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Title:

Land Suitability Analysis for Maize and Sorghum in Vhembe District, South Africa

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ABSTRACT

The impacts of climate change are being felt in various systems that directly rely on the state of the natural ecological system. This includes food systems upon which cities depend for their day-to-day functioning. Sustainable development goals (SDGs) 1 and 2 stand respectively for "No poverty" and "Zero hunger"; and achieving these goals cannot be separated from promoting sustainable agriculture and ensuring livelihoods, especially for the poor. For this reason, seeing that the food system is underscored by agriculture that in turn mainly depends on land, land suitability analysis has emerged and is being widely used as a tool to decide between competing alternatives for which land can be used. This research has sought to determine the suitability of land for the cultivation of Maize and Sorghum in Vhembe District, South Africa. The study used six criteria, namely: Soil pH, Soil Structure, Rainfall, Maximum Temperature, Minimum Temperature and Elevation to conduct the suitability analysis. The Analytical Hierarchy Process (AHP) process method was used to weigh these criteria and subsequently, the Weighted Linear Combination method was used to calculate the various levels of land suitability according to FAO suitability index. The results revealed that only a limited portion of the whole district is highly suitable for the cultivation of Maize (15.01%) and the same was true for the cultivation of Sorghum (19.39%). It was further found that the portion of land that is highly suitable for Maize is not highly suitable for Sorghum and vice versa. A further interpretation of the results suggested that planners should consider the integration of urban agriculture in their spatial vision as expressed in terms of Spatial Development Frameworks (SDFs). It was further determined that the limited availability of suitable land for the cultivation of maize and sorghum in the Vhembe district should compel spatial and land use planners to consider land suitability analysis for other crops as an integral component of the planning process, and that local residents should be encouraged to develop new livelihoods other than subsistence farming as climate is expected to continue to change, thereby reducing the suitability of land for agriculture.

KEYWORDS: Land suitability analysis; Vhembe district; Maize; Sorghum; Planning

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ACRONYMS AND ABBREVIATIONS

AHP	ANALYTIC Hierarchy Process
AI	Artificial Intelligence
CI	Consistency Index
CR	Consistency Ratio
DAFF	Department of Agriculture, Forestry and Fisheries
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GIS-MCDA	Geographic Information System-based Multi-Criteria Decision Analysis
LSA	Land Suitability Analysis
MCDA	Multi-Criteria Decision Analysis
MCE	Multi-Criteria Evaluation
OWA	Ordered Weighted Averaging
PLUS	Priority for Land-Use Suitability Analysis
RI	Random Index
SDG	Sustainable Development Goal
SDSS	Spatial Decision Support System
UNFAO	United Nations Food and Agriculture Organization
WLC	Weighted Linear Combination

CHAPTER 1: INTRODUCTION

1.1. Introduction

This chapter outlines the background of the study, statement of the problem, research objectives, research questions, brief methodology, and significance of the study and study area.

1.2. Background of the study

Increasing urbanization is probably one of the factors that have informed the conceptualization and development of the concept of sustainability (Ochao et al., 2018). This is due to the fact that cities play an important role in the emancipation of humanity and as such, they consume more resources than any other form of human agglomeration. The role played by cities in enhancing the quality of life of people living in them has many implications for various systems that support the functionality of cities (Fan & Fang, 2019). These systems include but are not limited to, food production and supply systems (Vieira et al., 2018), service delivery systems, urban governance systems, and urban spatial planning systems.

Implications for these systems include the need to revisit and re-examine the way they have been functioning and how best can they cater for more people without posing a lot of strain on the environment. Custodians of these urban systems have shown interests in the sustainable use and management of these systems in many countries (developed, transitional and developing). However, most of their focus has been on systems that are deeply entrenched.in urban areas, leaving behind those that are rooted in rural areas such as the food production system which is crucial to the vitality of cities.

For this reason, this research has focused on one of these systems, that is the food production system, and its sustainability in terms of agricultural production of certain crops namely: Maize and Sorghum through the use of Geographic Information Systems in analyzing the suitability of land for the production of these crops in the Vhembe District, South Africa.

1.3. Problem statement

In the face of rapid urbanization and climate change, arable land is prone to be lost and its suitability for the cultivation of certain crops is likely to decrease as climatic and other factors that influence the growth of these crops continue to change over time (Abass *et al*., 2018). There is, therefore, a need to determine which proportion of land is still suitable for the cultivation of certain crops and how the locations of suitable land for agriculture can be integrated into spatial planning and land use management so that the food security of cities is not threatened while managing the pressure of rapid urbanization.

The South African National Department of Agriculture, Forestry and Fisheries 'report on the trends in the Agricultural Sector, 2017 outlines that "*Maize is the most important grain crop in South Africa, being both the major feed grain and the staple food of the majority of the South African population*" (DAFF, 2017). Sorghum is the fifth most important cereal in the world and it is an indigenous crop in Africa. South Africa's production of Sorghum is still relatively small compared to domestic maize and wheat production. Most importantly, sorghum grain is well-positioned as a climate-change friendly crop and is likely to be more relevant to world food supply in the future. Though considered as a poor man's food, sorghum plays an important role in the food chain as it offers nutritional and health benefits not found in other cereals. One of these benefits is its composition of polyphenol compounds (Awika, 2017:22). For this reason, this study uses land suitability analysis as a means to determine the suitability of land for the cultivation of maize and sorghum and how this can inform spatial planning and land use management in Vhembe district, South Africa.

1.4. Main Research Question

This study has sought to answer the following question: Where are suitable locations for the sustainable cultivation of Maize and Sorghum in the Vhembe District?

1.5. Sub-questions

- Where should Maize and Sorghum be planted in the Vhembe District if sustainable agricultural production is to be achieved?
- What are the criteria for mapping suitable locations for the cultivation of Maize and Sorghum?
- How can these criteria be weighted?
- How can land-use suitability analysis for the cultivation of Maize and Sorghum help improve land use planning and spatial planning in the Vhembe District?

1.6. Aim

The aim of this study has been to identify suitable land in the Vhembe District for the cultivation of Maize and Sorghum.

1.7. Research Objectives

- To identify criteria for mapping suitable locations for the cultivation of Maize and Sorghum in the Vhembe District.
- To weigh these criteria using Multi-Criteria Decision Analysis (MCDA) techniques.
- To develop a GIS-Multi-Criteria Decision Analysis model for land use mapping of Maize and Sorghum.
- To determine how the Land Use Suitability mapping informs sustainable land use planning in the Vhembe District.

1.8. Significance of the study

This study is significant as it has sought to determine suitable locations for the cultivation of maize and sorghum in the Vhembe district. The knowledge of these locations is crucial both for sustainable agricultural development in the area to ensure food security and for spatial planning and land use management to ensure that increasing urbanization does not result in a complete loss of arable land in the face of climate change.

1.9. Study Area

Vhembe District Municipality is a Category C municipality located in the Northern part of Limpopo Province and was established in terms of Local Government Municipal Structure Act No.117 of 1998. The District shares borders with Capricorn District municipality to the East, and Mopani District municipality to the West. Vhembe District also shares borders with Zimbabwe and Botswana in the North West, and with Mozambique in the South East (Mokganya & Tshisikhawe, 2018). The District spreads over an area of 21 407 km² of which the Makhado local municipality covers 8 567.38 km², Thulamela covers 2 904.55 km², Mutale municipality covers 2 367.19 km² and Musina covers 7 567.88 km². The total population of the Vhembe District municipality was estimated at 1 294 722 people as per the 2011 Census and at 1.43 Million as per StatsSA's Midyear population 2017 (Limpopo Provincial Treasury, 2018).

Vhembe District is characterized by a subtropical climate. Its temperature ranges from a minimum of 10ºC during winter to a maximum of 40ºC in summer with an annual rainfall of approximately 500mm of which 87.1% falls between October and March. Semi-arid areas of the district experience droughts that are most parts of the Mutale and Musina Local Municipalities. The District presents the potential for agricultural development and reform. The district has a total area of 2,140,708 hectares of which 249,757 hectares are considered to be arable land. The agricultural system in Vhembe is characterized by two types; namely large-scale commercial farming and small-scale farming. There are currently two existing agricultural hubs in the Vhembe (Levubu and Nwanedi). There is another agricultural hub that is Nandoni, though it is still at the planning stage (Vhembe District Municipality, 2016).

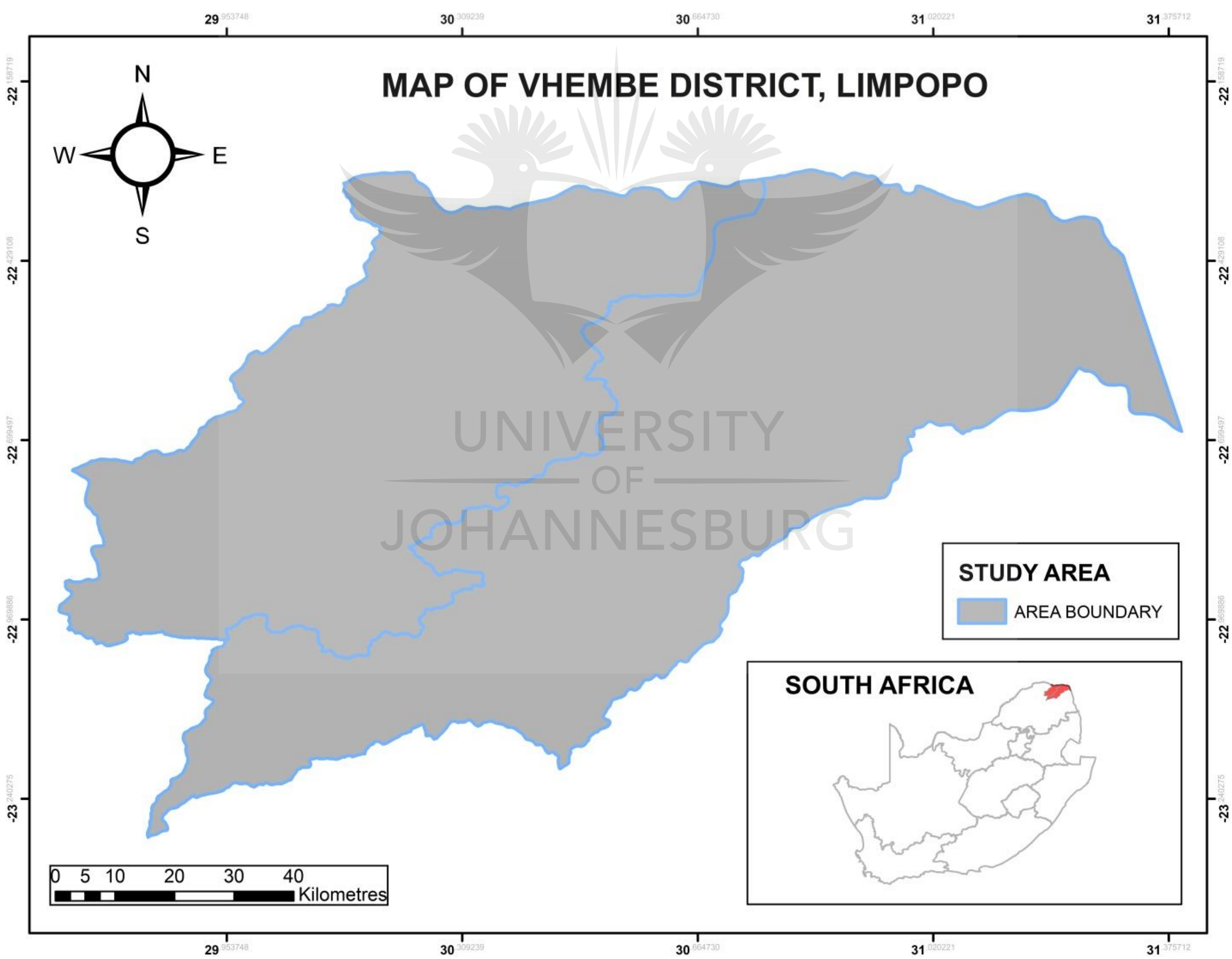


Figure 1; Map of the Vhembe District Municipality

1.10. Research Design and Methodology

This section of the proposal describes the research methodology which will be used in the study. The study design, the instrument(s) and technique that will be used for data collection, as well as methods that will be put in place to ensure and maintain validity and reliability of the instruments and of the data itself, are described.

1.10.1. Research Design

According to Creswell (1994), a research or study design is a process by which the researcher determines the road map that he/she will be following in conducting the study. The current research will utilize an experimental design as it seeks to develop a model to identify land that is suitable for the sustainable cultivation of maize and sorghum in the Vhembe District, Limpopo, South Africa. The study will consist of the identification of evaluation criteria for mapping suitable locations for the cultivation of maize and sorghum, the weighting of these criteria using Multi-Criteria Decision Analysis (MCDA) techniques, developing a GIS-MCDA model for land use mapping of maize and sorghum, and determining how the Land Use Suitability mapping can inform sustainable land use planning in the Vhembe District.

1.10.2. Methodology

This research has adopted a quantitative and spatial approach. The research is quantitative in the sense that it has involved the use of quantitative techniques of decision analysis, that is Multi-Criteria Decision Analysis techniques, for weighting criteria associated with the cultivation of maize and sorghum; it is spatial in the sense that it has used spatial data and the mapping of suitable locations for the cultivation of maize and sorghum. This study has made use of mainly secondary data, collected from the Department of Agriculture, Land Reform and Rural Development, the Agricultural Research Council as well as the South African Weather Service. Data collected from these three institutions were of a spatial nature. Secondary sources such as journal articles, books and official reports were also consulted to identify the criteria for mapping suitable location for the cultivation of maize and sorghum.

Most of the data which was used in this study was of a geographic information system's nature. GIS data come into different formats and sizes. For this reason, the data was prepared before it could be analyzed. Data preparation involved such activities as changing the format of some of these data to make them compatible with the GIS software, ESRI's ArcGIS 10.3, that was used to analyze the data, projecting all data layers to the same coordinate system, clipping and masking certain portions of data to make sure that only the data relating to the study area was utilized. The preparation of data was done using GIS functionalities. The Analytical Hierarchy Process, one of the GIS-based Multicriteria Decision Analysis techniques, was used to weigh criteria that were used to map suitable locations for maize and sorghum, namely: Soil pH, Soil structure, Rainfall, Maximum temperature, Minimum temperature, and Elevation; the Weighted Linear Combination (WLC) technique was used to develop a GIS-MCDA model for mapping suitable locations for the cultivation of maize and sorghum.

1.11. Structure of the study

The structure of this study is made of five chapters; with each chapter addressing a specific topic. In chapter 1 the researcher presented the background of the study, the objectives of the study, he stated the problem that has been addressed by the study, he further justified the reason behind the study together with a description of the study area. Chapter 2 constitutes a review of the literature relating to the study.

Chapter 3 describes the methodologies which were used, both qualitative and quantitative methods of data collection, data preparation as well as methods of data analysis. In chapter 4 the results that were obtained from the analysis described in chapter 3 are presented with a discussion that relates results to the objectives of the study as well as to the main question which this study sought to answer. Lastly, chapter 5 provides the final conclusion of the study by summarizing the results of the study and by demonstrating the extent to which this study has attained the objectives that were set at the beginning of the study.

1.12. Conclusion

In conclusion, chapter 1 introduced the topic of the study by providing a background to the study together with the objectives as well as the main question which this study has sought to answer. The chapter also described the methods that were used to collect, prepare and eventually to analyze the data for the purpose of answering the main question of the study; the main question being "where are suitable locations for the cultivation of maize and sorghum in the Vhembe District?"

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This chapter outlines a review of literature that has been produced on the subject of land suitability analysis or assessment, it highlights the purposes for which such land suitability analyses have been undertaken, where they were undertaken and the methods that were used to conduct them. The chapter goes on to describe the extent to which land suitability analysis practice is documented in developed, transitional and developing countries, especially in Africa and South Africa in particular.

2.2. Defining the concept of "Land Use Suitability Evaluation"

Land suitability analysis, assessment or evaluation has been primarily defined by various scholars as being the process through which a portion of land, city or region's capabilities are evaluated against the requirements of a specific use; this could be the agricultural production of s particular crop, the installation of a specific urban service, the establishment of new human settlements, etc. Liu *et al.* (2014), for example, outlined that the ultimate aim of land suitability analysis is to identify the most appropriate pattern for future land use. Akıncı et al.(2013) define it as being a process of determining the suitability of a given land or area for a certain use and the level of suitability. The United Nations Food and Agriculture Organization (FAO)(1976) has defined land suitability as the fitness of a given type of land for a specified kind of agricultural land use (Musakwa, 2018).

In his critical overview of GIS-based land suitability analysis, (Malczewski, 2004) describes land use suitability analysis as being an element of "spatial reasoning" which, in turn, is a notion that is fundamental to the description of the field of GI-Science or the science behind geographic information systems. Spatial reasoning is defined as being a situation whereby the user of a Geographic Information System is not limited to the mere input, display and management of geographic information but goes on to think spatially using the language of spatial analysis. It is, therefore, an important tool for anticipating and solving spatial problems.

This process is basically characterized by the identification of factors, both positive and negative, that influence the particular use for which the land evaluation or analysis is being conducted.

This is normally followed by the collection of information on the identified land or region, information that is directly related to the requirements of the intended land use. For example, if the intended use of land is the cultivation of maize and it has been identified that temperature is an important factor that influences the growth and production of corn, then temperature data should be collected on that particular area.

Various approaches to land suitability analysis have emerged over the years. Contemporary approaches to land suitability analysis are more technology-based with Geographic Information System (GIS)-related technologies saturating this field. This is probably explained by the fact that the historical development of land suitability development cannot be separated from that of Geographic Information System as outlined below.

2.3. The Roots of the concept of land suitability analysis

Much has been written on the topic of land suitability analysis (Maleki *et al.*, 2017); Anderson and Rocek, 2018); (Mcdowell *et al.*, 2018);(Juhos *et al.*, 2019);(Treglia *et al.*, 2018). Most of such literature can be associated with the realization of the limitedness of land resources. Land resources are amongst the most important natural resources, yet the scarcest. For this reason, it is very crucial that every portion of land be used in a manner that will maximize the potential offered by it. One of the ways in which a land's potential can be maximized is through the identification of the most suitable use for that specific land, also referred to as land suitability analysis or land use suitability assessment.

2.3.1. Food and Agriculture Organization of the United Nations and Land Use Suitability Analysis

The Food and Agriculture Organization of the United Nations (UNFAO) has been playing pioneering role since the early development of the concept of land use suitability analysis, especially in its relation to the use of land for agricultural purposes. One of the most pioneering contributions of the FAO to the development of the process of land evaluation is the introduction of their framework for land evaluation. The framework contained fundamental principles of land evaluation. Such principles include, among other things, the need to assess and classify land suitability with respect to specific kinds of use; the need to undertake land use suitability analysis in relation to the physical, economic and social context of the area under study; the importance of integrating the element of sustainability of the use in the assessment and the need to involve the comparison of more than just one use in the evaluation(Hall and Wang, 1992).

2.3.2. Land Suitability Analysis and Sustainable Development Goals (SDGs)

In the year 2015 leaders of 196 countries met to discuss a plan for the future of our world. They came up with a plan called "Sustainable Development Goals" also expressed in terms of 17 goals with their associated targets (Rosati and Faria, 2019). Of these goals, five can be said to speak directly to land and how it is managed for the overall attainment of the 17 goals; these are goals 1, 2, 5, 11 and 15.

The above goals are stated respectively as follow: "No poverty, end poverty in all its forms everywhere", "End hunger, achieve food security and improved nutrition and promote sustainable agriculture", "Gender equality, achieve gender equality and empower all women and girls", "Sustainable cities and communities, make cities and human settlements inclusive, safe, resilient and sustainable", and "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss".

The goals have targets and indicators which help measure progress towards achieving them. The following table outlines goals 1, 2, 5, 11 and 15 and their respective targets and indicators as they relate to land:

SDG	TARGETS	INDICATORS
SDG1: No poverty	**Target 1.4**: By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services including microfinance.	**Indicator 1.4.2**: Proportion of total adult population with secure tenure rights to land, with legally recognized documentation and who perceive their rights to land as secure, by sex and type of tenure
SDG 2: Zero Hunger	**Target 2.3**: By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure tenure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.	**Indicator 2.3.1**: Volume of production per labour unit by classes of farming/pastoral/forestry enterprise size. Indicator 2.3.2: Average income of small-scale food producers, by sex and indigenous status.
	Target 2.4: By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.	**Indicator 2.4.1**: *Proportion of agricultural area under productive and sustainable agriculture*

SDG	TARGETS	INDICATORS
SDG 5: Gender Equality	**Target 5.a**: Undertake reforms to give women equal rights to economic resources, as well as access to ownership and control over land and other forms of property, financial services, inheritance and natural resources, in accordance with national laws.	**Indicator 5.a.1**: (a) Proportion of total agricultural population with ownership or secure rights over agricultural land, by sex, (b) share of women among owners or rights-bearers of agricultural land, by type of tenure. **Indicator 5.a.2** Proportion of countries where the legal framework (including customary law) guarantees women's equal rights to land ownership and/or control.
SDG 11: Sustainable Cities and Communities	**Target 11.1**: By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums	**Indicator 11.1.1**: Proportion of urban population living in slums, informal settlements or inadequate housing
	Target 11.3: By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.	**Indicator 11.3.1**: Ratio of land consumption rate to population growth rate

	Target 11.7: By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities.	**Indicator 11.7.1**: Average share of the built-up area of cities that is open space for public us for all, by sex, age and persons with disabilities.
SDG	**TARGETS**	**INDICATORS**
GOAL 15: Life on land	**Target 15.1:** By 2020, ensure the conservation, restoration and sustainable use of territorial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements.	**Indicator 15.1.1:** Forest area as a proportion of total land area. **Indicator 15.1.2**: Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type.
	Target 15.2: By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally.	**Indicator 15.2.1**: Progress towards sustainable forest management.
	Target 15.3: By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world.	**Indicator 15.3.1:** Proportion of land that is degraded over total land area.

Table 1: SDGs related to land (United Nations, 2016)

2.3.2.1. Historical Development of the concept of land suitability analysis and The Development of Geographic Information Systems

Land suitability analysis, also referred to as land use suitability analysis, is not a new practice. According to (Collins, Steiner and Rushman, 2001), the practice and concept of land suitability analysis can be traced back to the late 19th century with the practice of hand-drawn overlays by landscape architects and its evolution can be characterized by five stages, namely; the early hand-drawn/sieve mapping overlay, advancement in the literature, computer-aided overlay mapping, redefinition of spatial data and multicriteria evaluation, and replicating expert knowledge in the process (current stage).

