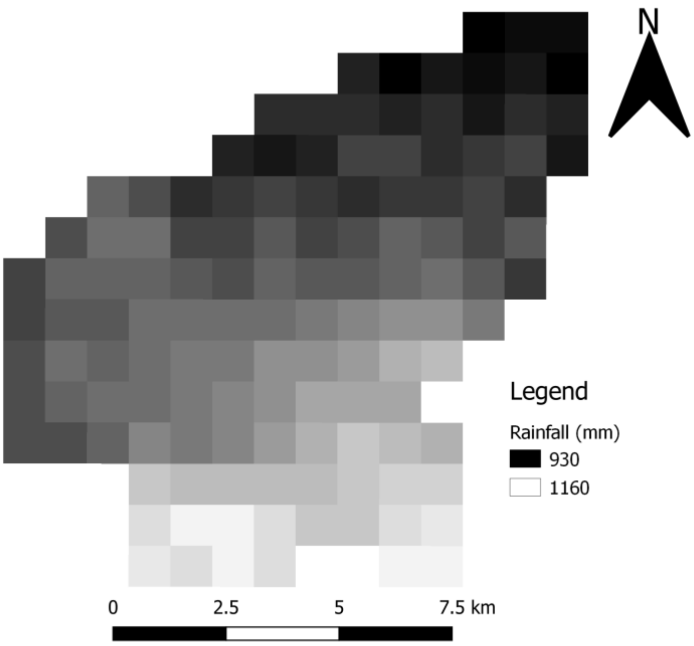

Figure 10: Precipitation data of Butuguri area (Source: WorldClim data

4.4.3 Topography data spatial distribution

Figure 11 present the DEM showing elevation differences in the study area. This result shows that the area has variations in altitude, which differ in elevation ranges. When preparing a guide for the use of digital elevation model data in soil survey, Klingebiel *et al.* (1988) used elevation to delineate soil, which was also done in this study. Based on elevation characteristics and slope the area was classified into three topographic landforms: level land, sloping and mountain landforms (FAO, 2006). The level land indicated flatter terrain represented by pale colours and mountainous land had steeper terrain represented by deep colours. From the map (Fig. 11), clear boundaries showing difference in elevation was seen; some boundaries were sharp while others were gradual.

