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DETERMINING LAND SUITABLE FOR ESTABLISHING SUSTAINABLE PALM PLANTATIONS IN TABORA REGION.

EMANUEL, EDMUND M.

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DETERMINING LAND SUITBLE FOR SUSTAINABLE PALM PLANTATION IN TABORA REGION.

EDMUND MULIMA EMANUEL

A Dissertation Submitted to the Department of Geospatial Sciences and Technology in Partially Fulfilment of the Requirements for the Award of Science in Geo-Informatics (BSc. GI) of Ardhi University

CERTIFICATION

The undersigned certify that they have supervised and proofread the dissertation and recommend for acceptance by Ardhi University a dissertation document titled **“Determining Land Suitable for Sustainable Palm Plantation in Tabora Region”** In fulfillment of the requirements for the Bachelor of Science degree in Geoinformatics.

Signature …………. Date…………

Ms. Beatrice Kaijage

Supervisor

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I, Edmund Mulima Emanuel hereby declare that, the contents of this dissertation are the results of my own findings through my study and investigation, and to the best of my knowledge they have not been presented anywhere else as a dissertation for diploma, degree or any similar academic award in any institution of higher learning.

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EDMUND MULIMA EMANUEL

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DEDICATION

I dedicate this dissertation to my late father Emanuel Mulima may his soul rest in peace. My mother Aida Felician and my aunt Justina Felician who always provide me with advice and never ceased to pray for me. Last but not least my brothers Edward Emanuel, George Tinabo and Marijani Kashonga who has always been my encouragement and supporters.

ABSTRACT

This study investigates the urgent need to address the escalating demand for cooking oil in Tanzania by assessing the suitability of establishing sustainable palm plantations in the Tabora region. Edible cooking oil is a highly consumed product globally, and Tanzania heavily relies on imports due to inadequate local supply, leading to skyrocketing prices. The objective of this research is to employ GIS and RS technology to identify suitable areas for palm plantation based on eight thematic layers: rainfall, temperature, slope, soil pH, proximity to water bodies, protected areas, and roads. Landcover, proximity to protected areas and proximity to water bodies were the criteria used to account for the sustainability aspect in this research as they play a greater role when it lands to environment conservation. These layers undergo reclassification to standardize their values, enabling their integration for determining suitable palm plantation areas.

The results indicate that a mere 1% of Tabora total area is classified as extremely suitable for palm cultivation. Another 48% is categorized as highly suitable, while 41% demonstrates moderate suitability and 1% categorized as marginally suitable. Moreover, 9% of the region shows it is not suitable for establishing sustainability palm plantations. A total of 49% of the area is summed to be sustainable for establishment of palm plantations. These findings highlight the pressing need for providing support to farmers operating in suitable areas and encouraging investment from companies to tackle the cooking oil scarcity in Tanzania. By adopting sustainable practices and establishing palm plantations, Tanzania can enhance self-sufficiency, decrease reliance on costly imports, and promote economic growth in the agriculture sector.

Generally, the findings of this study provide valuable information for the development of sustainable palm oil plantations in Tabora region. The government and private investors should use this information to make informed decisions about the future of palm oil production in the region.

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ACRONYMS AND ABBREVIATION

AHP	Analytical Hierarchy Process
ASA	Agriculture Seed Agency
BWM	Best Worst Method
GIS	Geographic Information System
MCDA	Multi Criteria Decision Analysis
MCDM	Multi Criteria Decision Making
MeTL	Mohammed Enterprises Tanzania Limited
RS	Remote Sensing
RSPO	Roundtable on Sustainable Palm Oil
TSPA	Tanzania Sunflower Processor Association
WLC	Weighted Linear Combination

CHAPTER ONE

INTRODUCTION

1.1 Background

Edible cooking oil is one of the most consumed products worldwide. It is used in many meals, and there are different sources of edible cooking oil, such as sunflower, avocado, soy beans, olive, and palm oil. Palm oil is extracted from the fruit of the oil palm tree, which is native to Africa and parts of Asia. It is also a popular ingredient in many processed foods (Chandra, 2018).

Tanzania is highly dependent on oil from sunflower seeds and palm seeds, but the demand for cooking oil is too high, resulting in a shooting of prices. Previously, the price for a 20-liter container was Tshs 53,000/=, but recently the price is about Tshs 100,000/=, a rise of more than 85%. According to statistics from Tanzania Sunflower Processor Association (TSPA), about 395,000 tonnes of palm oil is imported, but this does not satisfy the present demand. Tanzania is a net importer of edible oil, with a demand that is outpacing domestic production. In 2020, Tanzania imported an estimated 320,000 tonnes of edible oil, while domestic production was only 250,000 tonnes. A total of 600,000 to 700,000 tonnes of cooking oil is required to satisfy the demand present by 2030 in Tanzania since the demand is increasing daily (Tairo, 2021).

To address this problem, the government of Tanzania has announced plans to increase domestic production of cooking oil. The Ministry of Agriculture through Agriculture seed agency (ASA) is planning on producing about 15,000 tonnes of palm seeds that will be produce about 18 to 20 million palms. With this, a suitable area is also required by ASA for establishing palm plantations where by an area of about 120,000 to 150,000 hectares in order to get a minimum of 18 million palm oil trees is required with such amount of palm seeds (Mussa, 2022). With these farms, the prices for cooking oil are likely to drop at a high rate with surpass production of cooking oil.

“The overall area used for seeds multiplication, including hectares belonging to the private sector, is 30,000 hectares. As compared to the country’s increasing demand for quality seeds, the agency requires 300,000 hectares,” (Mussa, 2022). The demand for land for quality seeds production keeps growing following the fast expansion of the agriculture sector according to Dr. Kashenge (Mussa, 2022)

In response to this demand, private sectors like MeTL are investing in large-scale cultivation of palm oil. MeTL aims to acquire 25,000 hectares for this purpose (METL, 2022), which aligns with the tropical suitability of the region and benefits Tanzania's arable land. However, there are concerns about the environmental impact of palm oil production. Palm oil plantations can lead to deforestation and wildlife habitat destruction (RSPO, 2020).

To address this, consumers can choose products that utilize sustainable palm oil, which adheres to practices that minimize deforestation and protect wildlife habitats. Organizations such as the Roundtable on Sustainable Palm Oil (RSPO) certify sustainable palm oil, ensuring compliance with comprehensive principles and criteria (RSPO, 2020).

Overall, the demand for land for palm oil production in Tanzania is growing. Private sectors are investing in large-scale cultivation of palm oil to meet this demand. However, there are concerns about the environmental impact of palm oil production. Consumers can choose products that utilize sustainable palm oil to help address these concerns (RSPO, 2020). There are a number of organizations that certify sustainable palm oil. These organizations use a variety of criteria to assess the sustainability of palm oil production, including the use of land that is not cleared from forests, the protection of wildlife habitat, and the use of water resources in a sustainable way (Abdul et al., 2021). GIS and remote sensing can be used to collect data on these criteria, which can then be used to assess the sustainability of palm oil production (Wong et al, 2023).

By using GIS and remote sensing, we can identify areas of land that are suitable for palm oil production, monitor deforestation, assess the impact of palm oil production on wildlife habitat, and certify sustainable palm oil. This information can be used to manage the demand for land for palm oil production and to protect the environment (Wong et al, 2023).

1.2 Problem statement

In Tanzania, ascending demand for edible oil has led to inadequate supply and higher prices, particularly in palm oil. Urgent actions are needed to enhance local production of cooking oil, addressing shortages and import dependency. Achieving sustainable production involves balancing economic growth with environmental protection, especially in the expansion of palm plantations. Thus, the primary challenge is to establish a steady and eco-friendly supply of cooking oil to meet the population's needs, requiring increased local production, price stability management, and careful consideration of environmental impacts. Using GIS and RS technology this study will determine land suitable for palm plantation that will ensure the sustainability of these farms to be established also providing small scale farmers areas that may result into high yields since they are using traditional methods such as land observation, divination, trial and error as well as consulting elders in determining these areas.

1.3 Objectives

1.3.1 Main objective

The main objective for this study is to determine potential areas for establishment of sustainable plantations for palm oil through GIS and RS technology.

1.3.2 Specific objectives

For this study there were several specific objectives and are as follows;

(i) To determine criteria to be considered in determining land suitable for sustainable palm plantation.

(ii) To determine suitable area for each determined criterion.

(iii) To determine suitable areas for establishing plantations.

1.4 Research questions

Under this study several questions were to be answered and those questions are;

(i) What are the key criteria that need to be considered in determining land suitability for sustainable palm plantations?

(ii) How can the suitable area be determined for each of the identified criteria?

(iii) What areas are suitable for establishment of land suitable for sustainable palm plantations?

1.5 Significance of the study

Through this study different significances can be attained and they are as follows;

(i) Through mapping of suitable areas for palm cultivation, production of edible oil from palm seeds will increase then reducing purchasing costs.

(ii) Establishment of palm plantations will facilitate and increase the number of palm oil producing industries the creating a fair number of employments.

(iii) The study can provide valuable information about the characteristics of land that make it suitable for palm plantation, which can be used to guide the development of palm plantations in the region.

(iv) The study can provide a basis for further research and collaboration on issues related to sustainable palm plantation in Tabora and beyond.

1.6 Beneficiaries of the research

(i) The Government of Tanzania – Ministry of Agriculture

Through the ministry of Agriculture, the government can use obtained results for further establishment of palm plantations in addition to the existing ones also pushing forward some policies, initiatives also financial support to the dwellers of the areas that are likely to yield high production of palm seeds.

(ii) Researchers

Further developments in the research in terms of the accommodation of new criteria for establishment of sustainable palm plantations can be done by researchers based on the findings of this research. This can enhance this research further, and the agricultural sector at large.

(iii) The Tanzanian community at large.

The people of Tanzania are the final intended beneficiaries of this research since it will facilitate the initiatives to establish palm plantations hat will mitigate the shortage of cooking oil in the country as well as generation of employment opportunities which will benefit the citizens of Tanzania.

1.7 Scope and Limitations

The scope of a research project on determining land suitable for sustainable palm plantation in Tabora include the following:

(i) The study will focus on the Tabora region in Tanzania.

(ii) The study will investigate the climate, soil conditions, and topography of the region in order to identify the factors that make land suitable for palm plantation.

(iii) The study will develop recommendations for how to support sustainable palm plantation in the region.

Some potential limitations of the study may include:

(i) The study only focused on the Tabora region, so the findings may not be applicable to other regions.

(ii) The study only included information that was available at the time of the research, so it may not consider any changes that occur after the study was completed.

(iii) The study was limited by the availability and reliability of data and information, which could have impacted the accuracy of the findings.

1.8 Dissertation organization

This dissertation is structured into five chapters that explain the background, methods, and methodologies that were used together with the results and their discussions concerning palm plantation in Tanzania.

Chapter 1

Describes the background of the study which justifies the basis of the research problem, objectives, research questions, significances, scope and limitations, and beneficiaries together are described in this chapter.

Chapter 2

Describes the review of the literature concerning the research topic. It explains how palm plantation area determining suitability has been conducted and their respective approaches.

Chapter 3

Covers all methods involved in the study, including pre-processing and processing methods and algorithms that were applied to the data.

Chapter 4

Provides the analysis, discussion, and interpretation of processing results. The obtained results are discussed regarding other results.

Chapter 5

Portrays the finalization of the research in terms of conclusion and recommendations. This will help provide a basis for future research in similar related topics.

CHAPTER TWO

LITERATURE REVIEW

2.1 Palm Oil Overview

Palm oil, derived from the oil palm tree, is a crucial commodity with a diverse range of applications globally. Its cultivation spans regions like Africa and Asia due to its adaptability and high yield. Palm plantations, established worldwide, respond to the demand for edible oil, adapting to varying climates and environments. This expansion is intricately tied to the delicate balance between economic growth, sustainability, and environmental conservation (Murphy. D, et al., 2021).

