UNIVERSITY OF NAIROBI

SUITABILITY ANALYSIS OF MAKUENI COUNTY FOR THE GROWTH OF DUMA WHEAT USING GIS

By

MAVINDU SIMON MUTUNGA

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ABSTRACT

Wheat was introduced to Kenya in the early 1900s and was initially grown in the Rift Valley. In the 1950s and 1960s, the government encouraged farmers to grow wheat as a cash crop. In recent years, the government has made efforts to revive the wheat sector by investing in irrigation infrastructure and promoting new technologies. Duma is a popular drought wheat variety developed by KALRO in 2010.

Makueni is a semi-arid county in Eastern Kenya. The main livelihood of the county Is farming, to be specific maize and beans. Food security is a major issue in the county. There was a need to address this issue. Wheat is a high-value crop and one of the most consumed foods in the country. More farmlands other than the existing ones could be beneficial to the increment in agricultural production and hence the Gross Domestic Product of the county and the country.

The main objective of the study was to determine the areas in Makueni that were suitable for the growth of Duma wheat. Suitability criteria for the growth of the Duma wheat variety were determined. These were found to be Soil pH, Rain, Temperature and Altitude. Land Use of the area was also factored in into overall suitability. A geodatabase was created on ArcMap and these suitability criteria were loaded. Preprocessing was done on the datasets to standardize them for processing. The pairwise comparisons were done using the AHP tool of ArcGIS and were subjective based on the advice from Kenya Seeds Company The processing was doing the weighted overlay on the weights gotten from the pairwise comparisons that were done using the AHP tool. The result was a suitability raster model of 30-meter resolution. The raster output was converted to vector and based on that; areas covered by the different suitability classes on Makueni County gotten. 28% of Makueni was found to be Highly Suitable,52% Moderately Suitable,14% Marginally Suitable and 6% Not Suitable. Based on the results, Makueni was found to be generally moderately suitable and would thus require only minor adjustments to grow the Duma Wheat variety. It was therefore recommended that wheat farming be encouraged in the county since it would bring higher returns.

DEDICATION

I dedicate this project to my family (Kavyu and Mutunga) and all Kenyan people that will find it useful.

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I express my sincere gratitude to my supervisor Prof. Galcano C. Mulaku, Department of Geospatial and Space Technology, University of Nairobi, for his advice and guidance that has enabled the success of this project.

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ACRONYMS AND ABBREVIATIONS

AHP	Analytical Hierarchy Process
USAID	United States Agency for International Development
KALRO	Kenya Agricultural and Livestock Research Organization
KENSOTER	Soil and Terrain Database for Kenya
LULC	Land Use Land Cover
IDW	Inverse Distance Weighting
GIS	Geographic Information System
MCDM	Multi-Criteria Decision Making

CHAPTER 1: INTRODUCTION

1.1: Background of the study

Wheat is one of the most consumed foods in Kenya. However, Kenya has to import wheat to meet the growing demand for wheat. According to the United States Department of Agriculture (USDA), Kenya is one of the largest importers of wheat in Africa; in 2020, Kenya imported 1.8 million metric tons of wheat. This is due to the growing population and the variety of wheat products in the Kenyan market for example *Chapati*, a famous flatbread made of wheat flour. Therefore, there is a need to produce more wheat. Africa as a continent mainly imports wheat. To reduce dependency on imports from other continents, some approaches like subsidizing imports have been put in place. However, the wheat produced locally has never met the demand. This has mainly been due to the lack of suitable agro-ecologies and high costs of production. Agroecology involves the application of ecological concepts and principles to design and manage sustainable and resilient farming systems.

Geospatial technologies like GIS can be utilized to help promote agricultural practices that are environment-friendly, socially just, and economically viable through their analytic and decision-making capabilities. The land is a valuable asset as it is the primary factor of production and the ultimate source of wealth and the foundation on which many civilizations are constructed. Land misuse is and ha been a serious issue, as it can lead to long-term negative impacts on the environment, people's health, and the economy. Sustainable land use practices that take into account the needs of both people and the environment are crucial to address this problem. Part of the solution to the land-use problem is land evaluation in support of rational land-use planning and appropriate and sustainable use of natural and human resources. (Rossiter, 1996)

Land evaluation as defined by FAO(1976) is 'the assessment of land performance when used for a specified purpose, involving the execution and interpretation of surveys and studies of landforms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation' Knowing what crop is best suited for land at a specific time based on some specific variables is key to making better decisions on what crop should be there. This is part of the land valuation. GIS technologies can be used to this objective to give substantive results.