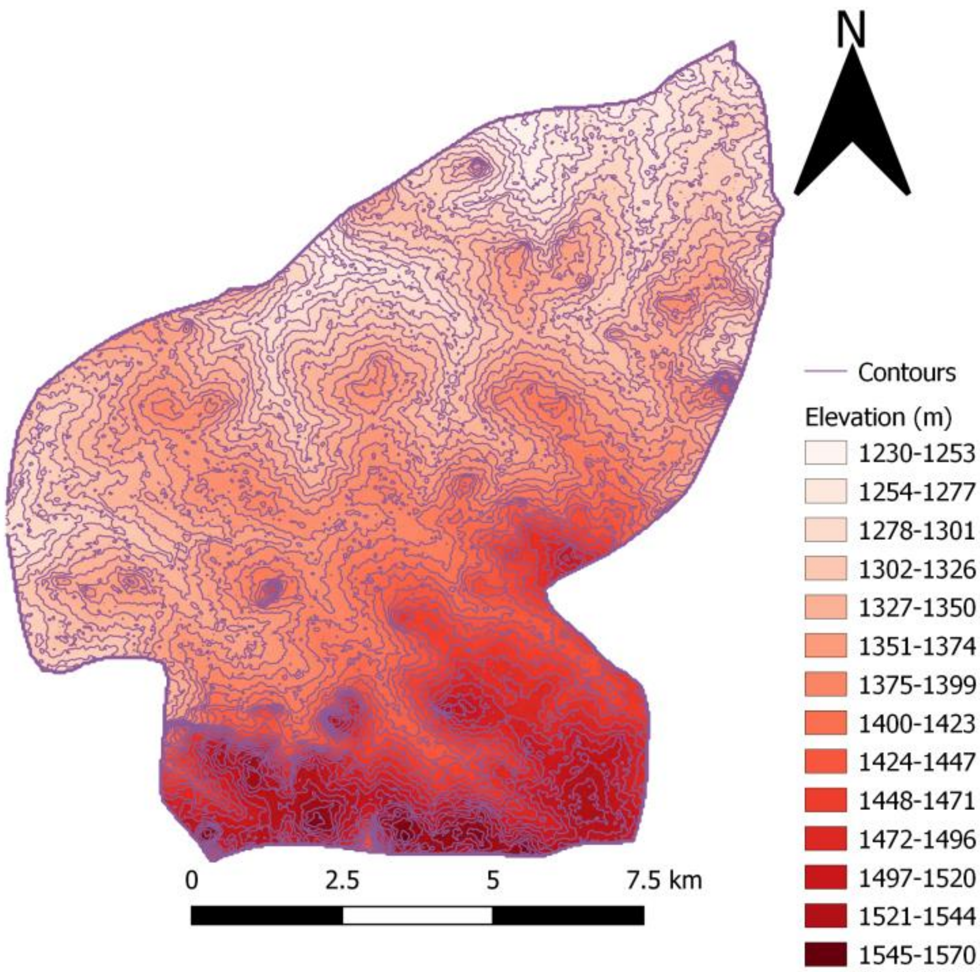

Figure 11: Elevation ranges of Butuguri area

On the lower part of the spatial maps, the boundaries were sharp, indicating moderately steep slopes while on the upper part of the map the boundaries were gradual, indicating level slopes. In the study area, spatial information indicated that the land had elevation ranging from 1230 to 1570 m.a.s.l. with slope ranging from 0.2 to 30%. Elevation ranging from 1270 to 1280 m showed flat Mbuga Land to Slight Erosion and Deposition Land of the area, while that ranging from 1281 to 1400 m presented upper Flat Land. Elevation values ranging from 1401 to 1520 m stood for area with Active Erosion Land while that with elevation between 1521 to 1570 m presented Mountainous Land in the area. In the study area pale colour presented areas with lower level land, bright colour stood for slopping land and dark colour were used to display mountainous land. The mountain and steep land were having poor development of soil due to erosion whereas level land was having well developed soil as result of deposition.

The map also shows terrain features like drainage basins, drainage networks, water sheds, peaks and other landforms features of the area. Jones (2002) when studying algorithms for using a DEM for mapping catchment areas of stream sediment samples in USA he observed water shed that lies upstream from point shed water downhill resulting in increment for all the downstream points through which the water flows. Jones (2002) observed that each point on drainage followed the flow path from downhill until it ends in a pit which was also observed in this study. Drainage network in term of catchment area was clearly seen on the level part of a map showing flow of water to different pits. There were many drainage points from the downhill ending into pits. It was seen from the map, water and eroded soil from slopping and mountainous part were shed in different pits on the level land.

4.5 Crops Suitability Analyses

4.5.1 Suitability based on elevation

According to elevation, the area was divided into 7 suitability class values that varied depending on crop grown. Figure 12 and 13 show elevation suitability.