Assessing land suitability for palm plantations involves factors like soil type, topography, and climate. Tools like GIS and remote sensing aid in identifying optimal areas, safeguarding ecological balance amid cultivation. Palm oil's economic importance is substantial, contributing to GDP and employment in producing nations. Beyond food, it's a versatile ingredient in cosmetics, biofuels, and industrial processes. The significance of palm oil encompasses economic growth, environmental responsibility, and social welfare, underscoring the need for sustainable practices to ensure its continued viability (Murphy. D, et al., 2021).

2.2 Remote Sensing in Determining Sustainable Land for Palm Plantations

Remote sensing involves gathering information about objects, areas, or phenomena without direct contact, achieved by analyzing data from devices like satellites (Lillesand, et al., 2007). It encompasses both scientific and artistic elements, capturing data through reflected or emitted energy, followed by processing and analysis. Sensors play a key role, measuring electromagnetic energy from objects of interest. They can be passive (detecting natural energy) or active (emitting energy for measurement). These sensors are mounted on platforms, such as ground-based, airborne, or spaceborne systems.

For example, remote sensing contributes to sustainable palm plantations in Tabora region. By utilizing satellite imagery and sensors, it aids in assessing land suitability, optimizing plantation layouts, and monitoring ecological impacts. This process aligns with responsible practices to ensure environmental conservation and economic growth.

2.3 Geographic Information System (GIS) in Determining Sustainable Land for Palm Plantations

GIS, or Geographic Information System, represents a comprehensive integration of computer hardware, software, data, and personnel, aimed at efficiently capturing, storing, updating, manipulating, analyzing, and displaying geographically referenced data (Jasrotia et al., 2009). This multifaceted system comprises five essential components: data, hardware, software, people, and procedures. It possesses the intrinsic capability to process and interpret diverse forms of geospatial data, enabling functions such as data exploration, analysis, management, and visualization. Ultimately, GIS translates these processes into the presentation of insights through maps or charts, facilitating the comprehension of intricate data patterns and relationships that inform strategic decision-making (Selvam et al., 2001).

Integral to GIS's utility are its components - geospatial data, data acquisition, data management, data exploration, data analysis, and data display. This comprehensive toolkit finds application across various domains, including agriculture, natural hazards, hydrology, meteorology, land use management, wildlife habitats, military operations, tourism, and more, each leveraging GIS for specific roles.

In the context of sustainable palm plantations in Tabora region, GIS emerges as a linchpin tool. By harnessing the power of spatial analysis and geospatial data, GIS enables land suitability assessments, aiding in identifying optimal areas for palm cultivation. It facilitates the visualization of various parameters such as slope, soil quality, and land cover, crucial for establishing plantations that harmonize with the local environment. Moreover, GIS assists in monitoring ecological impacts, ensuring a balance between economic development and environmental conservation. This strategic integration of GIS technology underlines its pivotal role in supporting responsible and sustainable practices in the establishment and management of palm plantations in the Tabora region.

2.3.2 Raster Overlay in Determining Sustainable Land for Palm Plantations

Raster overlay involves the fusion of attributes from two or more raster layers utilizing map algebra or raster calculus, which employs a series of operators to compute novel raster data (Tomlin, 1994). The process entails cell-by-cell integration of data from multiple layers, where values from one layer correspond to cells in another layer. These values are merged, generating an output value assigned to an equivalent cell in the resultant layer (Bolstad, 2016). This raster overlay technique plays a crucial role in determining suitable areas for sustainable palm plantations through land suitability analysis.

In sustainable palm plantation planning, diverse factors such as slope, soil quality, and land cover influence the land's suitability. By utilizing GIS's raster overlay capabilities, different raster layers representing these factors can be combined. Each layer contributes specific data slope gradients, soil pH values, and land cover classifications which are then fused to create a composite output. The result is a 'suitability map' that designates areas based on their compatibility for palm cultivation. This map assists land planners, policymakers, and stakeholders in identifying regions with optimal conditions, ensuring that environmental concerns and productivity goals are harmonized.

Similarly, vector overlay in GIS is another significant technique. It involves the combination of point, line, and polygon geometries along with associated attributes (Bolstad, 2016). This technique is employed to merge diverse thematic vector layers relevant to palm plantation suitability assessment. By overlaying layers containing information about land use, water bodies, and soil types, a comprehensive understanding of land attributes is attained. This aids in identifying areas that are most suitable for sustainable palm cultivation.

GIS's raster and vector overlay techniques enhances the precision of suitability analysis for sustainable palm plantations. By combining various geospatial layers that contribute to land suitability assessments, GIS empowers decision-makers with critical insights, ensuring the establishment of palm plantations that align with both economic objectives and environmental sustainability.

2.4 Multi-Criteria Decision Analysis (MCDA) for Enhanced Decision-Making in Sustainable Palm Plantation Planning

Multi-Criteria Decision Analysis (MCDA) is an interactive, computer-based system that serves as a valuable tool for decision-makers grappling with complex spatial decision problems (Malczewski, 2015). This methodology extends the principles of decision theory to scenarios involving multiple objectives. MCDA aids in navigating the intricacies of decision-making by systematically weighing the advantages and disadvantages of various alternatives in pursuit of a specific objective. This process involves framing decision problems, assessing alternative performance against criteria, exploring trade-offs, formulating decisions, and evaluating their resilience.

MCDA proves especially effective in situations where simplifying a multi-objective problem into a single objective is impractical or undesirable, particularly in participatory contexts encompassing diverse stakeholders with varying objectives (Esmail, 2017). The predominant strength of MCDA lies in its capacity to transparently and reproducibly amalgamate analytical evaluations of alternatives with stakeholder preferences and priorities. By accommodating these multifaceted perspectives, MCDA facilitates a comprehensive and balanced decision-making approach (Simon French, 2009).

In the context of sustainable palm plantation planning in Tabora, MCDA serves as a pivotal technique. By integrating the diverse criteria involved in identifying suitable plantation areas such as soil quality, water availability, and environmental impact. MCDA aids decision-makers in quantitatively evaluating potential sites. This ensures a comprehensive assessment that considers a range of factors, leading to the selection of sites that align with both agricultural and sustainability objectives. Through its structured and transparent process, MCDA enhances decision-making efficacy and contributes to the establishment of palm plantations that harmonize economic prosperity and ecological conservation.

2.5 Analytical Hierarchy Process (AHP) in Sustainable Palm Plantation Planning.

The Analytical Hierarchy Process (AHP) is a versatile decision-aiding methodology used to establish relative priorities among a set of alternatives on a ratio scale. This prioritization is based on the discernment of the decision-maker, underscoring the significance of their intuitive judgments and the consistency of alternative comparisons within the decision-making process (Al-Harbi, 1999). AHP has gained substantial prominence since its inception, serving as a pivotal tool for decision-makers and researchers engaged in multiple criteria decision-making. Notably, AHP's versatility lies in its capacity to seamlessly integrate with various techniques such as Linear Programming, Quality Function Deployment, Fuzzy Logic, and more. This adaptability empowers users to harness the advantages of multiple methods, leading to enhanced outcomes (Omkarprasad S. Vaidya, 2004).

In the context of sustainable palm plantation planning, AHP assumes a significant role in the land suitability analysis. AHP enables the systematic comparison of diverse criteria such as soil quality, water availability, and slope gradient. By quantifying these factors and assigning them relative weights based on expert knowledge and stakeholder preferences, AHP generates a comprehensive framework for evaluating potential plantation sites. This nuanced approach ensures that the selection of suitable areas not only considers objective data but also aligns with broader sustainability objectives.

A distinguishing feature of AHP is its ability to accommodate subjective factors, setting it apart as a progressive advancement in comparison to other decision-making approaches (Marra, 2017). By allowing the incorporation of personal insights and preferences, AHP contributes to a more comprehensive and nuanced decision-making process, ensuring that choices are aligned with both quantitative data and qualitative considerations.

2.6 Best Worst Method (BWM) for Multi-Criteria Decision Making

According to Best Worst Method (BWM), the decision-maker identifies the best (e.g. most desirable, most important) and worst (e.g. least desirable, least important) factors first. Each of these two criteria (best and worst), pairwise comparisons are made with the other criteria. The weights of various criteria are then determined by formulating and solving a maxi-min problem. Weights of the alternatives are calculated using the same method for various criteria (Razaei 2015).

The final scores of the alternatives are calculated by combining the weights from several sets of criteria and alternatives, and the best option is chosen. For the BWM, a consistency ratio is recommended to assess the comparability of the results. Similar to the AHP approach, it also uses a 9-point scale for measuring preferences (Razaei, 2015). This method contains some salient features compared to other MCDM techniques including:

(i) BWM is a vector-based method that requires fewer comparisons compared to matrix-based MCDM methods such as AHP. For BWM, we only need to have 2n-3 comparisons while, for instance, for AHP n (n-1)/2 comparisons are needed whereby *n* is the number of criteria.

(ii) The final weights derived from BWM are highly reliable as it provides more consistent comparisons compared to AHP. While in most MCDM methods (e.g. AHP), consistency ratio is a measure to check if the comparisons are reliable or not, in BWM consistency ratio is used to see the level of reliability as the output of BWM is always consistent.

(iii) Not only can BWM be used to derive the weights independently, but it can also be combined with other MCDM methods.

(iv) While using a comparison matrix, generally speaking, we have to deal with integers as well as fractional numbers (e.g. in AHP we use fractional numbers 1/9, 1/8, …, 1/2, and integer numbers 1, …, 9), in BWM, only integers are used, making it much easier to use. (Rezaei, 2015). These integers are set to show the comparison between two criteria using preference scale

Table 2.1 Preference Scale

Verbal judgement of preference	**Numerical rating**
Extreme preferred	9
Very strong to extreme preferred	8
Very strongly preferred	7
Strongly to very strongly preferred	6
Strongly preferred	5
Moderately to strongly preferred	4
Moderately preferred	3
Equally to moderately preferred	2
Equally preferred	1

The following are the steps involved in this method:

1) Determine a set of decision criteria.

This is the first step which involves the determination of the decision criteria in solving a certain multi-criteria decision problem. For instance, the criteria for wind farm land suitability are wind speed, land cover, slope, proximities, and main roads and grid lines. (Rezaei, 2015)

2) Determine the best (e.g. most desirable, most important) and the worst (e.g. least desirable, least important) criteria (Rezaei, 2015)

In this step, the decision-maker determines which criteria are the greatest and worst in general. At this point, no comparisons are made. For instance, say wind speed and slope can be chosen to be the best and worst criteria for wind farm site selection respectively.

3) Determine the preference of the best criterion over all the other criteria using a number between 1 and 9. (Rezaei, 2015)

Here decision-makers determine the preferences of the best criteria compared to other criteria making the best-to-others preference matrix on a scale of 1 to 9. In the example, the wind is compared to other factors to obtain the best-to-others preference matrix.

4) Determine the preference of all the criteria over the worst criterion using a number between 1 and 9. (Rezaei, 2015)

Likewise, the others to worst preference matrix are formed based on an expert's preference comparison of the other criteria with respect to the worst criteria on a scale of 1 to 9.

5) Find the optimal weights for each criterion. (Rezaei, 2015)

This stage involves computation of the weights for the individual criteria using the BW method which forms the basis of this research.

