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Site Suitability Analysis for Bamboo Farming in Nyandarua County

BY

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DECLARATION

I, **Kiama Maurean Ngima**, hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other institution of higher learning.

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Name of student	Signature	Date

This project has been submitted for examination with my approval as university supervisor.

Prof. G.C Mulaku	.....	29th July 2022 ~~June 2022~~
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Turn it in report summary

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Dedication

This thesis is dedicated to my dear family and friends who encouraged and supported me throughout my studies.

Acknowledgements

I would like to express my special thanks to the University of Nairobi for giving me an opportunity to further my studies. To my supervisor Prof. G.C Mulaku for your support, guidance and advice, it is highly appreciated.

Special thanks goes to my family, friends and colleagues who facilitated in the seamless progression of my studies.

All in all, I would like to acknowledge the Almighty God, for His mercy and favor throughout my studies.

Abstract

In both the County Development Plan and County Integrated Development Plan for the year 2021-2022 and 2018-2022 respectively, bamboo farming is one of the flagship projects and is considered as a high value crop.

The agricultural industry is the pillar of Kenya's economy. Farming is the core activity for the rural population in the country. Nevertheless, its productivity has since been affected as a consequence of extreme climatic changes and environmental degradation. As a result, a substantial number of the rural population live in abject poverty. It is thus imperative that environmental resilience and sustainable development projects are adapted to improve livelihoods.

Bamboo is a sustainable cash crop whose potential has not been fully exploited in the country. Its cultivation will offer resilient and a sustainable development approach towards fighting climate change and poverty. This research project aimed to identify potential areas for bamboo farming in Nyandarua County in Kenya.

The main objective of the study was to identify potential Bamboo growing areas in Nyandarua County, Kenya. A Multi-Criteria Decision Making Technique, in conjunction with GIS and Remote Sensing was used to come up with a Site Suitability model. In regards to advice from experts and discussion from available literature review on Bamboo growth requirements, three main variables were determined that is, climate, topography and soil. From the 3 main criteria, 7 sub-criteria were selected that is rainfall, temperature, elevation, land use land cover, soil texture, soil drainage and soil PHAQ. The factors were reclassified according to FAO guidelines into four classes highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N). An Analytical Hierarchical Process (AHP) was conducted to assign weight to each factor. The weights were used to conduct a weighted overlay analysis hence, generating the overall Bamboo farming Site Suitability Map.

Based on the results, Nyandarua County is suitable for the cultivation of Bamboo trees in varying degrees. With the highest percentage being 75.30% which is moderately suitable and 24.54% and 0.16% being highly and marginally suitable. Highly acidic soil and Soil texture are the core constraints that prevent Land in Nyandarua County from being highly suitable.

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List of Abbreviations

GIS	Geographic Information System
AHP	Analytic Hierarchy Process
FAO	Food and Agriculture Organization
USGS	United States Geological Survey
^0C	Degree Celsius
Ha	Hectares
MoALF	The Kenya Ministry of Agriculture, Livestock and Fisheries
CIPD	County Integrated Development Plan
KEFRI	Kenya Forestry Research Institute

CHAPTER 1: INTRODUCTION

1.1 Background

The Anthropocene era has proved to have a huge impact on every ecosystem. An increase in human population has resulted into an unsustainable utilization of available resources. In turn, this has resulted into several interlinked challenges such as climate change and poverty. Like many other African countries, agriculture is the core driver of Kenya's economy. In Nyandarua County, production from farming activities has declined as a result of climate change. The main economic activity in the county is farming of Irish potatoes, timber production and tourism. The human population in the area is rural. It mainly depends on the biogeography ecosystems in the area for livelihood. As a consequence, this has seen deforestation and land degradation occurring in the area, causing climate change and ultimately poverty.

Therefore, a need to implement development projects that will see the rise of the Nyandarua county productivity and income is in order. Bamboo farming is one of the projects that will guarantee resilience and sustainability. That is, adaptability and survival of the current state of the environment and also offering a sustainable feasible development solution.

Bamboo is a sustainable cash crop whose potential can be used in different ways. It is labelled as a cash crop because of the diverse benefits, it has to offer when it is grown as a tree and also processed to produce various products. Bamboo can be consumed as food, it can be used for construction, providing shelter, as a source of income and it helps conserve the environment by preventing soil erosion and deforestation (Government of Kenya, 2019). It is therefore, a crop that can facilitate the achievement of a number of the sustainable development goals. Consequently, it is would be wise to encourage the cultivation of Bamboo trees. The concept is to provide an alternative source of income while at the time conserving the environment. The Kenyan government has mainstreamed the adoption of bamboo farming for sustainable growth and development. According to Kenya Forestry Research Institute[KEFRI], bamboo has potential but is not exploited. The low levels of exploitation are caused by a number of factors, one of them being inadequate research (Government of Kenya, 2019). Subsequently, potential stakeholders are not sensitized on its benefits and where its cultivation is highly viable.

The County Government of Nyandarua used Pareto principle to identify flagship projects that would bring transformative change and in this case 80% revenue (Government of Kenya, 2018), Bamboo was considered as a high value crop and its farming is one of the flagship projects for the year 2018-2022. The initial capital for cultivation of the crop is expensive and the government has partnered with some financial institutions to give out loans.

1.2 Problem Statement

Destruction of natural resources such as forest as a consequence of human activities is rampant in Kenya and other East African countries. In Nyandarua County, forests are being cleared for the sole purpose of human settlement and agriculture. In addition, illegal charcoal production and logging has been taken up (Government of Kenya, 2016). This in turn has resulted into the degradation of the available land and a negative effect of the climatic conditions such as global warming. The region has experienced long and unpredictable seasons of drought and heavy rains hence affecting its domestic economic growth and development (Government of Kenya, 2016). Due to the low agricultural productivity the poverty level in the region has become high. Cultivating of potatoes has been the main economic activity in Nyandarua but it is no longer a reliable source of income for most households.

Poverty has a negative effect on both the rural and urban population. Poverty translates into food insecurity, poor health conditions, poor infrastructure, low levels of literacy and unemployment to mention but a few.

Thus, this research study has used geospatial techniques to determine and map potential sites for growing of bamboo trees in Nyandarua County. This will facilitate the cultivation of bamboo trees with the main aim of fighting climate change and therefore eradicating poverty.

1.3 Objectives

1.3.1 General Objective

The core objective of this research study was to identify suitable areas in Nyandarua County that can support the growth of bamboo trees. This was realized through the following specific objectives:

1.3.2 Specific Objectives

- To identify the different factors that influence the location of potential bamboo farming sites.
- To apply the factors in a multi-criteria weighted overlay to determine potential bamboo sites

1.4 Justification for the Study

According to Climate Risk Profile Nyandarua County, there is a decrease in agricultural productivity owing to the extreme changes in climatic conditions, lack of innovativeness when it comes to technology, poor road networks, lack of financial capabilities to support agricultural products and invasion of pest and diseases (Government of Kenya 2016).

In both the County Development Plan [CDP] for the year 2021-2022 and County Integrated Development Plan [CIDP2] for the year 2018-2022, an allocation of 10 and 4 Kenyan million shillings respectively, has been allocated for Giant Bamboo farming flagship project (Government of Kenya, 2018). In addition, the County Government has partnered with Tower Sacco to issue loans to farmers to facilitate their venturing into Giant Bamboo farming projects ("Business Daily Africa", 2019).

The Business Daily Africa talked to a farmer in Nyandarua who stated that "I tried my hand in dairy farming, kales, cabbages, potatoes, and other horticultural crops, investing all retirement benefits until I was broke. But I have hope in the bamboo; it is now my retirement scheme," ("Business Daily Africa", 2019). He went ahead and confirmed that, "they are lured to the crop farming by contracts guaranteeing a forty-year annual minimum return", ("Business Daily Africa", 2019).

The Kenyan government has encouraged the cultivation of bamboo trees for the purpose of both economic and environmental development and growth.

Kenya imports 60 percent of bamboo product from China meaning there is local ready market for bamboo products that we have not harnessed (“Kenya News Agency", 2019). In an effort to prevent global warming, Kenya is adopting going green activities. Bamboo trees are being replaced with eucalyptus in Nyandarua County because of their short maturity rate, 4 to 5 years (“Business Daily Africa”, 2019). Forest cover is diminishing in the county but the needs for forest cover products are insatiable, Bamboo trees are the best to provide a holistic sustainable livelihood for the people of Nyandarua County.

The results obtained from the research project can be used by the County government to manage, sensitize, advice, motivate and encourage the small scale farmers on cultivation of the Bamboo trees. Agricultural officers and the Forest Service will also be informed on the suitable areas to grow the tree. Both the government and non-governmental institutions can be able to make informed decision on where to set up processing plants for the bamboo after conducting a network analysis

GIS and Remote Sensing will offer a fast, cheap and reliable methodology for identifying suitable sites for Giant Bamboo farming.

1.5 Scope of work

The research study was limited to Nyandarua County. ArcGIS 10.8 and QGIS 3.18 were used in delineating and classifying land for the purpose of determining the most suitable areas for Bamboo cultivation in the region. A Multicriteria suitability analysis using GIS was be carried out, thus, coming up with maps representing suitable areas for cultivation of Bamboo trees.

1.6 Report Organization

The project report contains five chapters. Chapter one gives background of the study, problem statement, objectives of the study, justification of the study, scope of the study and a summary of the project organization. Chapter two entails relevant literature review on bamboo farming, Land Suitability and a case study.Chapter three contains the study area, data sources and tools and methodology that were used to achieve the project’s objectives. Chapter four covers the results of the spatial analysis and a discussion of the findings. Chapter five entails the conclusions of the study, recommendations from the study and lastly suggested areas for further research.

These are followed by a references section, which contains a lists all literature material that was used in the project research.

CHAPTER 2: LITERATURE REVIEW

2.1 Land suitability

Land suitability is a step in the land evaluation process. It is the determination of "the degree of appropriateness of land for certain land use," (Ritung *et al*., 2007). The suitability can be based on the current land, soil and climatic conditions in relation to the growth requirements of the crop of interest. Land suitability analysis entails classification and categorization of a given area of land based on its suitability to specific use. The classes used during classification of land suitability are "highly suitable, moderately suitable and marginally suitable" (Bedawi Ahmed et al., 2016). The land suitability classification, using the guidelines of FAO (1976) is divided "into Order, Class, Sub Class, and Unit. Order is the global land suitability group," (Ritung *et al*., 2007). Highly suitable areas are those areas with negligible limitations to a particular application for a given land use, moderately suitable areas are those areas with limitations which in the cumulative are fairly severe for continued use, marginally suitable areas are those areas with limitations which in the aggregate are severe for continued application of an assumed land use and not suitable as the range of inputs required (Ritung *et al*., 2007).

2.2 Requirements for Bamboo Cultivation

Optimum conditions for the development of bamboos are very imperative as it determines the overall performance. These are climatic, soil and topographical conditions; they include mean annual rainfall in the range of 1200 -3600mm but tolarates 700-4500mm, annual day time temperature range of 16.9^0 C - 20^0 C but can tolarates 15^0 C - 34^0C and relative humidity favoring growth of bamboos is between 75 % and 85 % beyond this range it makes the bamboo to be susceptible to pests and diseases (Ken, 2014). Bamboo Cultivation requires elevation of up to 1200m and thrives in full Sun or in light shade that is areas of space canopy (<10%). In addition, bamboo succeeds in alluvial soils of Ph. 6-6.5 tolerating Ph. 4.5-7.5, (Ken, 2014).

2.3 Management of Natural Vegetation

Over a long period of time there has been over reliance of forest resources mainly timber, ignoring all the other benefits that can accrue from the forest. People would always take care of the forest with the aim of gaining from it economically through the sale of timber giving less

attention to other advantages of forest such as water and soil conservation, carbon sequestration and forest as habitat for both the wild plants and animals (Buckingham, 2014).

With the rise in the appreciation of forest as a complex resource, people are realizing the importance of proper utilization and management of these resources in a more sustainable manner. There has been increasing concern on the need to conserve existing natural forests and even people thinking of a step further to see that there is an increase in forest cover (Government of Kenya, 2019). According to FAO and INBAR, there was an estimate of 35-40 square kilometers all over the world but it had been decreasing continuously (2018).

The world is currently under-going severe environmental challenges which are associated with climate change. These changes have raised concerns and the need for people to reduce deforestation and practice a proper management of forest resources so that they can get the full advantage of the forest such as maintaining stability of the ecosystem. "Forests and trees contribute to reduced water related risks such as floods and droughts and help to prevent desertification and soil salinity," (Government of Kenya, 2019).

Many of the world countries have now become strict on the policies that manage exploitation of natural forests for example banning exploitation of timber from forests. In fact the majority of countries are advising and encouraging their citizens to develop new plantations of forest through agroforestry and afforestation. The concept of community forestry is also on the rise. This means that the benefits of forests should not only aim at benefiting individuals but should also be carried out in such a manner as to benefit the entire society, this implies that the idea of environmental conservation should be met first (Buckingham, 2014).