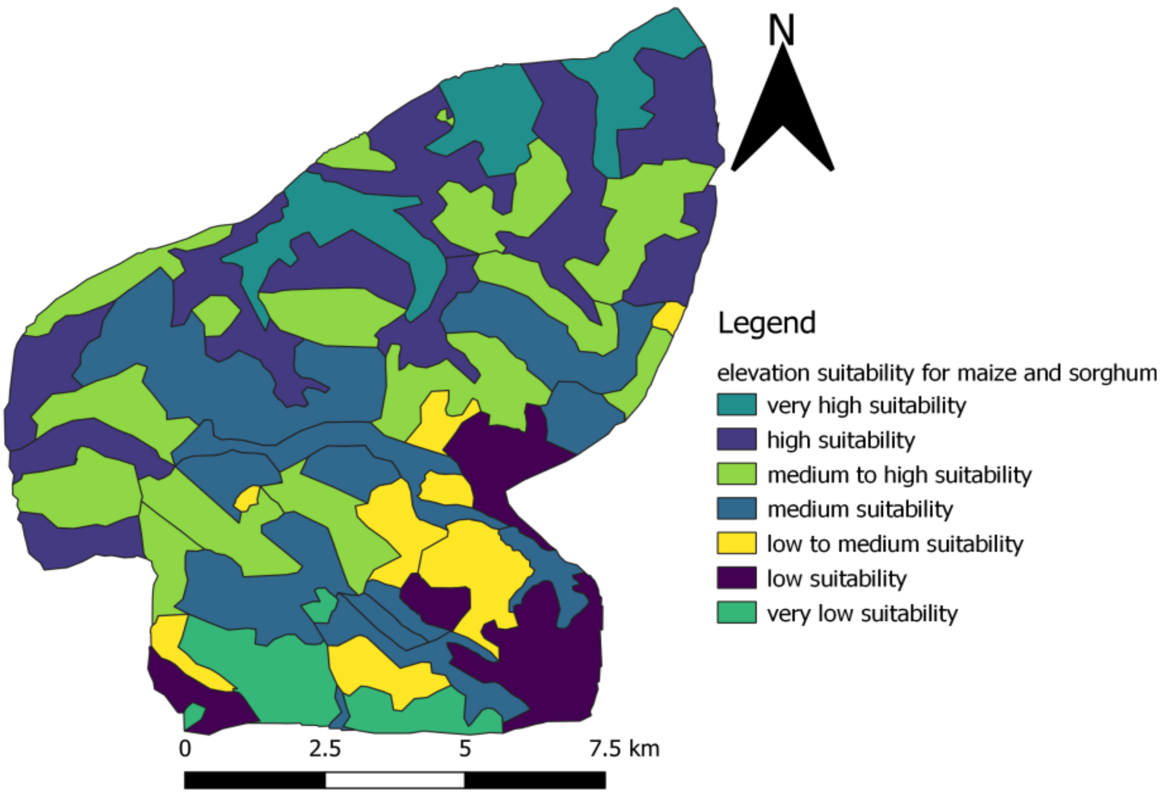

Figure 12: Elevation suitability class values for maize and sorghum

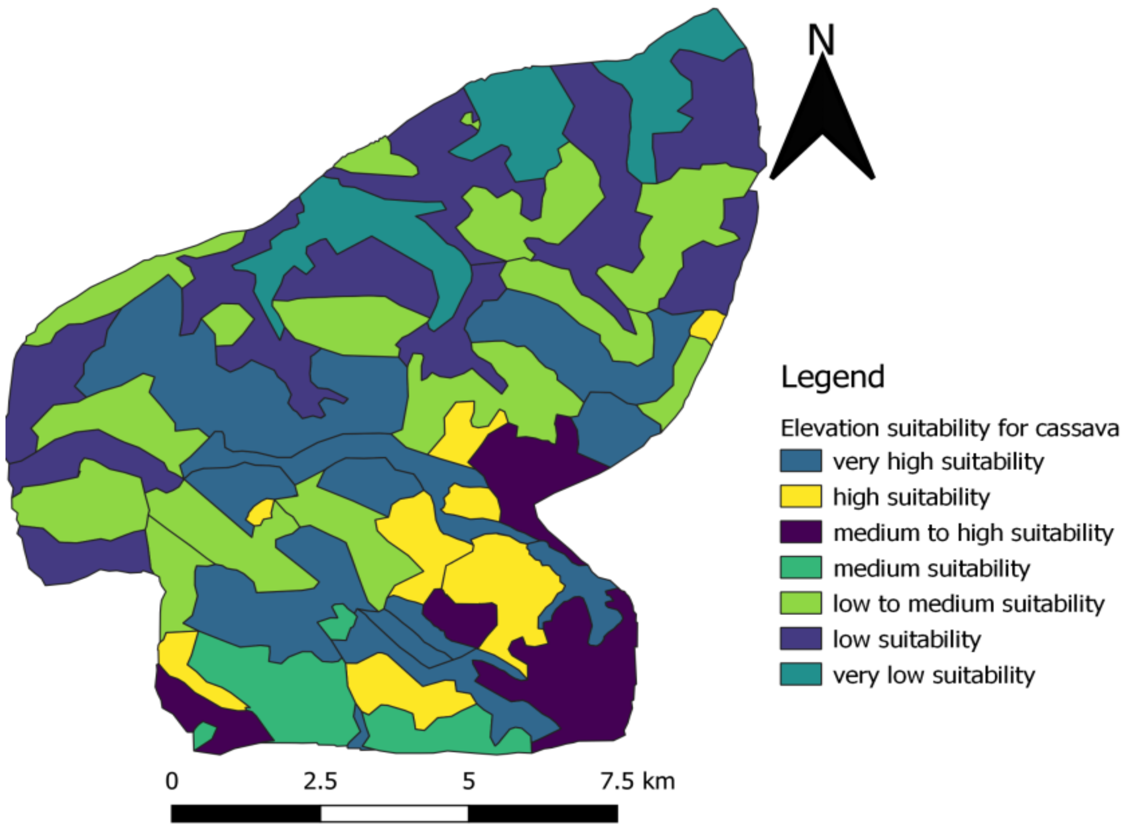

Figure 13: Elevation suitability class values for cassava

Figure 12 indicate that maize and sorghum production were considered suitable in elevation ranging from 1230 - 1366 m as the area had well developed soil hence received a high class value. Areas with elevation ranging from 1367 to 1570 m were considered less suitable due to poor developed soils as a result of erosion.

In Fig. 13 shows Mbuga Land soils (1230 - 1362 m) were considered not suitable for growing cassava as soils had high amounts of clay which is not suitable for growing cassava. Elevation between 1361 to 1570 m was considered suitable for cassava production hence received high class value (Appendix 1 - 3).

4.5.2 Suitability based on soil

4.5.2.1 Suitability based on soil physical properties

Suitability based on soil colour

Figure 14 shows soil colour ranging from black, dark brown to yellowish red.