1.2: Problem Statement

Makueni faces the issue of food security as a county. The main livelihood for the people is farming, to be specific subsistence farming. Farmers often fail to make it to the next season with food. Over the past few years, there has been an introduction of good farming practices to prevent land degradation and soil erosion.

This study aims to establish areas that would be suitable for wheat. This might introduce a new farming area that might help narrow the gap in the deficit of wheat products as it is the most highly consumed product in the Kenyan market. This can be applied to finding out some other food or cash crops that would be of higher benefit to the farmers leave alone the maize and beans which are mostly cultivated.

1.3 Project Objectives

1.3.1: General Objective

Determine the areas in Makueni County that are suitable for the growth of Duma wheat.

1.3.2: Specific Objectives

a. Determine the suitability criteria.
b. Collect relevant data and create a GIS database.
c. Use GIS MCA techniques to determine the suitable areas.

1.4: Justification of the Study

Sustainability in agriculture would go a long way in improving the well-being of Kenya's economy and improving food security. Kenya mainly depends on agricultural production for foreign exchange and hence revenue.

In the recent years the major areas that were used for agricultural production have reduced due to factors such as urbanization. Application of technology just like the western economies Kenya imports from would go a long way in exporting rather than importing. Most of Kenya's land is arable but the lands capabilities have not yet been established.

Geospatial technologies are well known and used in the developed countries to increase production and sustainability through their wide range of applications, which is what Kenya needs. As compared to other methods of research, the use of geospatial technologies like GIS is much cheaper and faster and the analysis can also be conducted on a large area easily. The results are also easy to understand to a non-professional and more reliable. The results can also be used to guide recommendations and policies that can be implemented for the improvement of the agricultural sector. In addition to finding the suitability of land to a particular crop, it also identifies land that is not fit for the crop to be used for other purposes. This prevents land degradation.

1.5: Organization of the report

This report has five chapters:

Chapter one introduces the project and the justification of the same. The problem statement behind the project is also presented in this chapter. The general objectives as well as the specific objectives, are also outlined in this chapter. Chapter two deep dives into the review of the GIS function in agriculture – in this case land suitability of Makueni for the growth of the Duma wheat variety in Makueni county, Kenya. A case study of project done using similar methodology is also put in this chapter. Chapter three presents into the methodology employed in the project. Chapter 4 is mainly on the final results and discussions of the results. Chapter 5 is mainly on Conclusions and recommendations that were drawn from the study.

CHAPTER 2: LITERATURE REVIEW

2.1: Land Suitability Analysis; Overview

The land is a solid terrestrial surface of planet Earth. Land suitability is the fitness of a given type of land for a defined/specific use. Suitability can also be defined as the measure of how well the qualities of a land unit match the requirements of a particular form of land use (FAO, 1976). MacDonald (2006) defined land suitability analysis as the separation of the nature or quality of land into its component parts based on the land's ability to serve a particular use or purpose.(Singha and Swain, 2016)

Land evaluation is formally defined as 'the assessment of land performance when used for a specified purpose, involving the execution and interpretation of surveys and studies of landforms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation.' FAO (1981). Land suitability analysis aims at establishing opportunities and constraints to the sustainable use of land. This case study uses land suitability analysis for wheat growth in Makueni County. This information is crucial in land use planning.

Agricultural Land suitability is a function of crop requirements and land characteristics. There are two approaches to this as reported by (Baja et al., 2007)

a. **Qualitative:** No specific measurable terms are used to show the suitability: the land is characterized as highly suitable, moderately suitable, or not suitable.
b. **Quantitative:** Measurable terms are used. Numeric indicators show the variability of suitability on the land.(Kurtener et al., 2008)

Potential land suitability for agriculture based on the physical human, animal and infrastructural preference in accordance with the framework for land evaluation was developed by FAO (1976).