The optimal weight for the criteria is the one where for each pair of w_B/w_j and w_j/w_W , we have $w_B/w_j = a_{Bj}$ and $w_j/w_W = a_{jW}$. To satisfy these conditions for all j we should find a solution where the maximum absolute differences $\left|\frac{w_B}{w_j} - a_{Bj}\right|$ and $\left|\frac{w_j}{W_w} - a_{jW}\right|$ for all j is minimized. Considering the non-negativity and sum condition for the weights, the following problem results:

$$\text{Min max}\left\{\left|\frac{w_B}{w_j} - a_{Bj}\right|, \left|\frac{w_j}{W_w} - a_{jW}\right|\right\} \ldots\ldots (1)$$

Subject to

$\sum_j w_j = 1$

$$w_j \geq 0, for\ all\ j$$

This problem can be written as;

Min ξ,

Subject to

$$\left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi, \text{ for all j}$$

$$\left|\frac{w_j}{W_w} - a_{jW}\right| \leq \xi, \text{ for all j}$$

$$w_j \geq 0, for\ all\ j \ldots\ldots \text{(2)}$$

whereby;

a_{xy} – Comparison of x to y

B – Best Criteria

j – criteria for suitability

ξ – ksi factor

W- Worst criteria

The weights are obtained on solving problem (2) above.

6) Consistency ratio (Rezaei, 2015)

A comparison is fully consistent when $a_{Bj} \times a_{jW} = a_{BW}$ for all j, where a_{Bj}, a_{jW} and a_{BW} are respectively the preference of the best criterion over the criterion j, the preference of criterion j over the worst criterion, and the preference of the best criterion over the worst criterion. Since it is possible that not all criteria will be consistent, a consistency ratio is proposed to indicate how consistent a comparison is. The consistency ratio is given by equation (3);

$$\text{Consistency Ratio} = \frac{\xi}{\text{Consistency Index}} \ldots\ldots \text{(3)}$$

2.7 Weighted Linear combinations

The weighted linear combination (WLC) technique is a decision rule for deriving composite maps using GIS. It is one of the most often used decision models in GIS (Malczewski J. , 2002). The concept of a weighted average, in which continuous criteria are standardized to a single value, underpins simple additive weighing, also known as weighted linear combination. A calculation that takes into consideration a variety of parameters is a common numeric range that is then concatenated using a weighted average. The decision-maker is the one who determines the relative relevance of each property by assigning weights to it. (Lisec, 2009).

$$S=\sum w_i\, x_i \;\times \prod c_j \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Whereby;

- S - Suitability score
- w - weights for individual factors
- x - factors in the suitability analysis
- c - constraints in the suitability analysis
- $\prod$ - the product of constraints (1-suitable, 0-unsuitable)

In sustainable palm plantation planning, the WLC method operates by evaluating diverse criteria and constraints within a unified framework. By systematically assigning weights and calculating suitability scores, decision-makers can identify areas that offer optimal conditions for palm cultivation. This approach ensures a comprehensive assessment that aligns with both agricultural and sustainability objectives, guiding the selection of suitable plantation sites. The transparent and adaptable nature of the WLC technique enhances the precision and effectiveness of the decision-making process, facilitating the establishment of palm plantations that balance economic prosperity and environmental considerations (Shouqiang. L, et al., 2020).

2.8 Criteria for the study

A total of eight criteria were used to determine the areas which could be suitable for the establishment of sustainable palm plantations are as follows;

I. Land cover

Land cover data is pivotal in assessing land suitability for sustainable palm plantations. It aids in defining suitability criteria, analyzing areas with appropriate land cover types, and excluding ecologically sensitive zones. By integrating land cover with other criteria, plantation layouts and assess potential environmental impacts can be optimized (Liu et al., 2014). Rangeland, crop land and bare Land Potentially suitable if land is underutilized and soil conditions permit palm cultivation. However, impacts on local ecosystems, biodiversity, potential erosion and land degradation should be considered should be assessed (Leijten, 2023).

II. Soil Ph

Palm trees exhibit adaptability to various soil types, thriving particularly in well-drained soil conditions. The cultivation of palm trees can be extended to a wide range of soil compositions, with optimal growth observed within the pH range of 5.5 to 6. Soils falling below a pH value of 4 are considered suboptimal for achieving ideal palm plantation outcomes due to potential limitations on growth and development (Broschart et al., 2019).

III. Slope

In the context of establishing sustainable palm plantations, the topography's significance, particularly the slope, is pivotal. The slope gradient significantly influences the suitability of an area, with higher slopes posing a greater risk of soil erosion. In line with sustainability objectives, areas characterized by slopes less than 8% are deemed highly preferable for the establishment of palm plantations due to their reduced susceptibility to erosion. Conversely, regions marked by slopes exceeding 40% are considered unsuitable for palm plantation due to the elevated risk of environmental degradation and challenges in maintaining sustainable agricultural practices (Zhao et al., 2013)

IV. Rainfall

Among criteria for palm plantation establishment, rainfall has a greater role for both early and mid-stages for palm trees growth where by annual average rainfall should range between 2200 ml to 2500 ml for better growth of palm trees. Annual rainfall below 700 ml may result into the death of palm trees (Ahmed. A et al., 2021).

V. Temperature

Temperature is important because palm oil trees cannot tolerate frost (Columbia University, 2018). For better growth and yield of palm seeds temperature also plays a role since it is one of the factors required for the fruit to ripe. The minimum temperature has to range between 22℃ and 23℃ while the maximum temperature should range between 30℃ and 35℃ (Ahmed. A et al., 2021).

VI. Protected areas

Protected areas should be avoided because they are important for biodiversity conservation (Treves et al., 2005). As a constraint, in order to enhance the sustainability of palm plantations protected areas such as national parks and game reserves are not suitable for the establishment of palm plantations since these areas are specific to tourism activities and conservation of wild life in the country (Hausser. Y. et al., 2009).

VII. Proximity to water bodies

Water bodies tends to very useful mostly in irrigation farming whereby in dry seasons the plants may not suffer from shortage of water. Source of water bodies play as a constraint in palm plantation since they have to be protected to enhance their sustainability thus sustainability of these plantations (Mahoo, H. et al., 2015).

VIII. Proximity to roads

In this study both main roads and tertiary roads were considered in determining areas that were suitable for the palm plantations establishment whereby through these the transportation of produced goods and crops harvested to the processing units and industries as well as storage facilities (Colchester et al., 2011).

CHAPTER THREE

METHODOLOGY

This chapter contains in detail how the actual work was performed during the conduction of the research. It starts from the data used, sources of data, data collection, data processing to the final output. All the methods used to process the data and how results were obtained has been clearly described hereunder.

3.1 Study Area description

The research focuses on the Tabora region in mid-western Tanzania, situated between 4 and 7 degrees south of the equator and 31 and 35 degrees east. This area exhibits an average elevation of 1250m above sea level. Notably, palm plantations have been established by both small-scale farmers and the Tanzania Agricultural Research Institute (TARI). The region's economy is primarily driven by agricultural activities, including the cultivation of maize, rice, groundnuts, beans, cowpeas, cassava, sweet potatoes, and tobacco. Additionally, beekeeping, forest timbering, and livestock farming are significant contributors to the local economy. Recently the natives in ths region are using traditional methods in selecting farms (Mgaya, 2012) and some of them are;

i. Observing the land: The natives would observe the land for signs of fertility, such as the presence of certain plants and animals. They would also look for areas that were not prone to flooding or erosion (Mgaya, 2012).

ii. Consulting with elders: The natives would consult with elders who had knowledge of the land and its resources. The elders would be able to advise the natives on which areas were suitable for farming (Msola, 2014).

iii. Using divination: The natives may use divination, such as throwing bones or reading the stars, to determine which areas were auspicious for farming (Msola, 2014).

iv. Trial and error: The natives may simply experiment with different areas until they found one that was suitable for farming (Mgaya, 2012).

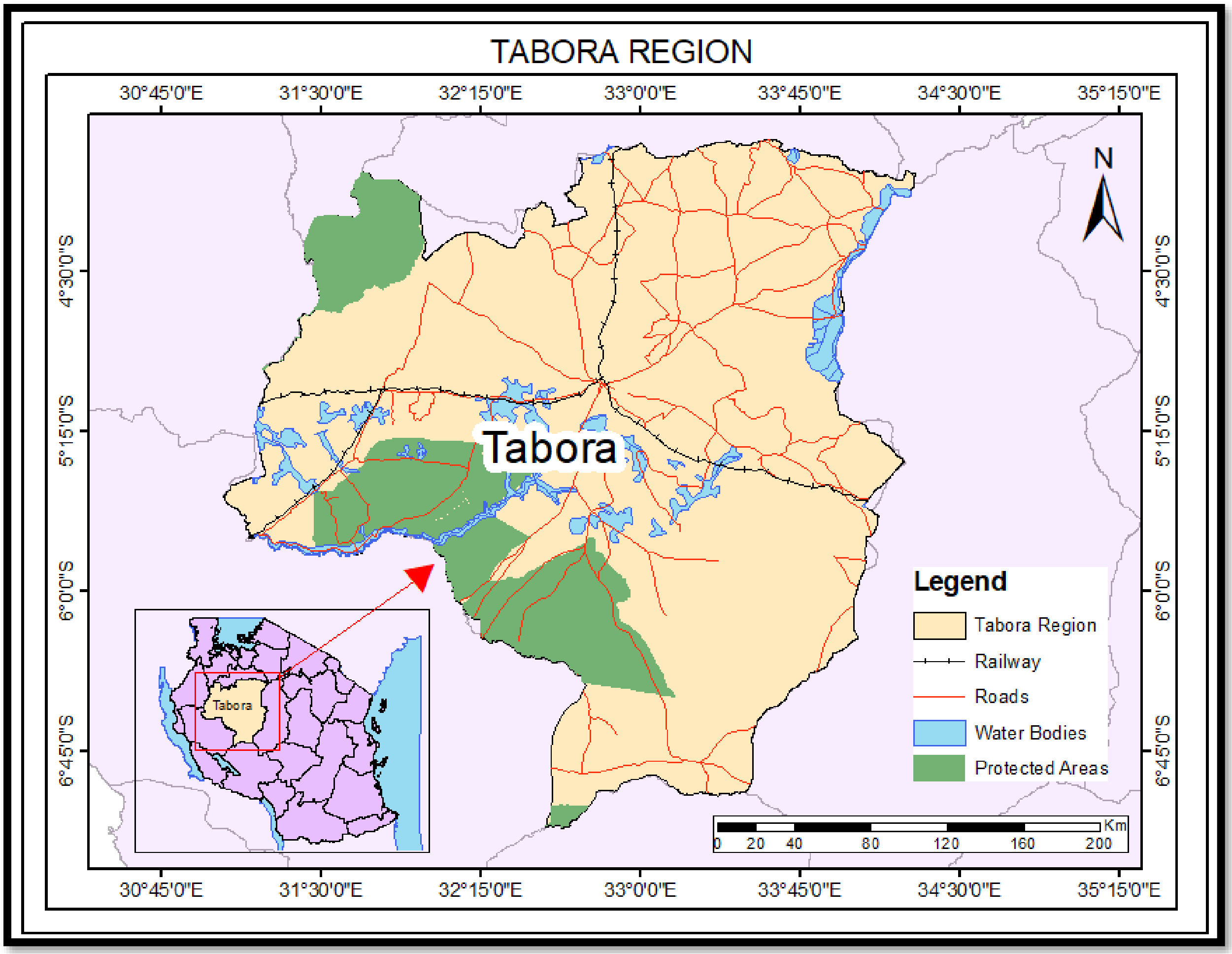

Figure 3.1 Study area overview

3.2 Methodology flow diagram

The methodology employed in this research is the Best-worst method and weighted overlay as it is illustrated in figure 3.2. The workflow begins with data acquisition followed by pre-processing steps to prepare the data for analysis. This was followed by processing steps including the preparation of thematic layers and using the BWM methodology to account for the weights of the criteria, and after validation of the weights, weighted linear combination was used to obtain the final suitability map.