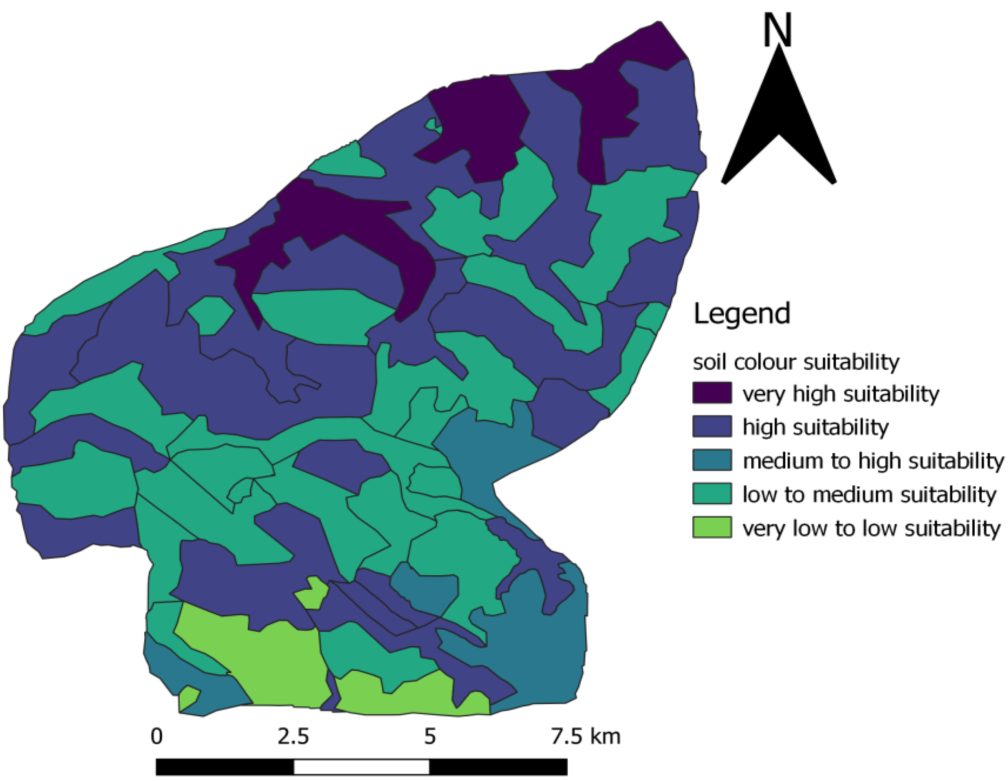

Figure 14: Suitability based on soil colour

This value was divided into 7-class value although some soils were having the same soil colour value. The black colour of soil shows fine particles of humified organic matter which indicate fertile soils and were considered suitable for all three crops hence received highest class while dark brown to yellowish red soils were considered low suitable for all three crops making them received lower class value (Appendices 1 - 3).

Suitability based on soil texture

Soil texture ranged from loamy sand to sandy clay loam. Figures 15 and 16 show 7 suitability classes although some mapping units were having same texture of soil.