2.2: Wheat Growing

Wheat is one of the most grown and also consumed crops in the world. Approximately 749,467,531 tons of wheat are produced annually in the world according to Atlas Big. China is the largest wheat producer in the world with approximately 131,696,392 tons of production volume per year. There is a need for scaling up the production of this crop as its one of the most consumed staples globally. This would be a major step to attaining food security across the globe.

2.3: Wheat Growing in Kenya

After maize, wheat is one of the most-grown cereal crops in Kenya. In 2020 wheat production for Kenya was 300,000 tons according to Knoema. Currently, Kenya faces food insecurity with hunger prevalent in most of the arid and semiarid regions of the country. This is most noticeable in Northern Kenya and some parts of Eastern provinces. The market is undersupplied: wheat has overtaken maize in terms of consumption. There is a need to boost production. This can be done by introducing other places where wheat can be grown. There is a need to bridge this gap.There is a variety of wheat grown in Kenya which include; Kenya Wren, Robin, Kenya Tai, Kenya , Korongo, Kenya Hawk12, Kenya Sunbird, Eagle10, Njoro-BW2, Kwale, Duma and the Njoro-BW1 The choice of variety depends on the area of production and resistance to disease. (Joshi et al., 2017).

2.4: Wheat Varieties in Kenya

a. Kenya Wren

Grown at altitudes of 1800-2400 m above sea level. It is grown in Njoro, Timau, Mau-Narok and Molo. It has a yield potential of 8.5 tons per Hectare. The maturity period is between 120-130 days. It was released in 2012. It also has a seed rate of 50 kg /acre. Some of the special attributes of this variety are;

i. Resistance to yellow and stem rust is moderate
ii. Tolerant to acidic soils
iii. Large red hard grain
iv. It is good for industrial and home baking
v. Excellent flour conversion

This variety may grow tall under high nitrogen application. Two or more fungicide applications are needed depending on seasonal rust and disease pressure.

b. Robin

Grown at altitudes of 1800-2700 meters above sea level. It is grown in Njoro, Timau, Mau-Narok, Molo, Narok and Eldoret. The yield potential is 8 tons/Ha. It has a maturity period of 110-120 days. It was released in 2009. It also has a seed rate of 50kg/acre. Some of the special attributes of this variety include;

i. Widely adapted and relatively early maturing
ii. Large red hard grain
iii. Good milling and baking qualities

Two and often several fungicide applications are needed due to its high susceptibility to stem rust and Fusarium Head Blight, especially under minimum tillage.

c. Kenya Tai

Grown at altitudes of 1800-2100 meters above sea level. It is grown in Njoro, Timau, Mau-Narok, Molo and Eldoret. The yield potential is 6.5 tons/Ha. It has a maturity period of 100-110 days. It was released in 2012. It also has a seed rate of 50kg/acre. Some of the special attributes of this variety include;

i. Moderately resistant to stem rust
ii. Red hard grain
iii. Heavy biomass hence an excellent source of straw for livestock feed

One or more fungicide applications are needed depending on seasonal rust disease pressure.

d. Kenya Korongo

Grown at altitudes of 2100-2400 meters above sea level. It is grown in Njoro, Timau, Mau-Narok, upper Narok, Molo and Eldoret. The yield potential is 8.5 tons/Ha. It has a maturity period of 120-130 days. It was released in 2012. It also has a seed rate of 50kg/acre. Some of the special attributes of this variety include;

i. White hard grain
ii. Very high flour conversion

iii. Excellent baking and confectionery qualities.

White grain makes it very good for home baking (*Chapatti*). Two or more fungicide applications are needed depending on seasonal rust disease pressure.

e. Kenya Hawk12

Grown at altitudes of 2100-2400 meters above sea level. It is grown in Njoro, Timau, Mau-Narok, upper Narok, Molo and Eldoret. The yield potential is 8.0 tons/Ha. It has a maturity period of 120-130 days. It was released in 2012. It also has a seed rate of 50kg/acre. Some of the special attributes of this variety include;

i. Red hard grain
ii. Lodging and pre-harvest sprouting tolerant
iii. Good for industrial and home baking.