Each of these stages has been marked by a breakthrough enhancing the practice of land use suitability analysis. Stage two, for example, saw the development of theories and approaches to improve the then hand-drawn and sieve mapping overlays which was later replaced by computer-assisted overlay mapping in stage 3 as a result of difficulties arising from the increasing number of maps that needed to be superimposed manually. The advent and integration of computer technologies in land-use suitability analysis were pioneered by researchers and their teams at various universities in the United States, namely; at Harvard University, University of Massachusetts, and Yale University.

Further, another cutting-edge innovation that improved the computerization of the land-use suitability analysis with promising alternative applications was the development of Geographic Information Systems (GIS) in the 1980s. The fourth stage of the historical development of land-use suitability analysis was underpinned by two research directions that emanated from the prominence of the application of GIS in land-use suitability analysis processes. These research directions are Boolean logic and alternative methods for using preferences (that is finding alternative methods to incorporate decision-makers' preferences within land-use allocation and suitability analysis). For example, the use of Multi-Criteria Decision Analysis (MCDA) or Multi-Criteria Evaluation (MCE) methods for analyzing multi-objectives decisions using mathematical programming methods.

This stage also saw the development of other methods as well as their reviews. For example, it was during this period that Saaty developed the Analytic Hierarchy Process which presented certain problems relating to preference acquisition, synthesis, and inconsistency diagnosis thus leading Xiang and Whitley to develop the PLUS (Priority for Land-Use Suitability Analysis) method in response to the said problems. The fifth stage, also considered to be the current stage in the evolution of land-use suitability analysis, is said to be characterized by the integration of artificial intelligence (AI) in land-use suitability analysis. A number of researches have been conducted in this line.

For example, (Liu *et al.*, 2018) asserted the significance of integrating artificial intelligence in land-use suitability analysis by combining GIS with artificial intelligence logarithms, the Generalized Rational Neural Network (GRNN) and the Neighbourhood Selection, in assessing land suitability in low-slope hilly areas of the Dali Prefecture, China. There are other instances where artificial intelligence (AI) has been integrated into land -suitability analysis. This includes, but are not limited to, (Li and Parrott, 2016) who proposed an application of the improved Genetic Algorithm in solving optimization issue associated with multi-site land use allocation, and (Xu *et al.*, 2011) who evaluated the suitability of urban construction land based on geo-environmental factors using K-means clustering and back-propagation (BP) neural network methods, which are also artificial intelligence logarithms.

Furthermore, as mentioned earlier, there have been various phases in the evolution of land use suitability analysis, and in the course of time various techniques have been developed and combined with Geographic Information Systems in conducting land suitability analysis in various fields of enquiry. Such techniques include Multicriteria Decision Analysis (MCDA) technique or Multi-Criteria Evaluation (MCE), and Analytic Hierarchy Process (AHP) technique, just to name a few. These techniques are often combined with Geographic Information Systems in conducting land use suitability analysis as they offer the flexibility of choosing among various alternatives in view of a pre-determined objective and its associated criteria (Dong and Cooper, 2016); Jelokhani-niaraki et al., 2018)

Moreover, a detailed look at the historical development of the practice of land use suitability analysis reveals that Geographic Information Systems technologies have dominated this field, technologies whose evolvement is also directly tied to advancement in information technologies and computer science. For a more comprehensive outline of the historical evolvement of the GIS reference can be made to the work of (Malczewski, 2004).

Paper Title	Author	Year of Publication	Source	Citations
GIS-based multicriteria decision analysis: A survey of the literature	Malczweski, J.	2006 2006	International Journal of Geographical Information Science 20(7), pp. 703-726	809 809
GIS-multicriteria decision analysis for landslide susceptibility mapping: Comparing three methods for the Urmia lake basin, Iran	Feizizadeh, B., Blaschke, T.	2013	Natural Hazards 65(3), pp. 2105-2128	109
A GIS based spatially-explicit sensitivity and uncertainty analysis approach for multi-criteria decision analysis	Feizizadeh, B., Jankowski, P., Blaschke, T.	2014	Computers and Geosciences 64, pp. 81-95	75
An uncertainty and sensitivity analysis approach for GIS-based multicriteria landslide susceptibility mapping	Feizizadeh, B., Blaschke, T.	2014	International Journal of Geographical Information Science 28(3), pp. 610-638	45
Multiple criteria decision analysis and geographic information systems	Malczewski, J.	2010	International Series in Operations Research and Management Science 142, pp. 369-395	38
Integrating geographical information systems and multi-criteria methods: A case study	Goncalves Gomes, E., Estellista Lins, M.P. Gonçalves Gomes, E., Estellita Lins, M.P.	2002 2002	Annals of Operations Research 116(1-4), pp. 243-269 Annals of Operations Research	37 37

Integrating geographical information systems and multi-criteria methods: A case study			116(1-4), pp. 243-269	
Paper Title	**Author**	**Year of Publication**	**Source**	**Citations**
A group multicriteria spatial decision support system for parking site selection problem: A case study A group multicriteria spatial decision support system for parking site selection problem: A case study	Jelokhani-Niaraki, M., Malczsewski, J. Jelokhani-Niaraki, M., Malczewski, J.	2015 2015	Land Use Policy 42, pp. 492-508 Land Use Policy 42, pp. 492-508	31 31
Where does solar-aided seawater desalination make sense? A method for identifying sustainable sites	Grubert, E.A., Stillwell, A.S., Webber, M.E.	2014	Desalination 339(1), pp. 10-17	26
Decision Support Systems for environmental management: A case study on wastewater from agriculture Decision Support Systems for environmental management:	Massei, G., Rocchi, L., Paolotti, L., Greco, S., Boggia, A. Massei, G., Rocchi, L., Paolotti, L., Greco, S., Boggia, A.	2014 2014	Journal of Environmental Management 146, pp. 491-504 Journal of Environmental Management 146, pp. 491-504	25 25

A case study on wastewater from agriculture				
Implementation of GIS-based multicriteria decision analysis with VB in ArcGIS	Ozturk, D., Batuk, F. Ozturk, D., Batuk, F.	2011 2011	International Journal of Information Technology and Decision Making 10(6), pp. 1023-1042	25 25

Table 2: Most Cited Authors in GIS-MCDA

2.4. Land Suitability analysis and Spatial Decision Support System (LSA for Spatial Planning and Land Use management)

Spatial Decision Support System is a currently growing area of spatial analytics which has proven to be largely dependent on Land Suitability Analysis practice. In reflecting on the structure of the field of Decision Support System (DSS), (Keenan and Jankowski, 2019) outlined that most Spatial Decision Support Systems are concerned with three types of problems which include land suitability problems. In other words, there is a relationship between land suitability analysis and Spatial Decision Support Systems, that is, a wide range of Spatial Decision Support Systems are underlined by land suitability analysis processes and procedures as was the case with (Kazak, Hoof and Szewranski, 2017) who developed a Spatial Decision Support System based on Land Suitability Analysis, Multi-criteria Decision Evaluation method as a potential solution to solve the problem associated with the choice of the location of wind turbines in Central Europe; (Ghavami, 2019) developed an SDSS for evaluating the performance of the transportation network in disaster situations by using GIS-based MCDA Analytic Hierarchy Process (AHP); (Ghabour *et al.*, 2018) proposed a SDSS for land use management which they developed based on land capability and suitability models, they also mentioned that an SDSS has three core components namely: geographic database management system for handling geographic data, a number of potential models that can be used to forecast the possible outcomes of decisions, and a user interface to provide interaction of the user to model scenarios; of which the said models are, in most cases, land suitability analysis models.

The above outline of the relationship between land suitability analysis and spatial decision support systems clearly indicates that land suitability analyses are not ends in themselves but means to specific ends, that is, land suitability analysis are meant to be a backdrop against which spatial development decisions are made. In the context of land suitability analysis for agricultural purposes, and based on the literature reviewed, there are no instances where land suitability analysis for agriculture was integrated into a spatial decision support system with the objective of informing spatial development in terms of future land use planning, livelihood, and the like.

2.5. Land Suitability Analysis using different methods

Land Suitability Analysis, agricultural land suitability analysis in particular, has been characterized as an inter-disciplinary task as it requires inputs from different streams requiring a wide range of expertise such as soil science, social science, management, meteorology and economics, to name a few. The number of factors involved in land suitability analysis implies that data from various sources is needed to conduct the analysis and therefore, there should be uncertainties associated with each data based on its source.

In the context of GIS-based land suitability analysis, various methods have been developed and each of them present uncertainty due to uncertainties in data source s. Methods that have emerged include, but are not limited to, weighted averaging, the analytical hierarchy process (AHP), ordered weighted averaging (OWA), weighted linear combination (WLC), and rule-based classification method.

2.5.1. Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is a conventional multi-criteria decision analysis method formulated by Professor Thomas Saaty in the 1970s. The method utilizes qualitative and quantitative factors to form a hierarchical structure in the decision-making process. The hierarchical structure is then used by the decision maker to select the best option on the basis of criteria presented in the model (Kai *et al*., 2019).

As Tezcan (2019) note, AHP model consists of three parts, namely; identifying and organizing decision objectives, criteria, constraints and alternatives into a hierarchy; evaluating pairwise comparisons between the relevant elements at each level of hierarchy; and synthesizing using the solution algorithm of the result of the pairwise comparisons over all levels. In the case of a GIS-MCDA, the said steps are wither done in ArcGIS or in Excel then the final hierarchical structure of weights is implemented in the GIS environment. More information on this method is provided in the next chapter on research methodology.

2.5.2. Ordered Weighted Averaging

Ordered Weighted Averaging (OWA) is yet another multi-criteria decision analysis method proposed by the American mathematician Ronald R. Yager in 1988. OWA is based on sorting criterion attributes and assigning them different order weights (Liao *et al.*, 2019).

2.5.3. Weighted Linear Combination

Weighted Linear Combination (WLC) is probably the simplest of all conventional multi-criteria decision analysis methods. The WLC is widely used in one-dimensional decision-making problems. The method is underlined by the decision-makers assignment of weights within each criterion. A total score is obtained for each option by multiplying the assigned weight value with a scaled value by the corresponding criterion.

As Baskurt and Aydin (2018) explain it, if there are p number of alternatives and q number of criteria, then each alternative is scored separately for each criterion. Each criterion is then given weights that indicate its importance in relation to other criteria; this is followed by the calculation of the weighted average score for all alternatives.

2.5.4. Land Suitability Analysis with various methods

According Akpoti *et al.* (2019) contemporary Land Suitability Analysis combines in most cases GIS, computer, and machines learning algorithms; and as (Malczewski, 2004) outlined, GIS-based land suitability analysis can be categorized into three major categories namely: (a) computer-assisted overlay mapping, (b) multi-criteria evaluation (MCE) methods, and (c) soft computing or geo-computation or Artificial Intelligence (AI) methods. A GIS-MCE method is capable of resulting into rational and objective decisions in agriculture. The GIS-based MCE combines and transforms a spatial data or input into a resultant decision map or output. Its procedures involve the use of geographical data, the preferences of the decision maker and the subsequent manipulation of the data and preferences according to specified decision rules.

(Vasu *et al.*, 2018) compared three methods for land suitability evaluation for the purpose of agricultural land use planning at village level for the cultivation of pigeon pea, maize, cotton, groundnut and rice. They compared the following three methods: parametric, Storie index and multi-criteria land suitability evaluation (MC-LSE). They concluded that the MC-LSE performed better than the other two methods.

Akbari *et al.*(2019) undertook land suitability assessment in the arid regions of eastern Iran for the purposes of determining risk and its management thereof in planning for spatial development. They employed a fuzzy inference system to create the land suitability map but before they could even map land suitability, they made use of the multi-criteria decision-making method to determine the significance and priority of each parameter that was considered. Parameters such as soil properties, climatic factors, elevation, land type, vegetation cover, and faults were considered and the authors suggested that the results of the analysis can be used or considered by developers for futures development endeavors. This study is probably an example of the application of land suitability analysis for sustainable land management for spatial development. However, it does not incorporate land suitability for sustainable agricultural development in urban/rural spatial planning, which should be an important element of contemporary land management seeing that cities are faced with the threat of food insecurity and its impact livelihood.

Further, Alabyad-mafraq *et al.*(2019) research study is an example of a scenario where land suitability analysis was conducted in the broad context of sustainable land management. The analysis(ses) was conducted for the semi-arid environment in the Jordan, for the purposes of determining different land use alternatives in the area as a result of limiting factors to specific land uses presented by land. The study resulted into the production of suitability maps for specific land uses and maps displaying the spatial representation of soils suitable for agriculture.

Furthermore, there are methods that have been introduced to revolutionize the already existing ones. One of such revolutionary methods is the Logic Scoring of Preference (LSP) method. It was introduced by Dujmovic *et al.* (2016) into GIS for the purpose of assessing land suitability for agriculture. They described the LSP method as offering the possibility of using a large number of inputs and other functions of suitability as well as the possibility of integrating a wide range of human decision-making logic into GIS-based land suitability analysis. One could go on and on in making reference to instances where various methods were employed to conduct Land Suitability Analysis and for various purposes. For this reason, Table 3**.** outlines a number of cases where different methods were used to conduct land suitability analysis for agricultural purposes.

It is worth noting that According to (Liu *et al.*, 2018) methods for assessing land suitability can be categorized into three types and these are: the multi-objective decision-making method in which multi-objective decision problems are converted to single-objective decision problems with the help of linear programming (difficult to operate in a GIS environment), the multi-attribute decision-making method based on GIS (subject to subjectivity and uncertainty), and the third one combines GIS and an artificial intelligence algorithm. It should further be noted that it is becoming more and apparent that of the three categories, Artificial Intelligence (AI)-based methods should be promoted in conducting land suitability analysis as they offer the flexibility of addressing uncertainties posed by the other methods.

Authors	Purpose	Criteria Used	Model or Method
Munene *et al.*(2017)	Land suitability analysis land for the production of soybean.	Texture, Phosphorus, pH, Drainage, Slope, Wetness, Elevation, Distance.	Weighted Linear Combination (WLC)
Nijbroek and Andelman (2016)	Regional land suitability analysis for agricultural intensification	Extension services, Fertility, Forest cover, Integrated Survey of agriculture, Population and infrastructure, Living standard measurement study, Annual water balance, OM, Protected areas, SG, Yield potential, IWU	Stepwise multivariate regression, WLC
Sani *et al.* (2016)	Assessment of ecological suitability	LULC, IWU, Texture, pH, Fertility, SE, H, Phosphorus, T, Soil, Slope Gradient,	WLC
Nzeyimana *et al.* (2014)	Spatial distribution analysis of potential production zones for Arabica coffee in Rwanda	Elevation, Rainfall, Temperature, Soil Type, Slope	Weighted Overlay (WO)
Yalew *et al.* (2016)	Developing a web-based framework for Agricultural Land Suitability Analysis	Soil group, Slope, Roads, Land Use, Elevation Soil water, Stoniness, Soil Depth	AHP
Romano *et al.*(2015)	GIS-MCDA for assessing the potential of a coastal area (in Italy) to improve its sustainable development through the restoration of manor farms	Slope gradient, Slope aspect, fast roads, slow roads, urban dwellings, Streams, Coastal line, Industrial area, Sewer, Historical sites and Land Use.	AHP, OWA, Boolean

Authors	**Purpose**	**Criteria Used**	**Model or Method**
Zabihi *et al.*(2015)	GIS-ANP in land suitability analysis for sustainable citrus planting	Altitude, Aspect, Slope, Min-temperature, Max-temperature, Rainfall, Sunshine hours, Water availability, distance to roads, and population areas.	ANP
Zolekar and Bhagat (2015)	Land suitability analysis in formulating strategies for improving agricultural productivity	Slope, Land Use/Land Cover, Soil depth, Soil moisture, Soil texture, Water holding capacity, Soil erosion, Soil Organic Carbon, potential of Hydrogen, Nitrogen, Phosphorus, Potassium	AHP
Zhang *et al.* (2015)	Land suitability assessment for the production of tobacco using AHP and Fuzzy methods	Precipitation, temperature differential, sunshine, soil nutrients, landform, altitude and slope.	AHP and Fuzzy
Chen *et al.*(2010)	Assessing the spatial sensitivity of multi-criteria weights in GIS-based land suitability analysis.	Texture, Slope, Electric conductivity of groundwater, Depth of water table, and hydraulic conductivity of soil.	AHP, OAT
Deng *et al.* (2014)	Determining land suitability for the cultivation of alfalfa using	Average annual rainfall mean temperature during the growth period, extreme low temperature, annual average temperature, low temperature during the greening stage, relative humidity during the flowering stage, slope, elevation, soil depth, soil pH, organic matter and coarse sand.	AHP, Fuzzy
Chen et al. (2013)	Assessing the spatial sensitivity of criteria	Texture, Slope, Electric conductivity of groundwater, Depth of water	AHP

	weights in OAT-AHP	table, and hydraulic conductivity of soil.	
Authors	**Purpose**	**Criteria Used**	**Model or Method**
Elaalem (2013)	Land suitability evaluations for Olive	Soil characteristics, Slope steepness, erosion hazard, and climate	Fuzzy, AHP, Parametric
Worqlul *et al.* (2017)	Determining land suitable for surface irrigation using groundwater in Ethiopia	Rainfall deficit, Soil, Land use, Slope, Population density, Road proximity, and Groundwater depth and yield.	AHP
Yan *et al.* (2017)	A spatial distribution model to study the spatial distribution of livestock manure and livestock manure nitrogen load on farmland at a patch scale.	Slope, distances to water, distances to habitation, distances to farmland, distances to forestland, distances to road, distances to market, land use	AHP and WLC

Table 3: Cases of land suitability analysis for agricultural purposes using various methods (Akpoti *et al.*, 2019)

2.6. Land suitability analysis for different purposes

Land suitability analysis has been conducted in different parts of the world in various fields and for different purposes such as crop production, service delivery, spatial planning and land use management, etc.

2.6.1. Land suitability analysis for service delivery

Land suitability for the purpose of planning future service delivery expansion has not been heavily documented but the reviewed literature revealed that it is an emerging application of land suitability analysis practice. For instance, Parry *et al.* (2018), using an AHP model, conducted a land suitability analysis for the provision of services in Srinagar and Jammu urban centers in

India. They employed Saaty's Analytic Hierarch Process method to weight the criteria which consisted of slope, land use/land cover and altitude.

Land suitability analysis proves useful in planning for future service delivery as it makes it possible to identify suitable location for infrastructure development which are in turn used as a basis for providing basic services such as waste collection, water and electricity. Such analysis takes into account factors such as existing backlogs and features of the physical environment that have the greatest impact on the development of supporting infrastructure for the provision of specific services.

2.6.2. Land suitability analysis for environmental management purposes

Land suitability analysis for the purposes of environmental management is one of the most documented practice of land suitability analysis with an increasing shift of focus from initial tendency to determining the impact of development on the natural ecosystem, towards the assessment of the impact of climate change on the suitability of natural habitats as well the ability to sustain such suitability for specific species in the long run.

Treglia *et al.* (2018) are an example of authors who undertook a land suitability assessment for environmental purposes; they quantified the effects of land cover change on habitat suitability for the endangered arroyo toad. This can be characterized as a passive suitability analysis in a sense that they did not assess the suitability of habitat for arroyo toad; rather, they assessed the effects of land cover change on the habitat suitability or its unsuitability thereof. Their study was focused in southern California, United States.

Nayak *et al.*(2018) are yet another case of land suitability analysis for environmental purposes; they used the underlying idea of land suitability analysis, that is the use of multi-criteria or parameters that influence a particular phenomenon, in this case the sustainable production of fish or fish stocks in the Central Himalayas, India, through the use of geographical information system (GIS) and multi criteria approach, Analytical Hierarchy Process (AHP). They assessed parameters or criteria relating to soil, water and infrastructure facilities as they happened to be influencing declined fish production in the region.

Further, land suitability analysis is used to assess how fast a region recovers from environmental disasters such as tsunami etc. This could be done by comparing the capability of land for particular purposes before the disaster and after the disaster had occurred. Or it can also be undertaken to determine the potential of land for a specific purpose after a natural disaster as was the case with (Rusdi *et al.*, 2015) who evaluated land suitability for settlement based on soil permeability, topography and geology ten years after tsunami in Banda Aceh, Indonesia.

2.6.3. Sustainable Land Management

An emerging trend in the arena of land resource management is the concept of sustainable land management. It is a practice advocated for by the United Nations Food and Agriculture Organization (FAO)(Ziadat *et al.*, 2017) and which is based on the idea that the livelihood of a community is a function of the harmonious relationships among the various uses for which land is used in that particular community. Sustainable Land Management is underscored by a number of activities, of which "Land Suitability Analysis for Agricultural purposes" is a part.

Being an emerging concept sustainable land management has not been satisfactorily documented. There are few instances where land suitability analysis has been conducted in context of sustainable land management. Alabyad-mafraq *et al.*(2019)'s research study is an example of such instances where land suitability analysis was conducted in the broad context of sustainable land management. The analysis was conducted for the semi-arid environment in the Jordan, for the purposes of determining different land use alternatives in the area as a result of limiting factors to specific land uses presented by land. The study resulted into the production of suitability maps for specific land uses and maps displaying the spatial representation of soils suitable for agriculture.

Liu *et al.*(2014) can be said to be another instance where land suitability analysis was conducted in the context and for the purpose of sustainable land management. The authors conducted an Urban Development Land-use suitability analysis for the City of Beijing. They did so by comparing the results of two Multi-criteria Evaluation methods, namely: The Ideal Point Method and the Ordered Weighted Averaging (OWA). They used the two methods to dilute the effect of technique bias. The output (suitability maps) of the study was then used to identify parcels of land earmarked for urban development which are located in areas classified as marginally or not suitable for urban development. It is against such a backdrop that the authors provided various recommendations on long-term urban development planning for Beijing. It is therefore evident that there is need to conduct urban development land-use suitability analysis before embarking on developmental initiatives such as spatial development frameworks etc. which are intended to inform sustainable land management.

2.6.4. Land suitability analysis for agricultural purposes

Though land suitability analysis has been documented and undertaken by various scholars, and though the rationale behind it has always been the promotion of sustainable use and management of land resources; however, as (Akpoti *et al.*, 2019) note, few have focused on land suitability analysis for agriculture. Of the few, one could cite(Vasu *et al.*, 2018);(Mosleh *et al.*, 2017);(Akıncı *et al.*, 2013);(Zolekar and Bhagat, 2015); (Dujmovic *et al.*, 2016).