2.4 Case Study: Integrated Advanced Remote Sensing GIS Study for Bamboo based Livelihood analysis and Rural Development planning in Nhamatanda, Dondo districts of Sofala province, Mozambique

The study is focused on an integrated approach to achieve a sustainable use of forest resources. According to the study, forests are source of livelihood and food security for the rural people. However, the forest cover is slowly diminishing as a result of deforestation and land degradation. The study aimed to establish a pilot model of integrated approach of remote sensing system and GIS and tests its utility in Mozambican context for livelihood development.

Base layers for terrain, climate soil and land use land cover were prepared from available maps. In addition, primary analysis was carried out for soil erosion, agriculture zonation, watershed delineation, stock mapping for bamboo and timber using the information contained in base layers. Output maps were used further for conditional analysis in GIS by giving probabilistic weightage and field data inputs (Kumar *et al*., n.d.).

To meet specified criteria e.g. suitable locations for bamboo nursery, plantations, ANR and industry setup for active carbon plant, gasifier plant and charcoal plant based on availability and distribution of bamboo and timber resources, site suitability analysis are carried out for forest and bamboo resource planning(Kumar *et al*., n.d.)

In conclusion, "the use of GIS and remote sensing for such resource based livelihood development not only provides a platform for analyzing various set of conditions based on physical attributes but its capability to query the database is enormously helpful for planners and monitor," (Kumar *et al*., n.d.).

CHAPTER 3: MATERIALS AND METHODS

3.1 Introduction

Chapter three sets out how the research project was executed. It entails the carrying out of the necessary steps and procedures adopted to realize the intended the objectives of this research study. The strategy implemented was the utilization of a Multicriteria site suitability model to come up with site suitability maps for growth of Bamboo trees in Nyandarua County.

3.2 Study Area

The study area is Nyandarua County and it is geographically located in latitude 0°8' North and 0°50' South and between Longitude 35° 13' East and 36°42' East (Government Kenya, 2018). The county headquarters is in Ol Kalou. The County covers an area of 3268 km^2 and a has population of 638,289 (Government of Kenya, 2019). In the County Government Integrated Development Plan, it is stated that, "The major economic activities in the County include farming, quarrying and trade. Agriculture is the backbone of Nyandarua's economy due to the fertile soils and favourable climate," (Government of Kenya, 2018). It is considered the food basket of Kenya because of its high production of potatoes, cabbages, carrots, peas and milk that are sold in Nairobi and most other towns in the country. "The County is an aspiring member of the Mt Kenya and Aberdare Regional Economic Bloc being considered," (Government of Kenya, 2018). Figure 3.1 shows the map of Nyandarua County.

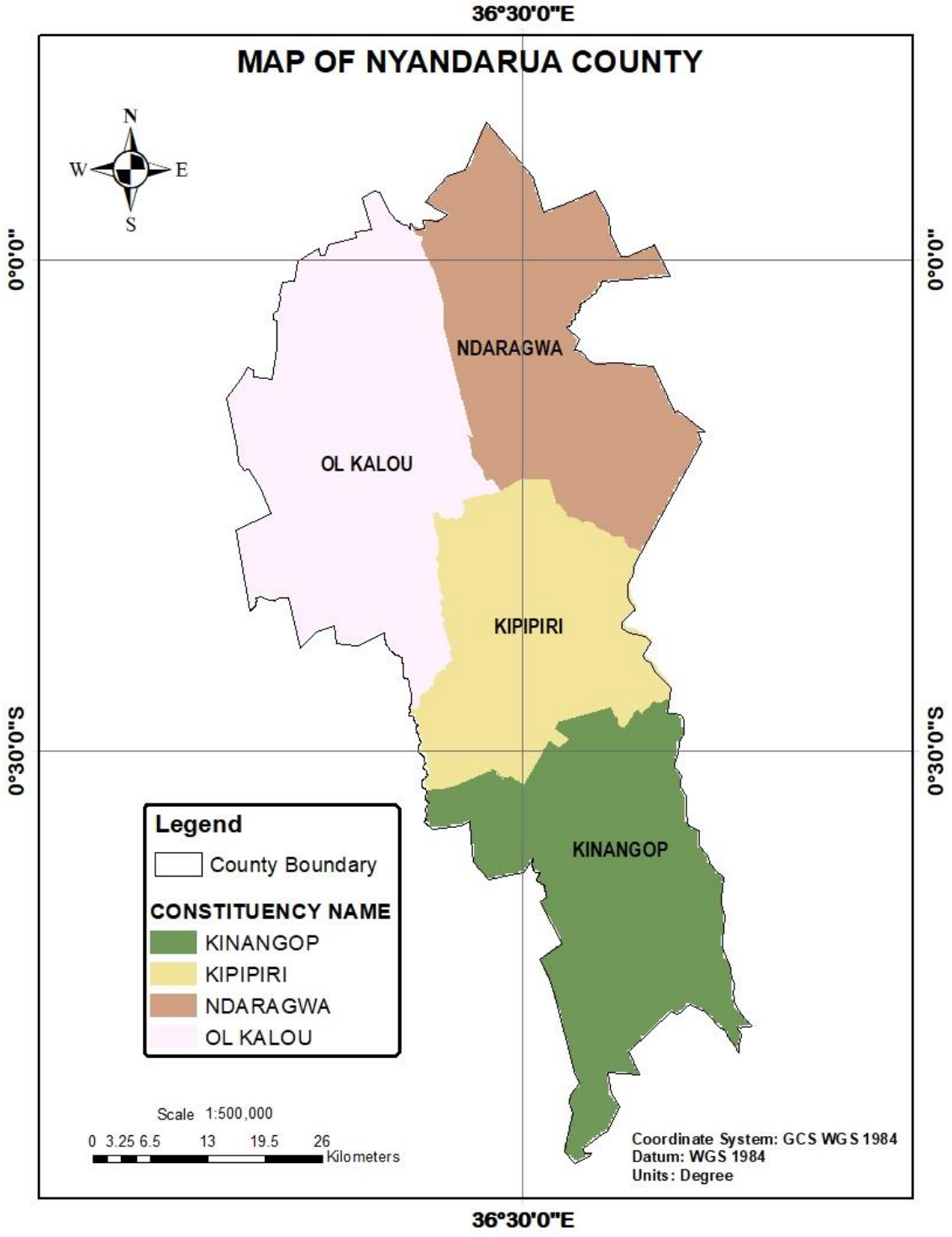

Figure 3.1 Nyandarua County Map

3.3 Data Sources

Table 3.1: Data types and sources

Data	Type/Format	Source
Kenya Sentinel 2	Raster	Regional Centre for Mapping of Resources for Development
Rainfall Data	Vector	Kenya Meteorological Department
Temperature Data	Raster	Kenya Meteorological Department
Elevation Data	Raster	USGS Portal
Soil Data	Vector	Kenya Agricultural and Livestock Research Organization (KALRO)
Kenya Administration Data	Vector	Independent Electoral and Boundaries Commission. (IEBC)

3.4 Tools

The following were the hardware and software used during the spatial analysis.

3.4.1 Hardware

- HP probook laptop, Intel Core i7, running Windows 10, 64-bit.

3.4.2 Software

- Esri ArcGIS 10.8 was the Geographic Information Systems Software used for managing, analyzing, visualizing and mapping the spatial data.
- Microsoft office 2016 was used as follows:
    - Microsoft Word to document the project.
    - Microsoft Excel to calculate the weights of the criteria.
    - Microsoft PowerPoint 2016 for presentations of results and findings.

3.5 Methodology

3.5.1 Research Methodology Flow Chart

Figure 3.2 shows the methodology that was used to carry out the project.

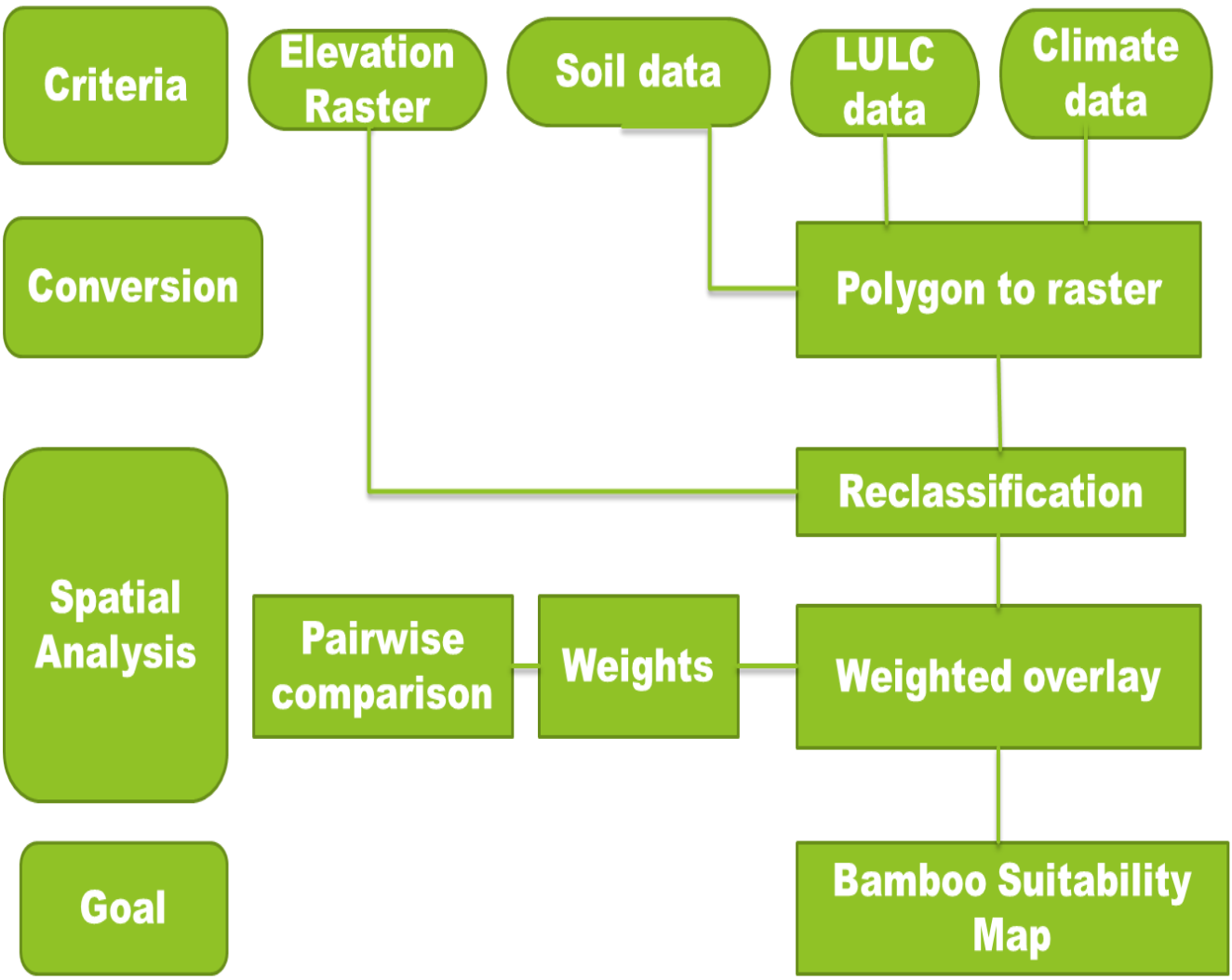

Figure 3.2 Methodology Flow Chart

3.6 Determination of the Evaluation Criteria

With the guidance and reference from agricultural experts and available literature review, three main criteria were used to determine the most suitable areas in Nyandarua County for the cultivation of bamboo. That is, climate, soil and topography and seven sub-criteria namely: rainfall, temperature, land use land cover, soil texture, soil ph., soil drainage and elevation.

3.6.1 Climate

Climate is the most critical requirement for the successful growth of Bamboo trees. Successful development of bamboo is highly dependent on the optimal conditions of both rainfall and temperature.

a. Rainfall

Rainfall is the most vital factor in the development of bamboo trees. That is, despite having optimal conditions for all other factors and rainfall is inadequate, the growth of bamboo is negatively affected. In Nyandarua County rainfall ranges from a minimum of 691 mm to a maximum of 2015 mm per annum. Figure 3.3 shows the rainfall distribution map for Nyandarua County.