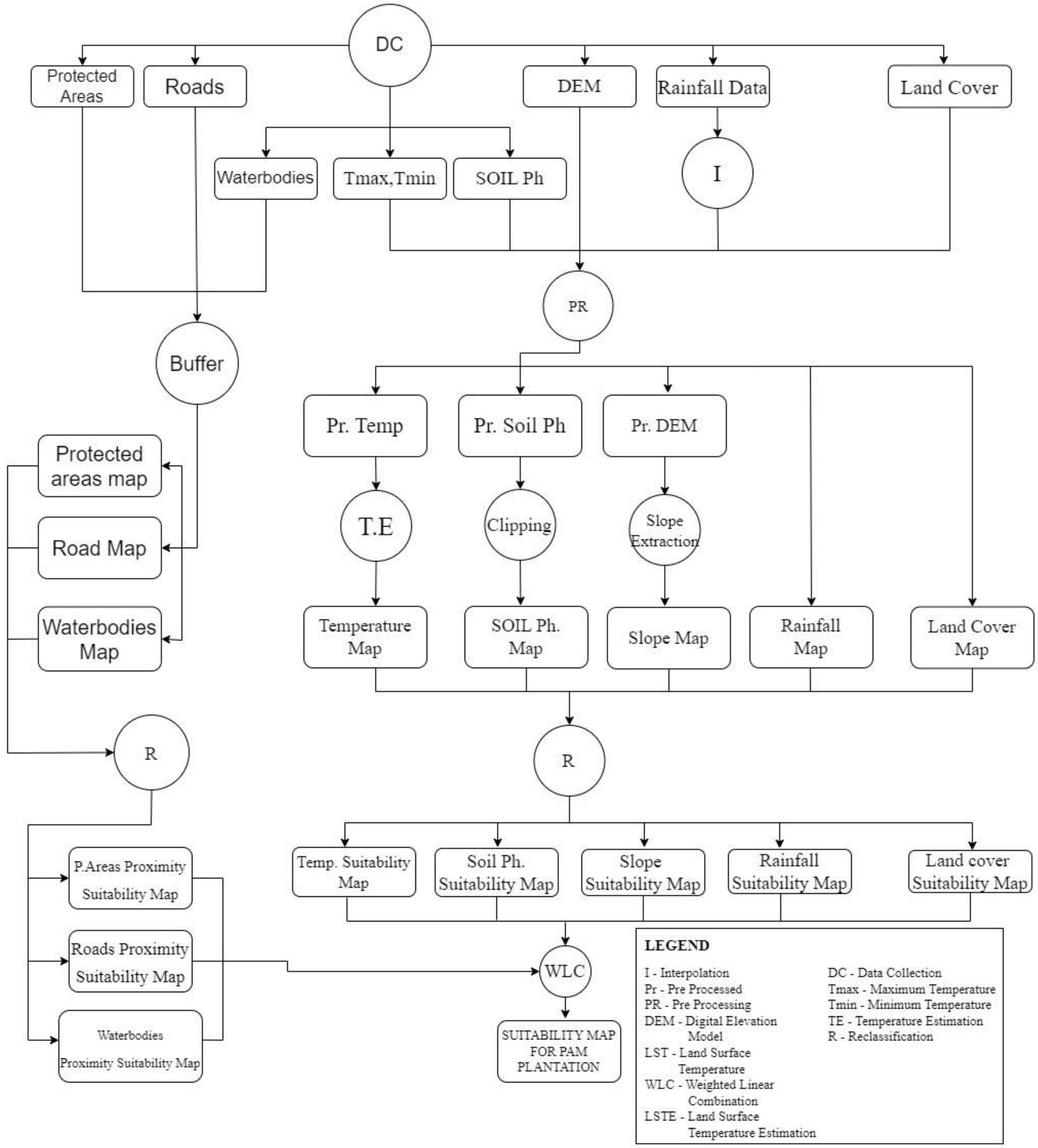

Figure 3.2 Methodology flow diagram

3.3 Data collection and their sources

This was the first stage involving the acquisition of relevant dataset that were required per each criterion in this research to meet the objectives. Table 3.1 indicates the data that were collected and their sources.

Table 3.1 Data and their sources

DATA	Format	Resolution	Source
Precipitation	csv	4 km	TerraClim
Temperature(tmin&tmax)	csv	4 km	
Elevation	TIFF	30m	USGS
Soil data (pH)	TIFF	250m	ISRIC
Tanzania boundaries data	shp	-	GADM
Protected areas	shp	-	TAWIRI
Land cover	TIFF	10 m	ESRI
Road network	shp	-	Open street map
Water bodies	shp	-	

3.4 Data Acquisition and Pre-processing

3.4.1 Acquiring and Pre-processing Digital Elevation Model (DEM) Data for Tabora Region

Digital elevation model was downloaded from the USGS website acquired from SRTM sensor. This dataset has a resolution of 1 arcsecond that is equal to 30m. The downloaded data tiles were mosaicked and a single tile covering entire area was obtained and was clipped to obtain the area of interest which is Tabora region.

3.4.2 Acquiring and Pre-Processing of Soil pH Data for Tabora Region

Soil pH data was obtained from the International Soil Reference and Information Centre (ISRIC) where this data had a resolution of 250 m and it was covering soil pH values to the soil depth of 200 cm. It was then clipped to produce a soil pH map of the area of interest.

3.4.3 Acquisition and Pre-processing of Rainfall Data for Tabora Region

Rainfall data were obtained from Terraclimate in form of raster where the Tabora region shapefile was used to generate the area of interest of Tabora region thus the rainfall data for the whole region were obtained using Rstudio software. Arc GIS was also used to regenerate the obtained raster into higher resolution by converting it into points and interpolating those point for more data.

3.4.4 Temperature Data Retrieval and Processing for Tabora Region

Temperature data were also obtained from Terraclimate in form of raster where the average temperature for twenty years was downloaded for both maximum and minimum temperature and the two were used to generate average temperature of the region using Rstudio and ArcGIS software.

3.4.5Acquiring and Preprocessing Protected Area Shapefiles for Tanzania in Proximity to the Study Area

Shapefiles for protected areas in Tanzania was downloaded from Tawiri and then only those areas that are within the proximity of the study area were extracted using the ArcGIS software. Since the data obtained were in form of vector, they were converted into raster format in order to be used in this study.

3.4.6 Acquiring and Pre-processing Land Cover of Tabora Region.

Land cover of the study area was downloaded from ESRI | Sentinel-2 Land Cover Explorer where by it was within one tile. The tile was then masked in order to obtain the land cover of the study area using ArcGIS software.

3.5 Data Processing

3.5.1 Preparation of thematic layers

Thematic layers were derived from the dataset that represented all the criteria involved in the analysis, in this study there were seven thematic layers of rainfall, temperature, slope, soil pH, proximity to water bodies, proximity to protected areas and proximity to roads. These layers had different values individually thus they had to be reclassified in order to assign their values to a common scale after determining the threshold required so they could be used together to obtain suitable areas for sustainable palm plantation in Tabora. A total of five classes were generated for all the layers to represent different suitability classes. Three layers which were proximity to roads, proximity to water bodies and proximity to protected areas did not have all five classes but had a several classes which also belonged in the five classes. Table 3.2 shows the criteria values and their classes.

Table 3.2 Criteria values and their classes (**1**-Extremely Suitable, **2**-Highly Suitable, **3**-Moderately Suitable, **4**-Marginally Suitable, **5**-Not Suitable)

Sn	**Criteria**	**Value**	**Classes**
1	Rainfall	<58	5
		58 – 70	4
		70 – 90	3
		90 – 110	2
		>110	1
2	Temperature	<21	5
		21 – 21.5	4
		21.5 – 22	3
		22 – 24	1
		24 – 24.5	2
		24.5 – 25	3
		>25	4
3	Slope	<8	1
		8 – 15	2
		15 - 25	3
		25 – 40	4
		>40	5
4	Soil pH	<4.0	5
		4.0 – 4.5	4
		4.5 – 5.0	2
		5.0 – 6.0	1
		6.0 – 6.5	2
		6.5 – 7.0	3
		7.0 – 7.5	4
		>7.5	5

Sn	Criteria	Value	Classes
5	Proximity to water bodies	<60 m	5
		60m – 3000m	1
		>3000m	4
6	Proximity to protected areas	<100 m	5
		>100 m	1
7	Proximity to roads	<60 m	5
		60m – 3000m	1
		>3000m	3

These layers were then later used to produce the final suitability using the weighted linear combination technique, one of the tools of Arc GIS software.

3.5.2 Computation of criteria weights

In this stage the individual weight for each criterion was computed where by the best criterion among all criteria was selected followed by the worst criterion among the other criteria basing on the literature. In these criteria the expertise in the sustainability of the practice as well as the productivity were the highly considered domains. The best criteria selected was rainfall bearing the score of 8 while the worst was proximity to roads bearing the score of 1. In this scale the score number nine was left out due to the number of criteria present and in order to emphasis on the accuracy of the result. Basing on these two criteria all other comparisons were conducted where rainfall was compared to others to give best to others comparison and proximity to roads was compared to others to give the others to worst comparison. Table 3.3 and table 3.4 shows the best to other comparison matrix and others to worst comparison matrix respectively.

Table 3.3 Best to other comparison.

Best to Others	Rainfall	Temperature	Soil pH	Proximity to water bodies	Slope	Proximity to Roads	Proximity to protected areas	Landcover
Rainfall	1	4	6	5	7	8	3	2

Table 3.4 Others to worst comparison

Others to the Worst	Proximity to Roads
Rainfall	8
Temperature	6
Soil pH	4
Proximity to water bodies	3
Slope	2
Proximity to Roads	1
Land cover	7
Proximity to protected areas	5

For each of the criteria comparisons the weight for each criterion was determined and whereby for those weights the consistency ratio was 0.095 while the associated threshold was 0.362 hence the pairwise comparison consistency ratio was acceptable.

3.5.2 Weighted Linear Combination

This process involved the aggregation of individual factors with their respective weights which were derived from BWM and constraints to obtain the suitable parts of Tabora region for the establishment of the sustainable palm plantations. The weighted linear combination was used to determine suitability score for each class through the entire region. This score was determined through the raster calculator present in ArcGIS software to generate the weighted suitable map. The equation used for computation was equation four (eqn 4) given by $S=\sum w_i x_i \times \prod c_j$ as it has been presented in the previous chapter.

CHAPTER FOUR

4. RESULTS, ANALYSIS AND DISCUSSION.

4.1 Overview

This chapter entails and provides output products of different processes conducted in the methodology of the research together with their critical discussion and interpretation. Results within this section involves thematic layers which were used as the input data, weights of the criteria computed from BWM method and the final suitability map of the area obtained through weighted overlay process and finally the discussion of obtained results.

4.2 Computed weights

As shown in figure 4.1 weights for each criterion were computed using best worst method (BWM). Landcover, Proximity to protected areas and Rainfall indicates to have high weights compared to other criteria while Proximity to roads has the lowest weight when they are compared to other criteria. The Landcover and Proximity to protected areas had the highest weights which indicates that this study highly considered sustainability of palm plantations in the area. Figure 4.1 display the histogram chart of weight against criterion to provide comparison among them where by from the obtained weights it is evident that rainfall has high influence on the growth of oil palms while the proximity to roads has a very low influence when related to other criteria.