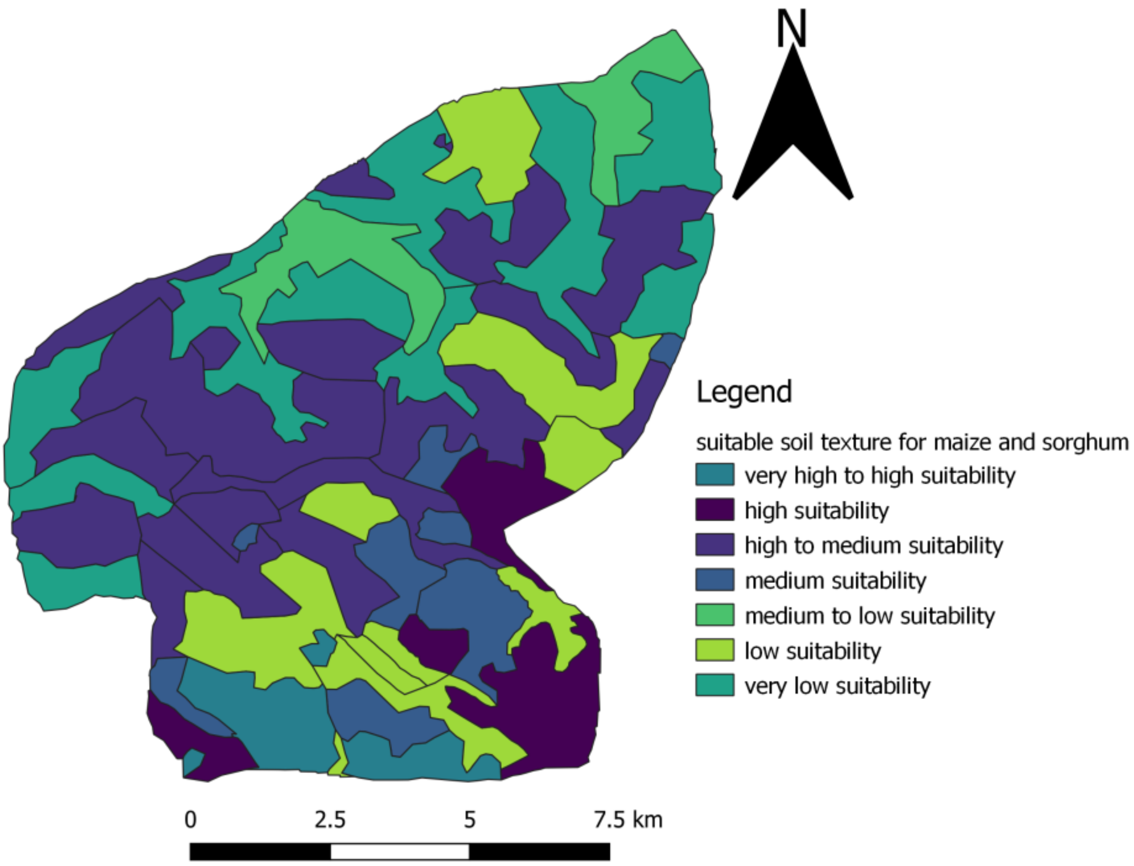

Figure 15: Soil texture suitability of: maize and sorghum

Sandy clay loam soils were treated as good texture for maize and sorghum production but sandy loam soils were considered suitable for cassava production. Farmers having piece of land in Mbuga land with sandy clay loam texture had an advantage of getting high yield of maize and sorghum compared to those having fields in sloping or mountainous land with sandy loam soils.

Areas of sandy loam were assigned low suitability class for maize and sorghum production but high suitability class for cassava production while those with sandy clay loam texture were assigned high suitability class for maize and sorghum production but low suitability class for cassava production (Appendices 1 - 3).

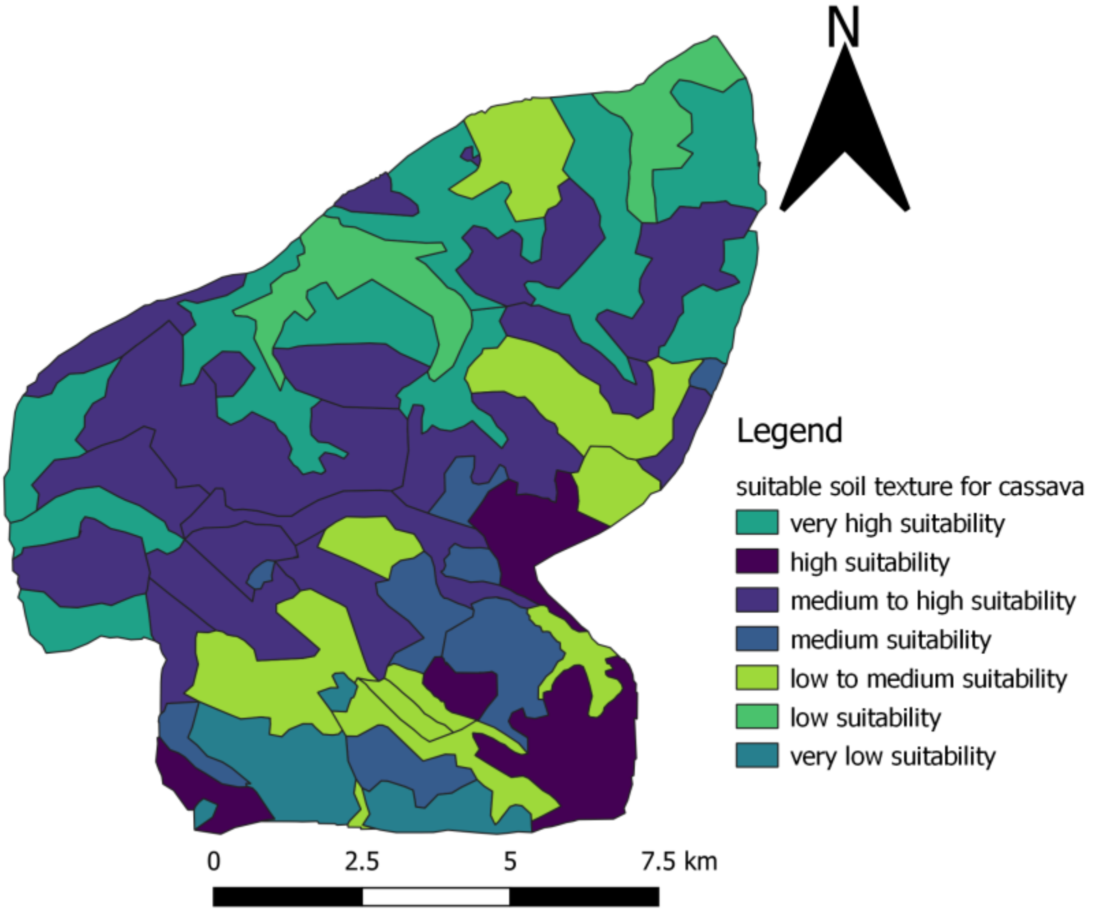

Figure 16: Soil texture suitability of cassava

Loamy sandy soils were common in the area. These soils had poor water retention, making them prone to drought which can result into yield reduction than crops grown on sandy clay loam soils. Despite the fact that sandy soils are not good for production of maize and sorghum, this soil type is still used by farmers to grow those two crops. This is highly contributed by scarcity of land as well as poor knowledge of soil physical properties.