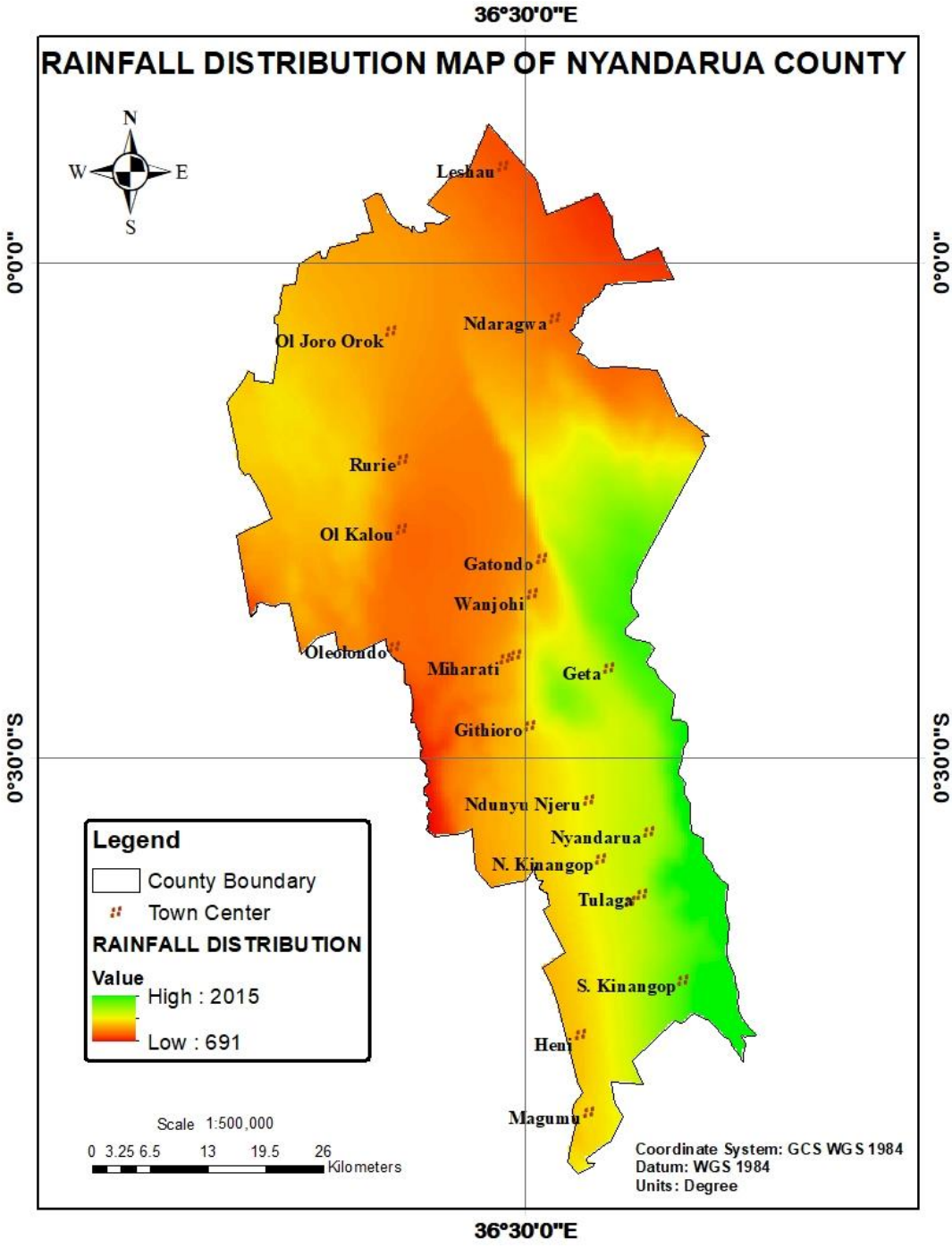

Figure 3.3 Rainfall Distribution Map

b. Temperature

The temperatures in Nyandarua County range from a minimum of 16.65°C to a maximum of 18.02°C. The coldest areas are in parts of Ol kalou, Kipipiri and Kinangop Constituencies while the hottest is Ndaragwa Constituency. Figure 3.4 shows temperature distribution in Nyandarua County.

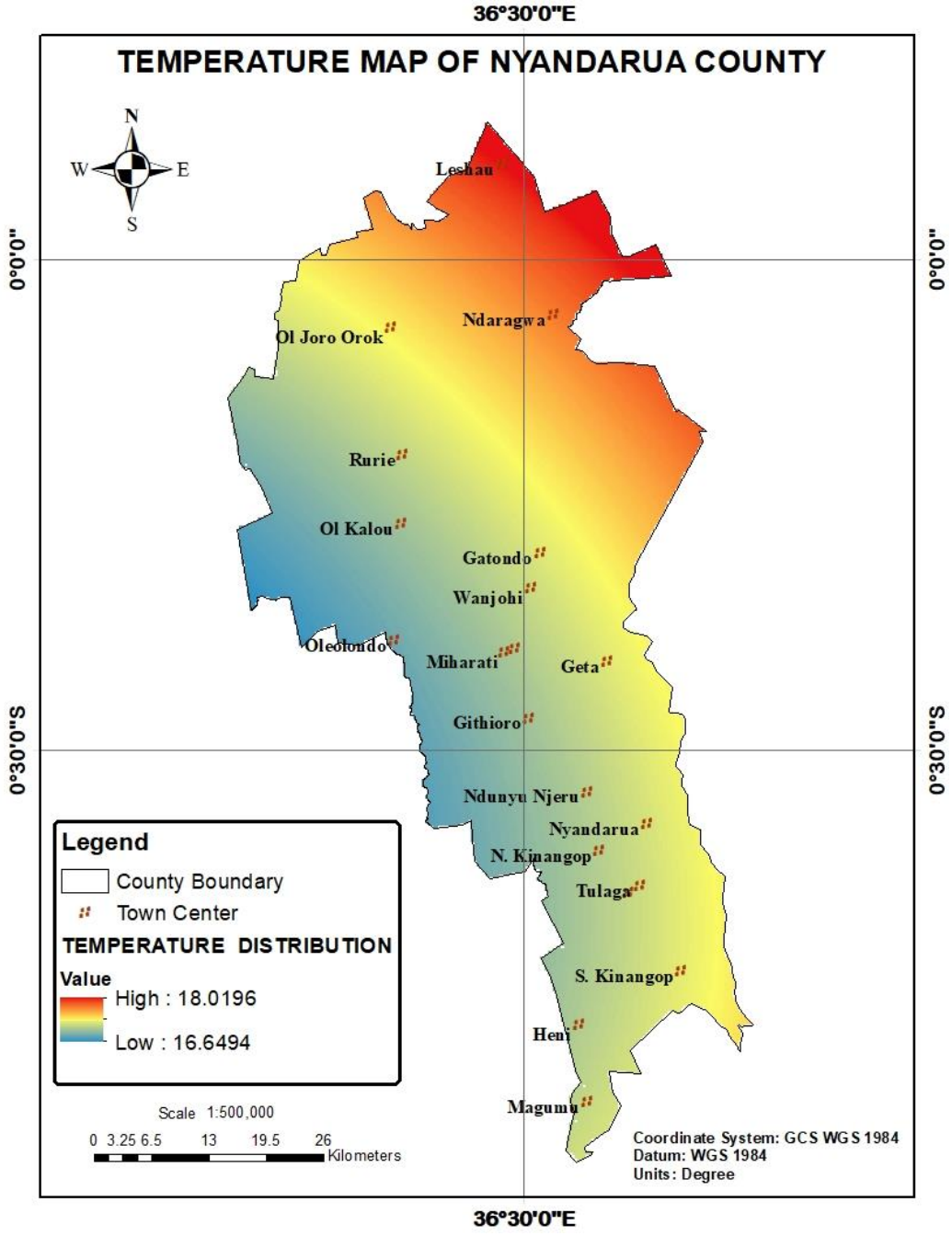

Figure 3.4 Temperature Distribution Map

3.6.2 Topography

Nyandarua County is comprised of both plateaus and hilly terrain.

a. Elevation

Nyandarua County altitude varies from 1910 m to 3961 m above sea level. The lowest areas are parts of Kinangop and Ol kalou where there are plateaus and the highest areas are at the Aberdare Ranges, which is in some parts of Ndaragwa, Kipipiri and Kinangop constituencies. Figure 3.5 shows an elevation map of Nyandarua County.

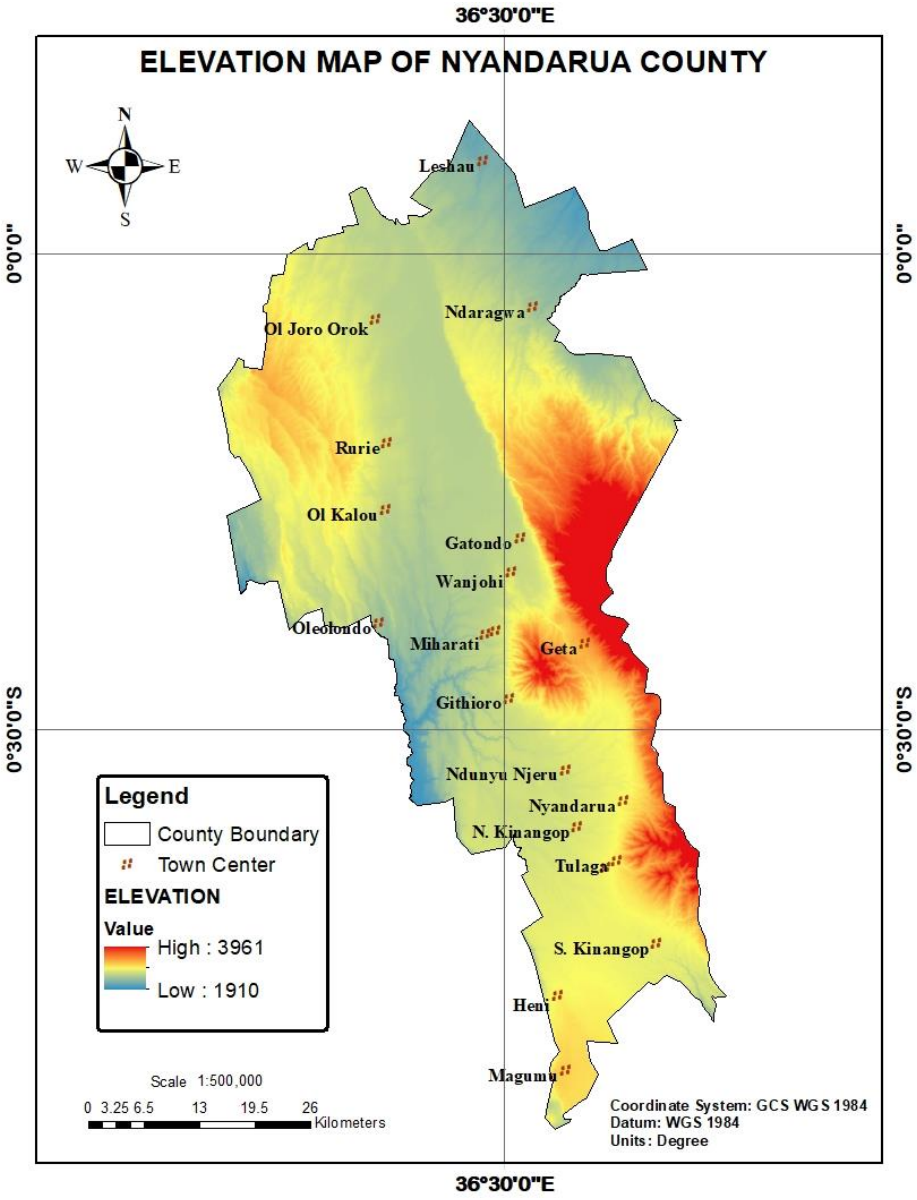

Figure 3.5 Elevation Map.

3.6.3 Soil

The different aspects of soil such as soil drainage, land use land cover, soil PHAQ, and soil texture are imperative determinants of the successful cultivation of bamboo trees.

a. Soil Drainage

Most of Nyandarua County is covered by well-drained soil. Figure 3.6 shows soil drainage map of Nyandarua County.