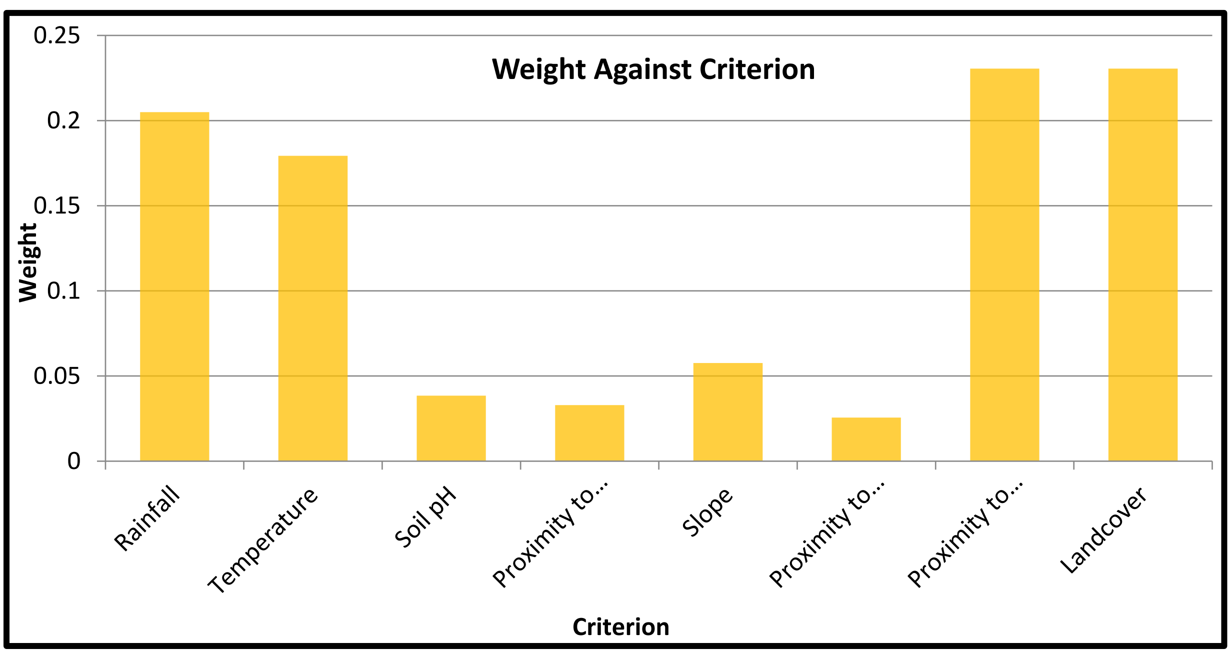

Figure 4.1 Histogram showing comparison of criteria weights

4.3 Thematic Layers

These were maps of individual datasets that were used in this research to produce the final suitable map for areas that are likely for establishment of sustainable palm plantations.

4.3.1 Reclassified rainfall map

Rainfall in Tabora as displayed in figure 4.2 indicates that the western part of the region experiences higher rainfall compared to other areas in the region thus these areas tends to be tremendously suitable while the eastern areas of the region tends to experience the very low amount of rainfall and this makes those areas not suitable for the palm plantations. The mid areas tend to receive average amount of rainfall and this makes these areas less suitable when compared to western areas and more suitable when compared to eastern areas of the region for the rainfall.

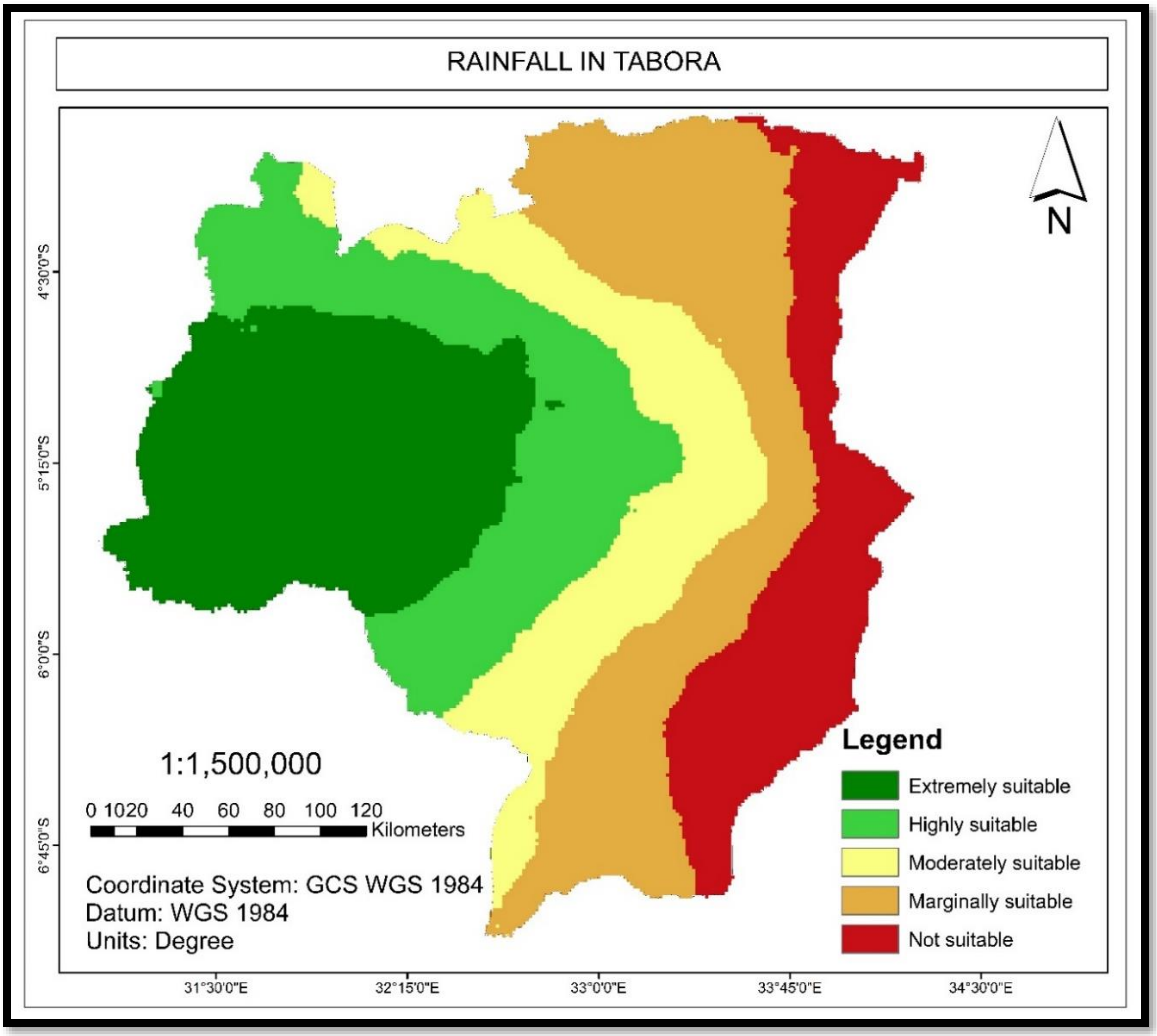

Figure 4.2 Reclassified rainfall map of Tabora

4.3.2 Reclassified Temperature map

The reclassified temperature map of Tabora region indicates that compared to other parts some parts of the south western part and northern part are highly suitable as they range within the required threshold for the cultivation of palm trees and some parts of northern east of the region are out of the required threshold thus are not suitable. The mid part of the region is moderately suitable since it experiences temperature whose values are close to the required threshold. Figure 4.3 below indicates the reclassified temperature map of Tabora region.

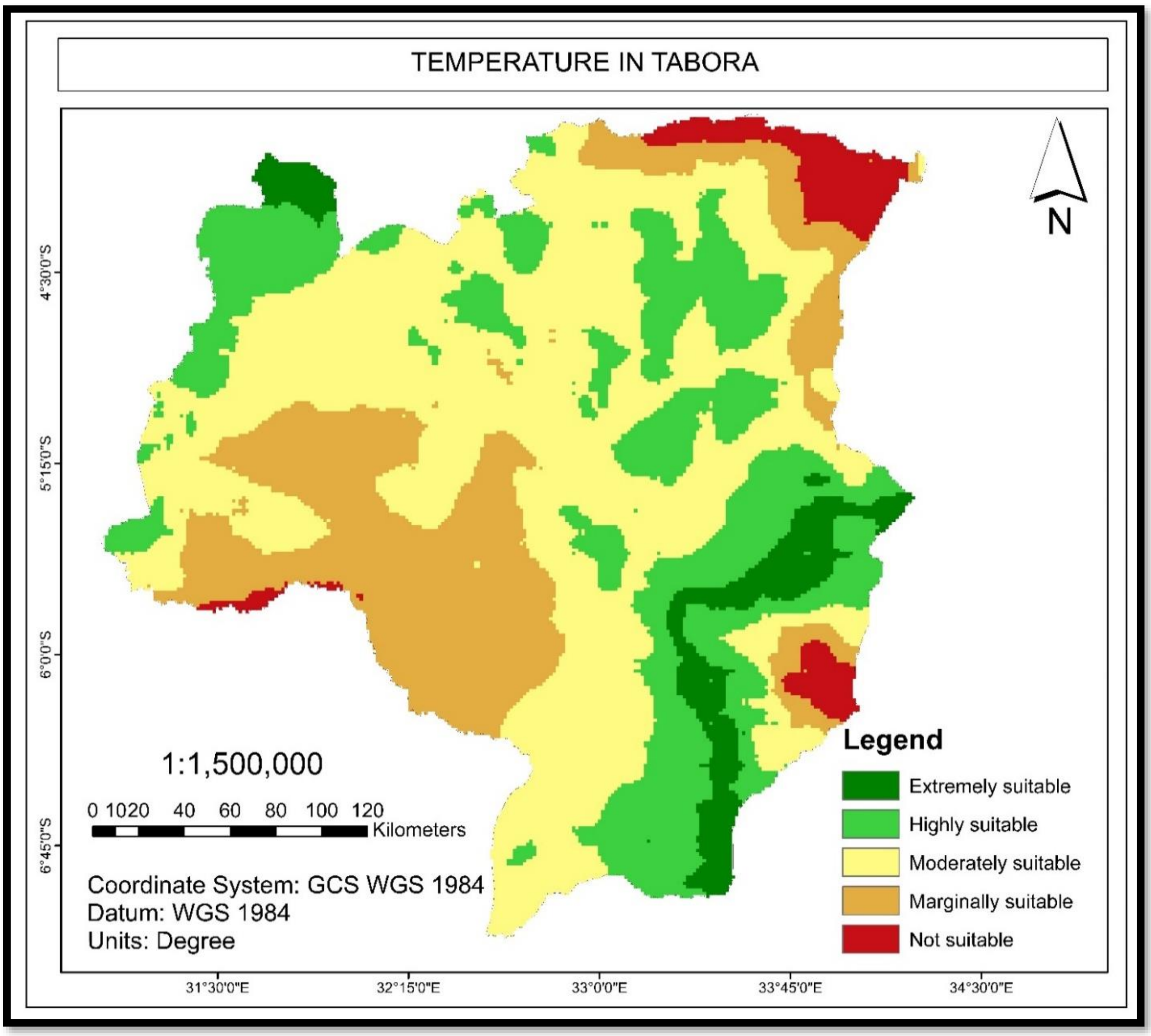

Figure 4.3 Reclassified Temperature map of Tabora

4.3.3 Reclassified slope map

Figure 4.4 below indicate the reclassified slope map of Tabora where by the required slope for establishment of these plantations is 15% but due the sustainability requirement of the practice the acceptable slope should be less than 8%. This slope allows the avoiding of soil erosion in the areas where this activity is conducted and if it exceeds this value different measure has to be adopted in order to ensure the sustainability of palm plantations. The slope in the area of interest ranges between 2% and 45% where the mid part of the region extending to the south western part of the region tends to have the slope greater than 15% thus these areas are not likely suitable for the establishment of sustainable palm plantations. Remaining areas are likely suitable for this plantation.