4.5.2.2 Suitability based on soil chemical properties

Suitability based on soil pH

Soil pH is the important soil criterion for growing crops. According to Islam *et al.* (1980) optimum pH for plant growth is 5.5 to 6.5. In the study area, pH was divided into two suitability classes; areas with pH 5.5 to 6.5 received higher suitability class for all crops while those with pH less than 5.5 received lower suitability class for crop growth (Fig.17). The areas showed high suitability were those of Mbuga Land, Common Deposition Land and Slight Erosion and Deposition Land. This was due to deposition of soil.

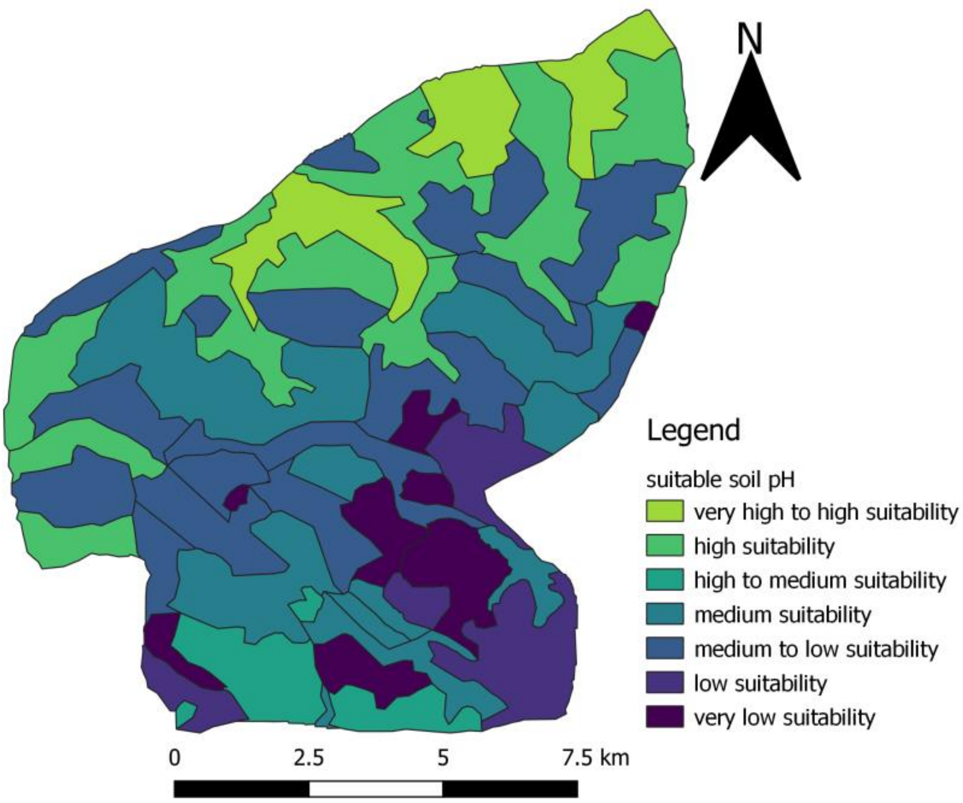

Figure 17: Suitability of the area following soil pH

Nutrients and water from Sloping and Mountainous Land. The Sloping and Mountainous Land areas have poor fertility due to erosion.

There is poor management of soil fertility by farmers in the area. Farmers do not use fertilizers for staple food crops in the area except for vegetables, which are grown in Mbuga Land. Failure to use fertilizers for maize, cassava and sorghum was due to experience farmers having for long time that these crops do not need any fertilizer to grow. Lack of awareness of soil fertility management and high fertilizer cost which cannot be afforded by small scale farmers were the other problems. Generally, farmers lack knowledge about nutrient recycling; grazing animals in farms during the off season time or taking plant residues to feed cattle at home without returning manure in the field has resulted to poor soil fertility in the area.

Suitability based on soil Cation Exchange Capacity (CEC)

Figure 18 shows suitability of area for cassava, maize and sorghum production based on CEC.