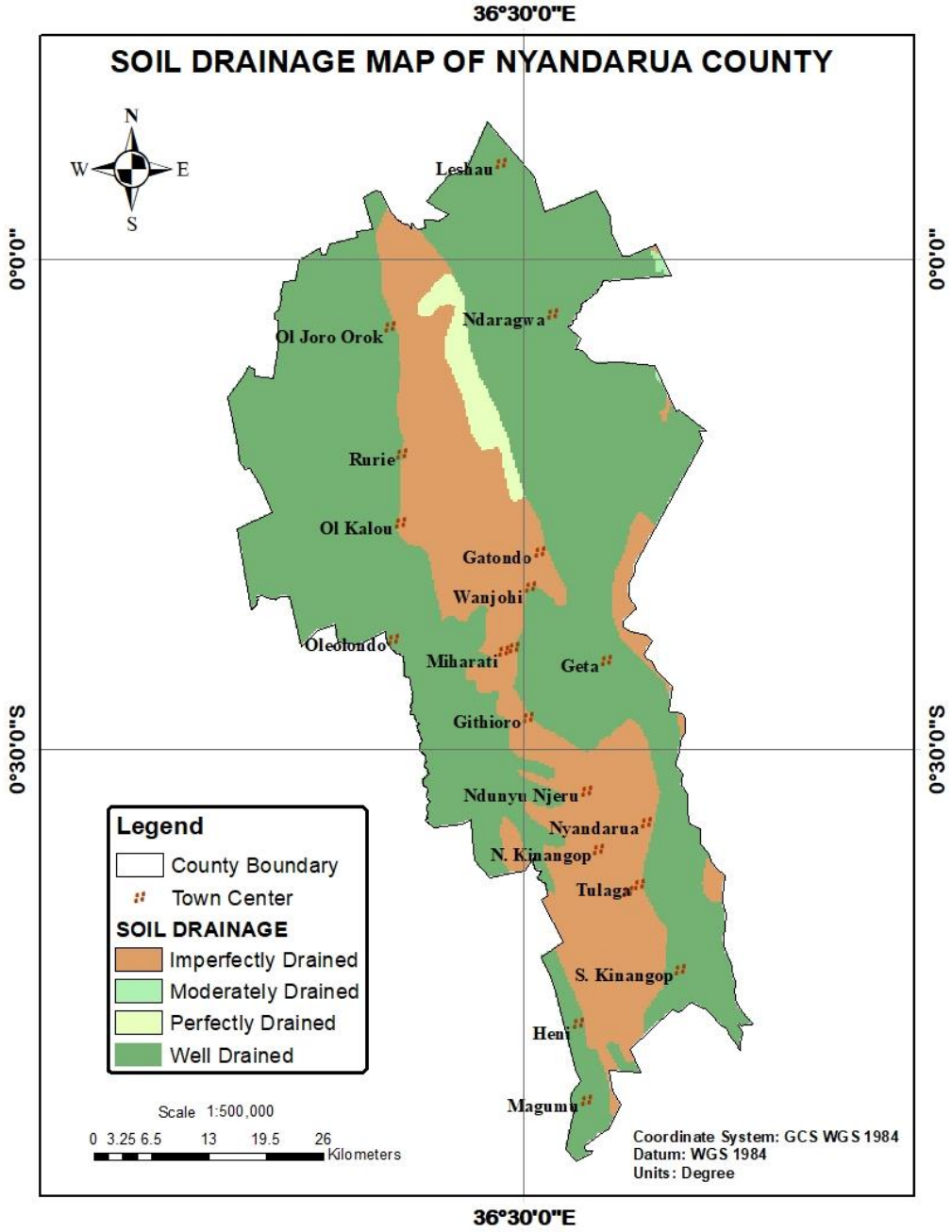

Figure 3.6 Soil Drainage Map.

b. Soil Texture

The soil texture or soil type in Nyandarua County is loamy, sand, clayey and very clayey. Figure 3.7 shows a Map of Soil Texture in Nyandarua County.

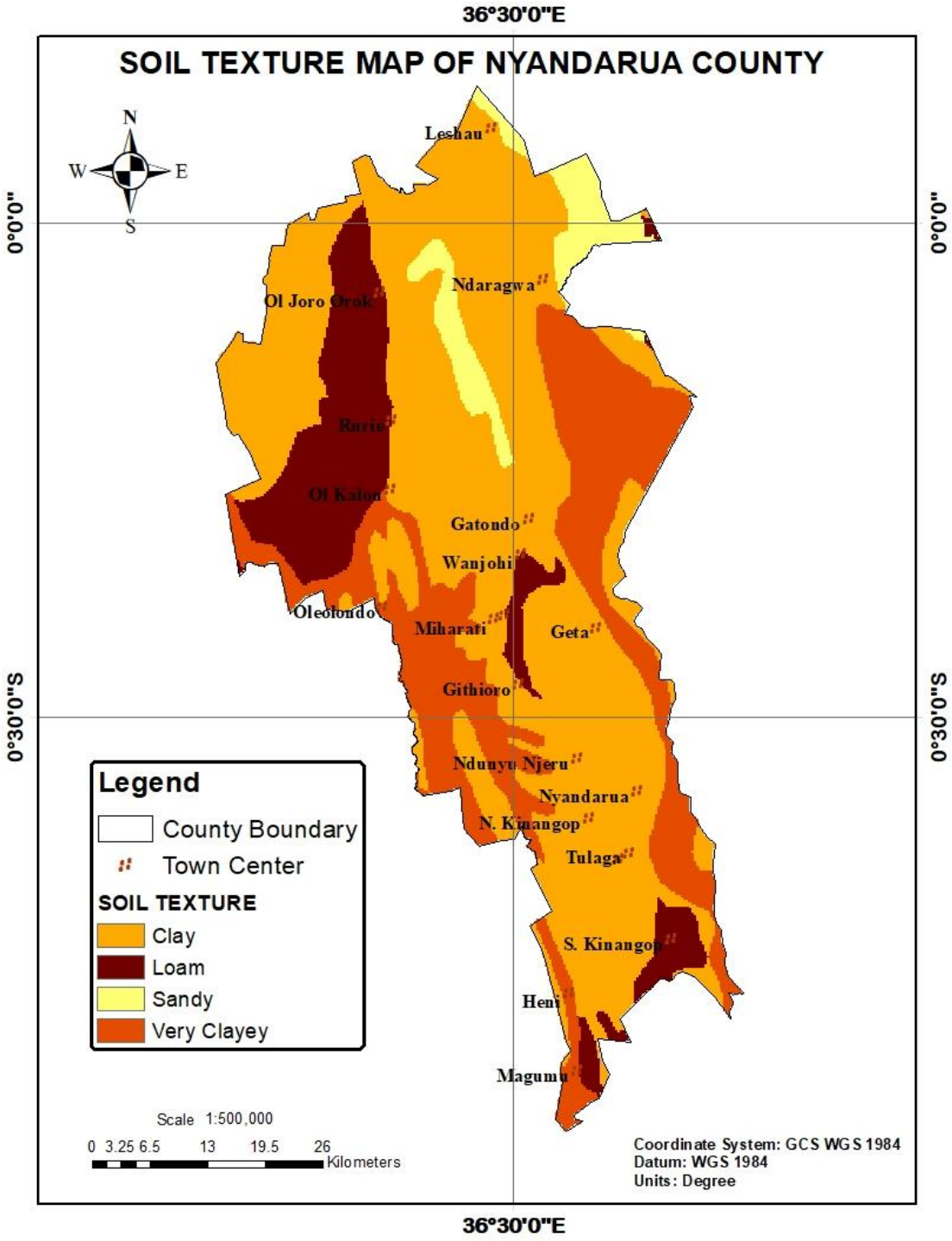

Figure 3.7 Soil Texture Map

c. Soil PHAQ

Nyandarua Soil PHAQ ranges from 0 - 6.7 ph. Below is a Map of Nyandarua County Soil PHAQ. Most of the land in the county is covered by acidic soil. Figure 3.8 shows a Map of soil ph. in Nyandarua County.

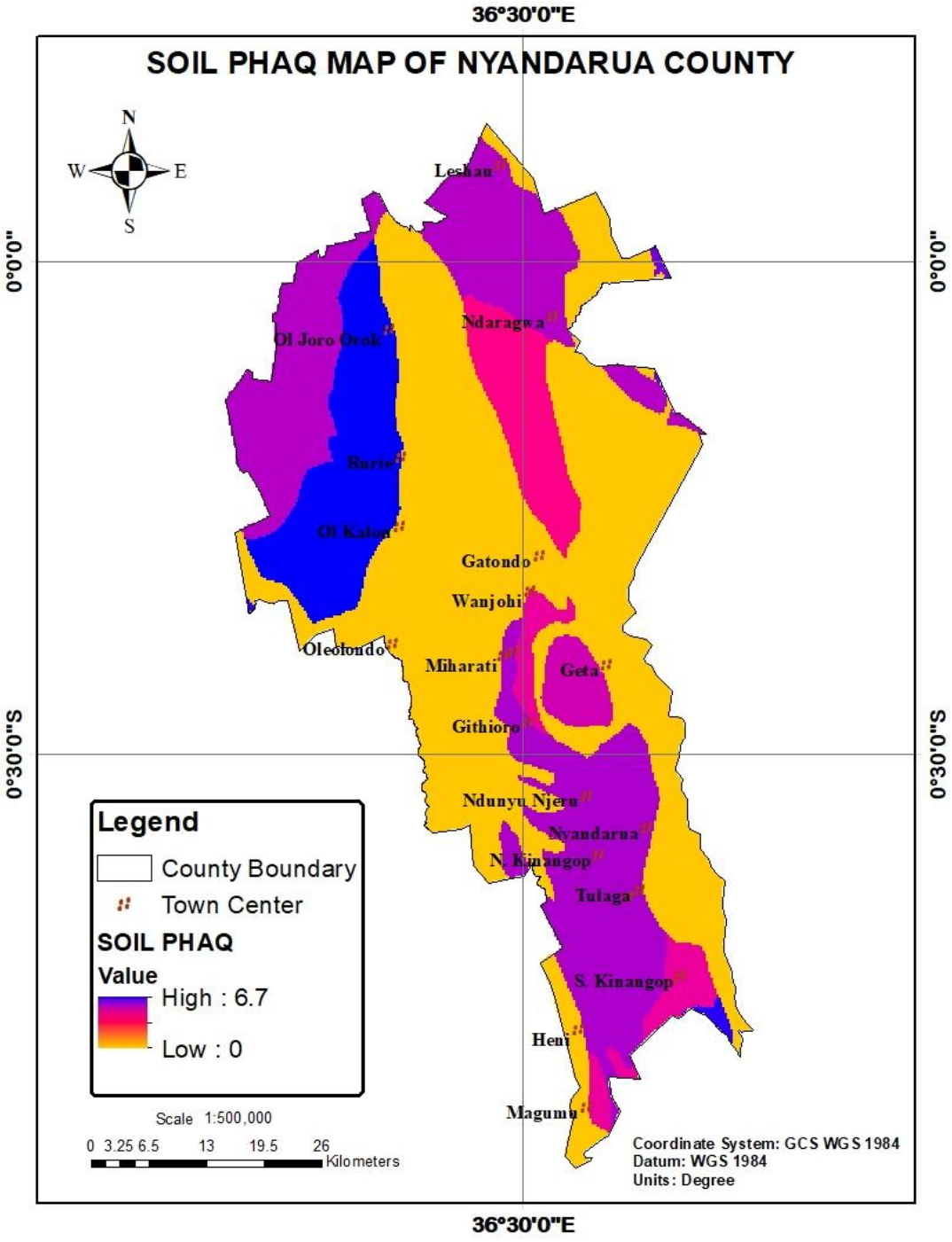

Figure 3.8 Soil PHAQ

d. Land Use Land Cover

The land use land cover for Nyandarua County is mostly agricultural land and forest cover. In addition, there is a bit of barren land. Figure 3.9 shows a Map of Land Use Land Cover in Nyandarua County.