The above scholars have focused respectively on the assessment of land capability and land suitability analysis for agricultural production in the Boulder County, Colorado, USA; developing a GIS-based approach for land use suitability able to assist land use managers and land use planners in their activities and matching the suitability for main crops based on their requirements and the quality and characteristics of land; land suitability analysis for agriculture in Yusufeli District, Turkey using the Analytic Hierarchy Process method and in light of the UNFAO (United Nations Food and Agriculture Organization)'s land suitability classification; the use of land suitability analysis in formulating strategies to improve agricultural productivity and land use suitability analysis for agriculture in hilly zones.

Based on the sample literature reviewed and according to the literature reviewed by (Akpoti *et al.*, 2019), it can be said that scholars from Asian countries have been leading research on land suitability analysis for agriculture. This is evident as outlined on the chart below, reflecting the percentage share of publications per continent and global studies between 1990 and 2017.

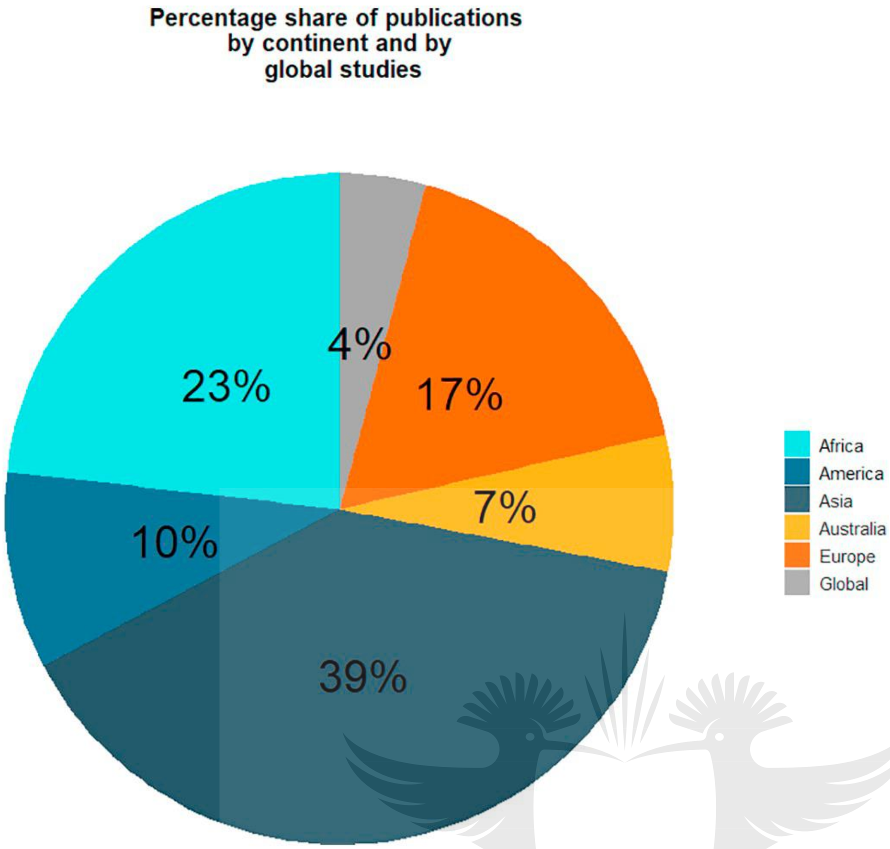


Figure 2; Percentage Share of Publications on Land Suitability Analysis for Agriculture per continent and global studies between 1990 and 2017 (Akpoti et al., 2019:5)

Figure 2 above reveals that Asia has the highest percentage share of publications on land suitability analysis for agriculture followed by Africa and Europe. However, though Africa has the second highest percentage share of publication on land suitability analysis for agriculture, South Africa has contributed little or nothing to that continental share of publication. South Africa, being a developing country and faced with the global trend of rapid urbanization, is no exception to those concerned with challenges of rapid urbanization, among which one could mention the threat to food security and loss of arable land; and the need to plan the use of land in a manner that will guarantee the livelihood of communities in the face of climate change and rapid urbanization.

2.7. The South African context

As mentioned earlier, South Africa is not immune to the threatening consequences of rapid urbanization and climate change; these consequences are manifested in the loss of arable land

and the subsequent degrading livelihood of local communities, thus calling for the integration of smart practices in agricultural production that can lead to sustainable management of land resources as well as the harmonious spatial planning and development of cities and rural areas.

In the case of sustainable agricultural production, the South African Department of agriculture, forestry and fisheries outlined 10 important field crops cultivated in South Africa, of which the maize and sorghum crops. Maize has been identified as the most important crop in South Africa (du Plessis, 2003) and constitutes the major feed crop and the basic food for South Africans (DAFF (Department of Agriculture Forestry and Fisheries), 2017). This implies that it is imperative to implement the most effective practices that have the potential to result into the sustainable cultivation of the 10 crops listed in DAFF's report on current trends in agriculture, in this case maize and sorghum.

According to Glodblatt (2016), the population of South Africa is expected to have grown to 82 million people by the year 2035, thus putting pressure on the current food production system which depend upon agricultural production to a considerable extent; this also means that the current agricultural production of field crops is expected to more than double for the country to be able to feed its expected population of 82 million people by the year 2035. This calls for intensification of the agricultural sector.

Further, the Bureau of Food and Agricultural Policy (BFAP) in its 2018-2027 agriculture outlook outlines that poor land suitability evaluations and land use planning have resulted in tremendous land use disasters since the 1980's (BFAP(Bureau of Food and Agricultural Policy), 2018). For this reason, if South African communities, especially rural communities, are to experience the degree of livelihood envisaged in the NDP, land use planning needs to be informed by precise land use suitability analysis as this is necessary to give effect to the vision of President Cyril Ramaphosa presented in his State of the Nation Address (SONA) on the 20th June 2019 at 19:00 p.m.; a vision that recognizes the role spatial planning and land use management has to play in charting and making a reality the developmental path of South Africa as a whole.

Furthermore, the 2012 South Africa's National Development Plan (NDP) identifies agriculture, forestry and fisheries as key sectors to drive inclusive growth in rural economies and the subsequent enhanced livelihoods thereof. This implies that the agricultural sector needs to reinvent itself by embracing best practices of land suitability analysis such as the GIS-based multi-criteria analysis for the purposes of informing spatial planning and land use planning with the objective of enhancing livelihood of local/agricultural communities in South Africa.

2.8. Conclusion

In conclusion, this chapter has outlined a review of literature that has been produced on the subject of land suitability analysis or assessment; it has highlighted the purposes for which such land suitability analyses have been undertaken, where they were undertaken and the methods that were used to conduct them. The chapter also described the extent to which land suitability analysis practice has been documented in developed, transitional and developing countries, and in Africa and South Africa in particular outlining the need to incorporate land suitability analysis practices in the broad context of agricultural reform and spatial planning in South Africa if the country is to achieve its 2030 goal of inclusive growth in rural economies and its subsequent evidence of improved livelihood.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Introduction

This chapter outlines the steps that were taken to answer the research questions. As mentioned in the introductory chapter of this report, the main of objective of the study was to identify suitable land in the Vhembe District for the sustainable cultivation of Maize and Sorghum. An objective whose attainment depend on the attainment of subsequent sub-objectives, namely: to identify criteria for mapping suitable locations for the cultivation of Maize and Sorghum, to Weigh the criteria using Multi-Criteria Decision Analysis (MCDA) technique of Analytical Hierarchy Process (AHP), to develop a GIS-Multi-Criteria Decision Analysis model for mapping the land use suitability of Maize and Sorghum using the Weighted Linear Combination (WLC) method, and lastly, to determine how the said Land Use Suitability mapping informs land use planning in the Vhembe District. Therefore, this chapter provides a description of the data that was collected, the sources of the various data, the preparation of data for analysis, and the techniques and methods used to analyze the data in a manner that led to the attainment of research objectives.

3.2. Study Area

Vhembe District Municipality is a Category C Municipality located in the Northern part of Limpopo Province and was established in terms of Local Government Municipal Structure Act No.117 of 1998. The District shares borders with Capricorn District municipality to the East, and Mopani District municipality to the West. Vhembe District also shares borders with Zimbabwe and Botswana in the North West, and with Mozambique in the South East (Mokganya & Tshisikhawe, 2018). The District spreads over an area of 21 407 km^2 with a population estimated at 1.4 million people as per StatsSA's midyear population 2017 (Provincial Treasury, 2018). Vhembe District is characterized by a subtropical climate. Its temperature ranges from a minimum of 10ºC during winter to a maximum of 40ºC in summer with annual rainfall of approximately 500mm of which 87.1% falls between October and March. Semi-arid areas of the district experience droughts, that is most parts of the Mutale and Musina Local Municipalities. The district presents potential for agricultural development with 249, 757 hectares of its area of jurisdiction considered as arable land.

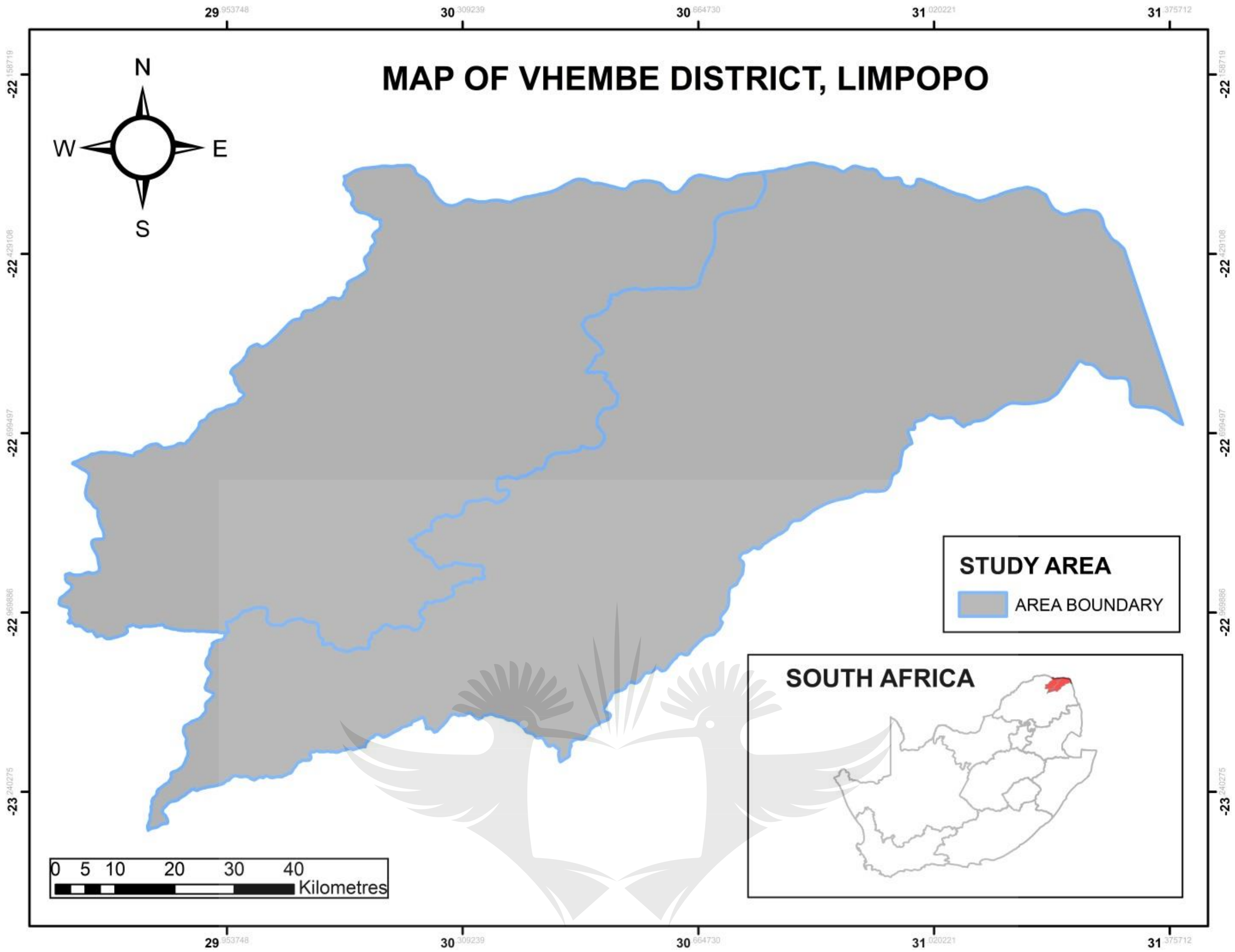


Figure 3; Study area

3.3. Data collection, sources, and type.

The data that was used in conducting this research was obtained from the South African Department of Agriculture, Land Reform and Rural Development; as well as from the Agricultural Research Council (ARC) of South Africa. The following datasets were requested as was necessary in conducting a land suitability analysis for the cultivation of Maize and Sorghum: Elevation raster, Natural soil pH raster, Rainfall-Mean annual raster, Maximum Annual Temperature raster, Minimum Annual Temperature raster, and structurally favorable soils raster.

Data Type	Description
Climate Variable: Minimum temperature, Maximum temperature and Average Annual Rainfall	Climatic factors play a very important role in the growth of plants. For example, temperature is crucial for plants' biological activity and growth. High temperatures limit biological reactions because the complex structures of proteins are disrupted; also, low temperatures can be very harmful as they limit biological reactions as a result of water unavailability (Barbour *et al*., 1987). Water or precipitation is also important as it shapes the climatic patterns and is a necessary component of the physiological processes (Brown, 1995).
Physical and Chemical properties of Soil: Soil pH and Soil Structure	The physical and chemical properties of soil provide information about the content of the soil. For example, pH values help determine the extent of the acidity and or alkalinity of soil which are determinant factors of the growth of crops (Mustafa *et al.*, 2011).
Topography: Elevation	Elevation is yet another very important factor that underlie the growth of plants. Elevation can affect the amount of sunshine a plant receives, the amount of water a plant can absorb and the nutrients available in the soil.

Figure 4: Data Description

These datasets also reflect the criteria that were considered in analyzing the suitability of land for the cultivation of maize and sorghum in the Vhembe District, Limpopo, South Africa as will be outlined later in this chapter. Each dataset contains data relating to one criterion. For example, the Natural Soil pH dataset contains data relating to the Soil pH criterion.

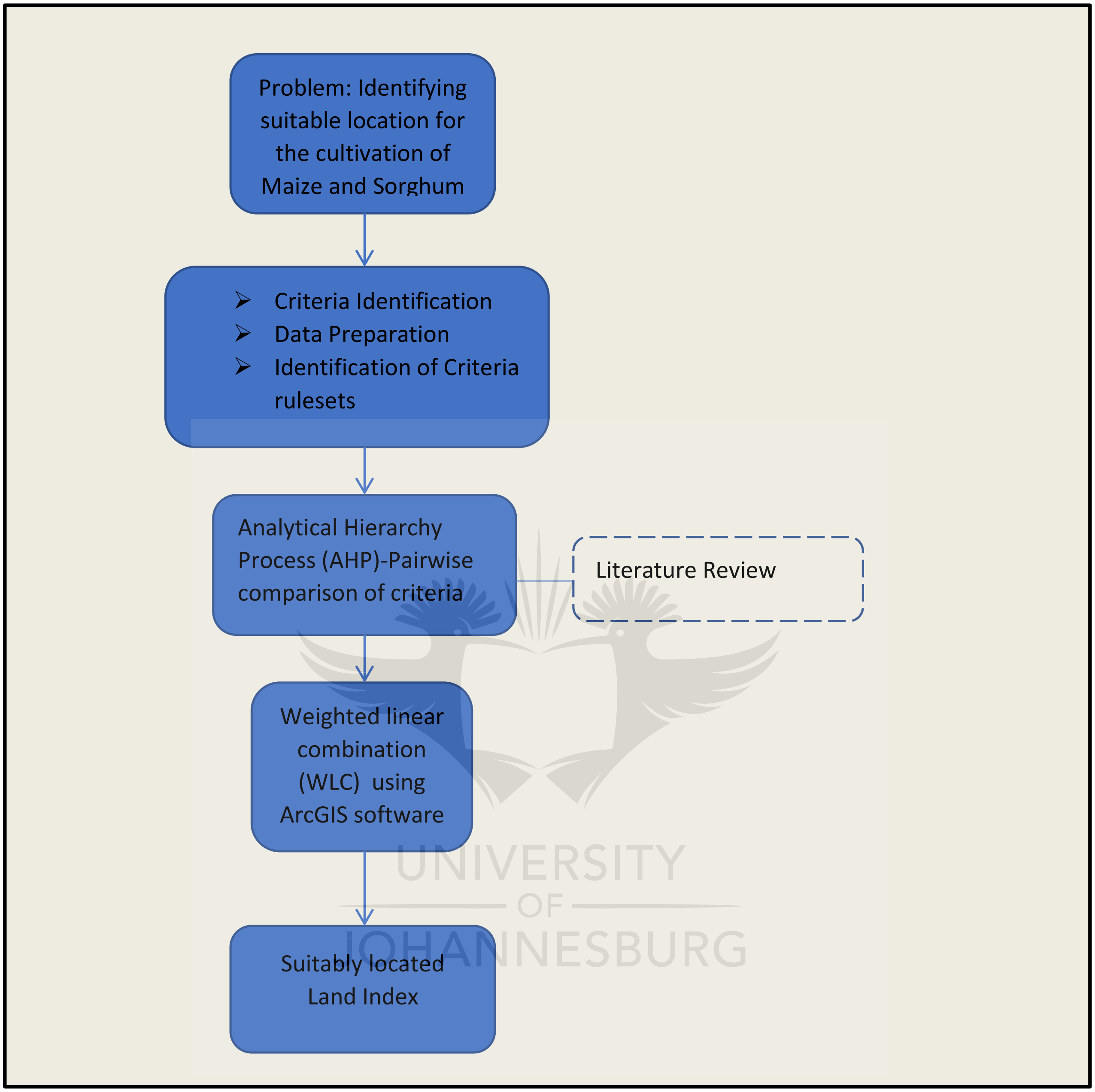


Figure 5; Steps followed in preparing and analyzing data

3.4. Data Preparation

3.4.1. Coordinate Systems

The datasets obtained from the Department of Agriculture, Land Reform and Rural Development and the Agricultural Research Council were country-wide datasets and were projected on different coordinate systems. For this reason, there was a need to project the different data layers on the Hartebeesthoek94 which is the official coordinate system of South Africa since the 1st of January 1999. This was done by adding the data layers to ArcMap 10.6.1. Thereafter, each layer's coordinate system was changed to Hartebeesthoek94 by using the Projections and Transformations Tools of ArcToolBox which are found under Data Management Tools.

3.4.2. Clipping

The datasets obtained from the Department of Agriculture, Land Reform and Rural Development were country-wide datasets; therefore, there was need to focus on the study area, the Vhembe District. In order to do this, the clip function of ArcMap was used to clip each dataset against the study area. The clip function was obtained from the "Geoprocessing" menu bar.

3.4.3. Criteria rule setting according to FAO classification

In order to facilitate further analysis of the data in ArcGIS, there was need to simplify the interpretation of the datasets. This was done by reclassifying the values pertaining to the measurement of each criterion as contained in their respective attribute tables in terms of the FAO land suitability classification scheme. The reclassification of data was done separately for each crop, seeing that Maize and Sorghum have different requirements for each criterion. The requirements of each crop in light of specific criterion was determined through literature review. Tables 4 and 5 below represent the requirements for each crop in light of the six criteria used in this study and the rules that were set to reclassify the data in terms of the FAO land suitability classification scheme.

3.4.3.1. Criteria rule setting for Maize

Table 4 below outlines the reclassification of attribute values that relate to each of the six criteria and the growth requirements of maize for each criterion. The rules that were set for each class under each criterion are also highlighted.

Criterion	Highly suitable	Moderately suitable	Marginally suitable	Unsuitable
Soil Structure	Soils with structure favouring arable land use if climate permits	Soils with structure somewhat favourable to arable land use if climate permits	Soils with structure favouring arable land use scarce or absent	Water Bodies
Soil pH	6.5-7.4	5.5-6.4	7.5-8.4	0-5.5
Minimum Temperature	> 8 Degree Celsius	4.1-6 Degree Celsius & 6.1-8 Degree Celsius	2.1-4 Degree Celsius	No values
Maximum Temperature	25.1-27; 27.1-29 and 29.1-31 Degree Celsius	0-25 Degree Celsius	31.1-33; 33.1-35 Degree Celsius	>35 Degree Celsius
Average Annual Rainfall	401-600mm & 601-800mm	801-1000mm & >1000mm	201-400mm	0-200mm
Elevation	Sea level-200m	200-400m & 400-800m	800-1200m	No value

Table 4: Criteria rule setting for maize

3.4.3.2. Criteria rule setting for Sorghum

Table 5 below outlines the reclassification of attribute values that relate to each of the six criteria and the growth requirements of sorghum for each criterion. The rules that were set for each class under each criterion are also highlighted.

Criterion	Highly suitable	Moderately suitable	Marginally suitable	Unsuitable
Soil Structure	Soils with structure favouring arable land use if climate permits	Soils with structure somewhat favourable to arable land use if climate permits	Soils with structure favouring arable land use scarce or absent	Water Bodies
Soil pH	6.5-7.4; 5.5-6.4 & 7.5-8.4	No values	No values	0-5.5
Minimum Temperature	6.1-8 Degree Celsius	4.1-6 Degree Celsius	2.1-4 Degree Celsius	> 8 Degree Celsius
Maximum Temperature	27.1-29 and 29.1-31 Degree Celsius	0-25 & 25.1-27 Degree Celsius	31.1-33 Degree Celsius	>35 Degree Celsius
Average Annual Rainfall	201-400mm; 401-600mm & 601-800mm	801-1000mm	No values	>1000mm
Elevation	Sea level-200m	200-400m & 400-800m	800-1200m	No value

Table 5: Criteria rule setting for sorghum

As can be observed from the above tables, Maize and Sorghum present different requirements for optimum growth in terms of soil, climate and topography. For this reason, it was necessary that data reclassification be done separately for Maize and Sorghum.