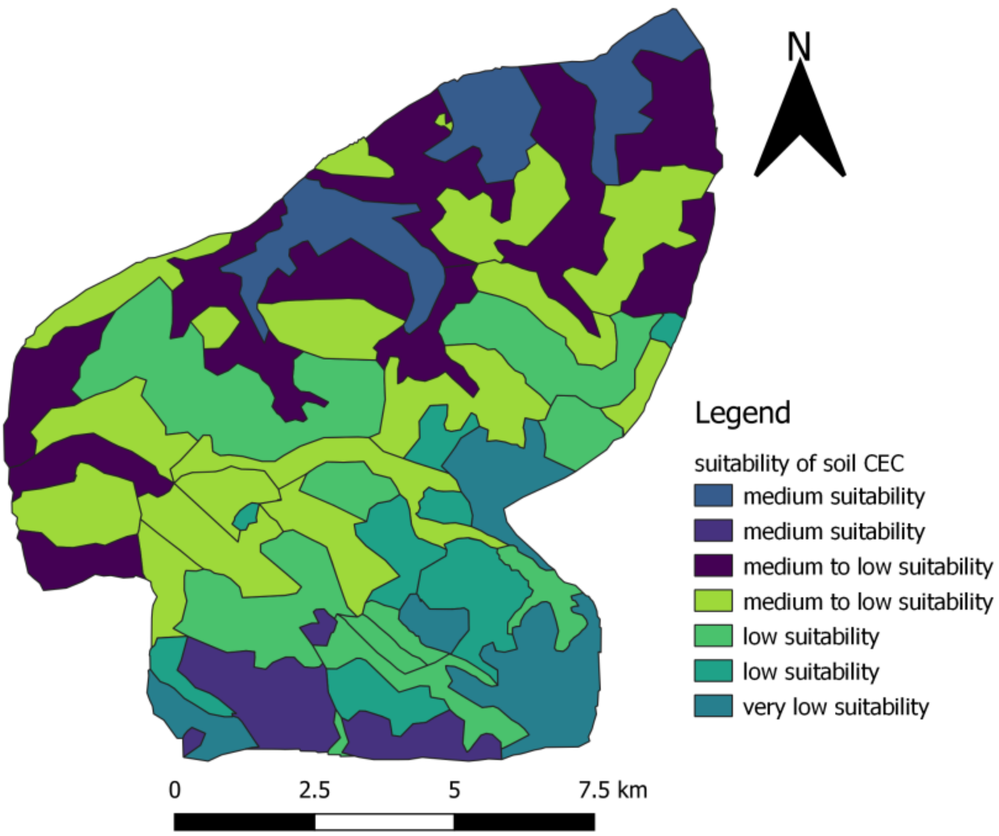

Figure 18: Suitability of Buturi area according to soil CEC

For soil to have optimum plant growth, CEC of that soil should be greater than 20 cmol (+) kg^{-1} (Msanya *et al.*, 2001b). The CEC value of the area ranged from 7.8 - 16.40 cmol (+) kg^{-1} which was counted into 4 suitability classes (Fig. 18). Area with high CEC were assigned with medium suitability class value hence considered medium suitable for cassava, maize and sorghum growth while those with low suitability class value were considered less suitable for growing the crops.

4.3.4 Suitability based on climate

According to Hollinger and Angel (2009), temperature is the main variable that determines when a crop will grow and how fast it will develop along with precipitation and solar radiation. Maize and sorghum are C4 crops, which originate from a tropical environment and can grow well at temperatures between 15 to 27 °C. This temperature is also optimum for cassava growth (FAO, 2013; Olowajoba *et al*., 2016). On planting, cassava prefers rainfall between 1000 to 1500 mm/year and temperatures of between 23 and 25^{o}C (Kouakou *et al.*, 2016; Olowajoba *et al*., 2016). Once established, cassava can grow in areas that receive just 400 mm of average annual rainfall (FAO, 2013).

A medium to good and fairly stable rainfall pattern during the growing season of about 400 to 800 mm per year is suitable for sorghum production. (DAFF, 2010) while well distributed rainfall amount of 480 to 800 mm is suitable for maize production (IITA, 1982). Since the temperature of Butuguri ranges from 21.1 to 22.2 ^{o}C and rainfall ranges between 930 to 1160 mm, the area was considered suitable for all crops. However rainfall is not evenly distributed in the area.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From this study it clear that soil, topography and climate have an impact in production of maize, cassava and sorghum. From the seven mapping units, the classified soils show low fertility and low moisture content. This has resulted in poor suitability for production of maize, cassava and sorghum. The following conclusion can, therefore, be drawn from this study.

(i) In joint ranking of criteria by farmers and extension officers soil chemical fertility was ranked highest by scoring highest value for cassava and sorghum production but rainfall scored highest for maize production.

(ii) The spatial soil information shows that Inceptisols and Regosols dominate the area. There were differences in the soil data collected from all the mapping units resulting into different subgroups.