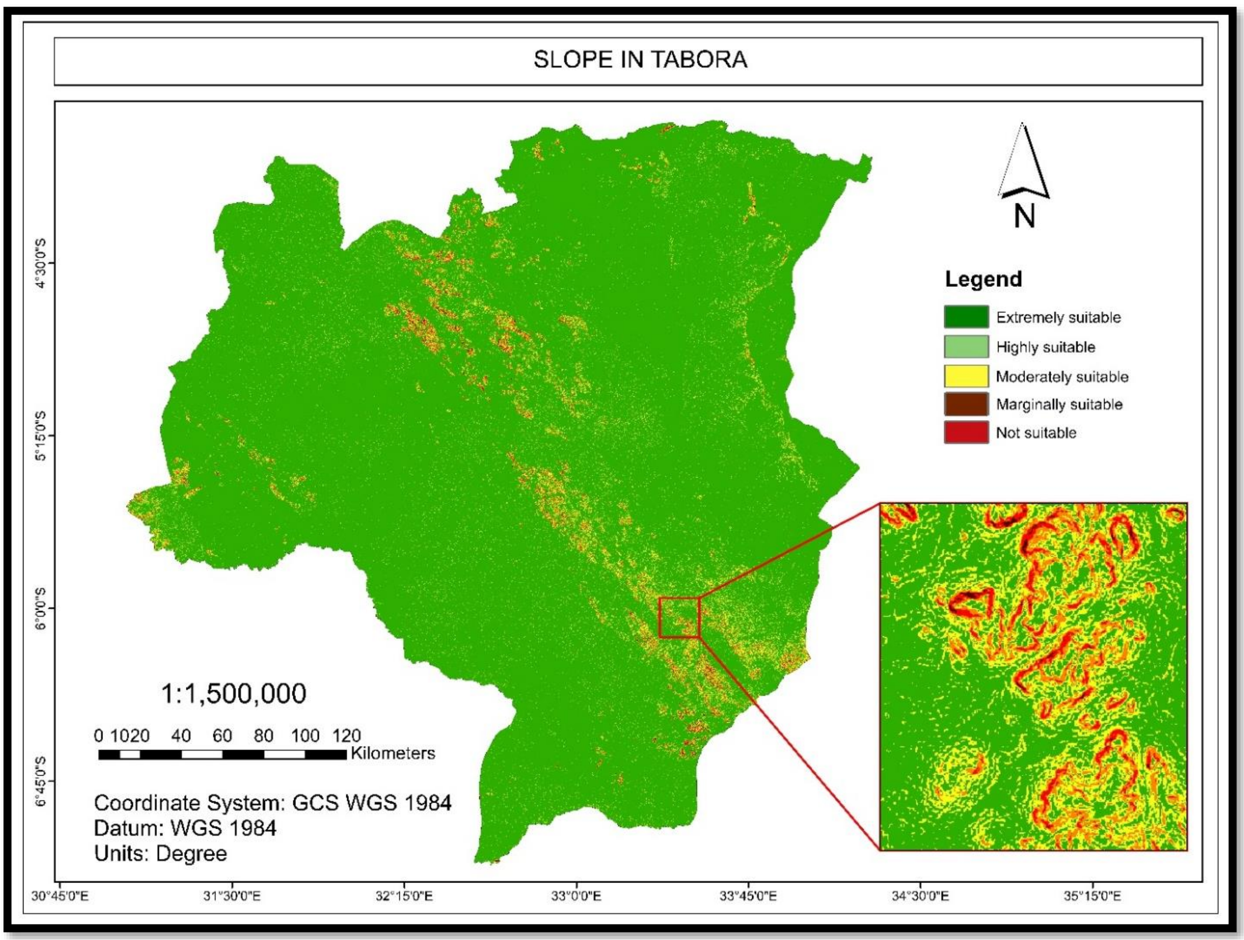

Figure 4.4 Reclassified slope map of Tabora

4.3.4 Reclassified soil pH map

The reclassified soil pH map indicates that most parts of the region are moderately suitable compared to other areas which are highly suitable for the establishment of palm plantation in the region. These areas re the north western part of the region that are extremely suitable when compared to other areas. Figure 4.5 illustrates the reclassified soil pH map of the Tabora region

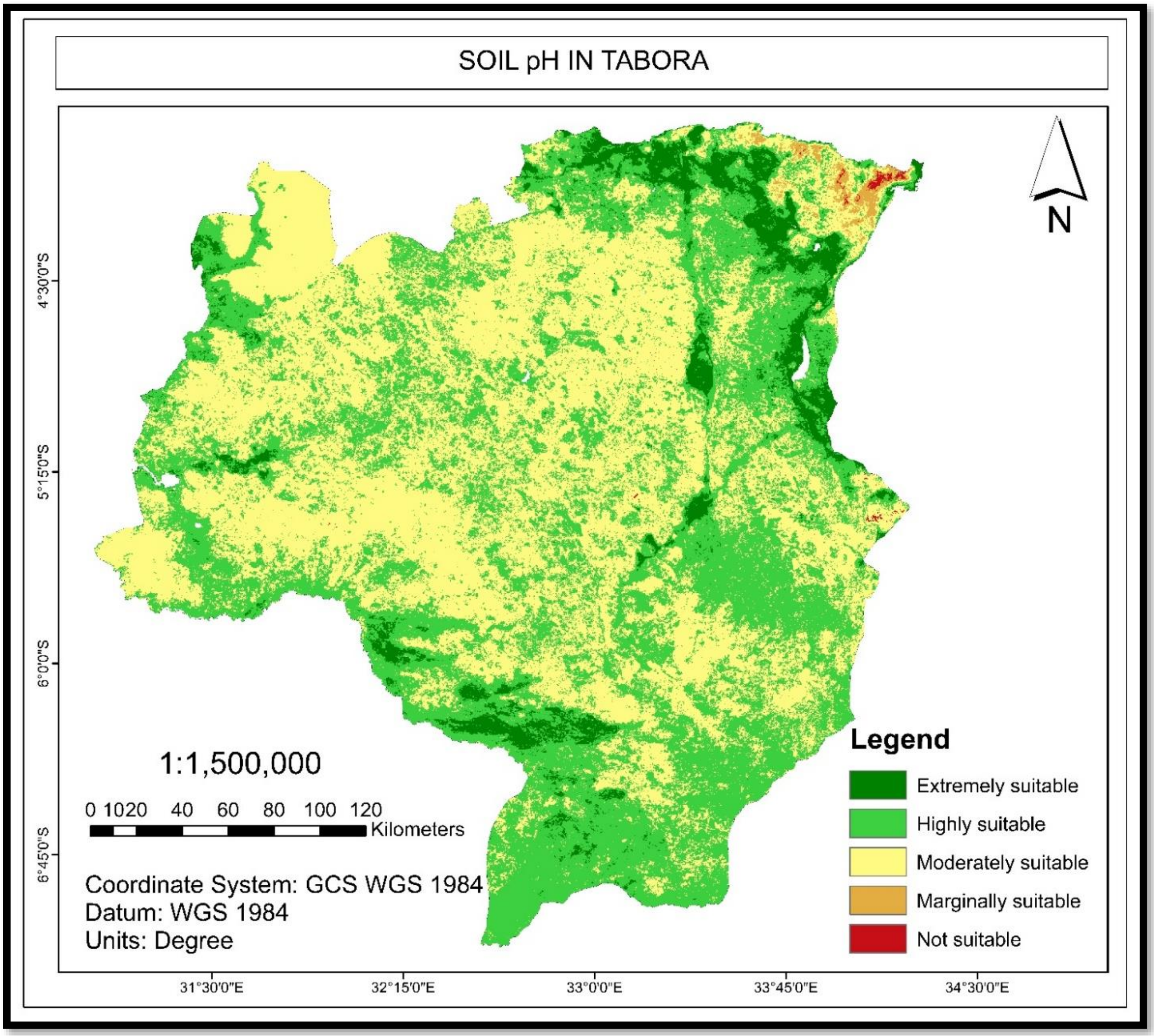

Figure 4.6 Reclassified soil pH map of Tabora

4.3.5 Protected areas constraint

This is the other output result that is contained in this part where by it indicates that the western part of the region has many protected areas compared to other part thus making these parts not suitable for the establishment of the sustainable palm plantations. Leaving other parts that are not within the protected areas suitable as shown in figure 4.6 below.

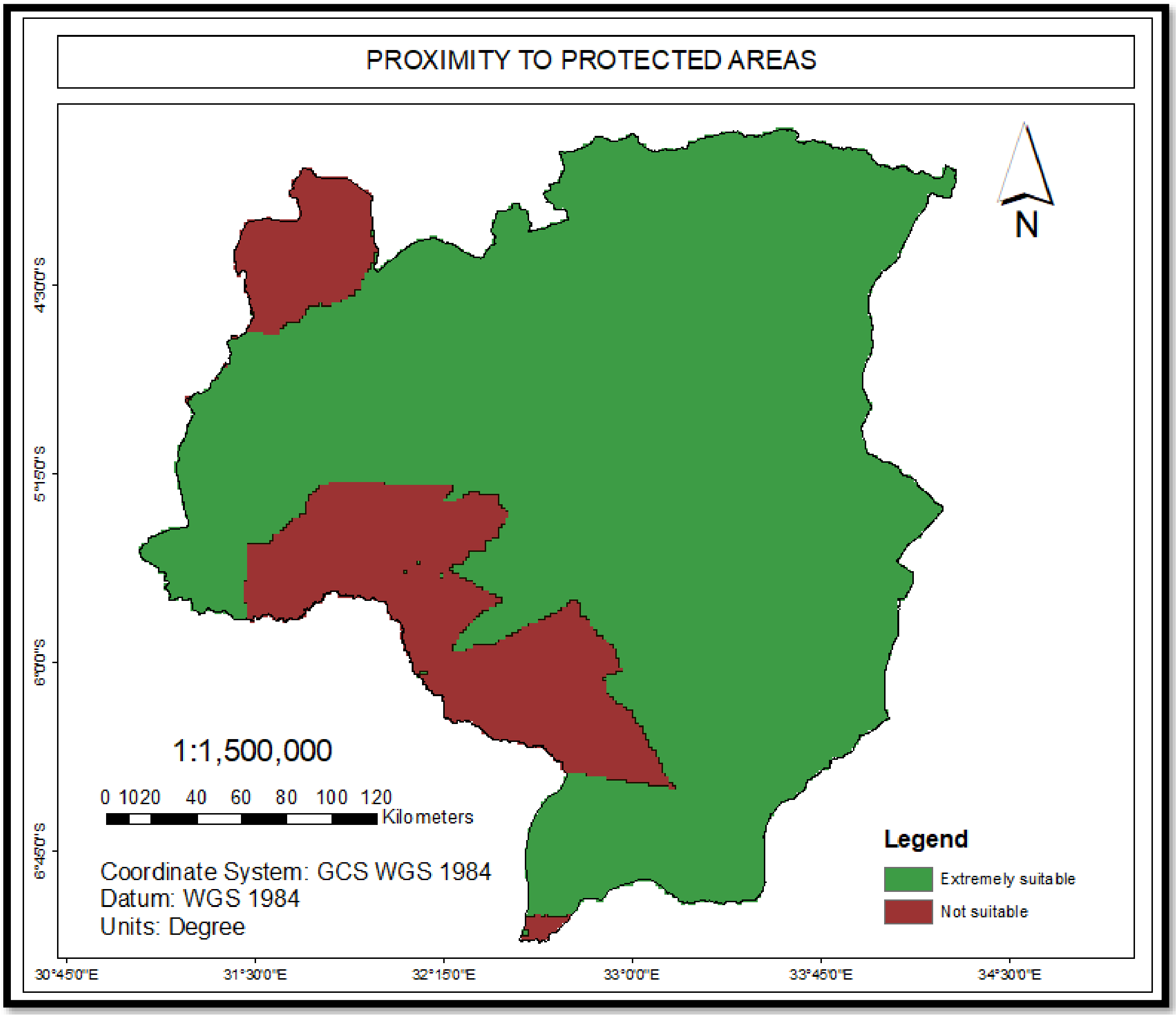

Figure 4.6 Reclassified proximity to protected areas map

4.3.6 Proximity to water bodies

Tabora region is not characterized by having many water bodies thus has very few water bodies and this calls highly for the sustainability of these water sources whereby the area was reclassified in terms of the distance from water bodies and figure 4.7 below indicates the reclassification of the area from water bodies in distance covered from them.