Table

Natural soil pH

FID	Shape *	sde_sde_so	sde_sde__1	sde_sde__2	sde_sde__3	sde_sde__4	SE_Area_sh	SE_Length_
0	Polygon	1	4	7.5 - 8.4 mm	7.5 - 8.4	1	0.000326	0.072263
1	Polygon	2	4	7.5 - 8.4 mm	7.5 - 8.4	2	0.030026	1.047818
2	Polygon	3	3	6.5 - 7.4 mm	6.5 - 7.4	3	0.004243	0.325185
3	Polygon	4	4	7.5 - 8.4 mm	7.5 - 8.4	4	0.008159	0.578107
4	Polygon	5	3	6.5 - 7.4 mm	6.5 - 7.4	5	0.000326	0.072263
5	Polygon	6	3	6.5 - 7.4 mm	6.5 - 7.4	6	0.000326	0.072264
6	Polygon	7	4	7.5 - 8.4 mm	7.5 - 8.4	7	0.001632	0.180658
7	Polygon	8	4	7.5 - 8.4 mm	7.5 - 8.4	8	0.348894	4.119011
8	Polygon	9	1	0 - 5.5 mm	0 - 5.5	9	0.009791	0.541975
9	Polygon	10	2	5.5 - 6.4 mm	5.5 - 6.4	10	0.000326	0.072264
10	Polygon	11	3	6.5 - 7.4 mm	6.5 - 7.4	11	0.000653	0.108395
11	Polygon	12	3	6.5 - 7.4 mm	6.5 - 7.4	12	0.000326	0.072263
12	Polygon	13	4	7.5 - 8.4 mm	7.5 - 8.4	13	0.034269	1.228477
13	Polygon	14	4	7.5 - 8.4 mm	7.5 - 8.4	14	0.330944	5.094567
14	Polygon	15	1	0 - 5.5 mm	0 - 5.5	15	0.064622	1.662057
15	Polygon	16	2	5.5 - 6.4 mm	5.5 - 6.4	16	0.002285	0.252922
16	Polygon	17	2	5.5 - 6.4 mm	5.5 - 6.4	17	0.000326	0.072263
17	Polygon	18	3	6.5 - 7.4 mm	6.5 - 7.4	18	0.000326	0.072263
18	Polygon	19	2	5.5 - 6.4 mm	5.5 - 6.4	19	0.006201	0.397449
19	Polygon	20	3	6.5 - 7.4 mm	6.5 - 7.4	20	0.000326	0.072264
20	Polygon	21	4	7.5 - 8.4 mm	7.5 - 8.4	21	0.003264	0.397449
21	Polygon	22	4	7.5 - 8.4 mm	7.5 - 8.4	22	0.002937	0.289054
22	Polygon	23	4	7.5 - 8.4 mm	7.5 - 8.4	23	0.000326	0.072263
23	Polygon	24	4	7.5 - 8.4 mm	7.5 - 8.4	24	0.002285	0.289054

1 (0 out of 510 Selected)

Natural soil pH

Figure 6; Soil pH dataset before reclassification and rulesetting

Table

Soil_pH_Clip

FID	Shape	sde_sde_so	sde_sde__1	sde_sde__2	sde_sde__3	sde_sde__4	SE_Area_sh	SE_Length_	rset
0	Polygon	8	4	7.5 - 8.4 mm	7.5 - 8.4	8	0.348894	4.119011	0
1	Polygon	9	1	0 - 5.5 mm	0 - 5.5	9	0.009791	0.541975	-1
2	Polygon	10	2	5.5 - 6.4 mm	5.5 - 6.4	10	0.000326	0.072264	1
3	Polygon	11	3	6.5 - 7.4 mm	6.5 - 7.4	11	0.000653	0.108395	2
4	Polygon	15	1	0 - 5.5 mm	0 - 5.5	15	0.064622	1.662057	-1
5	Polygon	97	3	6.5 - 7.4 mm	6.5 - 7.4	97	7.398259	73.925419	2
6	Polygon	234	2	5.5 - 6.4 mm	5.5 - 6.4	234	16.395426	127.147383	1

Figure 7; Soil pH dataset after reclassification and rulesetting in light of soil pH required for the optimum growth of Maize crop

	FID	Shape	sde_sde_so	sde_sde__1	sde_sde__2	sde_sde__3	sde_sde__4	SE_Area_sh	SE_Length_	rset
▸	0	Polygon	8	4	7.5 - 8.4 mm	7.5 - 8.4	8	0.348894	4.119011	2
	1	Polygon	9	1	0 - 5.5 mm	0 - 5.5	9	0.009791	0.541975	1
	2	Polygon	10	2	5.5 - 6.4 mm	5.5 - 6.4	10	0.000326	0.0722[illegible]4	2
	3	Polygon	11	3	6.5 - 7.4 mm	6.5 - 7.4	11	0.000653	0.108395	2
	4	Polygon	15	1	0 - 5.5 mm	0 - 5.5	15	0.064622	1.662057	1
	5	Polygon	97	3	6.5 - 7.4 mm	6.5 - 7.4	97	7.398259	73.925419	2
	6	Polygon	234	2	5.5 - 6.4 mm	5.5 - 6.4	234	16.395426	127.147383	2

Figure 8; Soil pH dataset after reclassification and rulesetting in light of soil pH required for the optimum growth of Sorghum crop

Each dataset was reclassified for each crop in terms of its requirements. For this reason, a new folder was created for each crop; the folder contains reclassified datasets. The reclassification was done by creating a new field in each attribute table for each dataset. The field was named "rset" standing for "ruleset". Once the new field has been created, the default values in that column is "0" and therefore, using the "Select by Attribute" and "field calculator" options in the Attribute Table, new values were assigned to cells in the new field in relation to the criteria under consideration and in light of the requirements of the crop for which the analysis was being made.

3.5. Weight Calculation Using Saaty's Analytical Hierarchy Process (AHP)

Once the data had been prepared the next step was to calculate the weight of each criterion as relating to the sustainable cultivation of Maize and Sorghum. Maize and Sorghum grow under different climatic conditions and soil conditions. For this reason, it is normal to expect them to have different weights for the same criterion. Literature on the cultivation and growth of these two crops was reviewed to determine what criteria are slightly more important than others and this information was taken into consideration when calculating criteria weights using the Analytical Hierarchy Process (AHP).

3.5.1. Description of the Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) is a conventional multi-criteria decision analysis method formulated by Professor Thomas L. Saaty in the 1970s. The method utilizes qualitative and quantitative factors to form a hierarchical structure in the decision-making process. The hierarchical structure is then used by the decision maker to select the best option on the basis of criteria presented in the model (Kai *et al*., 2019).

As Tezcan (2019) note, AHP model consists of three parts, namely; identifying and organizing decision objectives, criteria, constraints and alternatives into a hierarchy; evaluating pairwise comparisons between the relevant elements at each level of hierarchy; and synthesizing using the solution algorithm of the result of the pairwise comparisons over all levels. In the case of a GIS-MCDA, the said steps are either done in ArcGIS or in Excel then the final hierarchical structure of weights is implemented in the GIS environment.

3.5.2. Steps Followed in Saaty's AHP process

The following steps were followed in calculating criteria weights for Maize and Sorghum:

- Identifying Criteria.
- Set up a matrix that is nXn (n being the number of criteria).
- Do a pairwise comparison of each criterion using the following ranking:

Ranking	**Meaning**
1	Criteria A and B are equally important
3	Criterion A is thought to be moderately more important than B
5	Criterion A is thought to be strongly more important than B
7	Criterion A is thought to be or has been demonstrated to be much more important than B
9	Criterion A has been demonstrated to have much more importance than B

Table 6: AHP levels of comparison

- Add up each column of the comparison matrix or [c] matrix (criteria matrix).
- Normalize the criteria matrix or [c] matrix.
- Average each row in the normalized matrix (The average corresponding to each criterion is the weight of that criterion).
- Consistency check:
    - ❖ Determine a weight sums vector, Ws
    - ❖ Find the Consistency Vector
    - ❖ Determine the average of the elements of the consistency vector, λ.

❖ Determine the Consistency Index, CI.

3.5.2.1. Criteria Weights for Maize using the AHP method

The table was populated based on the author's review of literature on the cultivation and growth of the Maize crop. In other words, the pairwise comparison was done based on the author's understanding of the importance of the various factors/criteria that impact on the cultivation and growth of the Maize crop.

CRITERIA COMPARISON MATRIX [C]						
Criteria	Soil Structure	Soil pH	Min Temperature	Max Temperature	Rainfall (Precipitation)	Elevation
Soil Structure	1	1.5	1.8	1.9	0.8	1.8
Soil pH	0.66	1	2	2	1.5	2
Min Temperature	0.55	0.5	1	1.1	0.8	0.6
Max Temperature	0.52	0.5	0.9	1	0.8	0.6
Rainfall (Precipitation)	1.25	0.66	1.25	1.25	1	3
Elevation	0.55	0.5	1.66	1.66	0.33	1
Sum Columns	**4.53**	**4.66**	**8.61**	**8.91**	**5.23**	**9**

Table 7: Criteria comparison matrix for maize

Once the comparison matrix was computed, there was need to compute a priority vector, that is the normalized Eigen vector of the comparison matrix. This was done by normalizing each column of the comparison matrix. The normalization was done by dividing each value of a column by the sum of the respective column. The results are shown in the table below.

NORMALIZED CRITERIA COMPARISON MATRIX [C]						
Criteria	**Soil Structure**	**Soil pH**	**Min Temperature**	**Max Temperature**	**Rainfall (Precipitation)**	**Elevation**
Soil Structure	0.220750552	0.321888412	0.209059233	0.213243547	0.152963671	0.2
Soil pH	0.145695364	0.214592275	0.232288037	0.224466891	0.286806883	0.222222
Min Temperature	0.121412804	0.107296137	0.116144019	0.12345679	0.152963671	0.066667
Max Temperature	0.114790287	0.107296137	0.104529617	0.112233446	0.152963671	0.066667
Rainfall (Precipitation)	0.27593819	0.141630901	0.145180023	0.140291807	0.191204589	0.333333
Elevation	0.121412804	0.107296137	0.192799071	0.18630752	0.063097514	0.111111
Sum Columns	1	1	1	1	1	1

Table 8: Normalized criteria comparison matrix for maize

The normalization was followed by obtaining the normalized principal Eigen vector, also called the *priority vector*. This was done by averaging across the rows of the *Normalized Criteria Comparison Matrix* as shown in the table below. From its name, priority vector, there is an indication of the term “importance”. In other words, the priority vector shows relative weights among the criteria considered for the cultivation of the Maize crop.

NORMALIZED CRITERIA COMPARISON MATRIX [C]							
Criteria	**Soil Structure**	**Soil pH**	**Min Temperature**	**Max Temperature**	**Rainfall (Precipitation)**	**Elevation**	**Criteria Weights {W}**
Soil Structure	0.220750552	0.321888412	0.209059233	0.213243547	0.152963671	0.2	**0.219650903**
Soil pH	0.145695364	0.214592275	0.232288037	0.224466891	0.286806883	0.222222	**0.221011945**
Min Temperature	0.121412804	0.107296137	0.116144019	0.12345679	0.152963671	0.066667	**0.114656681**
Max Temperature	0.114790287	0.107296137	0.104529617	0.112233446	0.152963671	0.066667	**0.109746637**
Rainfall (Precipitation)	0.27593819	0.141630901	0.145180023	0.140291807	0.191204589	0.333333	**0.204596474**
Elevation	0.121412804	0.107296137	0.192799071	0.18630752	0.063097514	0.111111	**0.130337359**

Table 9: Normalized criteria comparison matrix with criteria weights for maize

From the above table criteria weights for Maize are ranked as follow from the most important to the least important:

Criterion Rank	**Criterion Name**	**Criteria Weight (%)**
1	Soil pH	22.10
2	Soil Structure	21.97
3	Rainfall	20.46
4	Elevation	13.08
5	Minimum Temperature	11.47
6	Maximum Temperature	10.94
Total		***100***

Table 10: Criteria ranking per weight of importance

The above table shows that Soil pH ranks the highest followed by soil structure and rainfall. This is not surprising as Soil pH is a major determinant of plant growth. Soil pH influences the availability of essential nutrients. Soil pH is also very interesting in the sense that a pH reading of below 7 is indicative of acidity of the soil and any pH reading above 7 is indicative of alkalinity of the soil. Few plants, however, tend to be more acidic than alkaline and few tend to be more alkaline than acidic and Maize does not fall under any of the two categories hence Soil pH is of great importance for the optimum growth of Maize.

Soil Structure is ranked second highest after Soil pH and this due to the important role played by soil structure in the growth of a plant. For example, soil structure determines how plat roots grow and are distributed underground as the structure of the soil impacts on soil temperature, aeration and availability of water (Ball *et al.*, 2004). Soil structure has to do with the physical and/or mechanical properties of the soil which are also linked to climatic factors such as temperature and rainfall. Hence, “Rainfall” ranked third after “Soil Structure”. Rainfall is an important factor as it determines soil moisture from which the crop draws water. In the case of Maize, between 450 to 600 mm of water per season is required for an optimal yield (du Plessis, 2003).

3.5.2.2. Consistency Check for Maize criteria weighting

The consistency check was undertaken to determine whether there were inconsistencies in the weighting of the criteria. This was done by using the consistency ratio (CR), random index (RI) and the consistency index (CI). The efficiency in calculating weights is assessed by the CR (, also expressed mathematically as:

$$CR = \frac{CI}{RI}$$

Where RI stands for the random index for studies using 1 to 10 different criteria, in this case RI = 1.24 for six (6) criteria or n=6 (Saaty, 1980); and CI represents the consistency index calculated using the following equation:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

With λ_{max} being the principle eigenvector of the matrix and n being the order of the matrix. For a CR less than 0.10, the matrix is said to be consistent and in the case where CR is greater than 0.10 the matrix is said to have inconsistencies (Saaty, 1980). The above calculations were done using Excel and the results are depicted in the table below. The λ_{max} or principle eigenvector was calculated by averaging the Consistency Vector {Consis}; this was found to be equal to: λ_{max} = 6.220977. Therefore, the Consistency Index was found to be equal to: CI = 0.04419543.

Thus,

$$CR = \frac{0.04419543}{1.24}$$

= 0.035641476

NORMALIZED CRITERIA COMPARISON MATRIX [C]							CONSISTENCY CHECK	
Criteria	Soil Structure	Soil pH	Min Temperature	Max Temperature	Rainfall (Precipitation)	Elevation	Criteria Weights {W}	Consistency Vector {Consis}
Soil Structure	0.220750552	0.321888412	0.209059233	0.213243547	0.152963671	0.2	**0.219650903**	6.211464959
Soil pH	0.145695364	0.214592275	0.232288037	0.224466891	0.286806883	0.222222	**0.221011945**	6.254673725
Min Temperature	0.121412804	0.107296137	0.116144019	0.12345679	0.152963671	0.066667	**0.114656681**	6.179941184
Max Temperature	0.114790287	0.107296137	0.104529617	0.112233446	0.152963671	0.066667	**0.109746637**	6.191913515
Rainfall (Precipitation)	0.27593819	0.141630901	0.145180023	0.140291807	0.191204589	0.333333	**0.204596474**	6.33707995
Elevation	0.121412804	0.107296137	0.192799071	0.18630752	0.063097514	0.111111	**0.130337359**	6.150789591
							CI	**0.044195431**
Sum Columns	1	1	1	1	1	1	**RI**	**1.24**
							CR	**0.035641476**

Table 11: Consistency Check

The Consistency Ratio of 0.035 falls much below the threshold of 0.10, which means that the criteria weights in the table above are consistent and therefore acceptable. In addition, the sum of all the weights was verified as being equal to 1 as per the rule of Weighted Linear Combination (Ali *et al.*, 2018:6). Hence the criteria weights used to determine the suitability levels of various areas in the Vhembe District for the cultivation of Maize are acceptable.

3.5.2.3. Criteria Weights for Sorghum using AHP method

The table was populated based on the author's review of literature on the cultivation and growth of the Sorghum crop. In other words, the pairwise comparison was done based on the author's understanding of the importance of the various factors/criteria that impact on the cultivation and growth of the Sorghum crop.

PAIRWISE COMPARISON MATRIX [C]						
Criteria	Soil Structure	Soil pH	Min Temperature	Max Temperature	Rainfall (Precipitation)	Elevation
Soil Structure	1	0.7	1.2	1.3	3	0.7
Soil pH	1.42	1	1.6	1.7	1.8	1.2
Min Temperature	0.83	0.62	1	0.9	1.1	1.3
Max Temperature	0.76	0.58	1.11	1	1.2	1.3
Rainfall (Precipitation)	0.33	0.55	0.9	0.83	1	1.5
Elevation	1.42	0.83	0.76	0.76	0.66	1
Sum Columns	**5.76**	**4.28**	**6.57**	**6.49**	**8.76**	**7**

Table 12: Pairwise comparison matrix for sorghum

Once the comparison matrix was computed, there was need to compute a priority vector, that is the normalized Eigen vector of the comparison matrix. This was done by normalizing each column of the comparison matrix. The normalization was done by dividing each value of a column by the sum of the respective column. The results are shown in the table below.

NORMALIZED CRITERIA COMPARISON MATRIX [C]						
Criteria	Soil Structure	Soil pH	Min Temperature	Max Temperature	Rainfall (Precipitation)	Elevation
Soil Structure	0.173611111	0.163551402	0.182648402	0.200308166	0.342465753	0.1
Soil pH	0.246527778	0.23364486	0.243531202	0.261941448	0.205479452	0.171428571
Min Temperature	0.144097222	0.144859813	0.152207002	0.138674884	0.125570776	0.185714286
Max Temperature	0.131944444	0.135514019	0.168949772	0.154083205	0.136986301	0.185714286
Rainfall (Precipitation)	0.057291667	0.128504673	0.136986301	0.12788906	0.114155251	0.214285714
Elevation	0.246527778	0.193925234	0.115677321	0.117103236	0.075342466	0.142857143
Sum Columns	1	1	1	1	1	1

Table 13: Normalized criteria comparison matrix for sorghum

The normalization was followed by obtaining the normalized principal Eigen vector, also called the *priority vector*. This was done by averaging across the rows of the *Normalized Criteria Comparison Matrix* as shown in the table below. From its name, priority vector, there is an indication of the term "importance". In other words, the priority vector shows relative weights among the criteria considered for the cultivation of the Sorghum crop.

NORMALIZED CRITERIA COMPARISON MATRIX [C]							
Criteria	Soil Structure	Soil pH	Min Temperature	Max Temperature	Rainfall (Precipitation)	Elevation	Criteria Weights {W}
Soil Structure	0.173611111	0.163551402	0.182648402	0.200308166	0.342465753	0.1	**0.193764139**
Soil pH	0.246527778	0.23364486	0.243531202	0.261941448	0.205479452	0.171428571	**0.227092219**
Min Temperature	0.144097222	0.144859813	0.152207002	0.138674884	0.125570776	0.185714286	**0.148520664**
Max Temperature	0.131944444	0.135514019	0.168949772	0.154083205	0.136986301	0.185714286	**0.152198671**
Rainfall (Precipitation)	0.057291667	0.128504673	0.136986301	0.12788906	0.114155251	0.214285714	**0.129852111**
Elevation	0.246527778	0.193925234	0.115677321	0.117103236	0.075342466	0.142857143	**0.148572196**

Table 14: Normalized criteria comparison matrix with criteria weights for sorghum

From the above table criteria weights for Maize are ranked as follow from the most important to the least important:

Criterion Rank	**Criterion Name**	**Criteria Weight (%)**
1	Soil pH	22.71
2	Soil Structure	19.88
3	Maximum Temperature	15.22
4	Elevation	14.86
5	Minimum Temperature	14.85
6	Rainfall	12.99
Total		***100***

Table 15: Criteria ranking per weight of importance

The above table shows that Soil pH and Soil Structure rank the highest this was also the case for Maize. This is mainly due to the fact that all crops need nutrients and their roots must growth and be distributed in a manner that will allow for the constant access to water and other elements in the ground. However, it is worth noting that though Soil pH and Soil Structure rank highest for Maize and Sorghum, their respective weights differ for the two crops. The weight of Soil pH for Sorghum is slightly higher than that for Maize and the weight of Soil Structure for Sorghum is lower than that for Maize, this is due to the fact that Sorghum is a hot weather crop and which implies that soil structure does not affect Sorghum the same way it would affect Maize. This leads to the third criterion in terms of ranking, that is Maximum Temperature. Is a very important determining factor for the growth of Sorghum as Sorghum is a hot weather crop and thus, higher temperatures are good for the germination and the ultimate growth of the Sorghum plant as opposed to Maize. Whereas Rainfall was ranked third for Maize, Rainfall ranks sixth for Sorghum. This is not to say that Sorghum does not require water; rather, it simply relates to the nature of the Sorghum plant being a drought resistant crop.

3.5.2.4. Consistency Check for Sorghum criteria weighting

The consistency check was undertaken to determine whether there were inconsistencies in the weighting of the criteria. This was done by using the consistency ratio (CR), random index (RI) and the consistency index (CI). The efficiency in calculating weights is assessed by the CR (, also expressed mathematically as:

$$CR = \frac{CI}{RI}$$

Where RI stands for the random index for studies using 1 to 10 different criteria, in this case RI = 1.24 for six (6) criteria or n= 6 (Saaty, 1980); and CI represents the consistency index calculated using the following equation:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

With λ_{max} being the principle eigenvector of the matrix and n being the order of the matrix. For a CR less than 0.10, the matrix is said to be consistent and, in the case, where CR is greater than 0.10 the matrix is said to have inconsistencies (Saaty, 1980). The above calculations were done using Excel and the results are depicted in the table below. The λ_{max} or principle eigenvector was calculated by averaging the Consistency Vector {Consis}; this was found to be equal to: $\lambda_{max} = 6.225499253$. Therefore, the Consistency Index was found to be equal to: CI = 0.04419543.

Thus,

$$CR = \frac{0.045099851}{1.24}$$

$$= 0.036370847$$

NORMALIZED CRITERIA COMPARISON MATRIX [C]							CONSISTENCY CHECK	
Criteria	Soil Structure	Soil pH	Min Temperature	Max Temperature	Rainfall (Precipitation)	Elevation	Criteria Weights {W}	Consistency Vector {Consis}
Soil Structure	0.173611111	0.163551402	0.182648402	0.200308166	0.342465753	0.1	**0.193764139**	6.308539018
Soil pH	0.246527778	0.23364486	0.243531202	0.261941448	0.205479452	0.171428571	**0.227092219**	6.21169912
Min Temperature	0.144097222	0.144859813	0.152207002	0.138674884	0.125570776	0.185714286	**0.148520664**	6.215310597
Max Temperature	0.131944444	0.135514019	0.168949772	0.154083205	0.136986301	0.185714286	**0.152198671**	6.208971614
Rainfall (Precipitation)	0.057291667	0.128504673	0.136986301	0.12788906	0.114155251	0.214285714	**0.129852111**	6.172766691
Elevation	0.246527778	0.193925234	0.115677321	0.117103236	0.075342466	0.142857143	**0.148572196**	6.235708477
							CI	**0.045099851**
Sum Columns	1	1	1	1	1	1	RI	**1.24**
							CR	**0.036370847**

Table 16: Consistency check

The Consistency Ratio of 0.036 falls much below the threshold of 0.10, which means that the criteria weights in the table below are consistent and therefore acceptable. In addition, the sum of all the weights was verified as being equal to 1 as per the rule of Weighted Linea Combination (Ali *et al.,* 2018:6). Hence, the criteria weights used to determine the suitability levels of various areas in the Vhembe District for the cultivation of Sorghum are acceptable.