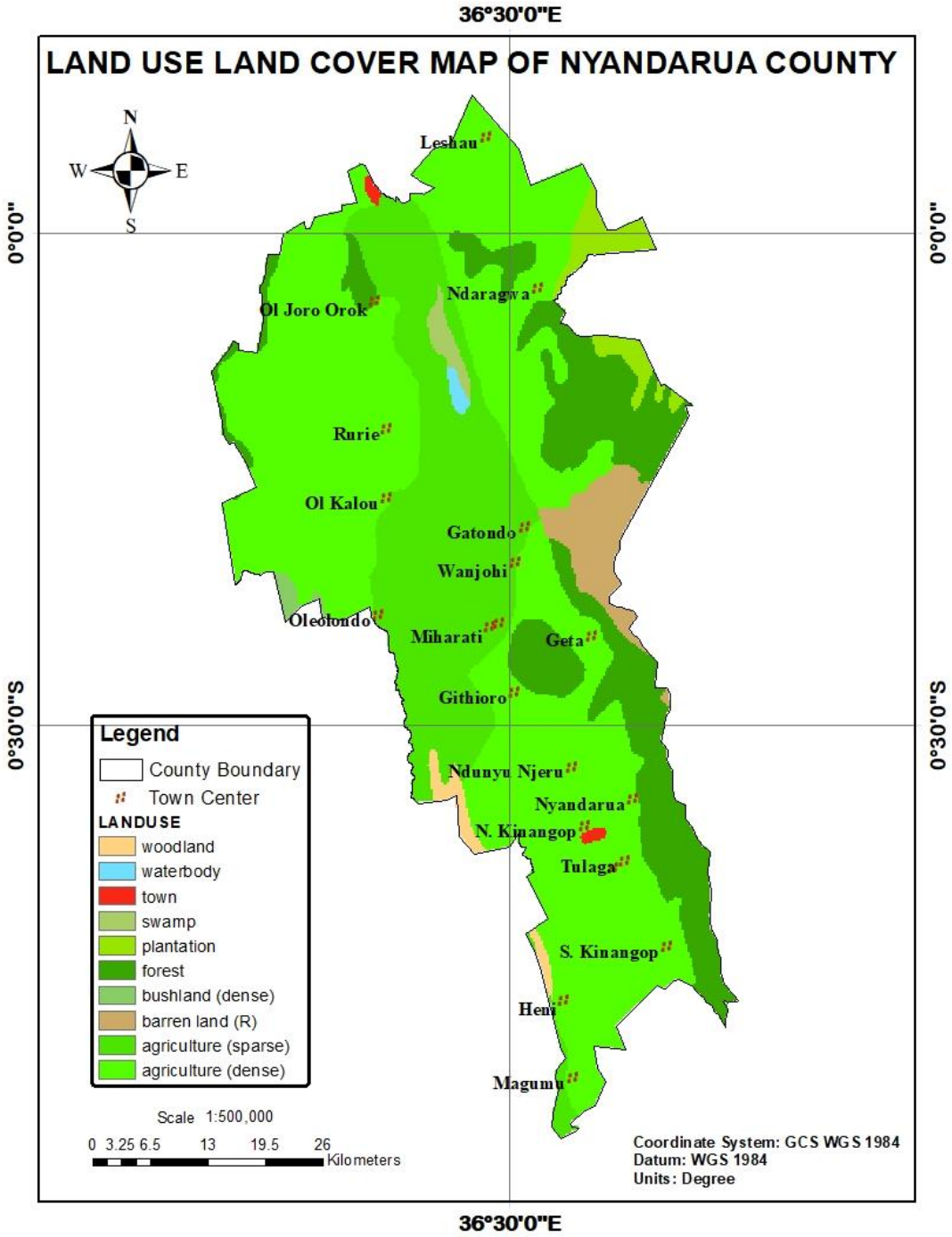

Figure 3.9 Land Use Land Cover Map

3.7 Data Analysis

3.7.1 Analytical Hierarchical Process

The suitability of a certain land use is determined by a number of different factors or criteria. To determine the importance of each factor compared to others an Analytic Hierarchy Process(AHP) is employed. AHP was introduced by Saaty (1977), "with the basic assumption that comparison of two elements is derived from their real-time importance", (Baniya, 2008). All relevant criteria are compared against each other in a pair-wise comparison matrix to give weights to each factor. Weights in this case is the relevance of each factor (Lupia, 2014). The Analytic Hierarchy Process consists of three main steps: selection of determination factors, pairwise comparison of the factors and generation of weights (Bello *et al*., 2009).

3.7.2 Development of A Pairwise Comparison Matrix

A pair wise comparison matrix was developed with reference from expert opinion and previous research done (Table 3.3). Saaty's scale having a range of 1-9 was used in the determination of the weights of the factors, (Saaty, 1977). Table 3.2 shows the scale of relative importance between two factors.

Table 3.2 Scale of Relative Importance Between Two Elements

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective.
3	Somewhat more important	Experience and judgement slightly favour one over the other.
5	Much more important	Experience and judgement strongly favour one over the other.
7	Very much more important	Experience and judgement very strongly favour one over the other. Its importance is demonstrated in practice
9	Absolutely more important	The evidence favouring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed

Source: Atthirawong and MacCarthy (2002) and Saaty (2000)

Table 3.3 Pairwise comparison amongst the seven sub-criteria

	Temperature	Rain	Elevation	LULC	Soil Type	Soil PHAQ	Soil Drainage	Weights	Percentage
Temperature	0.15	0.11	0.17	0.23	0.19	0.20	0.38	0.20	20.22
Rainfall	0.62	0.42	0.29	0.30	0.33	0.27	0.38	0.37	37.16
Elevation	0.04	0.06	0.04	0.02	0.02	0.03	0.03	0.04	3.54
LULC	0.05	0.11	0.17	0.08	0.09	0.13	0.03	0.09	9.40
Soil Type	0.04	0.06	0.08	0.04	0.05	0.02	0.03	0.05	4.57
Soil PHAQ	0.05	0.11	0.08	0.04	0.14	0.07	0.03	0.07	7.37
Soil Drainage	0.05	0.14	0.17	0.30	0.19	0.27	0.13	0.18	17.73
Totals	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**		

During the ranking, inconsistencies were checked to ensure the consistency ratio (CR) was less than 10% according to Atthirawong and MacCarthy (2002). The CR was obtained by working with the Consistency Index (CI) and the Random Consistency Index (RCI).

$$CI = (\lambda \text{ max} - n) / (n - 1) \qquad \textbf{Equation 3.1}$$

$$CR = CI / RI \qquad \textbf{Equation 3.2}$$

Where:

CI = Consistency Index

λ = the maximum Eigen value;

n = number of factors being compared;

CR = Consistency Ratio

RI = Random Consistency Index (RI) which depend on the number of elements being compared, as shown below.

Table 3.4 Random Inconsistency Indices

n	1	2	3	4	5	6	7	8	1
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45

Source: Saaty (2000)

The Consistency Ratio was 9.9 % which was good.

3.7.3 Assigning of weights of Factors

Based on FAO guidelines on land suitability categories the data of the seven sub criteria was divided into four classes that is: Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable(S3) and Not Suitable (N). After the pairwise comparison the weight of each factor was obtained. Table 3.5 shows the seven sub criteria categorized into four classes together with their assigned weights.

Table 3.5 Bamboo Suitability Table and Assigned Weights

Criteria	S1	S2	S3	N	Weights
Rainfall	2015-1200mm	1200-900mm	900-700mm	700-691mm	37.16%
Temperature	18.02-16.9°C	16.9-16.7°C	16.7-16.64°C	<16.64°C	20.22%
Elevation	1910-2427m	2427-2732m	2732-3179m	3179-3961m	3.54%
Land Use /Land Cover	Forest Land, Barren land, woodland, Bushland	Agriculture (dense), Agriculture(Sparse)	Plantation	Town, Waterbody, Swamp	9.40%
Soil Drainage	Perfectly Drained, Well Drained	Moderately Drained	Imperfectly Drained	-	17.73%
Soil PHAQ	6.7-6	6-4.5	4.5-2.5	<2.5	7.37%
Soil Texture	Loamy, Sandy	Clayey	Very Clayey	-	4.57%

3.7.4 Conducting A Weighted Overlay Analysis

All the variable layers had already been developed to allow for the processing of the data on ArcMap 10.8. The factor layers were converted to raster layers and reclassified to class 4, 3, 2, 1 to represent, Highly (S1), Moderately (S2), Marginally (S3) and Not suitable (N) classes. The reclassification allowed for a weighted overlay analysis to be conducted over ArcMap 10.8. The percentage stake obtained was used in the weighting. A weighted overlay analysis was conducted which resulted into a Suitability Map for Bamboo Farming in Nyandarua County.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter gives the results of the spatial analysis. It entails the spatial variation of each factor as per the suitability classes and the final site suitability map for Bamboo farming in Nyandarua County.

4.2 Climate

The outcome of the spatial variation of temperature and rainfall are discussed below.

4.2.1 Rainfall Spatial Variation

In regards to rainfall, a large percentage of Nyandarua County is suitable for bamboo farming. With 27.01% being highly suitable, 53.70% moderately suitable, 19.22% marginally suitable and 0.061% not suitable shown in Table 4.1. Figure 4.1 shows the rainfall suitability map of Nyandarua County.

Table 4.1 Spatial Variation of Reclassified Rainfall

Suitability Class	Rainfall	Area (Ha)	Percentage
S1	2015-1200mm	88,514.012	27.01%
S2	1200-900mm	175,992.876	53.70%
S3	900-700mm	63,009.782	19.22%
N	700-691mm	200.791	0.06%

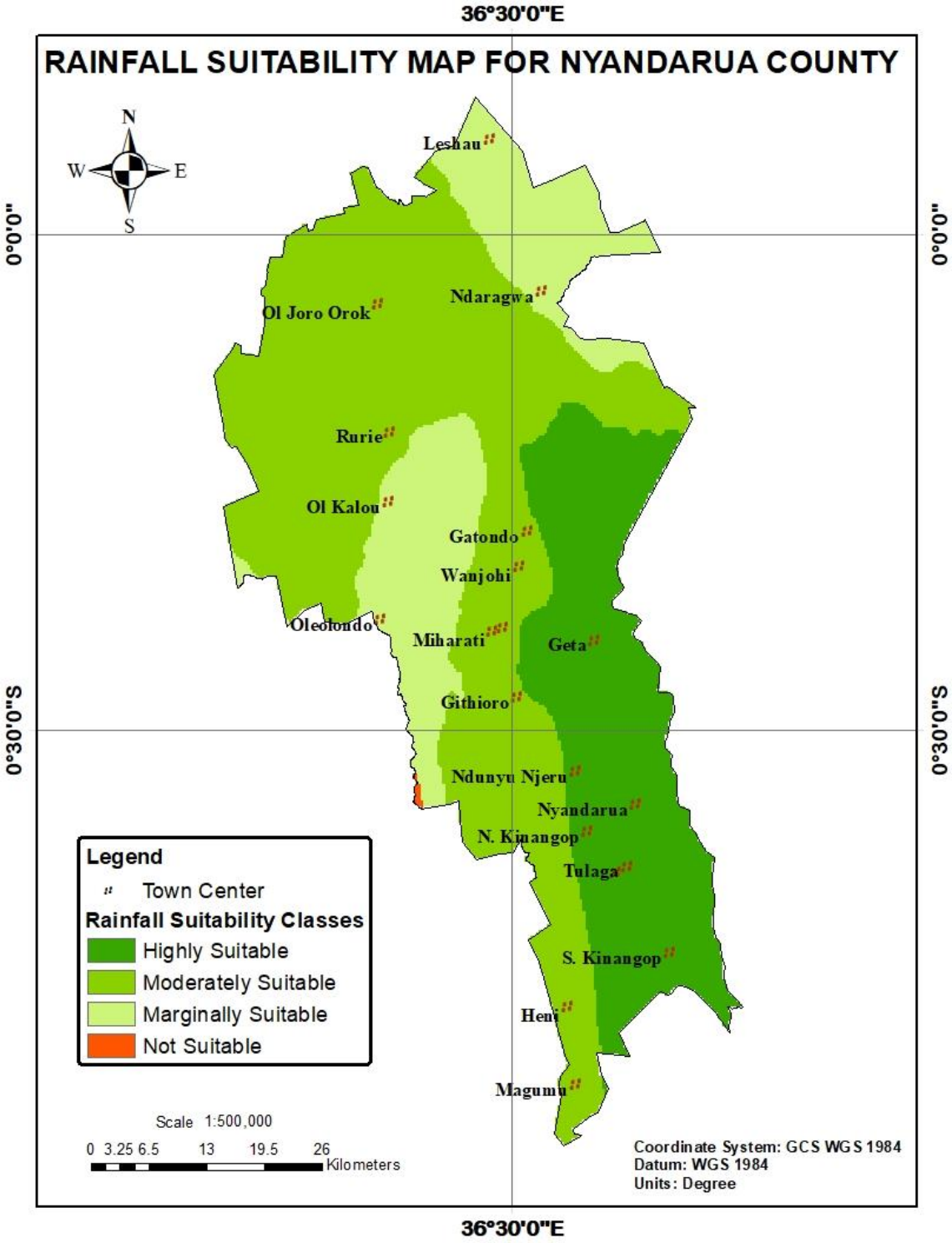

Figure 4.1 Rainfall Suitability Map of Nyandarua County

4.2.2 Temperature Spatial Variation

The reclassified temperature map shows that 84.64% of Nyandarua County has highly suitable temperature for growth of Bamboo farming .Table 4.2 and Figure 4.2 shows the spatial variation of reclassified temperature and temperature suitability map for Nyandarua County respectively.