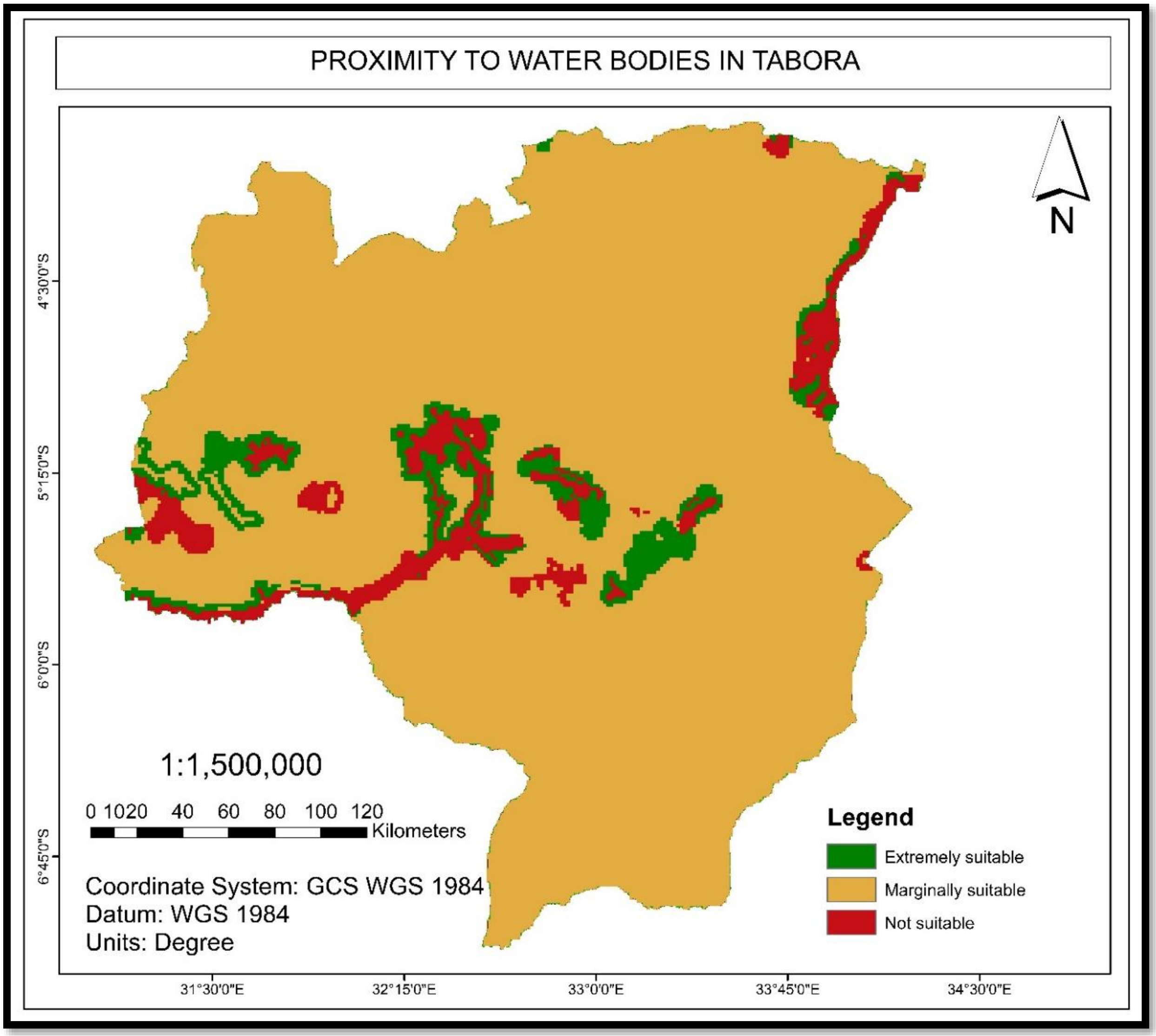

Figure 4.7 Reclassified proximity to waterbodies map

4.3.7 Proximity to roads

Since roads are one of the necessities required for any plantation activities, figure 4.8 indicates the reclassification of the distances from the roads in order to support the transportation of produced goods as well as personnel from one area to the other where by most of the area are suitable since the areas has a well road network distribution.

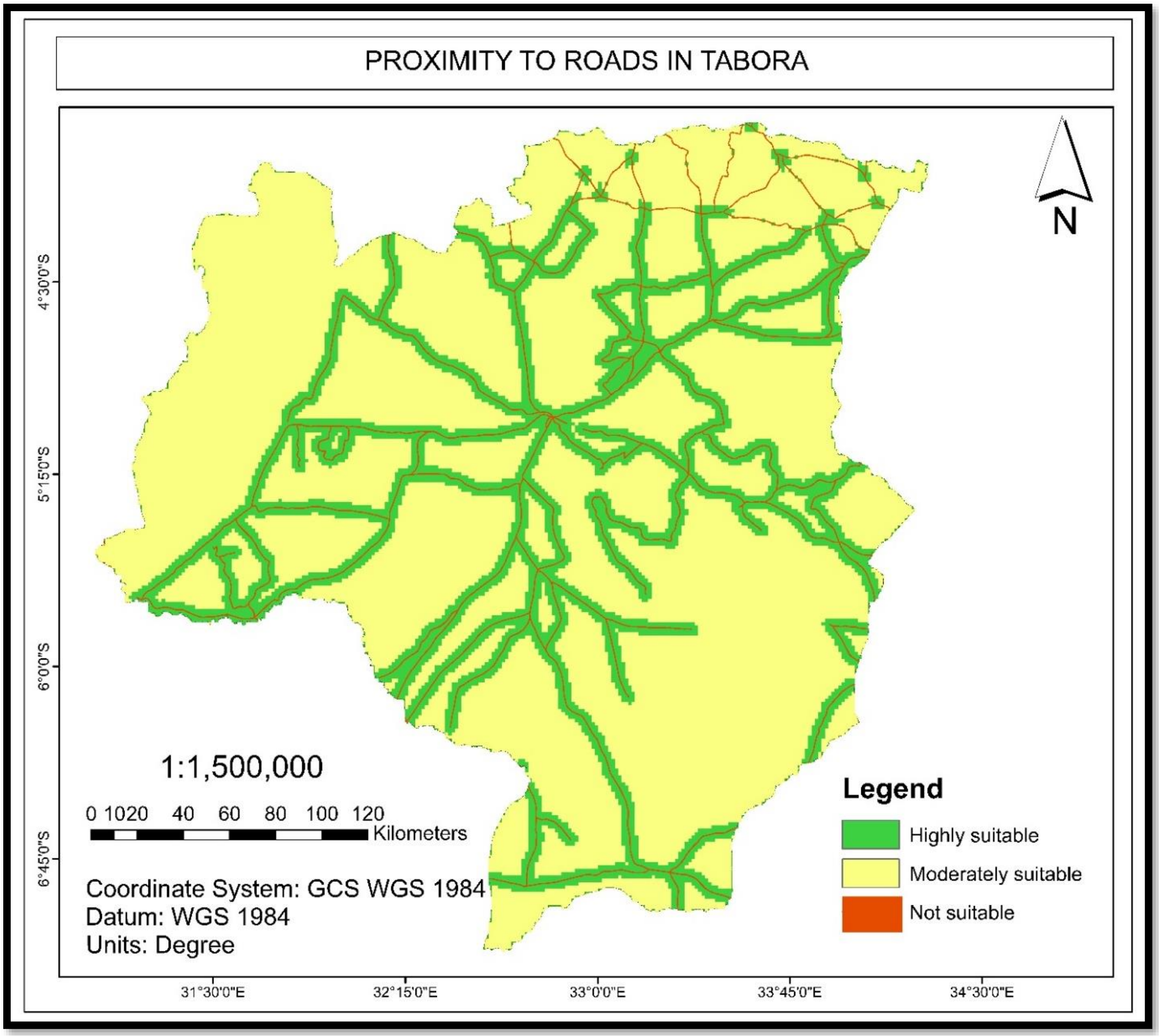

Figure 4.8 Reclassified proximity to roads map

4.3.8 Land cover

From the study areas' reclassified land cover map a total of three classes were obtained where by some areas were Extremely suitable marking a total of 54.16%, moderately suitable marking a total of 2.61% and Not suitable marking a total of 45.23% of an entire study area. Thes southern part was highly Not suitable for the establishment of sustainable palm plantations while most of northern areas were Extremely suitable. Only fewer parts of the region fell into the moderately suitable class located in some western and North east of the region.