3.6. Deriving Optimum locations for cultivating Maize and Sorghum in Vhembe District using Weighted Linear Combination (WLC) model

Once the criteria had been weighted for the Maize and Sorghum crops using the AHP method in Microsoft Excel, the weights were then applied in the Weighted Linear Combination (WLC) method using ArcGIS 10.6.1 to determine the different levels of land suitability for the cultivation of Maize and Sorghum in the Vhembe District. The WLC method was applied by using the following formula:

$$S = \sum W_i X_i$$

Where S is the suitability, W_i is the weight of criteria I, and X_i is the criterion score of criteria i (Al-hanbali *et al.*, 2011).

The Weighted Linear Combination method was used to aggregate the "preference information" (Chou, 2013) as expressed in terms of the criteria weights, which led to the subsequent ranking of land suitability types. The next chapter outlines the results of the analysis and provides a discussion of the findings.

3.7. Limitations

The methodology described and used in this study presented certain limitations to some extent. One limitation of this methodology relate to deciding the acceptability of the weights that were calculated for Maize and Sorghum using the Analytical Hierarchy Process (AHP). Though the consistency check for both sets of criteria weights was done, it is worth noting that no experts in the culture of Maize and Sorghum were consulted to discuss the subsequent ranking of the criteria as obtained through the AHP and therefore, the present study heavily relied on available literature on Maize and Sorghum to justify the ranking of criteria according to their weights.

Further, in identifying the criteria to be considered in conducting land suitability analysis for Maize and Sorghum, it is worth noting that criteria relating to the socio-economic context of the Vhembe District were not considered; however, the discussion of the results in the next chapter (Chapter 4) integrates the implications of the results for the socio-economic sustainability of communities in the Vhembe District.

3.8. Conclusion

This chapter has described and outlined the method was used to collect, prepare and eventually analyze the data for the purpose of answering the main question of the study as well as the achievement of the objectives thereof. The data was obtained from the Department of Agriculture, Land Reform and Rural Development; and the data collected was in three types as they relate to the six criteria that were considered in analyzing the suitability of land in the Vhembe District for sustainable cultivation of Maize and Sorghum. The three types were climatic data, physical and chemical properties of soil, and topographic data. The six criteria that were considered are: Soil Structure, Soil pH, Minimum Temperature, Maximum Temperature, Average Annual Rainfall (Precipitation) and Elevation. The Analytical Hierarchy Process (AHP) method was used to weight these criteria for both Maize and Sorghum and in light of accessible literature on the cultivation of the two crops; ArcGIS 10.6.1 software was used to prepare for and to analyze the data. The Weighted Linear Combination method was used in the ArcGIS platform to determine the different level of suitability for the two crops based on the weights that were calculated in Excel using the AHP method.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Introduction

This chapter outlines the results that were obtained as outcomes of the data analysis stage undertaken as part of this research project. This chapter also discusses the results that were obtained in relation to the main question of this research and its subsequent research objectives. The main objective of the research being to determine suitable locations for the cultivation of Maize and Sorghum and the Vhembe District, Limpopo South Africa. Achieving this main objective involved achieving four subsequent objectives; namely, to identify criteria for mapping suitable locations for the cultivation of Maize and Sorghum in the Vhembe District, to weigh these criteria using the Analytical Hierarchy Process (AHP) method, to develop a GIS-Multicriteria Decision Analysis model for land use mapping of Maize and Sorghum and to determine how the Land Use Suitability mapping informs sustainable land use planning in the Vhembe District.

4.2. Results

4.2.1. Criteria Weights

The following criteria were identified for mapping land use suitability for the cultivation of Maize and Sorghum:

CRITERIA WEIGHTS RANKING FOR THE CULTIVATION OF MAIZE		
Criterion Rank	**Criterion Name**	**Criteria Weight (%)**
1	Soil pH	22.10
2	Soil Structure	21.97
3	Rainfall	20.46
4	Elevation	13.08
5	Minimum Temperature	11.47
6	Max Temperature	10.94
Total		***100***

Table 17: Criteria weights ranking for the cultivation of maize

CRITERIA WEIGHTS RANKING FOR THE CULTIVATION OF SORGHUM		
Criterion Rank	**Criterion Name**	**Criteria Weight (%)**
1	Soil pH	22.71
2	Soil Structure	19.88
3	Max Temperature	15.22
4	Elevation	14.86
5	Minimum Temperature	14.85
6	Rainfall	12.99
Total		***100***

Table 18: Criteria weights ranking for the cultivation of sorghum

When comparing the above two tables, it is evident that Soil pH ranks the highest followed by soil structure. In the case of Maize, rainfall ranks third whereas in the case of Sorghum, maximum temperature ranks third and rainfall ranks sixth instead. It is not surprising to have Soil pH rank first as it is a major determinant of plant growth. Soil pH influences the availability of essential nutrients. Soil pH is also very interesting in the sense that a pH reading of below 7 is indicative of acidity of the soil and any pH reading above 7 is indicative of alkalinity of the soil. Few plants, however, tend to be more acidic than alkaline and few tend to be more alkaline than acidic and Maize does not fall under any of the two categories hence Soil pH is of great importance for the optimum growth of Maize.

Soil Structure is ranked second highest after Soil pH for both Maize and Sorghum. This is due to the important role played by soil structure in the growth of a plant. For example, soil structure determines how plant roots grow and are distributed underground as the structure of the soil impacts on soil temperature, aeration and availability of water in the soil (Ball *et al.,* 2004). Soil structure has to do with the physical and/or mechanical properties of the soil which are also linked to climatic factors such as temperature and rainfall. Hence, "Rainfall" ranked third after "Soil Structure" for Maize. Rainfall is an important factor as it determines soil moisture from which the crop draws water, especially in the case of Maize, a crop that requires between 450 to 600 mm of water per season for an optimal yield (du Plessis, 2003). Rainfall ranked sixth for Sorghum because Sorghum is a more drought resistant crop as opposed to Maize which tends to be water intensive when compared to Sorghum.

However, it is worth noting that though Soil pH and Soil Structure rank highest for Maize and Sorghum, their respective weights differ for the two crops. The weight of Soil pH for Sorghum is slightly higher than that for Maize and the weight of Soil Structure for Sorghum is lower than that for Maize, this is due to the fact that Sorghum is a hot weather crop and which implies that soil structure does not affect Sorghum the same way it would affect Maize. This leads to the third criterion in terms of ranking for the cultivation of Sorghum that is Maximum Temperature. Temperature is a very important determining factor for the growth of Sorghum as Sorghum is a hot weather crop and thus, higher temperatures are good for the germination and the ultimate growth of the Sorghum plant as opposed to Maize. Whereas Rainfall was ranked third for Maize, Rainfall ranks sixth for Sorghum. This is not to say that Sorghum does not require water; rather, it simply relates to the nature of the Sorghum plant being a drought resistant crop.

4.2.2. Criteria Maps

As mentioned earlier, six criteria were identified for mapping suitable locations for the cultivation of Maize and Sorghum. The data relating to each criterion was collected; however, there was need to reclassify the attribute values of each criterion and set rules for each criterion as relating to the requirements of each crop in relation to the optimum growth of these crops. Seeing that Maize and Sorghum present different requirements in terms of the said criteria, the criteria maps that were produced based on the criteria rule setting show the different suitability classes for each criterion according to the suitability index provided by the Food and Agriculture Organization (FAO) of the United Nations.

4.2.2.1. Criteria Maps for Maize

The following maps represent the different suitability classes for each criterion in relation to the growth requirements of maize. These maps were produced after the reclassification of the attribute values of each criterion had been done, followed by the rule setting.

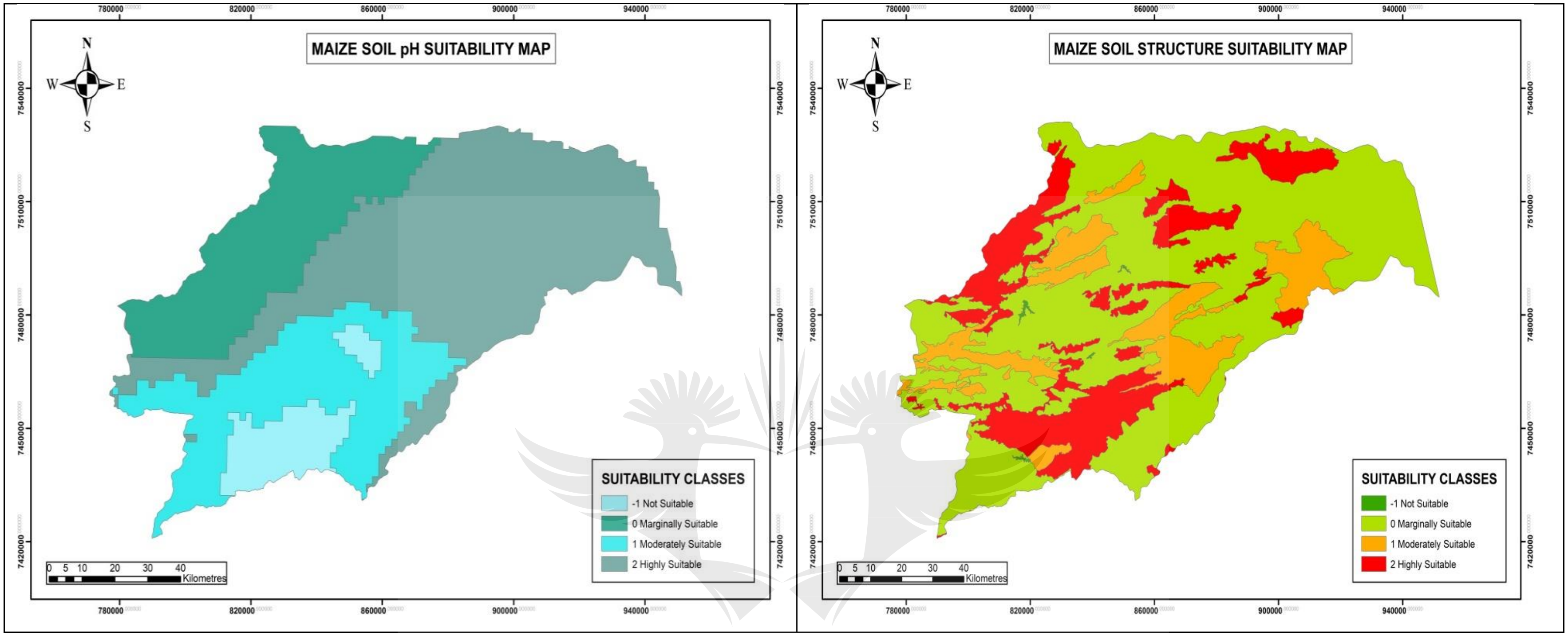


Figure 9; Criteria maps for maize: soil pH and soil structure

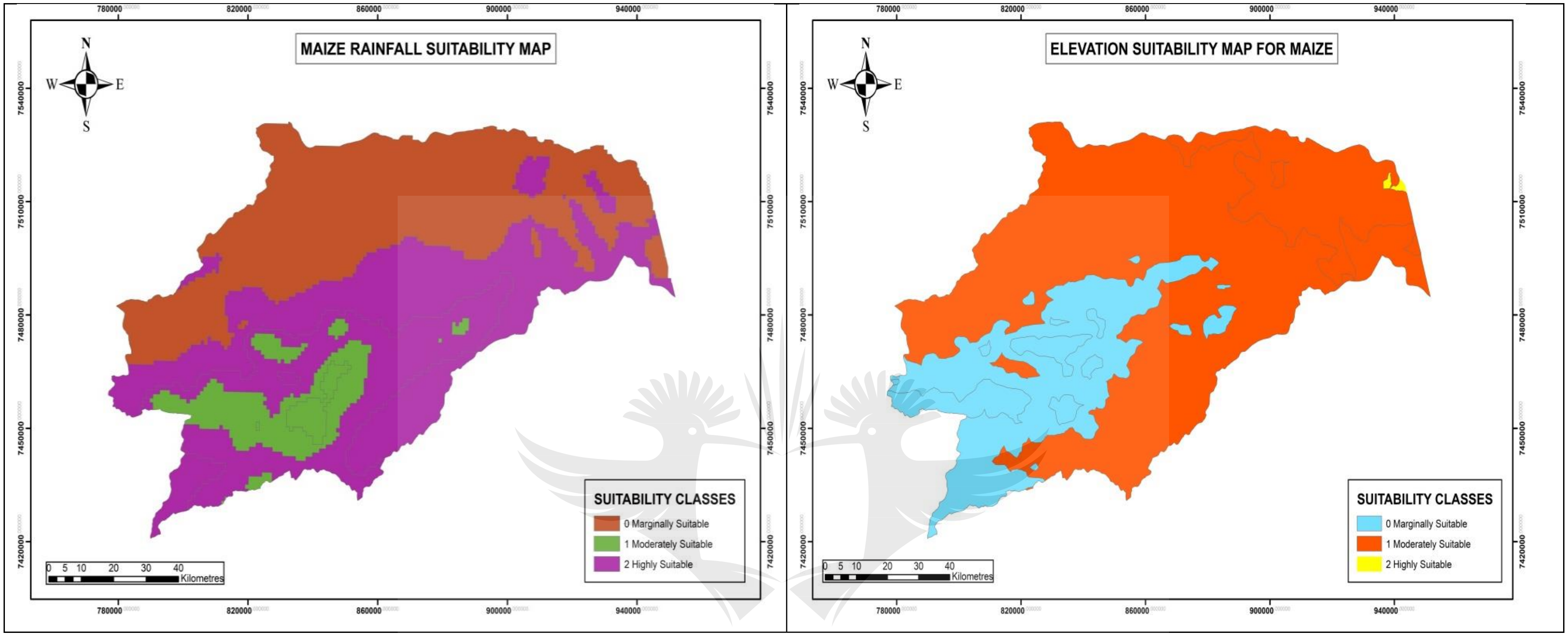


Figure 10; Criteria maps for maize: rainfall and elevation

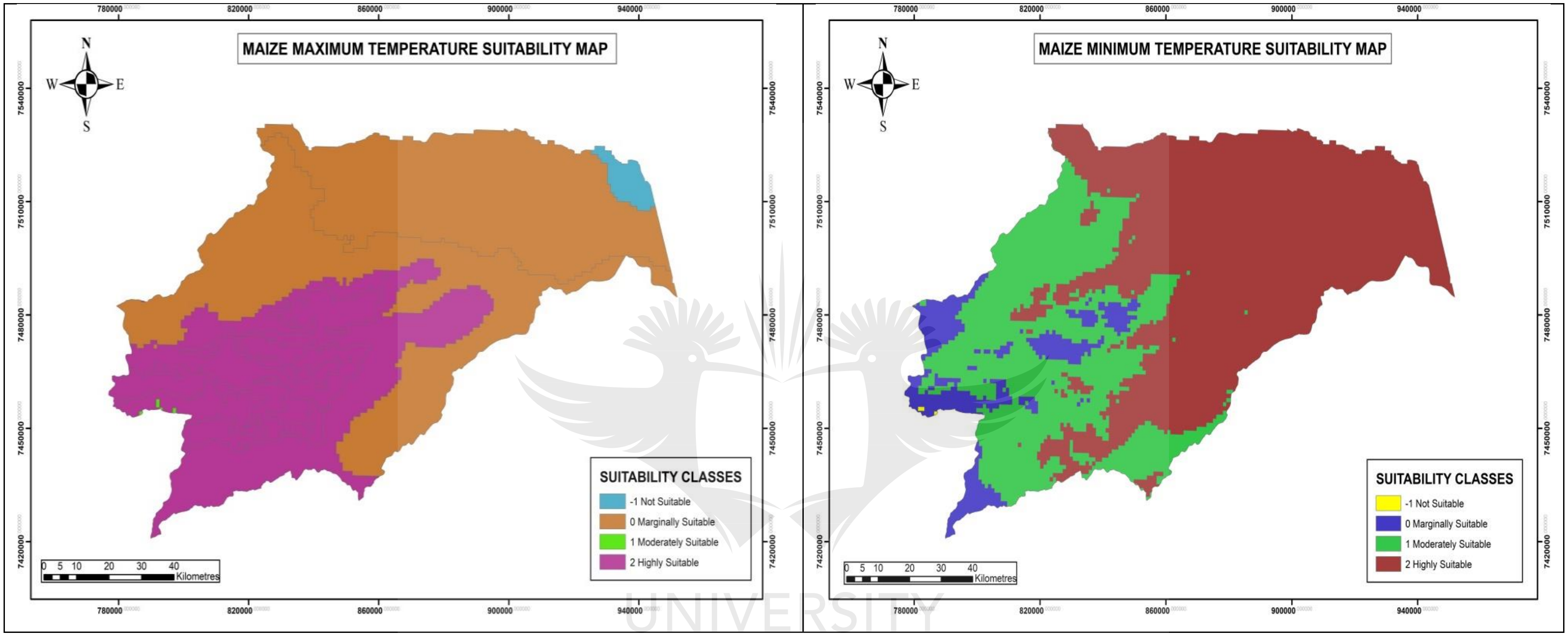


Figure 11; Criteria maps for maize: maximum temperature and minimum temperature

4.2.2.2. Criteria Maps for Sorghum

The following maps represent the different suitability classes for each criterion in relation to the growth requirements of sorghum. These maps were produced after the reclassification of the attribute values of each criterion had been done, followed by the rule setting.

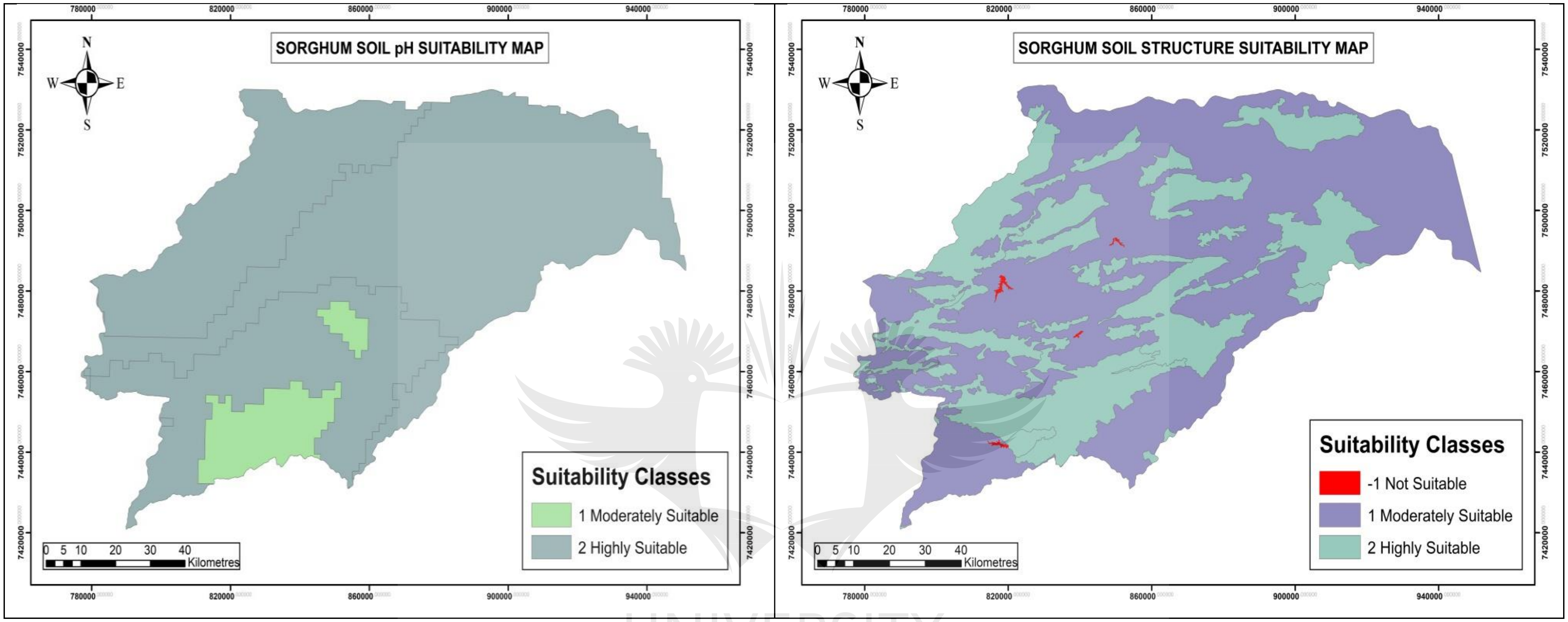


Figure 12; Criteria maps for sorghum: soil pH and soil structure

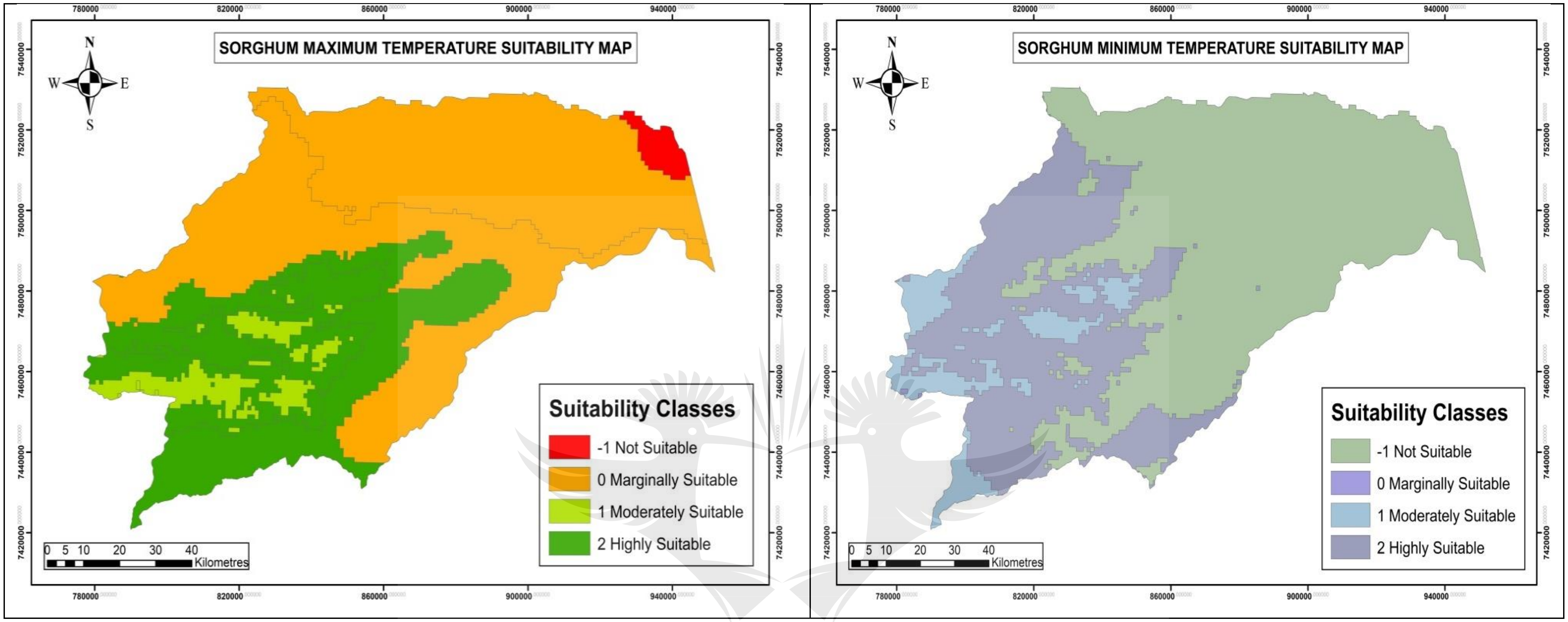


Figure 13; Criteria maps for sorghum: maximum temperature and minimum temperature