Table 4.2 Spatial Variation of Reclassified Temperature

Suitability Class	Temperature	Area (Ha)	Percentage
S1	18.0196 – 16.9°C	277,355.072	84.64%
S2	16.9-16.7°C	48,845.760	14.91%
S3	16.7-16.64°C	1,472.010	0.45%
N	<16.64°C	6.090	0.002%

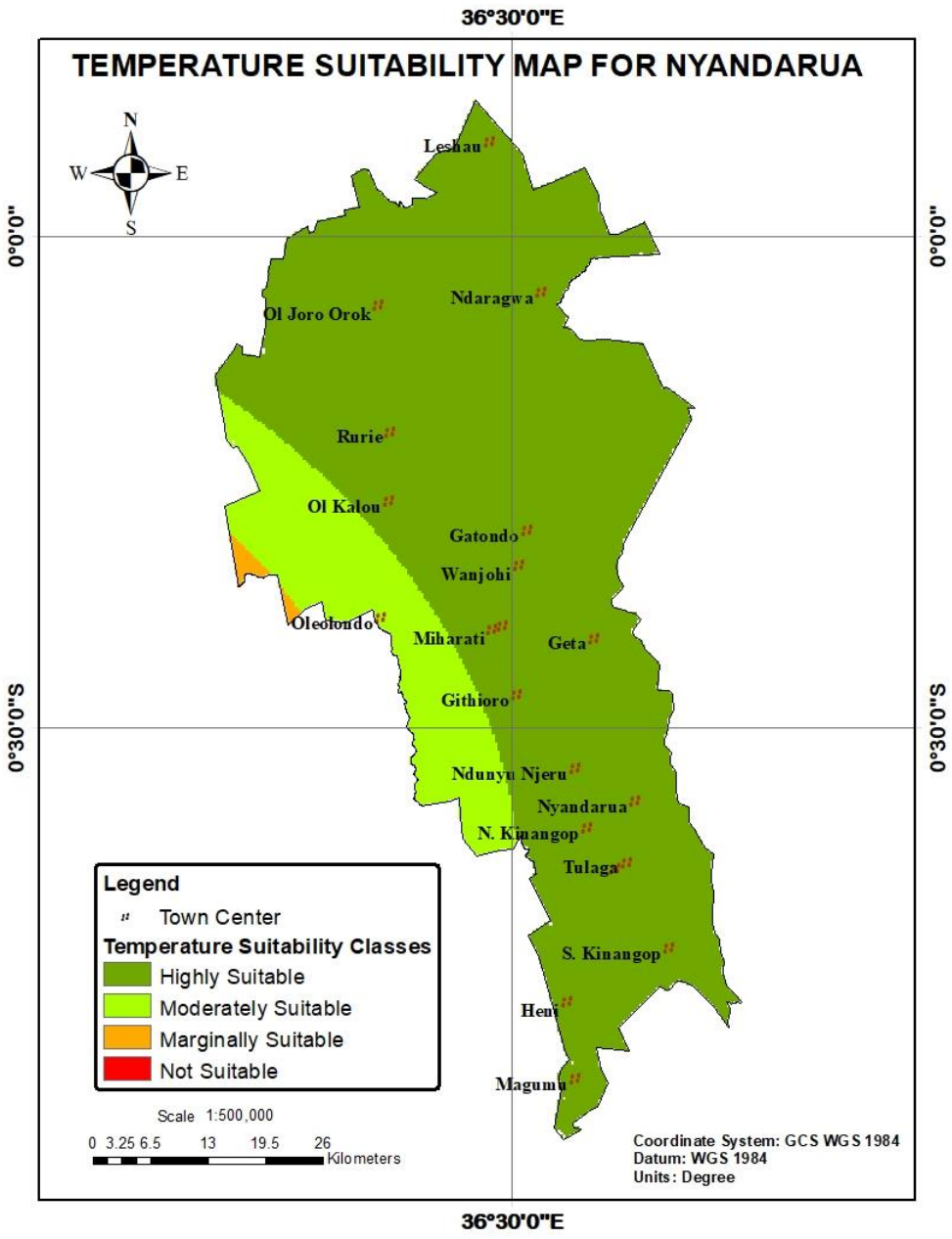

Figure 4.2 Temperature Suitability Map of Nyandarua County

4.3 Topography

4.3.1 Elevation Spatial Variation

The reclassified map shows that the highest percentage of the area 42.72% is highly suitable for bamboo farming with moderate, marginal and not suitable taking 41.28%, 11.49% and 4.52%,

respectively. Table 4.3 and Figure 4.3 shows the spatial variation of reclassified elevation and elevation suitability map for Nyandarua County respectively.

Table 4.3 Spatial Variation of Reclassified Elevation

Suitability Class	Elevation	Area (Ha)	Percentage
S1	1910-2427m	139,997.878	42.72%
S2	2427-2732m	135,279.596	41.29%
S3	2732-3179m	376,39.598	11.46%
N	3179-3961m	14,811.070	4.52%

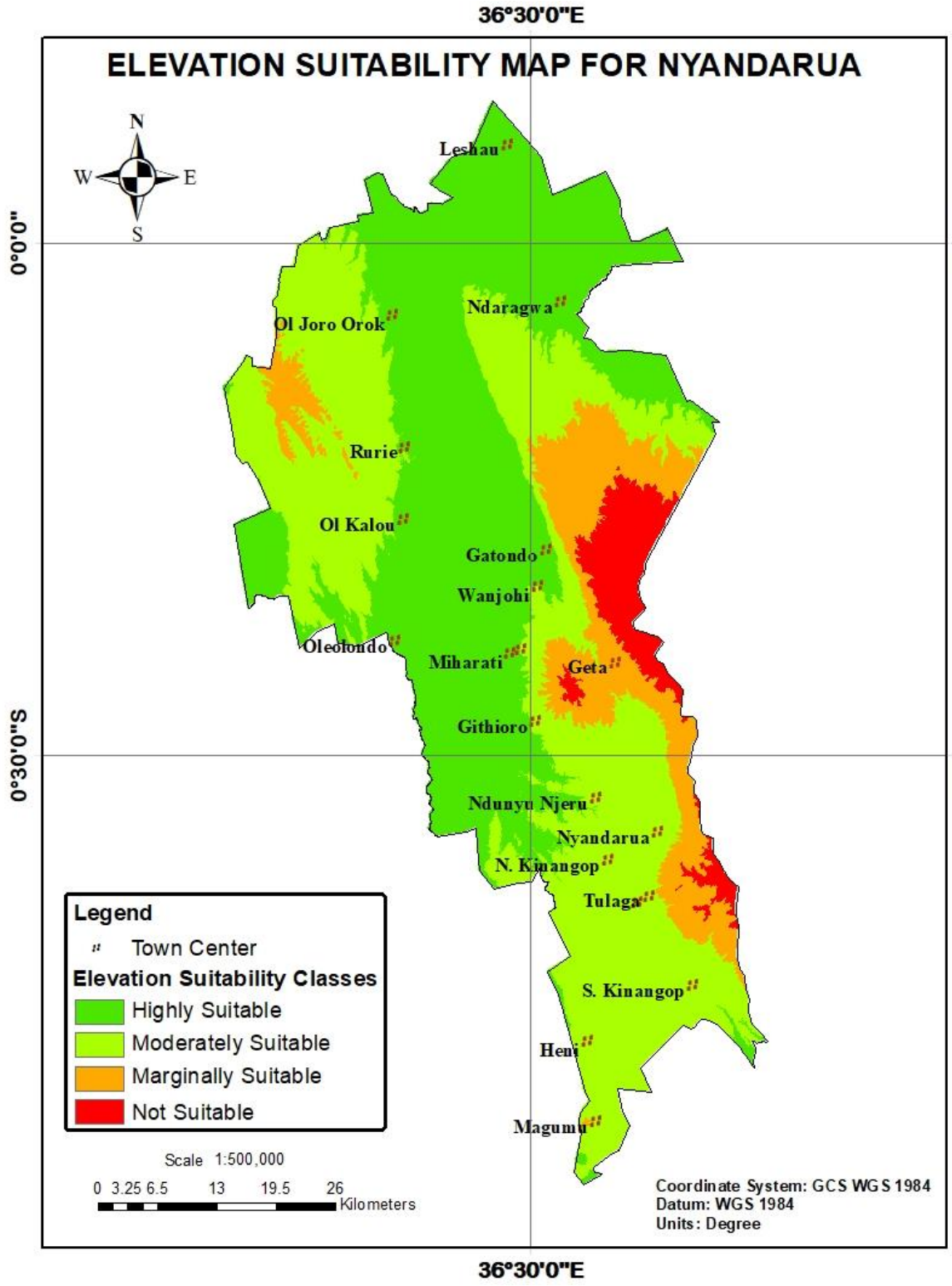

Figure 4.3 Elevation Suitability Map of Nyandarua County

4.4 Soil

4.4.1 Land Use Land Cover Spatial Variation

The reclassified map shows that the highest percentage of the county 76.28% is moderately suitable for bamboo farming with highly, marginal and not suitable taking 20.61%, 2.03% and 1.07% respectively. Table 4.4 and Figure 4.4 shows the spatial variation of reclassified land use land cover and land use land cover suitability map for Nyandarua County respectively.

Table 4.4 Spatial Variation of Reclassified Land Use Land Cover

Suitability Class	LULC	Area (Ha)	Percentage
S1	Forest Land, Barren land, woodland, Bushland	67,499.598	20.61%
S2	Agriculture (dense), Agriculture(Sparse)	249,843.314	76.28%
S3	Plantation	6,661.344	2.03%
N	Town, Waterbody, Swamp	3,516.793	1.07%

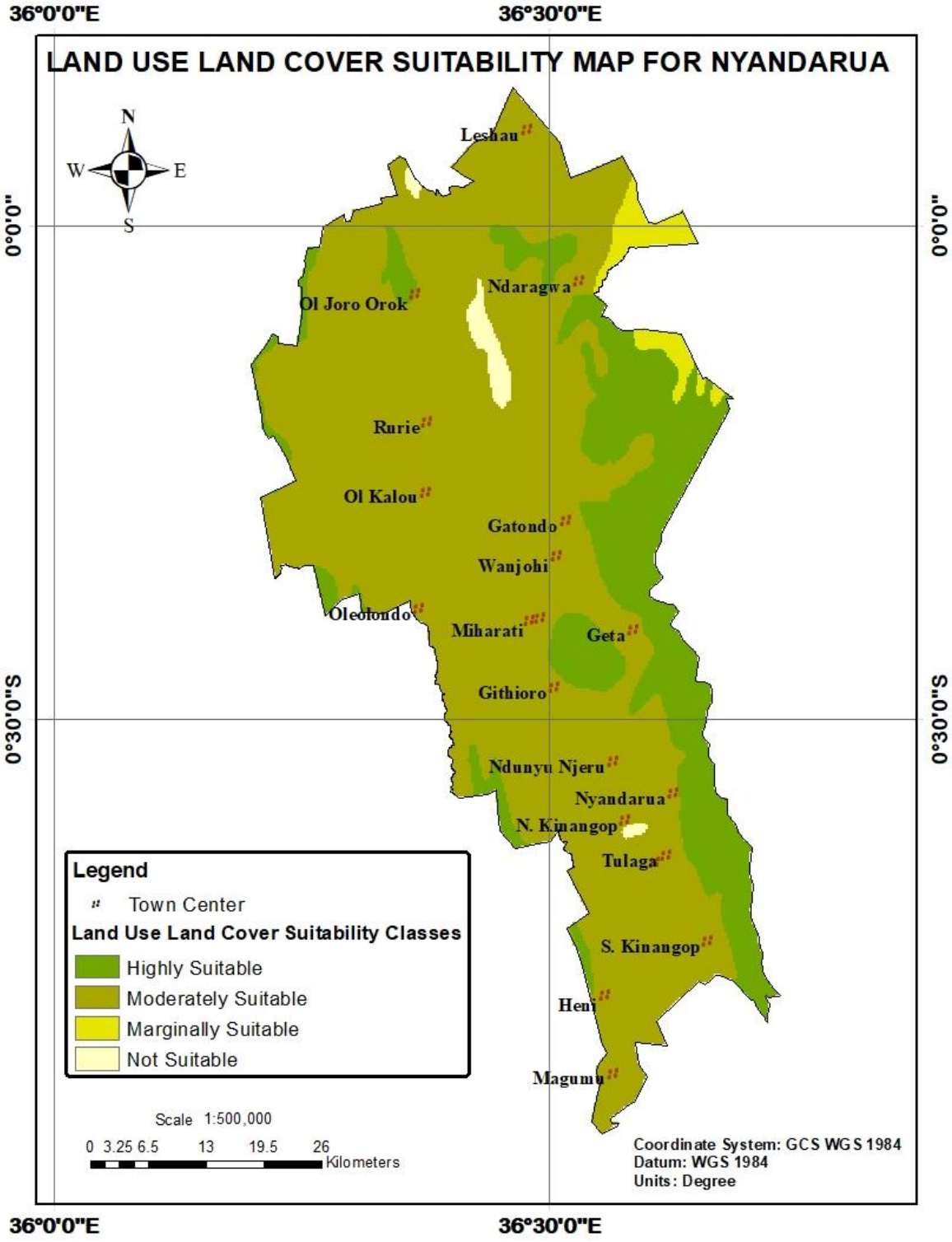

Figure 4.4 Land Use Land Cover Suitability Map of Nyandarua County

4.4.2 Soil Drainage Spatial Variation

The reclassified soil drainage map shows that the highest percentage 71.50% is suitable for Bamboo farming with moderate and marginal suitability taking 28.40% and 0.11%, respectively. Table 4.5 and Figure 4.5 shows the spatial variation of reclassified soil drainage and soil drainage suitability map for Nyandarua County respectively.