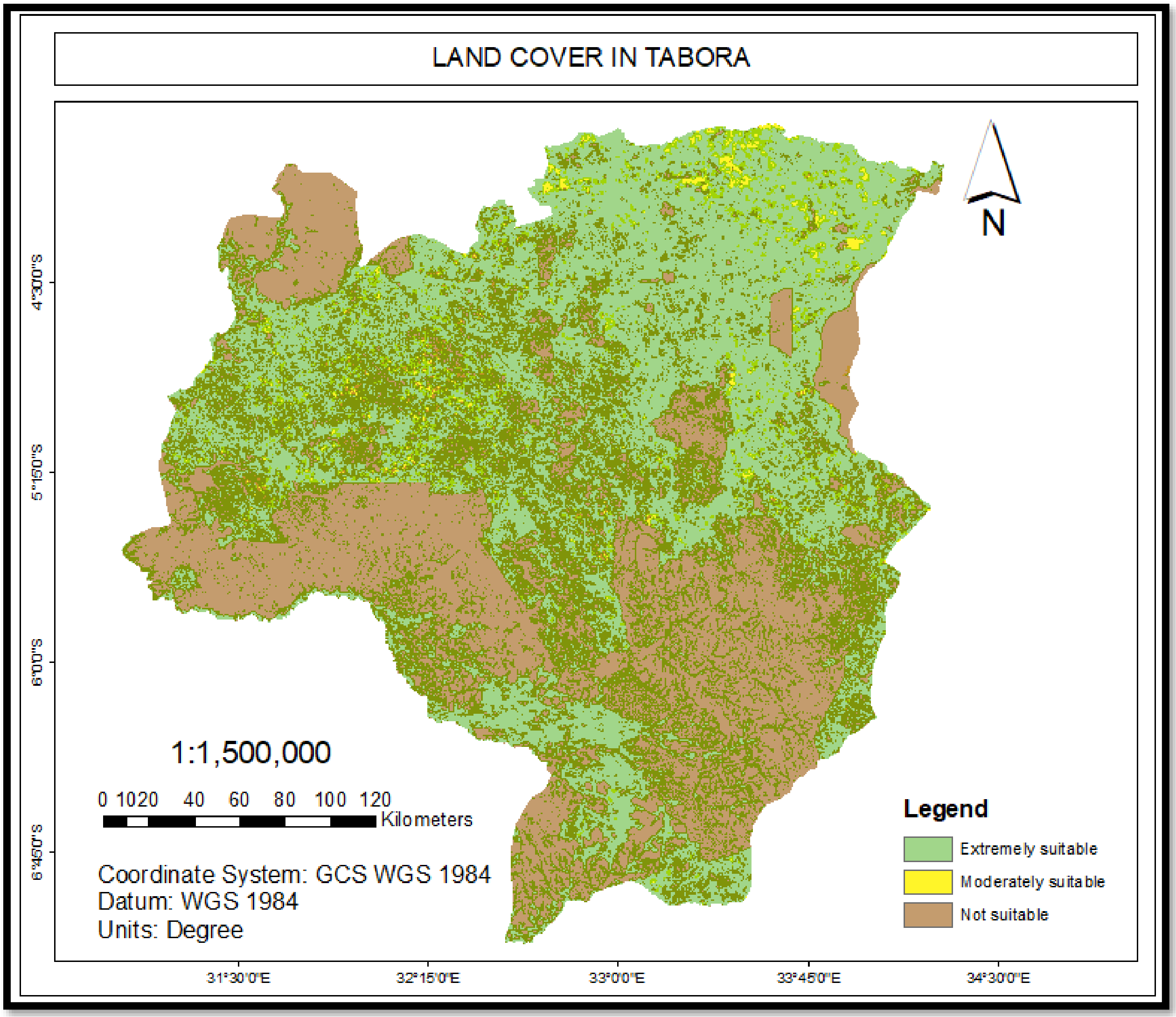

Figure 4.9 Reclassified landcover map of Tabora

4.4 Suitability map for sustainable palm plantations in Tabora region

The final map showing the areas suitable for establishment of sustainable palm plantations in Tabora region was developed based on the weighted overlay process aided by the established weights for each criterion together with the constraint layers which portray areas that are excluded from the suitability analysis. Figure 4.9 show the suitable areas for sustainable palm plantation in Tabora region by the mid-part extending to the western part of the region tends to be highly suitable compared to the eastern parts of the regions.

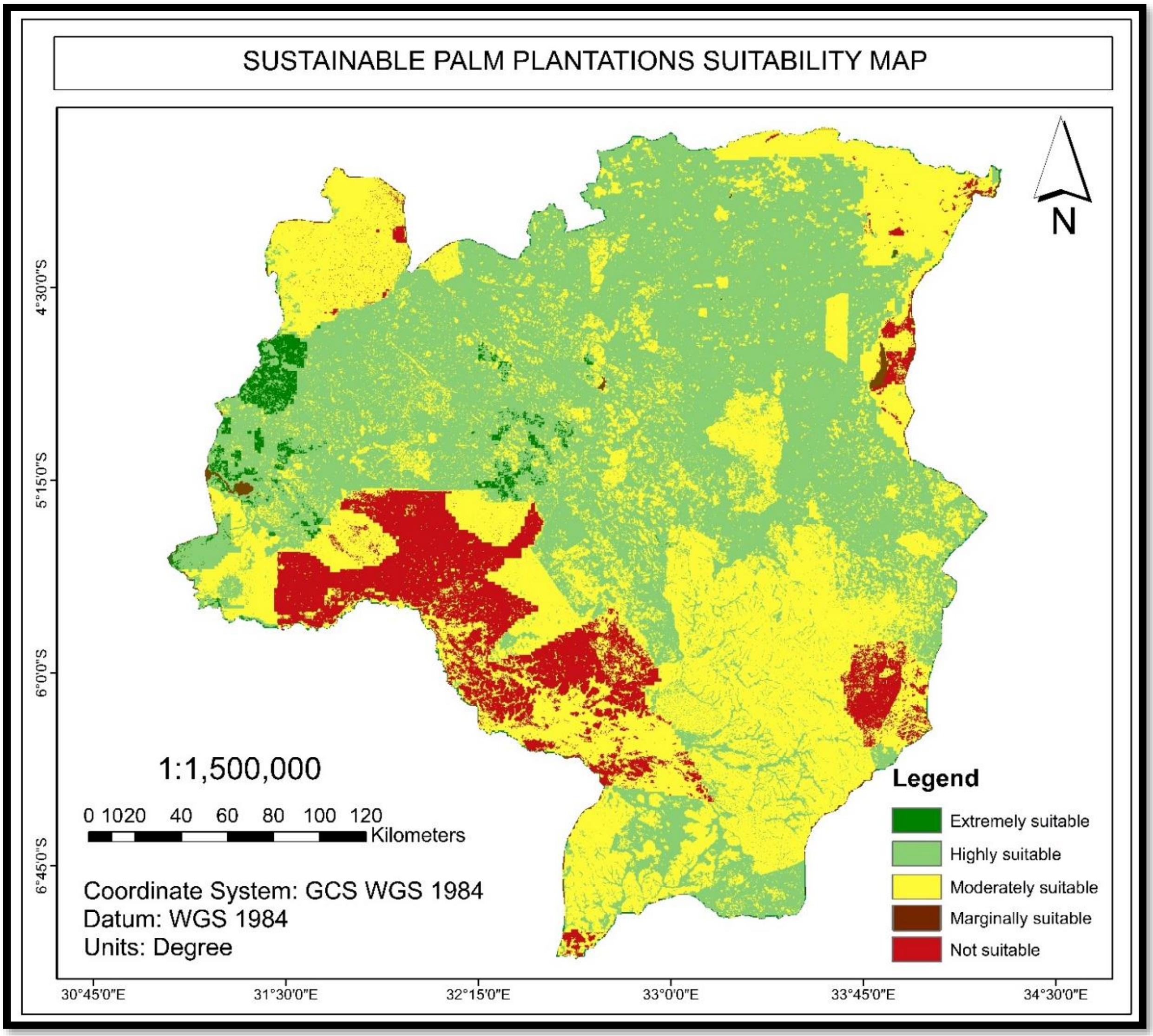

Figure 4.10 Sustainable palm plantation suitability map

Basing on the criteria and constraints the final suitability map has elaborated areas of different suitability based on the criteria and constraints of this research whereby only 769.41 square kilometres that constitutes only 1% of the total area is extremely suitable, while 36,931.54 square kilometres making 48% is Highly suitable, 31,545.69 square kilometres making 41% of entire area has Moderate suitability, 769.41 square kilometres making 1% of entire area has Marginal suitability and finally an area of 6,924.66 square kilometres making 9% of Tabora region was determined to be Not suitable for establishment of sustainable palm plantations. These classes are portrayed in figure 4.11, with these results, it is vivid that the peasants in the areas that has been identified to happen being in suitable areas for the practice should be provided with support to establish these plantations as well as different investment companies should take a lead in investing in those areas to help in eradicate the shortage of cooking oil problem in Tanzania.

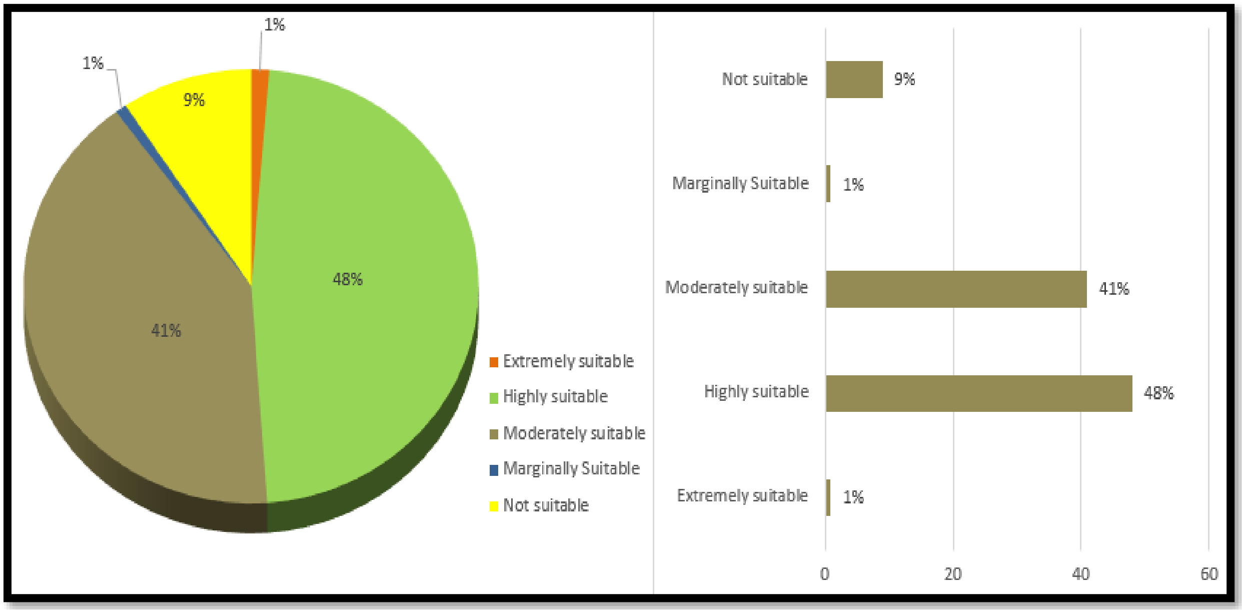

Figure 4.11 Graphs showing the comparison of classes

4.5 Discussion of the result

The findings of this study have important implications for the development of palm oil plantations in Tabora region. The government and private investors should focus on developing plantations in the mid-part and western parts of the region, where the conditions are most favorable. This will help to ensure that the plantations are productive and sustainable.

The findings of this study also have implications for the sustainable management of palm oil plantations. The government and private investors should take steps to ensure that palm oil plantations are developed in a sustainable manner, taking into account the environmental and social impacts of these plantations. This includes using sustainable agricultural practices, minimizing the use of pesticides and fertilizers, and protecting the rights of local communities.

The study also has some limitations. First, the study was conducted at a single point in time, so it is possible that the suitability of land for palm oil plantations has changed since then. Second, the study did not consider the economic and social factors that may influence the development of palm oil plantations. Future research should address these limitations.

Overall, the findings of this study provide valuable information for the development of sustainable palm oil plantations in Tabora region. The government and private investors should use this information to make informed decisions about the future of palm oil production in the region.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The results of this study indicate that the mid-part and western parts of Tabora region are the most suitable for the establishment of sustainable palm plantations. This is consistent with the findings of other studies, which have shown that these areas have favorable climatic conditions, soil types, and slope gradients for palm oil cultivation. The eastern parts of the region are less suitable for palm oil plantations due to their drier climate and steeper slopes.

The study used eight criteria to determine the suitability of land for sustainable palm oil plantations: rainfall, soil pH, slope, proximity to water bodies, proximity to protected areas, proximity to roads, land cover and temperature. The results of the suitability analysis showed that the mid-part and western parts of Tabora region are the most suitable areas for sustainable palm oil plantations. These areas have all eight of the criteria in place, making them the most likely to be successful.

Overall, the findings of this study provide valuable information for the development of sustainable palm oil plantations in Tabora region. The government and private investors should use this information to make informed decisions about the future of palm oil production in the region.

5.2 Recommendation

The following recommendations are worth taking based on the findings of this research;

- Several criteria were considered thus further studies should be considered in order to produce a further reliable suitability map by taking into consideration other factors such as social and economic factors.
- Prior to land use planning the suitability analysis should be conducted in different developing areas to provide a room for proper land use in different locations.
- Ministry of agriculture and other agriculture sectors should employ suitability analysis knowledge in determining areas for conducting cultivation of different crops that may result into high yield.

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