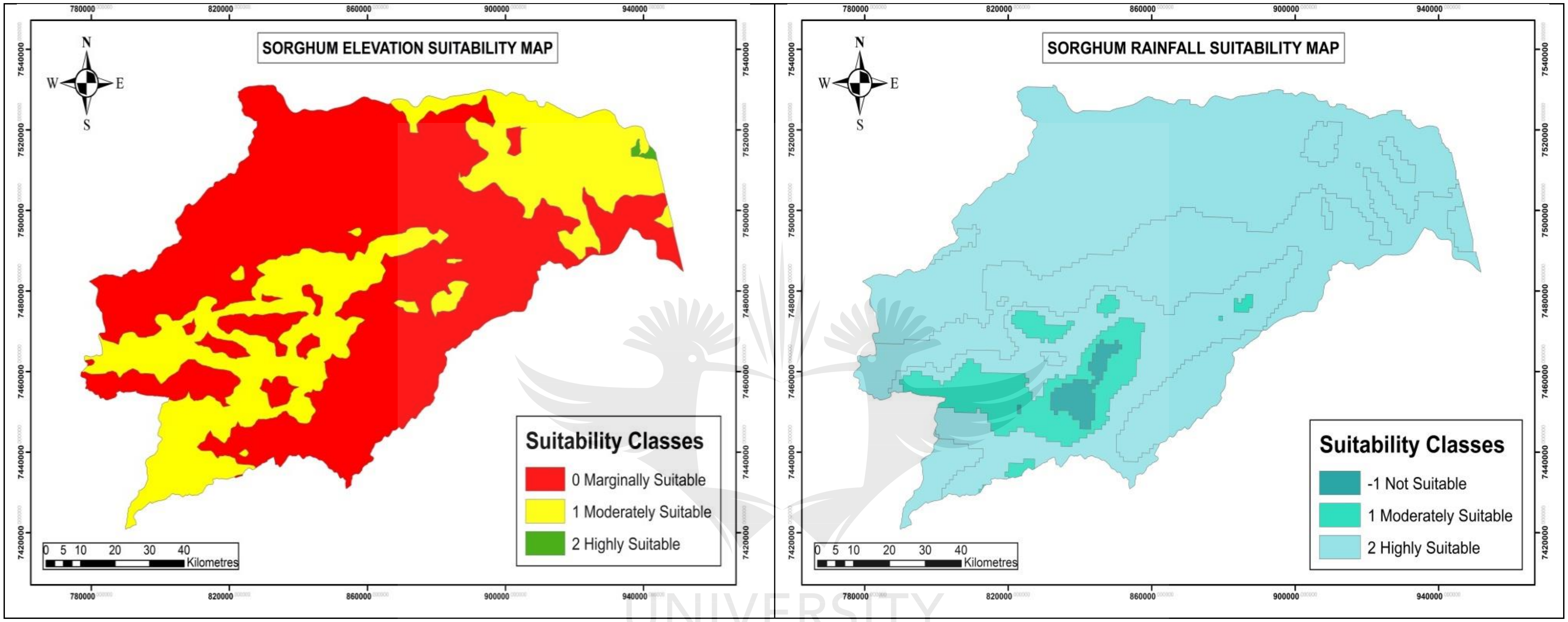


Figure 14; Criteria maps for sorghum: elevation and rainfall

Figures 9, 10, 11, 12 ,13 and 14 represent the different suitability classes for each criterion in relation to the growth requirements of maize and sorghum. As can be observed from Figure 9 representing soil pH and soil structure suitability classes for maize, the north-eastern part and the central part of the district is highly suitable for maize in terms soil pH, whereas the district shows some forms of high suitability for maize in terms of soil structure in almost every part of the district. Such mismatches are evident for all the criteria which is understandable because attribute values for each criterion measured differently throughout the district. In other words, parts of the district where soil pH is highly suitable for maize is not necessarily the case for soil structure or any other criterion; the same is true for sorghum as can be observed from Figure 14 representing elevation and rainfall suitability classes for the cultivation of sorghum. Hence the weight of each criterion was calculated and these were integrated in ArcGIS to determine final suitability maps for maize and Sorghum.

Further, it is worth noting that some criteria maps represent two or three suitability classes instead of four as advocated for by the FAO. This is due to the fact that after reclassification of attribute values of these criteria in light of the growth requirements of the respective crop, it was found that the attributes values can be classified only into two classes or three instead of four. As a result, the criteria maps reflect the possible classes and their respective suitability class in terms of the FAO classification index. Figure 12 above is a perfect example of this reality, where soil pH values were classified into two classes, that is, highly suitable and moderately suitable for the cultivation of sorghum; and soil structure values were classified into three classes, namely highly suitable, moderately suitable and unsuitable.

4.2.3. Suitability Map for Maize

The suitability map for Maize was obtained after criteria weights had been determined using the Analytical Hierarchy Process (AHP) method. The said criteria weights were integrated in the GIS-based land suitability analysis model using the Weighted Linear Combination (WLC) technique.

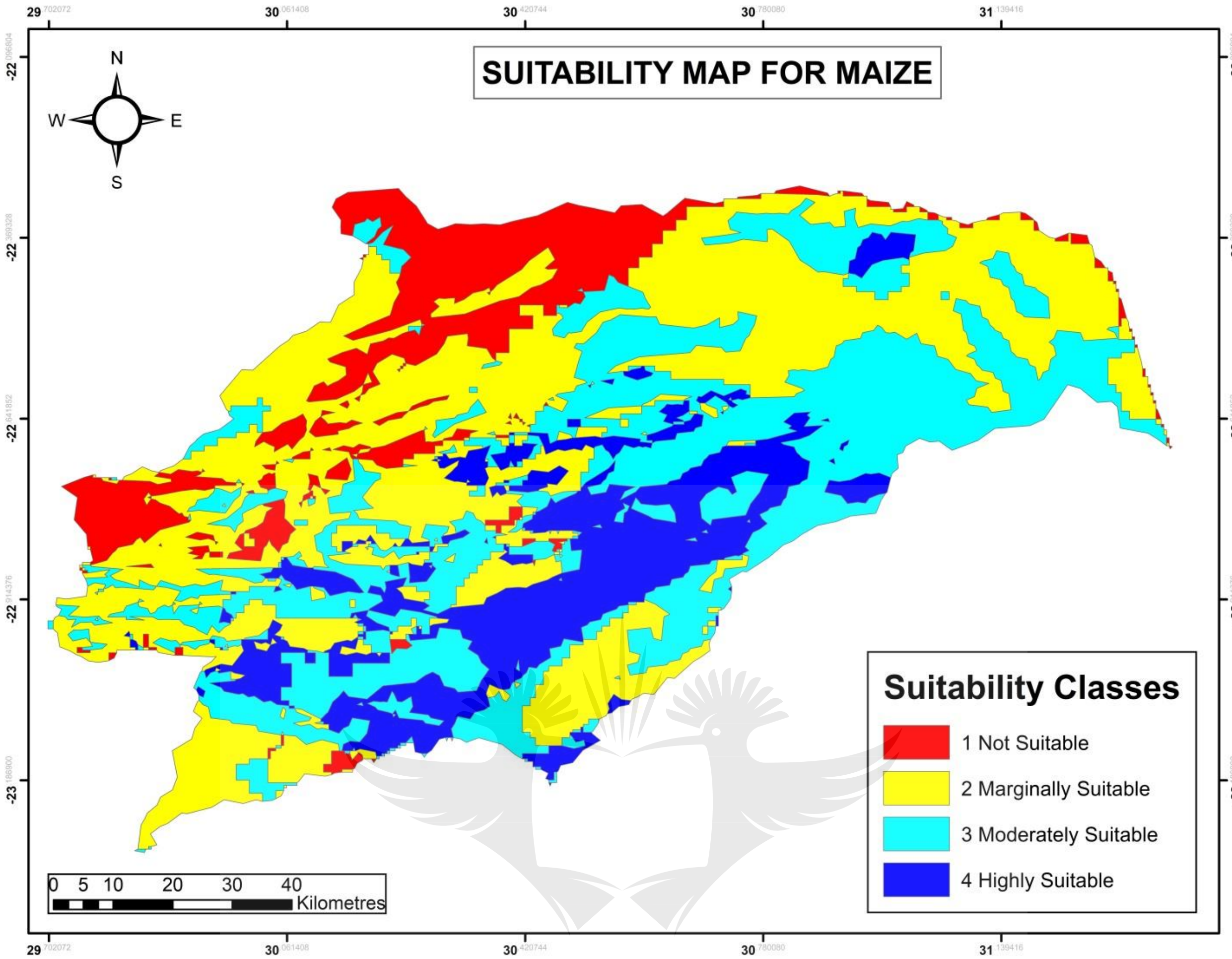


Figure 15; Suitability map for maize

The above figure represents the land suitability map for the cultivation of Maize in the Vhembe District. Land in the Vhembe District was categorized into four levels of suitability as per the FAO land suitability index whereby:

Index	Interpretation
4	Highly Suitable
3	Moderately Suitable
2	Marginally Suitable
1	Not Suitable

Table 19: Land suitability classification index

Hence, as can be observed from the suitability map, only a small portion of the whole district is highly suitable for the cultivation of Maize. The South-Eastern part of the district appears to be highly suitable than any other part of the district. This has implications for agricultural development policy directives in the district as will be discussed further in the discussion section of this chapter. The ownership of the land earmarked for high suitability is yet another interesting point to be discussed in the later section of this chapter as it relates to the livelihood of people in the Vhembe District. Most importantly, the current development on land earmarked for high suitability is yet another point to ponder as it relates to sustainable land use planning in the area.

A further analysis of the results, that is after calculating the area in hectares for each suitability class, the following results were obtained:

OBJECTID	**SUITABILITY CLASS**	**AREA (Ha)**	**PERCENTAGE OF TOTAL AREA**
1	1: Not Suitable	124, 644	12.25
2	2: Marginally Suitable	417, 367	41.01
3	3: Moderately Suitable	322, 962	31.73
4	4: Highly Suitable	152, 841	15.01
TOTAL AREA		**1, 017, 814**	**100**

Table 20: Suitability classes and their respective area percentage for maize

Table 20 above shows that only 152, 841 ha of the whole district is highly suitable for Maize which constitute 15.01 % of the total area of the district; it also shows that when combined together, the areas that are highly suitable and moderately suitable for Maize are less than 50 % of the total area, that is they add up to 46.76% which is slightly higher than the total area earmarked as marginally suitable. Therefore, most of the land is either marginally suitable or unsuitable because the state of growth factors such as soil pH, soil structure and rainfall is not conducive for the growth of Maize in most parts of the district, and these factors or criteria carry the highest weights.

4.2.4. Suitability Map for Sorghum

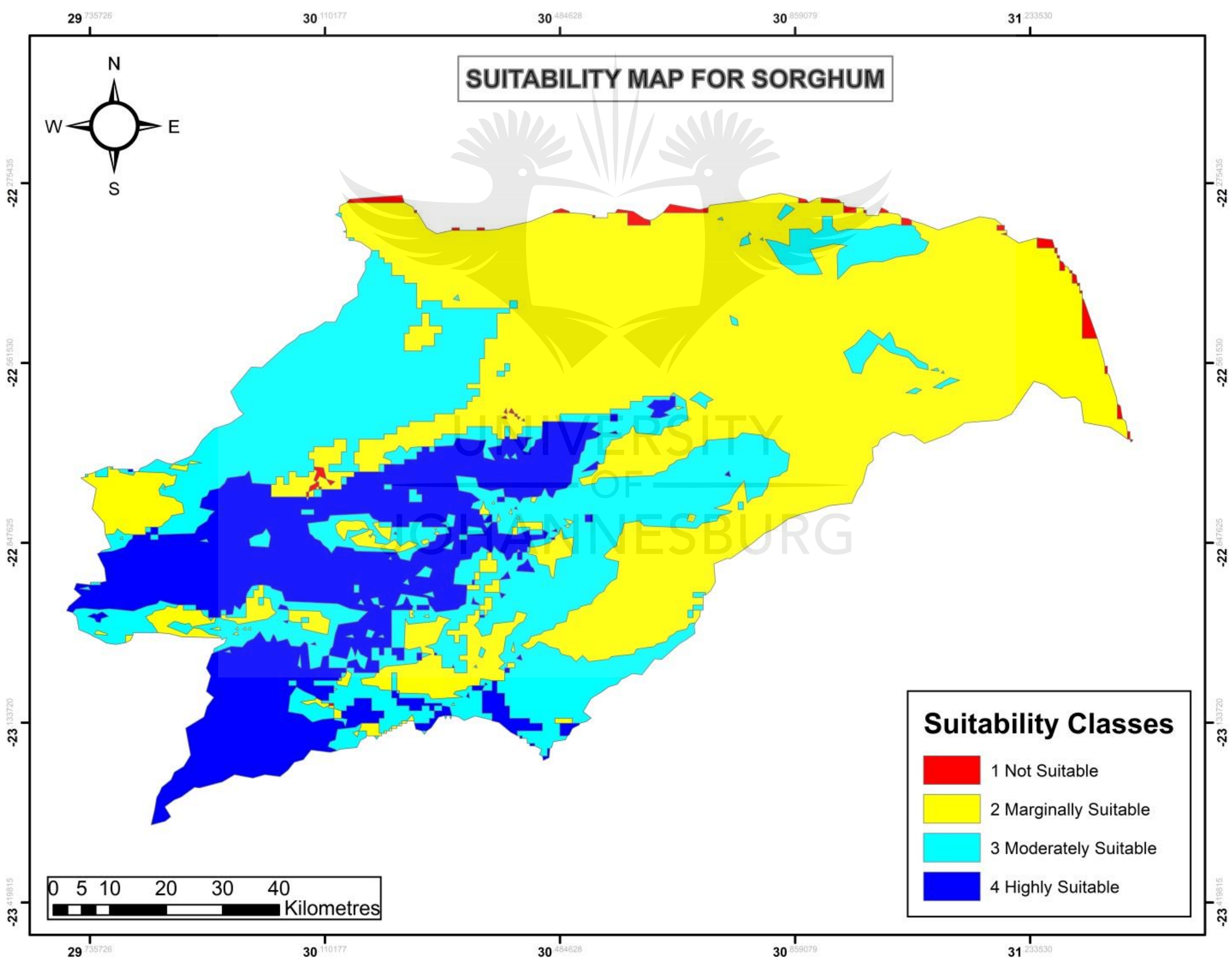


Figure 16; Suitability map for sorghum

The above figure represents the land suitability map for the cultivation of Sorghum in the Vhembe District. Land in the Vhembe District was categorized into four levels of suitability as per the FAO land suitability index whereby:

Index	Interpretation
4	Highly Suitable
3	Moderately Suitable
2	Marginally Suitable
1	Not Suitable

Table 21: Suitability index for sorghum

Hence, as can be observed from the suitability map, only a small portion of the whole district is highly suitable for the cultivation of Sorghum just as in the case of Maize. This has also implications for agricultural development policy directives in the district as will be discussed further in the discussion section of this chapter. The ownership of the land earmarked for high suitability is yet another interesting point to be discussed in the later section of this chapter as it relates to the livelihood of people in the Vhembe District. Most importantly, the current development on land earmarked for high suitability is yet another point to ponder as it relates to sustainable land use planning in the area.

A further analysis of the results was also done for Sorghum, that is after calculating the area in hectares for each suitability class, the following results were obtained:

OBJECTID	SUITABILITY CLASS	AREA (Ha)	PERCENTAGE OF TOTAL AREA
1	1: Not Suitable	6, 282	0.62
2	2: Marginally Suitable	514, 326	50.54
3	3: Moderately Suitable	299, 736	29.45
4	4: Highly Suitable	197, 370	19.39
TOTAL AREA		**1, 017, 714**	**100**

Table 22: Suitability classes and their respective areas for sorghum

This table shows that only 197, 370 ha (19.39%) of the whole district is highly suitable for Sorghum as compared to 15.01% for Maize. The table also shows that less than 1% of the entire area is not suitable for the cultivation of Sorghum, this is mainly due to the fact that Sorghum is a drought-resistant crop and thus, it is likely to grow in most areas of the district with variations in yield potential.

It is worth noting that areas highly suitable for Maize are not highly suitable for Sorghum. This explains the difference in requirements for the growth of the two plants in terms of Soil pH, Soil Structure, Rainfall, Minimum Temperature, Maximum Temperature, and Elevation.

4.3. Discussion

4.3.1. Suitability classes and land ownership in the district

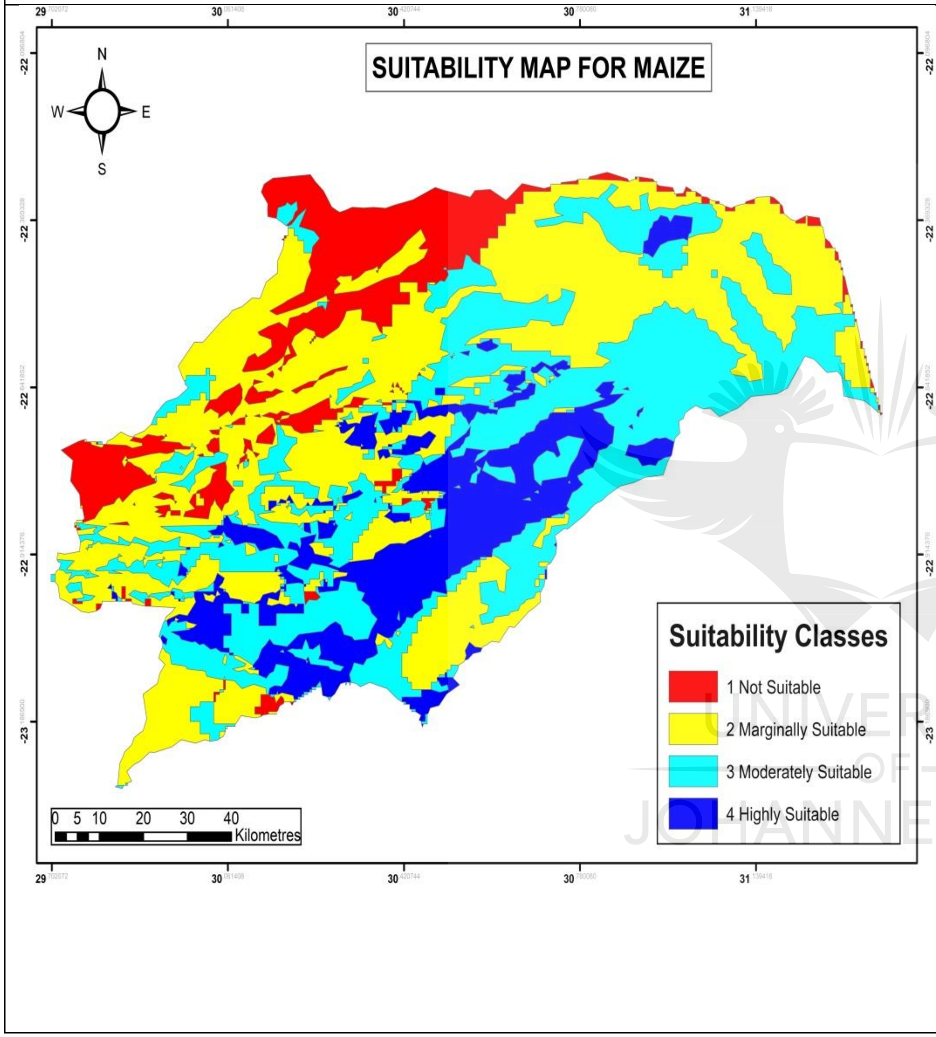
4.3.1.1. Suitability classes for Maize and land ownership

Figure 4.9. Below compares the suitability map for Maize with the land ownership map for the Vhembe District; as can be noticed, it appears that most of the area classified as highly suitable is owned by the National government and a smaller portion is privately owned. This implies that subsistence farming for Maize is not likely in highly suitable areas thus impacting on the livelihood of local residents. Such a ratio of privately-owned land and land owned by the national government also implies that commercial farming of Maize may be undertaken in those highly suitable areas, subject to the land being leased to commercial farmers which means that local residents (the majority of whom are low-income earners) are excluded from such a practice.

4.3.1.2. Suitability classes for Sorghum and land ownership

When comparing the suitability map for Sorghum with the ownership category map as depicted in Table 4.8. it appears that the area of the district that is classified as highly suitable for the cultivation of Sorghum is shared among private owners, traditional authority, the government and a considerable portion has no ownership-related data. Such a diversity in the ownership of the land would implies lack of consensus in the use of land, that is, most likely it is difficult for these land owner to agree on what to use the land for; hence, a reduced percentage of highly suitable land for the cultivation of Sorghum.