Table 4.5 Spatial Variation of Reclassified Soil Drainage

Suitability Class	Drainage	Area (Ha)	Percentage
S1	Perfectly Drained, Well Drained	234,259.634	71.50%
S2	Moderately Drained	93,051.253	28.40%
S3	Imperfectly Drained	342.305	0.11%

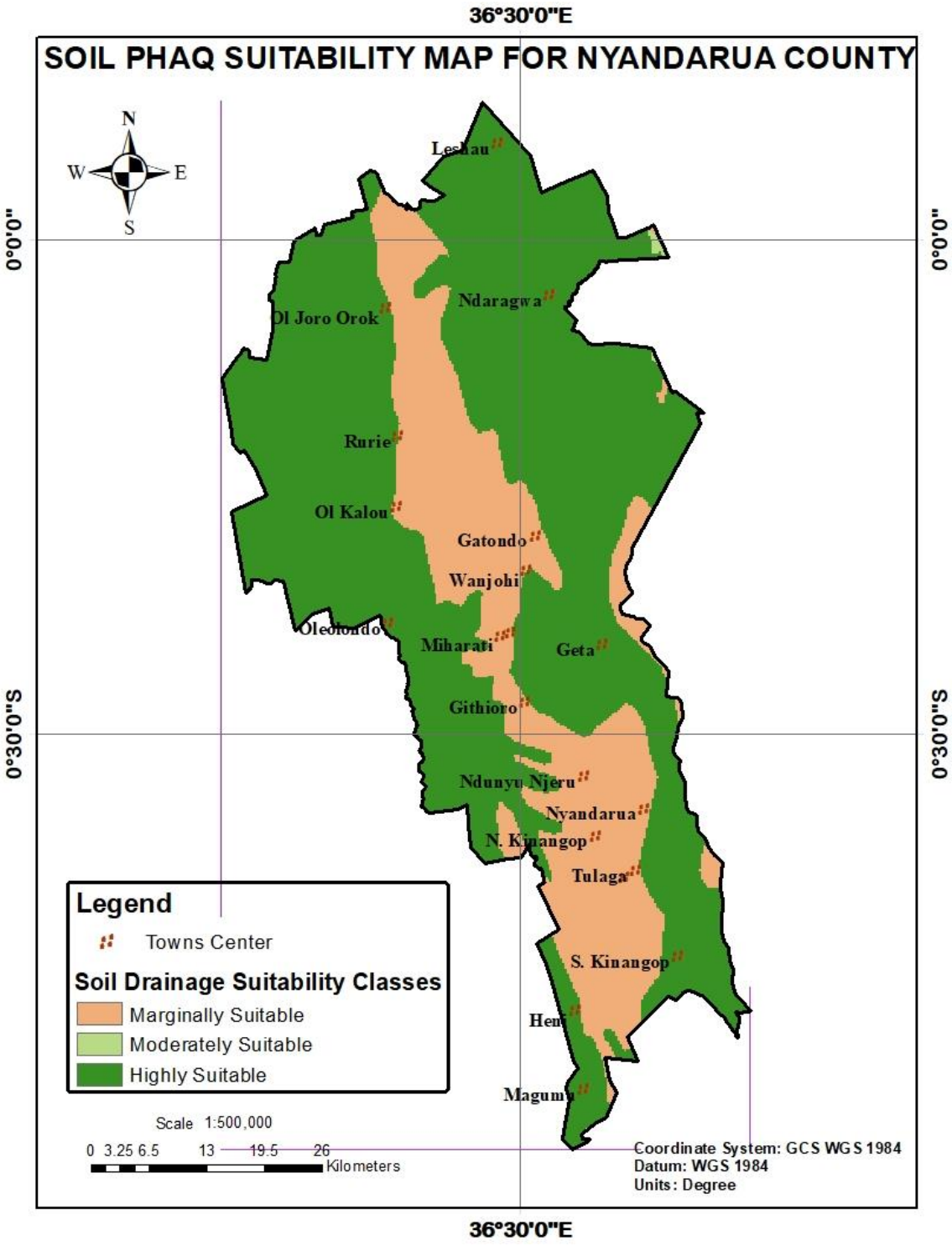

Figure 4.5 Soil Drainage Suitability Map of Nyandarua County

4.4.3 Soil Texture Spatial Variation

The reclassified texture map shows that on the basis of texture, the highest percentage 58.317% is moderately suitable for Bamboo Farming with highley and marginal suitability taking 18.422% and 23.261%, respectively. Table 4.6 and Figure 4.6 shows the spatial variation of reclassified soil texture and soil texture suitability map for Nyandarua County respectively.

Table 4.6 Spatial Variation of Reclassified Soil Texture

Suitability Class	Soil Texture	Area (Ha)	Percentage
S1	Loamy & Sandy	60,355.799	18.42%
S2	Clayey	191,059.536	58.32%
S3	Very Clayey	76,208.597	23.26%

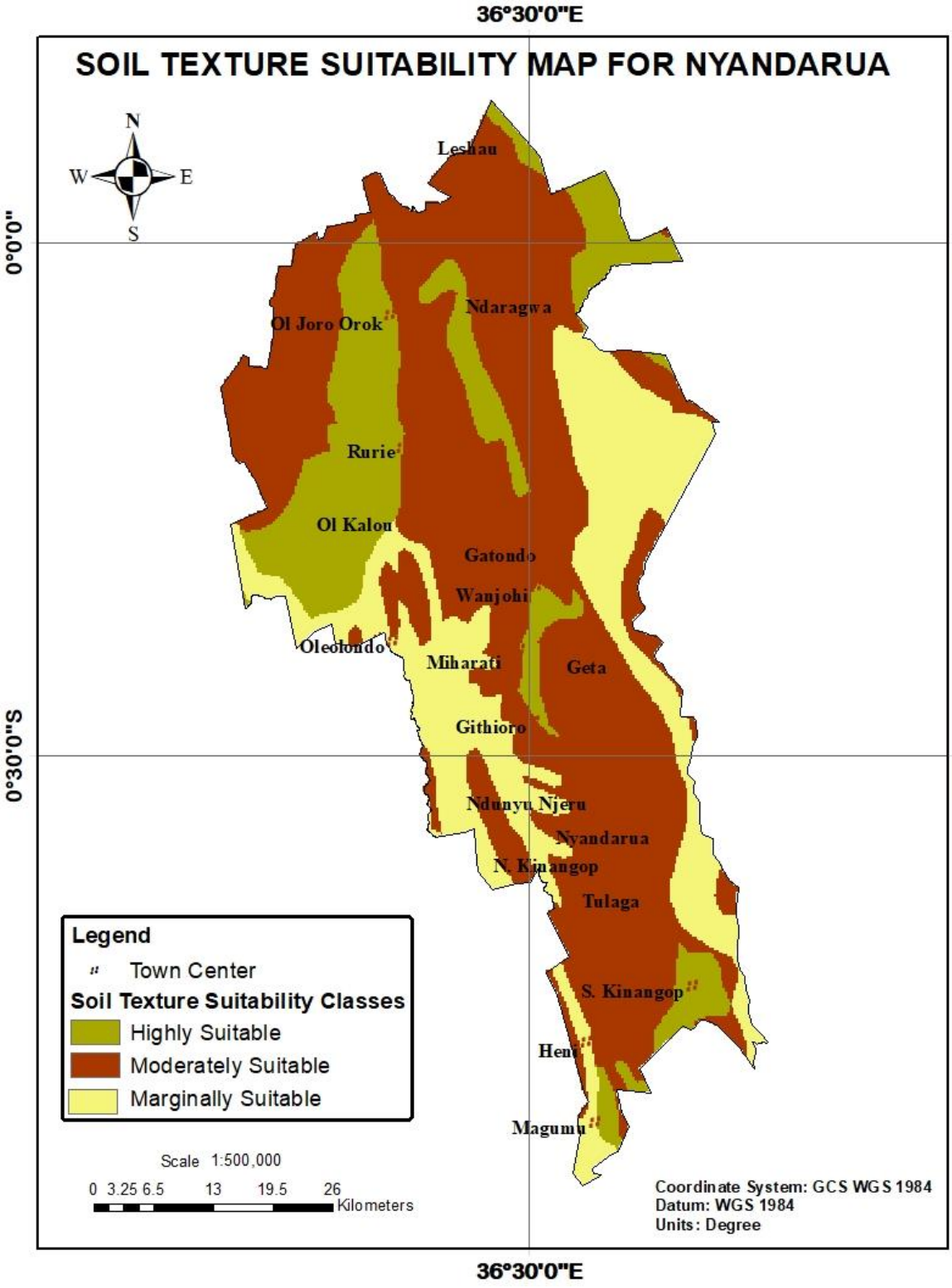

Figure 4.6 Soil Texture suitability Map of Nyandarua County

4.4.4 Soil PHAQ Spatial Variation

The reclassified pH map shows that the highest percentage of land 49.58% is not suitable for Bamboo cultivation with high, moderate and marginal suitability taking 10.72%, 34.41% and 5.30%, respectively. Table 4.7 and Figure 4.7 shows the spatial variation of reclassified Soil PHAQ and Soil PHAQ suitability map for Nyandarua County respectively.

Table 4.7 Spatial Variation of Reclassified Soil PHAQ

Suitability Class	Soil PHAQ	Area (Ha)	Percentage
S1	6.7-6	35,119.044	10.72%
S2	6-4.5	112,777.904	34.41%
S3	4.5-2.5	17,369.107	5.30%
N	<2.5	162,502.637	49.58%

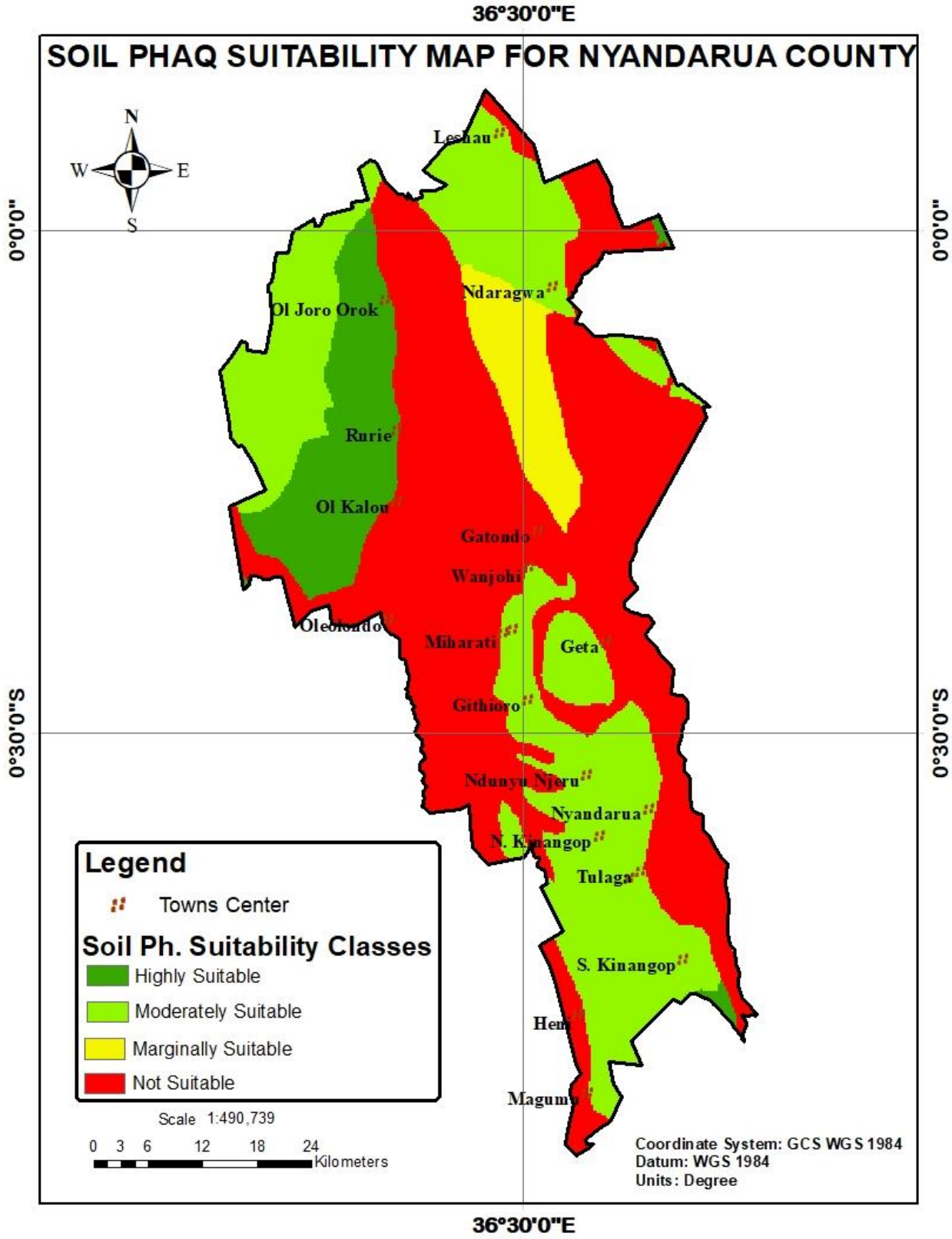

Figure 4.7 Soil PHAQ Suitability Map of Nyandarua County

4.5 Bamboo Farming Site Suitability Map.

After conducting a Pairwise Comparison and individual weights assigned, an overlay analysis produced three suitability classes of Bamboo farming. With the highest percentage being 75.30% which is moderately suitable and 24.54% and 0.16% being highly and marginally suitable (Table 4.8 and Figure 4.8 show bamboo farming site suitability variation and bamboo farming site suitability map respectively.