(iii) Soil pH OC and CEC had consistent trends regarding elevation high in Mbuga and Deposition Land and low in Sloping and Mountain Land. Organic carbon (OC) was also high in Mountain Land because of forest influence.

(iv) Mbuga and Deposition mapping units were medium to highly suitable for maize and sorghum production but least suitable for cassava production. Slight Erosion and Deposition Land, Flat Land, Sloping Land and Active Erosion Land were suitable for cassava production but least suitable for maize and sorghum production. Mountainous Land was less suitable for all crops due to less developed soil profile.

5.2 Recommendations

From the results obtained in the study area, the following recommendations are made to provide further insights into suitability of evaluated land:

(i) In this study land evaluation and suitability assessment were done using digital information. Special devise for storage of available and future obtained data is recommended for national and international reference and so that they can be easily reached and exploited by many users.

(ii) Involvement of indigenous people in land evaluation and suitability assessment is a guarantee to sustainable production of crops hence food security. Therefore it is recommended that same research approach to be conducted to different locations.

(iii) It has been observed that most farmers in the area cannot afford industrial fertilizer and they don’t consider cassava, maize and sorghum as cash crops hence not worth to expensive fertilizers. They don’t even believe that using manure can have any contribution to productivity of maize, cassava and sorghum. Therefore, this study opens a room for further study on manure, crop residues and legumes plants to assess their independent as well as joint influence on soil physical and chemical fertility with the aim of sustainably managing land while increasing production.

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APPENDICES

Appendix 1: Cassava suitability assessment using each criterion

CASSAVA							
Suitability class value	**Elevation**	**Soil texture**	**Soil colour**	**Soil pH**	**Soil CEC (cmol(+) kg^{-1})**	**Temperature (ºC)**	**Rainfall (mm)**
7	1363-1366	Sandy loam	Black-dark grey	6		21.1-22.2	930-1160
6	1367-1425	Loamy sand	Dark brown-very dark grayish brown	5.97		21.1-22.2	930-1160
5	1426-1500	Sandy loam-Sandy clay loam	Dark reddish brown-dark brown	5.5		21.1-22.2	930-1160
4	1501-1570	Sandy loam-Sandy clay loam	Dark brown-yellowish red	5.44	14.4-16.40		
3	1321-1362	Loamy sand-sandy clay loam	Dark brown-yellowish red	5.32	9.4-10.6		

2	1271-1320	Loamy sand-sandy clay loam	Dark brown-strong brown	5.21	7.8-8.8
1	1230-1270	Sandy clay loam	Dark brown-strong brown	5.14	5.8

Appendix 2: Maize suitability assessment using each criterion

MAIZE							
Suitability class value	**Elevation (m)**	**Soil texture**	**Soil colour**	**Soil pH**	**Soil CEC (cmol (+)kg^{-1})**	**Temperature (°C)**	**Rainfall (mm)**
7	1230-1270	Sandy clay loam	Black-dark grey	6		21.1-22.2	930-1160
6	1271-1320	Loamy sand-sandy clay loam	Dark brown-very dark grayish brown	5.97		21.1-22.2	930-1160
5	1321-1362	Loamy sand-sandy clay loam	Dark reddish brown-dark brown	5.5		21.1-22.2	930-1160
4	1363-1366	Sandy loam-Sandy clay loam	Dark brown-yellowish red	5.44	14.4-16.40		
3	1367-1425	Sandy loam-Sandy clay loam	Dark brown-yellowish red	5.23	9.4-10.6		
2	1426-1500	Loamy sand	Dark brown-strong brown	5.21	7.8-8.8		
1	1501-1570	Sandy loam	Dark brown-strong brown	5.14	5.8		

Appendix 3: Sorghum suitability assessment using each criterion

Suitability class value	Elevation (m)	Soil texture	Soil colour	Soil pH	Soil CEC (cmol (+) kg^{-1})	Temperature (ºC)	Rainfall (mm)
7	1230-1270	Sandy clay loam	Black-dark grey	6		21.1-22.2	970-1150
6	1271-1320	Loamy sand-sandy clay loam	Dark brown-very dark grayish brown	5.97		21.1-22.2	970-1150
5	1321-1362	Loamy sand-sandy clay loam	Dark reddish brown-dark brown	5.5		21.1-22.2	970-1150
4	1363-1366	Sandy loam-Sandy clay loam	Dark brown-yellowish red	5.44	14.4-16.40		
3	1367-1425	Sandy loam-Sandy clay loam	Dark brown-yellowish red	5.23	9.4-10.6		
2	1426-1500	Loamy sand	Dark brown-strong brown	5.21	7.8-8.8		
1	1501-1570	Sandy loam	Dark brown-strong brown	5.14	5.8		