Land Suitability Map for Maize	Land Ownership Map



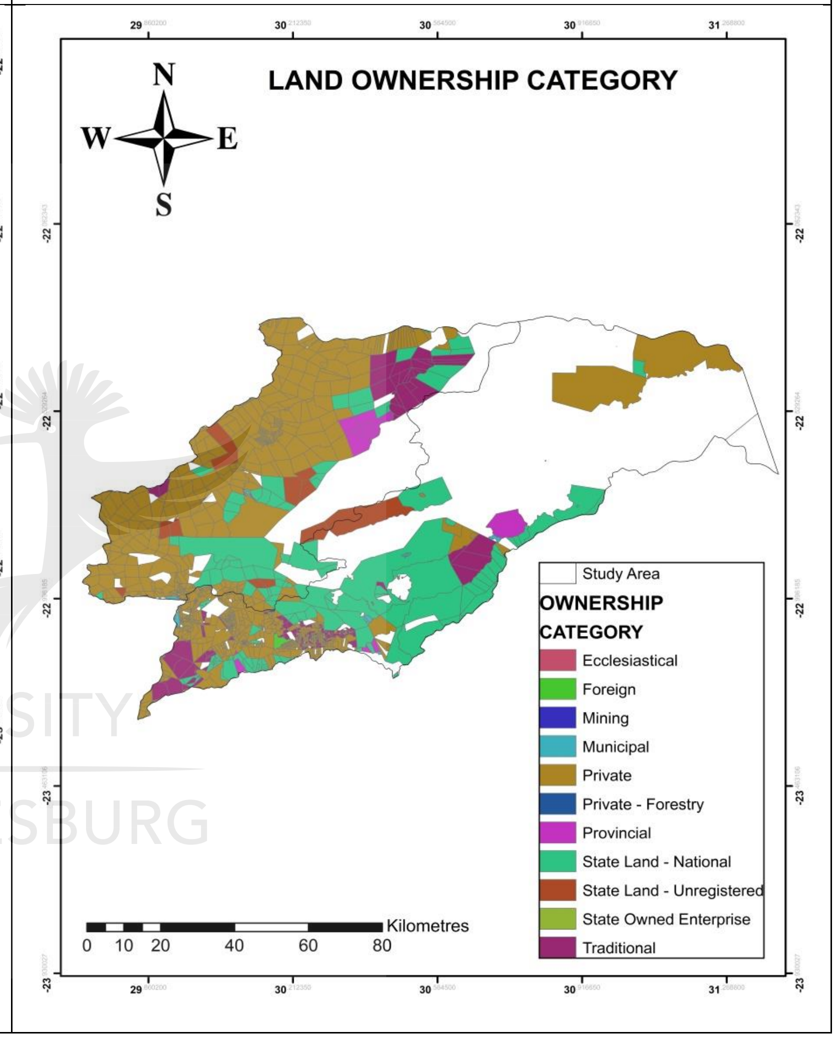
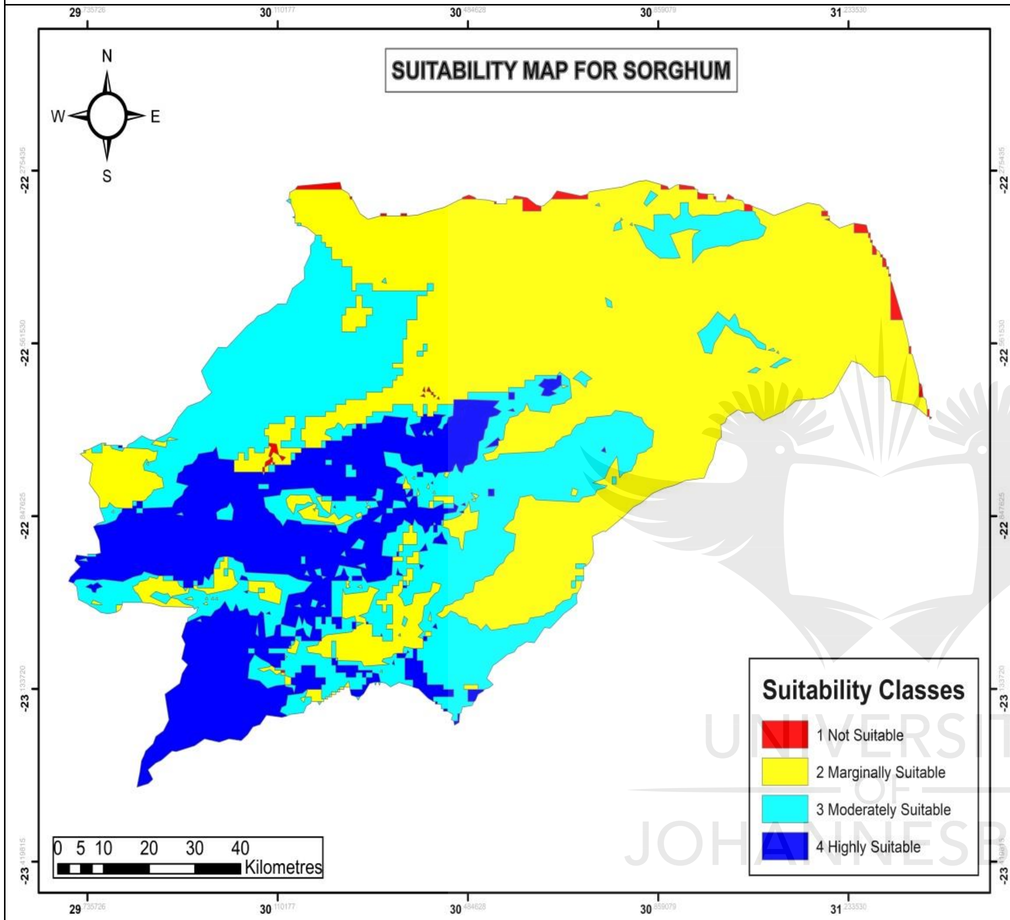


Figure 17; Comparison of suitability classes for Maize with land ownership in Vhembe District

Land Suitability Map for Sorghum



Land Ownership Map

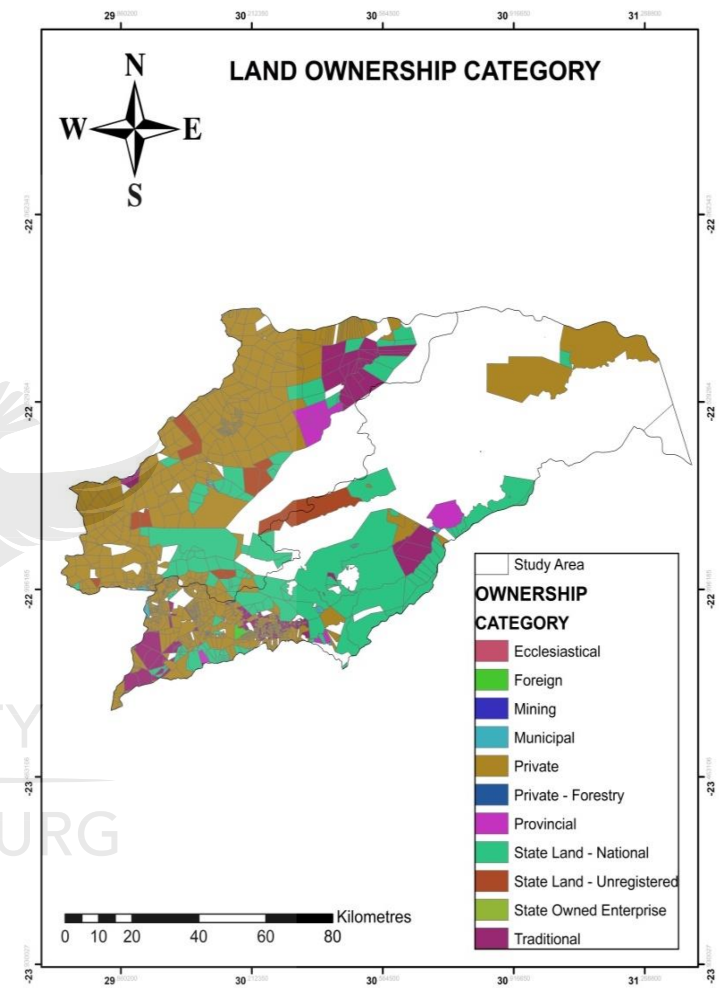
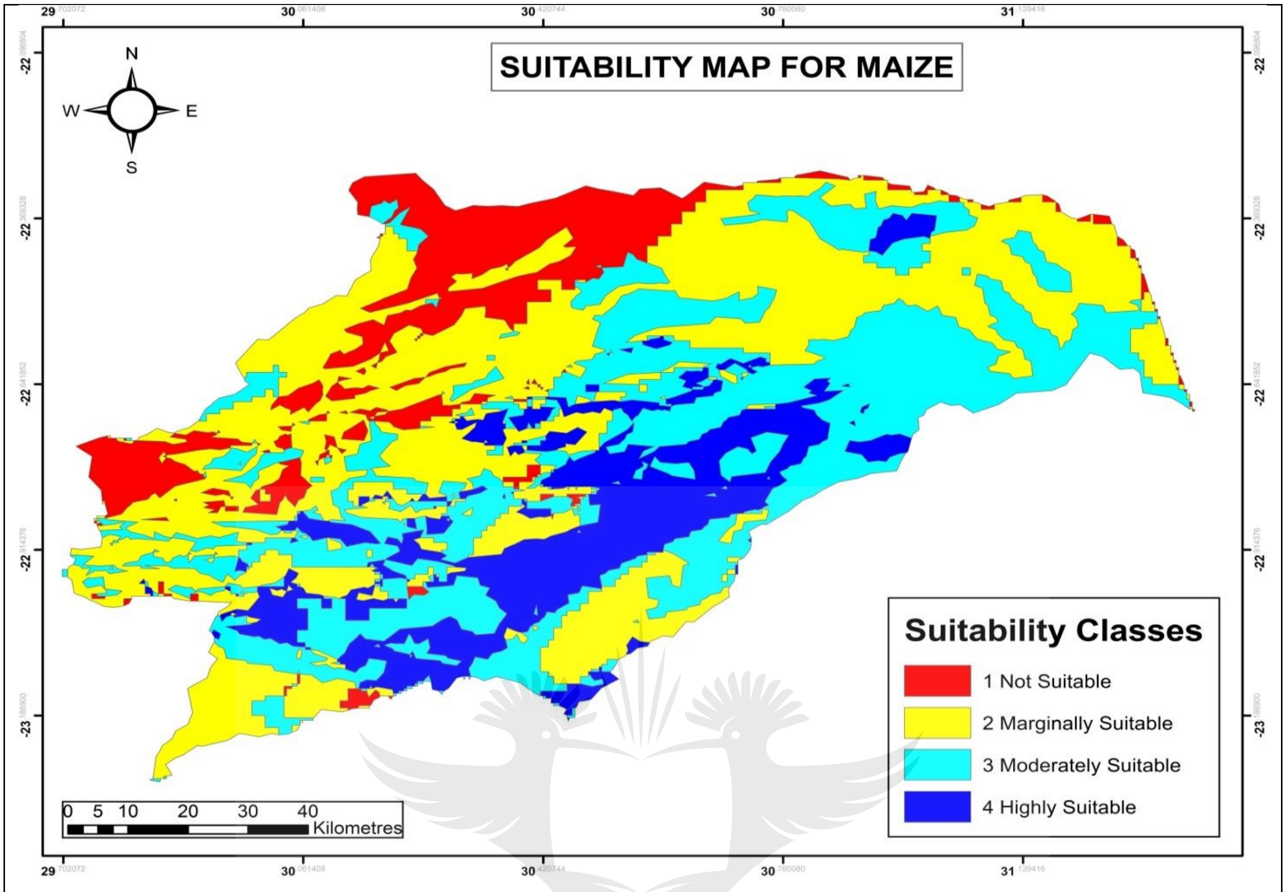


Figure 18; Comparison of suitability classes for Sorghum with land ownership in Vhembe District

4.3.2. Suitability Classes considering national park and conservation sites

It is worth considering crucial uses for which land is being used in some parts of the district as these uses have the potential to reduce the total area classified as highly suitable; especially in cases where the land where such uses take place has been classified as highly suitable. These uses include national park and areas that have been earmarked for conservation sites.


SUITABILITY MAP FOR MAIZE
N
W
E
S
Suitability Classes
1 Not Suitable
2 Marginally Suitable
3 Moderately Suitable
4 Highly Suitable
0 5 10 20 30 40
Kilometres

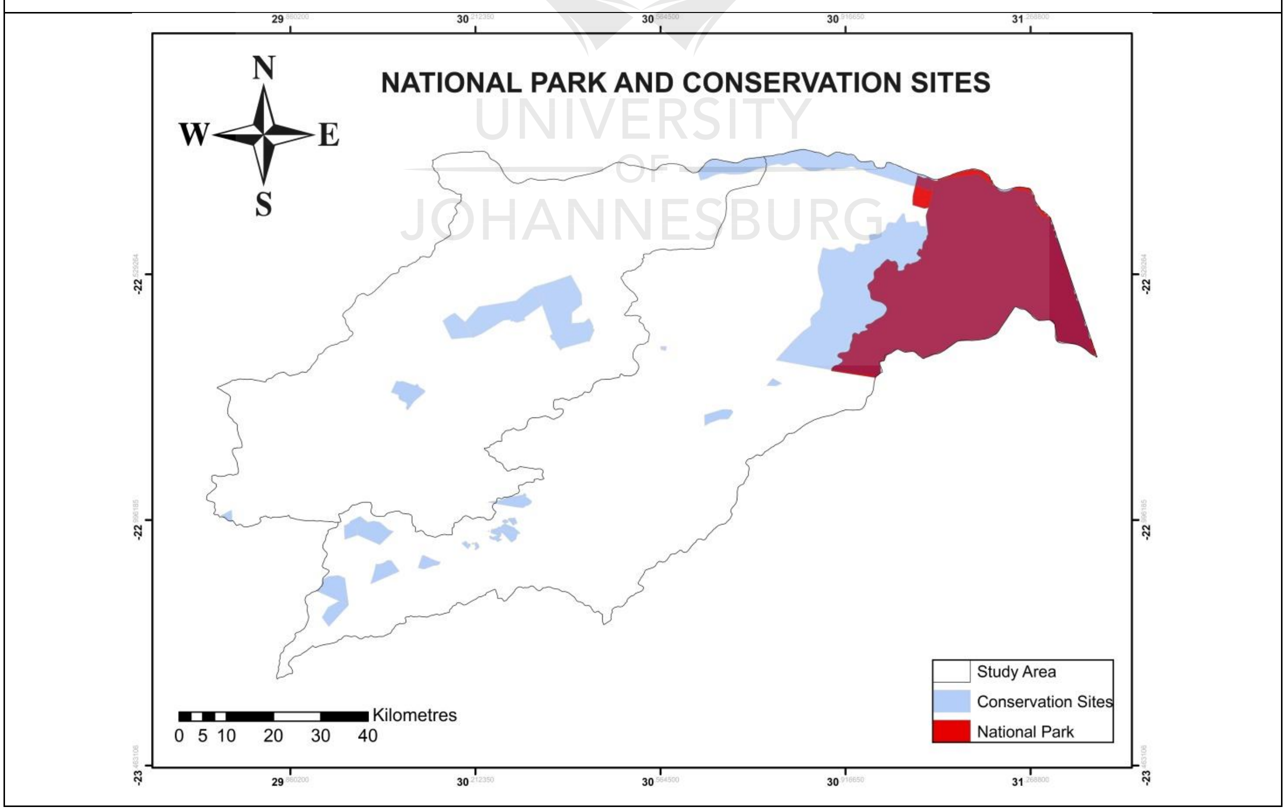

NATIONAL PARK AND CONSERVATION SITES
N
W
E
S
Study Area
Conservation Sites
National Park
Kilometres
0 5 10 20 30 40

Figure 19; Comparing Maize Suitability Classes with the location of national parks, conservation sites and protected areas

As can be noted from Table 4.9, locations that are classified as highly suitable for the cultivation of Maize do not fall under forest area or conservation sites. Only a small portion of highly suitable areas do fall under conservation sites. However, the forest and conservation sites do cover a good portion of moderately and marginally suitable areas. This is significant, especially when considering that moderately suitable areas can be used for agricultural purposes subject to improvement measures in terms of soil quality, availability of water etc.

Further, Table 4.10 below compares suitability classes for the cultivation of Sorghum to national park and conservation sites. As can be observed, part of the area classified as highly suitable for the cultivation of Sorghum falls under conservation sites, especially in the Southern part of the Vhembe district. This implies that this part of the district cannot be used for the cultivation of Sorghum. This reality also emphasizes the fact that there is limited suitable land for the cultivation of Sorghum in the Vhembe District.

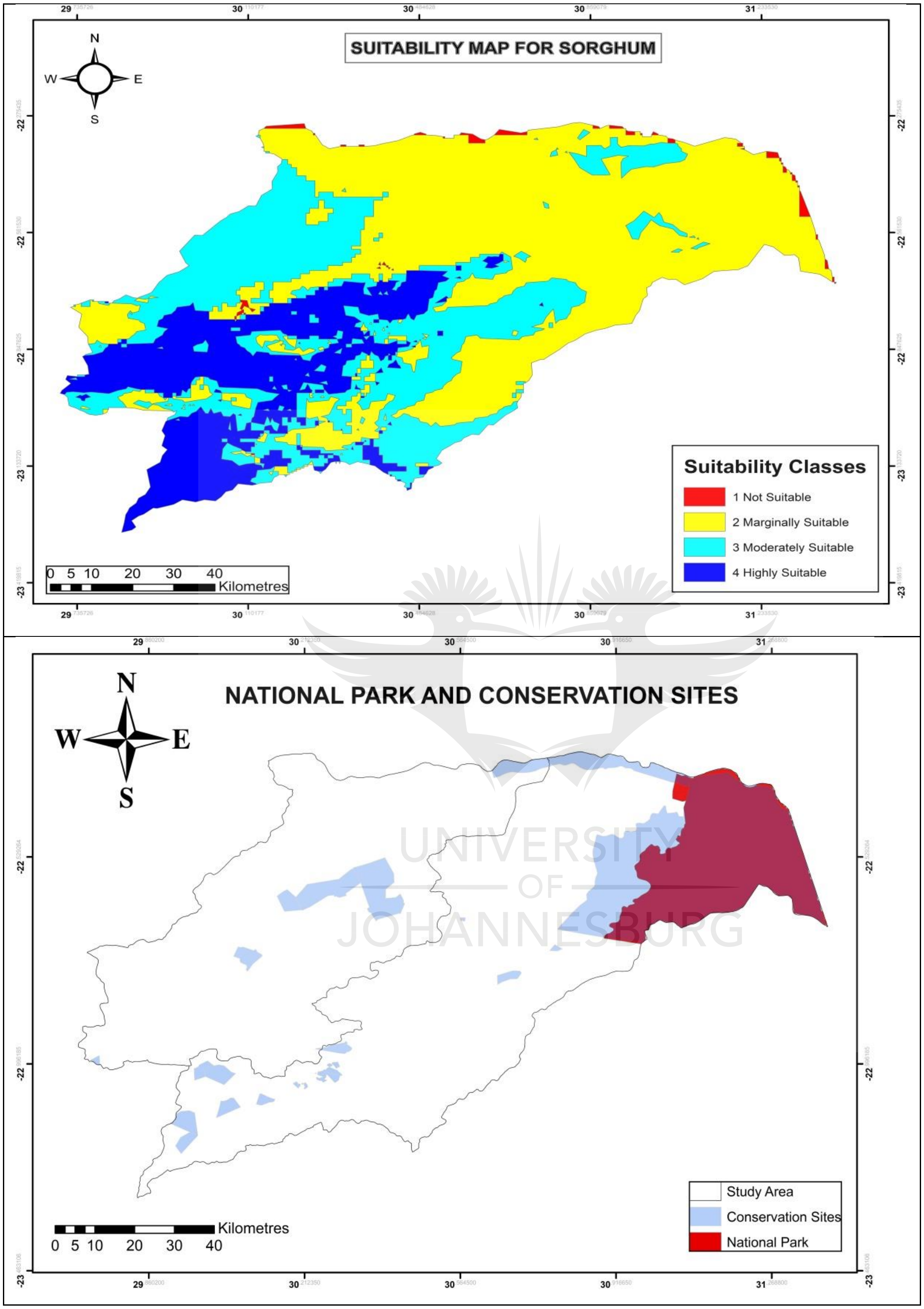


Figure 20; Comparing Sorghum Suitability Classes with the location of national parks, conservation sites and protected areas

4.3.3. Implications for spatial and land use planning in Vhembe Districts

The above findings on the location of the various suitability classes for the cultivation of Maize and Sorghum have implications for spatial planning and land use management, especially when considering the need to balance urban growth with a continuous supply of food with its associated livelihood for local residents. The knowledge of suitable locations for the two crops should prompt urban planners to consider the integration of urban agriculture in their spatial vision as expressed in terms of Spatial Development Frameworks (SDFs) in the South African context.

Further, the limited availability of suitable land for the cultivation of Maize and Sorghum in the Vhembe district should draw the attention of spatial and land use planners to consider land suitability analysis for other crops as an integral component of the whole planning process. This is due to the fact that the majority of residents in the Vhembe District rely on subsistence farming.

Furthermore, with the ownership category associated with land that is highly suitable for the cultivation of Maize and Sorghum, it is evident that land in those areas does not belong to the previously marginalized segment of the population in the Vhembe district. As a result, spatial planners should develop local economic development strategies that would benefit areas that are owned by people living in areas that are not suitable for agricultural activities.

4.3.4. Implications for policy, climate change and livelihoods

4.3.4.1. Implication for policy

The results imply that policies advocating for agricultural development as a means of achieving local economic development should build their strategies based on the outcome of land suitability analysis as it may appear that the crops that form part of their strategies cannot be produced sustainably on the land that is available for agriculture. The analysis of the suitability of land for the cultivation of maize and sorghum has revealed that there is limited availability of highly suitable land for the cultivation of these two crops. It would not be surprising to find out that there is also limited suitability for the cultivation of crops other than maize and sorghum.

Further, the results also imply that the provisions of laws such as the Spatial Planning and Land Use Management Act (SPLUMA) (Act No. 16 of 2013) should be implemented with careful consideration of the suitability of land for a wide range of land uses. For example, the SPLUMA Act places on municipalities the responsibility to develop their respective Spatial Development Frameworks (SDFs) under Section 20 of the act. The SDF should outline the spatial vision of each municipality and inform the use and management of land. The act also requires municipalities to development their respective land use schemes as are necessary for the use and management of land in their areas of jurisdiction. These two instruments, SDFs and Land Use Scheme, cannot be well developed without taking into consideration the suitability of land for a wide range of uses including agricultural use.

4.3.4.2. Implication for climate change

The attained results make proof of the impact of climate change on not just the agriculture industry but also on the spatial configuration of areas in terms of land uses as the outcome of land suitability analysis has the potential to inform the spatial vision of a city, district or province.

In the case of the implication for climate change and agriculture, it appears that highly suitable land for agricultural purposes, not just for maize and sorghum, will keep shrinking as changes in climatic variables or factors such as temperature and precipitation become more noticeable over the years. This, however, does not mean that agricultural activities should cease; it simply means that as climate change becomes more apparent in an area the suitability of land for crops needs to be undertaken so as to determine whether it is viable to continue with the culture of the same crops or new crops should be introduced for which land is still or has become suitable to ensure food security.