Table 4.8 Bamboo Farming Site Suitability

Suitability Class	Area (Ha)	Percentage
S1	79,726.165	24.54%
S2	244,601.851	75.30%
S3	509.714	0.16%

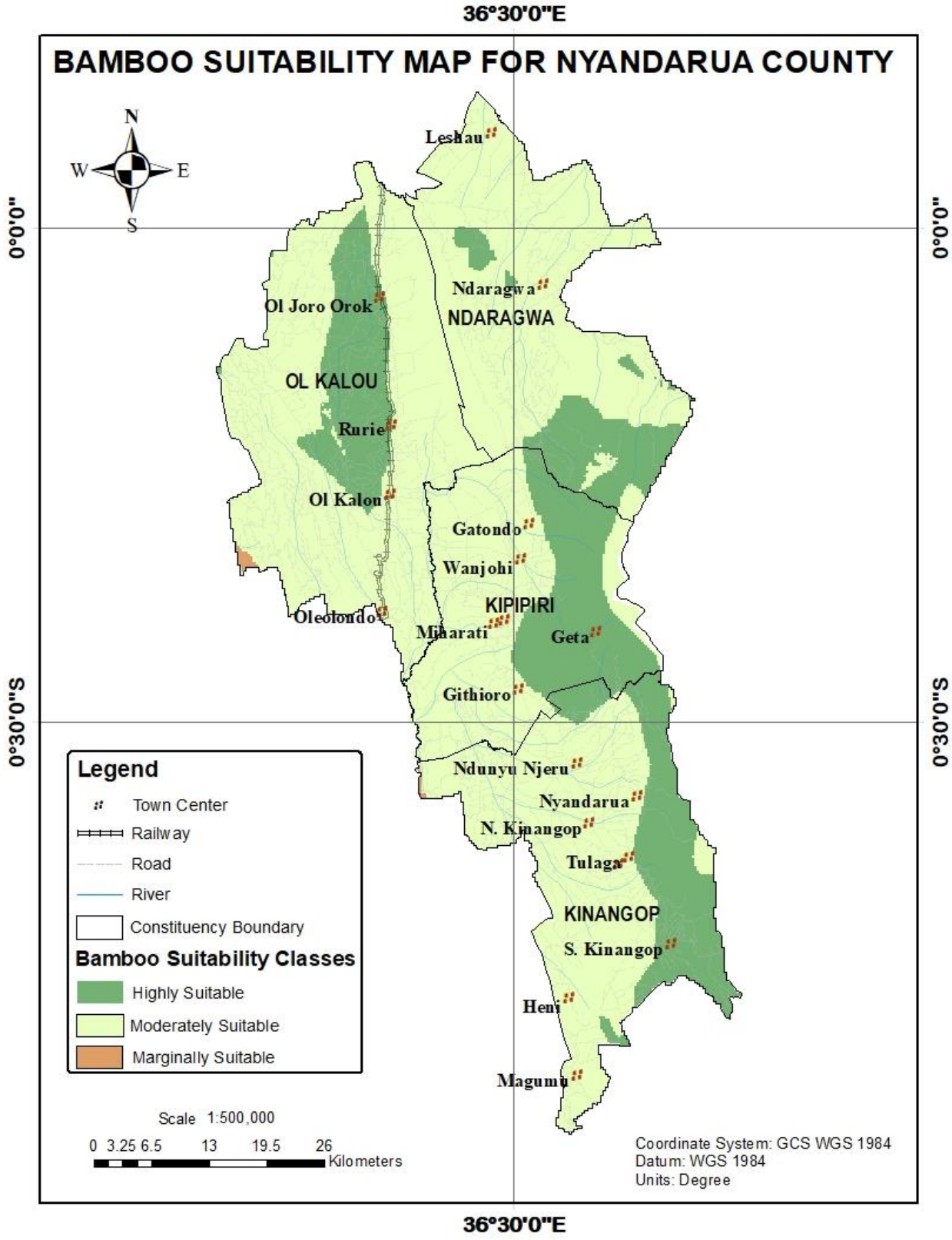

Figure 4.8 Bamboo Farming Site Suitability Map of Nyandarua County

4.6 Discussion of the Results

Most of the bamboo in Kenya is grown in mountain ranges and forest (Kinyili,2021). Nyandarua is such a location owing to the fact that it hosts the Aberdare Ranges and Forests.

The county's suitability in respect of rainfall indicates that 99.932 % is suitable for Bamboo farming while only 0.061 % is not suitable. The highly and moderately suitable areas to a large extent are in Kinangop, Ol Kalou and Ndaragwa Constituencies while pockets of marginally suitable can be found in Kipipiri, Ndaragwa and Ol Kalou Constituencies. Rainfall is the core factor necessary for successful growth of bamboo (Peijian *et al*., 2020). Rainfall distribution in Nyandarua is adequate.

With regards to temperature, areas of high and moderate suitability are found in Ndaragwa, Kipipiri, Ol Kalou and Kinangop Constituencies while Kipipiri and Ol Kalou Constituencies contained pockets of marginally suitable land. Nyandarua County land is suitable for bamboo farming considering that the class highly suitable took up the largest percentage of 84.642 %, with 14.907%, 0.450%, 0.002% taking up moderately, marginally and not suitable respectively. Extreme temperatures that is below 15 °C and above 34 °C could result into slow growth of the bamboo trees.

Elevation in the county allows for the successful cultivation of Bamboo trees. The reclassification resulted into four classes the highest percentage of the area, 42.72%, is highly suitable for bamboo farming with moderate, marginal and not suitable taking 41.29%, 11.49% and 4.52%, respectively. Land that was highly suitable in regards to elevation was found in parts of all the four constituencies, the marginally suitable and not suitable were also found in small degrees in all the four constituencies. However, elevation does not have a strong influence on bamboo growth considering they grow in both areas of high and low altitudes.

In respect of Soil PHAQ, Nyandarua County is to a large extent covered by acidic soil which made the largest percentage not suitable for the growth of bamboo trees. For optimal growth the land has to be improved by making the soil less acidic and more neutral. The highest percentage of land 49.58% is not suitable for Bamboo Growth growth with high, moderate and marginal suitability taking 10.72%, 34.41% and 5.30%, respectively. Ol Kalou Constituency is the only area that had land of high suitability in respect to soil ph.

On the basis of soil texture, the highest percentage 58.32% is moderately suitable for Bamboo Farming with highly and marginal suitability taking 18.43% and 23.26%, respectively. The best

soil for growth of bamboo trees is the loam soil which is not found in abundance within the county. This however has been complemented by the presence of well and perfectly drained soil to a large percentage. Nyandarua county is suitable for Bamboo cultivation with the highest percentage, 71.50%, is suitable for Bamboo farming with moderate and marginal suitability taking 28.40% and 0.11%, respectively, with regards to soil drainage. Soil drainage is a critical factor in the successful cultivation of bamboo trees.

Based on the above findings Nyandarua County is suitable for Bamboo farming. From the weighted overlay analysis, it is clear that 99.84 percent of the County is highly and moderately suitable for cultivation of Bamboo. The remaining 0.16% is marginally suitable. The moderately suitable land is spread throughout the four constituencies that is, Ndaragwa, Kipipiri, Kinangop and Ol, Kalou. Pockets of high suitability can also be found in each and every of the four constituencies.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions of the study

The objectives of the project were, to identify the different factors that influence the location of potential bamboo farming sites and to apply the factors in a Multicriteria weighted overlay analysis to determine potential bamboo sites.

These have been achieved and it is concluded that:

- Nyandarua County moderately to highly suitable is suitable for Bamboo farming.
- Nyandarua County has huge potential for the cultivation of Bamboo.
- Soil is an important factor to be considered for the optimal growth of bamboo trees. In Nyandarua county, highly acidic and the lack of loamy and alluvial soils proved to be limiting factors to the realization of high suitability.

5.2 Recommendations from The Study.

From the study it is recommended that:

- All players in Bamboo cultivation value chain should make the most of highly suitable areas and sufficiently prepare for cultivation as a good harvest is highly vaible. The environment is already conducive for optimal growth of Bamboo trees.
- In areas that are moderately or marginally suitable players in the value chain should pay more attention to improving the land.
- In Nyandarua County seeing that the soil is highly acidic then proper improvements to the land can be made by making the soil less acidic.

5.3 Suggested Areas for Further Research

The Success of Bamboo farming is determined by many factors such as availability of processing plants, access to markets, population density, to mention but a few. Different aspect of these factors can be mapped and included in the Bamboo Farming Suitability database.

Furthermore, a validation exercise should be carried out with current cultivation figures of bamboo trees in future, this would strengthen the results of the research project.

REFERENCES

Atthirawong, W., and MacCarthy, B. (2002). An application of the analytical hierarchy process to international location decision-making. In Gregory, Mike, Proceedings of The 7th Annual Cambridge International Manufacturing Symposium: *Restructuring Global Manufacturing*, Cambridge, England: University of Cambridge (pp. 1-18).

Baniya, M. S. N. (2008). *Land suitability evaluation using GIS for vegetable crops in Kathmandu valley/Nepal* [Doctoral dissertation, Humboldt-Universität zu Berlin].

Bello, D. A., Farmani, R., Javadi, A.A., and Evans, B.M. (2009). The Analytical Hierarchy Process for contaminated land management. *Advanced Engineering Informatics*, 23(4): 433-441.

Buckingham, K. (2014). Bamboo: The Secret Weapon in Forest and Landscape Restoration?.

Business Daily Africa. (2019). Farmers in Nyandarua build retirement nests on Bamboo https://www.businessdailyafrica.com/bd/news/counties/farmers-in-nyandarua-build-retirement-nests-on-bamboo-2250800

FAO. (1976). *A framework for land evaluation: Soils Bulletin 32*. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO and INBAR. (2018). *Bamboo for land restoration. INBAR Policy Synthesis Report 4*. INBAR: Beijing, China.

Ken, F. (2014). Tropical Plants Database, tropical.theferns.info.

Government of Kenya. (2019). *National Bamboo Policy, 2019*. Kenya Forestry Research Institute (KEFRI). Nairobi, Kenya.

Government of Kenya. (2019). *The 2019 Kenya population and housing census*. Kenya National Bureau of Statistics (KNBS). Nairobi, Kenya.

Government of Kenya. (2018). *The Socio-Economic Transformative Agenda For Nyandarua County: County Integrated Development Plan 2018-2022.*

Government of Kenya. (2016). *Climate Risk Profile for Nyandarua. Kenya County Climate Risk Profile Series.* The Kenya Ministry of Agriculture, Livestock and Fisheries (MoALF), Nairobi, Kenya.

Kenya News Agency. (2019). Bamboo varieties will diversify people livelihoods https://www.kenyanews.go.ke/kefri-says-new-bamboo-varieties-will-diversify-people-livelihoods/

Kinyili, Benjamin. (2021). *Bamboo Growing for Forest Conservation* NDC Kenya 16OCT2020. 10.13140/RG.2.2.21345.43365.

Kumar, R., Subramanian, S., & Duraisamy, J. *Integrated Advanced Remote Sensing Gis Study For Bamboo Based Livelihood Analysis And Rural Development Planning In Nhamatanda, Dondo Districts Of Sofala Province, Mozambique*.

Lupia, D. F.(2014). *Crop/land suitability analysis by ArcGIS tools*. Technical report.

Peijian S, Haiganoush K. Preisler, Brady K. Quinn, Jie Zhao, Weiwei Huang, Alexander R, Xiaofei Cheng, Huarong Li, Dirk Hölscher (2020). *Precipitation is the most crucial factor determining the distribution of moso bamboo in Mainland China,Global Ecology and Conservation.*

Ritung S, Wahyunto, Agus F, Hidayat H. (2007). *Land Suitability Evaluation with a case map of Aceh Barat District*. Indonesian Soil Research Institute and World Agroforestry Centre, Bogor, Indonesia.

Saaty, T. L (2000). *Fundamentals of decision making and priority theory with the analytic hierarchy process*. RWS Publications, Pittsburgh, 6: 21-28pp.

Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of mathematical psychology*, 15(3), 234-281.