Further, in the context of the Vhembe District and that of the Limpopo province at large, the following data obtained from the South African Weather Service (depicted by figures 4.13. and 4.14.) reveals that there have been changes in annual maximum temperatures, minimum temperatures and precipitations. These changes are indicatives of climate change in the area between the year 1968 and the year 2017. There is evidence of increase in maximum temperatures in the past fifteen (15) years between the year 2002 and 2017. This increase in temperature has also been coupled with a decrease in precipitations or rainfall over the same period of time. This then implies that climate will continue to change thus, impacting on the suitability of land for agricultural activities and on the livelihoods of residents who still rely on subsistence farming.

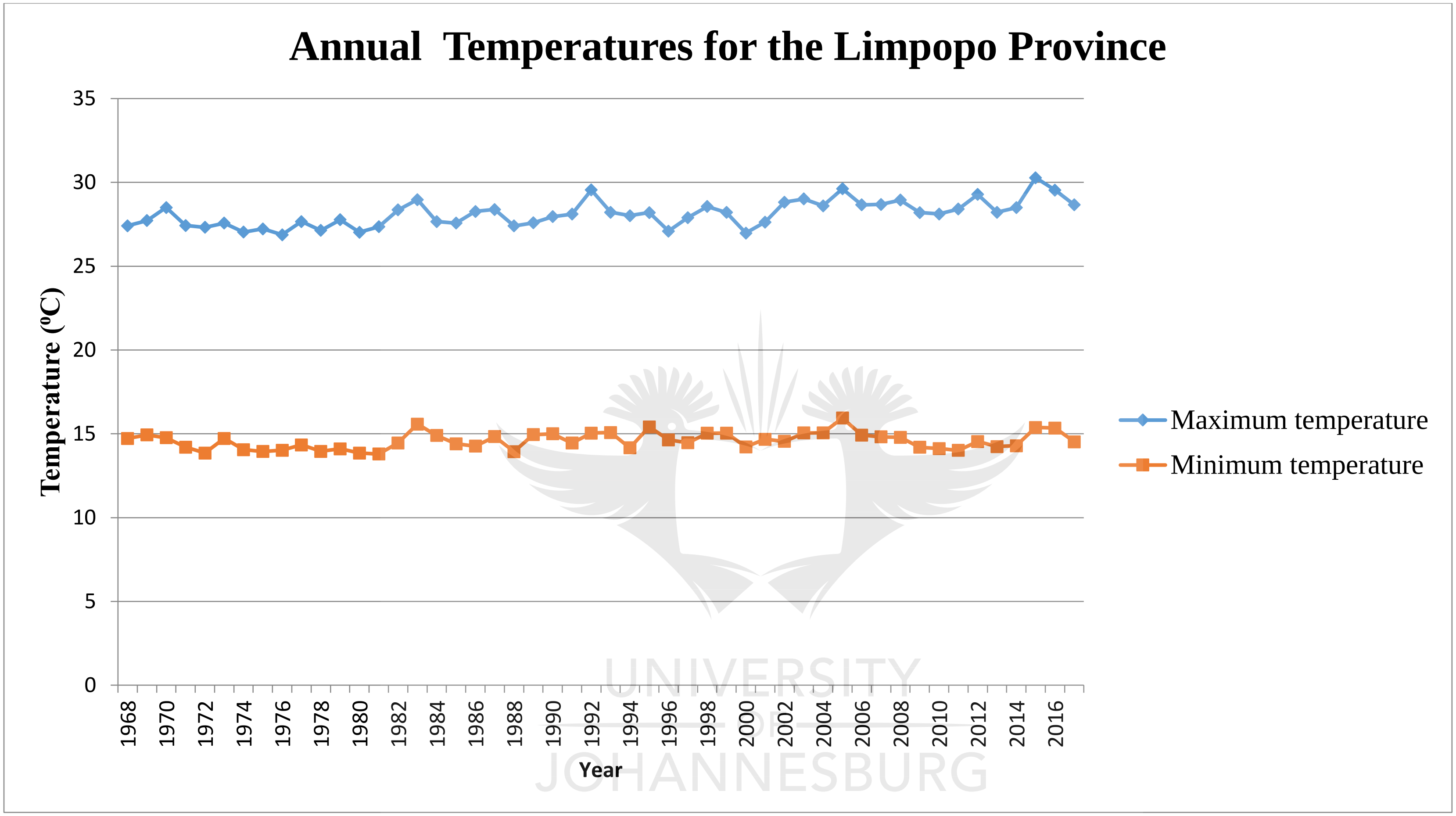


Figure 21; Annual Temperature for the Limpopo Province

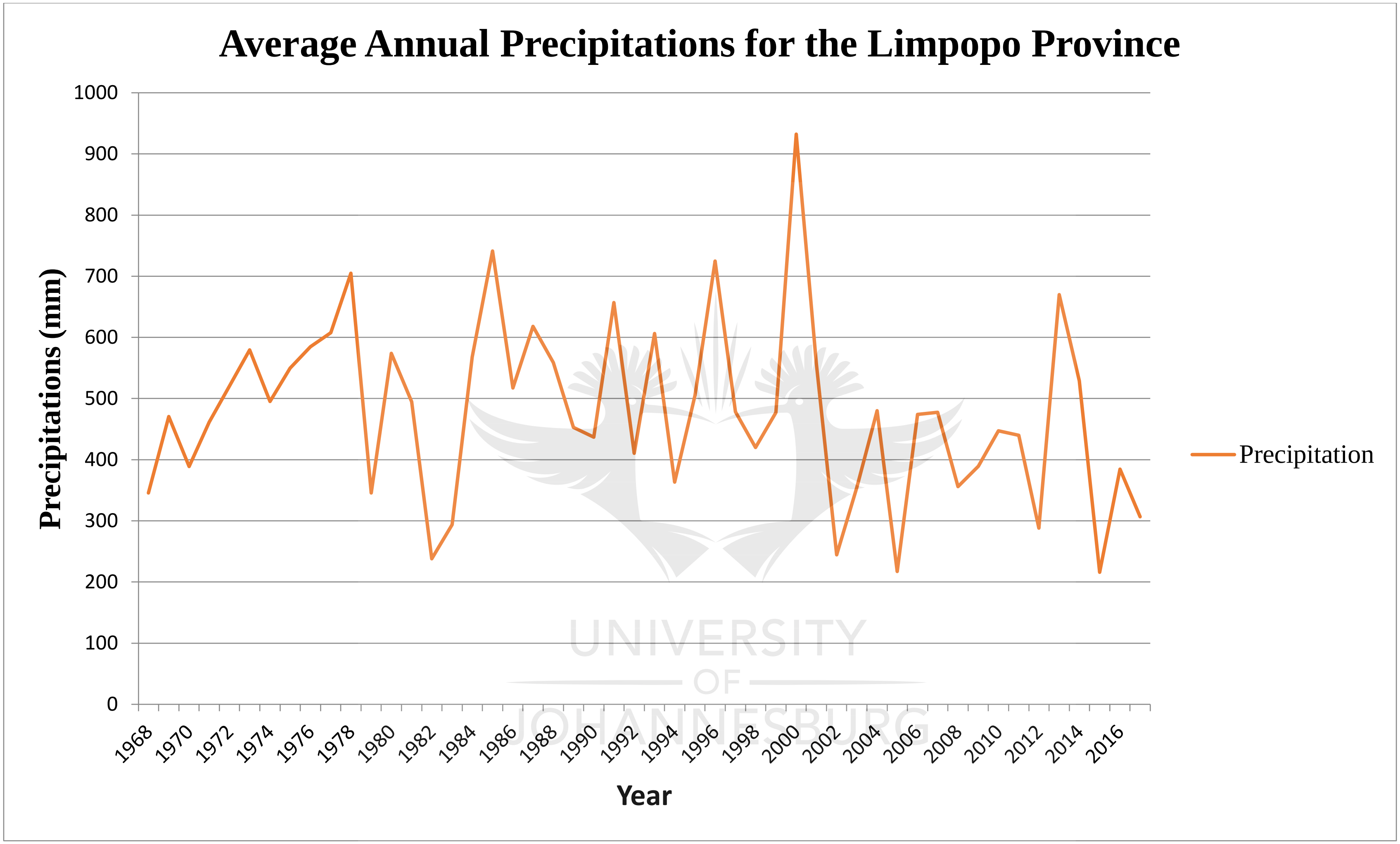


Figure 22; Average Precipitations for the Limpopo Province

4.3.4.3. Implication for livelihoods

The proportions of highly suitable, moderately suitable, marginally suitable and not suitable lands for the cultivation of maize and sorghum implies that local residents should think of new livelihoods, especially those residents who rely on subsistence farming. This also implies that maybe agriculture should be left to corporations that can maximize on the limited available land that is highly suitable for agriculture in order to ensure food security in the area, while local residents are encouraged to develop new skills other than farming.

It is worth considering the urgent need to develop these new livelihoods especially when considering the reality of increasing migration and its implication in the competition for land that has agricultural development potential. These new livelihoods may include, among other things, the trade of agricultural products not necessarily those that have been produced by local residents but those that have been produced by corporation that may be maximizing on the limited agricultural land that is still highly suitable. The local government should also promote the development of the Information and Communication Technology industry in the area as a sector for new livelihoods.

4.4. Conclusion

In conclusion, this chapter has outlined the results that were obtained from the analysis of the data collected with the objective of answering the main question of this research project, which is: Where are suitable locations for the sustainable cultivation of Maize and Sorghum in the Vhembe District? The chapter also discussed these results in relation to the research objectives that were set in the introductory chapter of this report. It was found that six criteria were identified as necessary for the mapping of suitable locations for the cultivation of Maize and Sorghum. It was also found that the said criteria, namely Soil pH, Soil Structure, Rainfall, Maximum temperature, Minimum temperature and Elevation ranked differently for Maize and Sorghum reason being the difference between growth requirements for the two crops. The chapter further discussed the suitable locations for the cultivation of Maize and Sorghum as expressed in terms of suitability classes; this was done in relation to land ownership in the Vhembe District, the area of the district that is covered by the national park as well as the areas of the district which fall under conservation sites. This led to the finding that highly suitable locations for the cultivation of Maize and Sorghum are limited as compared to the other suitability classes; hence, the chapter also briefly discussed how these findings can inform spatial planning and land use management in the Vhembe District; and what their implications are for policy, climate change and livelihoods.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1. Introduction

This chapter summarizes this research study from the inception to the finishing line. The chapter briefly highlights the various steps that were taken to attain the objectives of the study leading to answering the main research question. This chapter also outlines the strengths and limitations of this study; it, further, provides suggestions for future research in the area and recommendations for stakeholders such as policy makers, spatial and land use planners as well as local residents.

5.2. Summary of study

The present study was undertaken with the objective of determining suitable locations for the cultivation of maize and sorghum in the Vhembe district. In the process of attaining this objective, the following results were obtained as indicative of the progress made at every stage of the study to attain the main objective of the study:

Criteria for mapping suitable locations of the cultivation of maize and sorghum were identified through review of literature on the cultivation of maize and sorghum as well as the review of literature on land suitability analysis for agricultural purposes. The following criteria were identified: Soil pH, Soil structure, Rainfall, Minimum temperature, Maximum temperature, and Elevation.

These criteria were weighted based on the growth requirements of each of the two crops and the weighting was done using the Analytical Hierarchy Process (AHP). The six criteria ranked as follow for the two crops:

Maize: *Soil pH (22.10%), Soil structure (21.97%), Rainfall (20.46%), Elevation (13.08), Minimum temperature (11.47%) and Maximum temperature (10.94%).*

Sorghum: *Soil pH (22.71%), Soil structure (19.88%), Maximum temperature (15.22%), Elevation (14.86%), Minimum temperature (14.85%), and Rainfall (12.99%).*

It was found that criteria weighed differently for maize and sorghum and this is mainly due to the growth requirements of the two crops. For example, *Rainfall* weighed 20.46% for maize but the same criterion weighed 12.99% for sorghum. The difference in the two weights is explained by the fact that maize is a water-intensive crop as compared to sorghum which is a drought-resistant crop.

Once criteria weights had been calculated, these were incorporated in the GIS-MCDA model for mapping suitable locations for the cultivation of maize and sorghum. The ensuing maps revealed the following findings:

Suitability map for Maize: only 15.01% of the whole district was classified as highly suitable for the cultivation of maize, 31.73 % was classified as moderately suitable, 41.01% was classified as moderately suitable and 12.25% was classified as not suitable.

Suitability map for Sorghum: 19.39 % of the whole district was classified as highly suitable for the cultivation of sorghum, 29.45% classified as moderately suitable, 50.54% classified as marginally suitable with only 0.62% classified as not suitable.

These results indicated that a limited portion of the Vhembe district is highly suitable for the cultivation of maize and sorghum. These have implications for policy, climate change, livelihoods and spatial planning and land use management.

Implications for spatial and land use planning: it was determined that the results on suitable locations for the cultivation of maize and sorghum should prompt urban planners to consider the integration of urban agriculture in their spatial vision as expressed in terms of Spatial Development Frameworks (SDFs). It was further determined that the limited availability of suitable land for the cultivation of maize and sorghum in the Vhembe district should compel spatial and land use planners to consider land suitability analysis for other crops as an integral component of the planning process. Furthermore, the results implied that planners should develop local economic development strategies that would benefit areas that are not highly suitable for agricultural activities.

5.3. Summary of objectives

In proposing the current study, the main objective was to determine suitable locations for the cultivation of Maize and Sorghum in the Vhembe District. The attainment of this objective required the identification of sub-objectives namely: To identify criteria for mapping suitable locations for the cultivation of Maize and Sorghum in the Vhembe District, To weigh these criteria using Multi-Criteria Decision Analysis (MCDA) techniques, To develop a GIS-MCDA model for land use mapping of Maize and Sorghum and To determine how the Land Use Suitability mapping can inform sustainable land use planning in the Vhembe District.

5.4. Objectives revisited

5.4.1. Attaining Objective 1: "To identify criteria for mapping suitable locations for the cultivation of Maize and Sorghum in the Vhembe District"

The criteria for mapping suitable locations for the cultivation of Maize and Sorghum in Vhembe District were identified through the review of literature on the planting and growth of these two crops. The following criteria were identified: Soil pH, Soil Structure, Rainfall, Maximum Temperature, Minimum Temperature and Elevation. These criteria were used for mapping both Maize and Sorghum.

5.4.2. Attaining Objective 2: "To weigh these criteria using Multi-Criteria Decision Analysis (MCDA) techniques"

The weighting of these criteria was done by using the Analytical Hierarchy Process (AHP) method which is a Multi-Criteria Decision Analysis technique (refer to Chapter 3 for a more detailed description of the AHP method). As a result of the use of the AHP method, the following criteria weights were obtained for mapping Maize and Sorghum:

Maize: Soil pH (22.10%), Soil Structure (21.97%), Rainfall (20.46%), Elevation (13.08%), Minimum Temperature (11.47%) and Maximum Temperature (10.94%).

Sorghum: Soil pH (22.71%), Soil Structure (19.88%), Maximum Temperature (15.22%), Elevation (14.86%), Minimum Temperature (14.85%), and Rainfall (12.99%).

The consistency of the steps followed in the AHP method for determining the above weights was checked and it was found that the whole process of determining the weights was consistent both for Maize and Sorghum; hence, the weights were used to develop the model for mapping the locations for the cultivation of Maize and Sorghum in terms of the suitability index proposed by the Food and Agriculture Organization of the United Nations.

5.4.3. Attaining Objective 3: "To develop a GIS-MCDA model for land use mapping of Maize and Sorghum"

Once the criteria weights had been determined using the Analytical Hierarchy Process, a model was developed on the ArcGIS Software platform for mapping locations for the cultivation of Maize and Sorghum in terms of suitability classes. The model was developed using the Weighted Linear Combination method and its associated formula:

$$S = \sum W_i X_i$$

Where S is the suitability, W_i is the weight of criteria I, and X_i is the criterion score of criteria I. The Weighted Linear Combination method was used to aggregate the "preference information" as expressed in terms of the criteria weights, which led to the subsequent ranking of land suitability types. Such a ranking was expressed in terms of suitability maps for Maize and Sorghum as outlined in Chapter 4.

5.4.4. Attaining Objective 4: "To determine how the Land Use Suitability mapping can inform sustainable land use planning in the Vhembe District"

It was determined that spatial and land use planner in the Vhembe district should be prompted by the outcome of the analysis to integrate urban agriculture in their spatial vision as expressed in terms of Spatial Development Frameworks in the South African context. Further, it was outlined that the limited availability of highly suitable land for the cultivation of Maize and Sorghum should cause spatial and urban planners to consider land suitability analysis for other crops as an integral component of the whole planning process seeing that the majority of residents in the Vhembe district rely on subsistence farming.

5.4.5. Attaining the Main Objective: "To determine suitable locations for the cultivation of Maize and Sorghum in the Vhembe District"

Once objective 3 had been achieved, automatically the main aim or objective of this study was attained which was to determine suitable locations for the cultivation of Maize and Sorghum in the Vhembe District. The results showed that locations that are highly suitable for the cultivation of Maize are different from locations that are highly suitable for the cultivation of Sorghum; a finding that is justified by the difference in growth requirements in terms of Soil pH, Soil

Structure, Rainfall, Maximum Temperature, Minimum Temperature and Elevation for the two crops.

5.5. Limitations

This study was faced with a number of limitations which can be said to have impacted the extent to which the research objectives have been attained. These limitations can be stated in the following statements:

The data that was collected from the Department of Agriculture, Land Reform and Rural Development and the Agricultural Research Council (ARC) dated from the years 2002-2003. This constitutes a limitation in the sense that the results that were derived from this data do not reflect the current suitability levels of the Vhembe District in relation to the cultivation of Maize and Sorghum. Rather, these results reflect the levels of suitability of the district as of the year 2002-2003. Nevertheless, the results obtained from the analysis of this data are still valid especially when considering that climate change is not merely variations in climatic conditions but a change that has been observed after longer period of time such as 50 years and beyond. Hence, the climatic conditions of the Vhembe District between the years 2002 and 2003 cannot be very different from its current climatic conditions and their resultant geological and topographic conditions.

Only six criteria were considered to analyze the suitability of land in the Vhembe District, namely: Soil Structure, Soil pH, Rainfall, Minimum temperature, Maximum temperature and Elevation; for the cultivation of maize and sorghum. These criteria fall into three categories including climate, physical and chemical properties, as well as topography. Other variables or criteria of other categories such as socio-economic criteria could have been considered. However, this does preclude the validity of the results that were obtained because these results were discussed in light of socio-economic considerations such the livelihood of local residents as well as the implication of these results for policy making and spatial planning and land use management which, in turn, play important roles in influencing the socio-economic environment of an area.

5.6. Suggestions for future research

It is suggested that further study be undertaken to forecast what would be the impact of climate change on the suitability of land for agricultural purposes in the Vhembe District in the long run; would currently not suitable areas become suitable? What kinds of crops are likely to survive the impact of climate change? etc., are among many questions to be answered.

It is further suggested that the livelihood of local residents be integrated into the impact of clime change on the suitability of land for agricultural purposes and in the development of strategies for climate change mitigation strategies in the agriculture industry for the Vhembe District.

Furthermore, future research can also focus on the relationship between the patterns of land use-land cover change and that of land suitability change for agricultural purposes. Meaning that land suitability change should be monitored over a considerable period of time to be able to determine the pattern of change in land suitability and how it relates to land use change and land cover change. Such a study would be beneficial for spatial planning and land use management.

5.7. Recommendation

5.7.1. Recommendation for policy makers and spatial or land use planners

It is recommended that land suitability analysis should form an integral part of policy design and implementation; especially in the context of policies that have a direct influence on how land is used and managed in the area. This also implies that the Spatial Planning and Land Use Management Act, 2013 (SPLUMA) (Act No.16 of 2013) should be implemented in conjunction with outcomes of land suitability analyses. This would contextualize the applicability of the SPLUMA Act and thus, adding specificity to the Act.

Further, based on the proportions of highly suitable, moderately suitable, marginally suitable and not suitable areas both for maize and sorghum as highlighted by the results of this study, it is recommended that the provisions of the National Development Plan (NDP), in relation to agricultural development, be implemented in the country (and especially in the Vhembe District) by giving land suitability analysis a top priority.

Furthermore, it is recommended that land suitability analysis for agricultural purposes form part of the land reform in the country so as to give beneficiaries land that is still suitable for agricultural development.

5.7.2. Recommendation for local residents

Based on the limited availability of highly suitable land for the cultivation of maize and sorghum and considering that cultivating these crops on moderately suitable land would require more financial resources to improve the quality of land, it is proposed that local residents should consider new ways of making a living other than agriculture.

5.8. Final conclusion

In conclusion, this research project has sought to answer the question: "Where are suitable locations for the sustainable cultivation of Maize and Sorghum in the Vhembe District?" This question resulted into the "identification of suitable land in the Vhembe District for the sustainable cultivation of Maize and Sorghum" as being the aim or main objective of the study. Attaining this objective required that other sub-objectives be stated, in this case four sub-objectives were stated including "to identify criteria for mapping suitable locations for the cultivation of Maize and Sorghum in the Vhembe District", "to weigh these criteria using multi-criteria decision analysis (MCDA) techniques", "to develop a GIS-Multicriteria Decision Analysis model for land use mapping of Maize and Sorghum" and "to determine how the land use suitability mapping informs sustainable land use planning in the Vhembe District". Six criteria were identified for mapping suitable locations for the cultivation of maize and sorghum namely, Soil pH, Soil Structure, Rainfall, Maximum temperature, Minimum temperature, and Elevation. These criteria were weighted using the Analytical Hierarchy Process (AHP) method; their respective weights for the cultivation of maize and sorghum were incorporated into the GIS-MCDA model using the Weighted Linear Combination technique which led to the mapping of suitable locations for the cultivation of maize and sorghum. The suitability maps that ensued from the running of the GIS-MCDA model showed that there is limited availability of highly suitable land for the cultivation of maize and sorghum in the Vhembe District, with only 15.01% of the whole district being highly suitable for the cultivation of Maize and only 19.39% being highly suitable for the cultivation of Sorghum. These findings were used to determine how land use suitability mapping could inform sustainable land use planning in the Vhembe District. Thus, all objectives of this study were attained leading to the attainment of the main objective. The study also highlighted some limitations to the findings of the research project while suggesting areas of focus for future endeavors as well as recommendations for policy makers, spatial and land use management planners, and local residents.

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