A good choice for areas that receive rain during harvesting e.g. Mau Narok and Timau. Two or more fungicide applications are needed depending on seasonal rust disease pressure.

f. Kenya Sunbird

Grown at altitudes of 1800-2100 meters above sea level. It is grown in Njoro, Timau, Mau-Narok, upper Narok, Molo and Eldoret. The yield potential is 6.5 tons/Ha. It has a maturity period of 100-110 days. It was released in 2012. It also has a seed rate of 50kg/acre. Some of the special attributes of this variety include;

i. Moderately resistant to stem rust
ii. Heavy biomass hence an excellent source of straw for livestock feed
iii. Good for industrial and home baking.

May succumb to yellow rust under high pressure. One or more fungicide applications are needed depending on seasonal rust and disease pressure.

g. Eagle10

Grown at altitudes of 1800-2100 meters above sea level. It is grown in Njoro, Rongai, Lower Narok, Kinamba and Naivasha. The yield potential is 6.5 tons/Ha.

It has a maturity period of 100-110 days. It was released in 2010. It also has a seed rate of 50kg/acre. Some of the special attributes of this variety include;

i. Resistant to stem rust
ii. Early maturing
iii. Good for industrial and home baking.

Suitable for short rain and drought-prone areas. A good choice for a second crop. One or more fungicide applications are needed depending on seasonal rust disease pressure

h. Njoro-BW2

Grown at altitudes of 2100- 2400 meters above sea level. It is grown in Njoro, Timau, Mau-Narok, upper Narok, Molo and Eldoret. The yield potential is 8.0 tons/Ha. It has a maturity period of 140- 160 days. It was released in 2002. It also has a seed rate of 45-50kg/acre. Some of the special attributes of this variety include;

i. High-yielding red hard wheat
ii. Tolerant to acid soils, lodging and pre-harvest sprouting
iii. Excellent baking qualities

A good variety especially under acidic soils prevalent in Uasin Gishu and Molo.

i. Kwale

Grown at altitudes of 2100- 2400 meters above sea level. It is grown in Njoro, Timau, Mau-Narok, upper Narok, Molo and Eldoret. The yield potential is 8.0 tons/Ha. It has a maturity period of 140- 160 days. It was released in 1987. It also has a seed rate of 50kg/acre. Some of the special attributes of this variety include;

i. Red hard wheat
ii. High biomass
iii. Highly responsive to nitrogen application
iv. Good baking qualities.

It also popular for its high-test weight. Spraying against stem rust might be required especially under high disease pressure.

j. Duma

Grown at altitudes of 1800- 2100 meters above sea level. It is grown in Njoro, Rongai, Lower Narok and Naivasha. The yield potential is 6.0 tons/Ha. It has a maturity period of 100- 110 days. It was released in 1993. It also has a seed rate of 50kg/acre. Some of the special attributes of this variety include;

i. White hard grain
ii. Early maturing
iii. Drought tolerant
iv. Excellent baking quality.

Susceptible to stem rust under high pressure. Several spraying might be needed to control stem rust. However, earlier maturity often helps escape disease.

k. Njoro -BW1 (Drought Resistant)

Njoro-BW1 was released as the first mutant variety in 2001 by Kenya Agricultural Research Institute (KARI) and is today is cultivated on more than 10,000 hectares in Narok, Naivasha, Katumani, and Mogotio. Its popularity among Kenyan wheat farmers is increasing steadily, so much so that KARI's seed unit can barely keep up with farmers´ demand. Key side benefits include a moderate susceptibility to wheat rust; high yields, with grains valued for flour production of good baking quality. (Kamwaga *et al.*,2016)

2.4: Wheat Varieties in Kenya

There have been developments towards the wheat growing of drought-resistant varieties in the past. The Kenya Agricultural Research Institute developed appropriate wheat varieties for production in the ASALs (Arid and Semi-Arid Lands) as a strategy to improve food security in these areas. From several such varieties developed and tested (introduction, development and improvement) in selected ASAL districts, farmers in Machakos and Makueni chose two varieties Duma and Njoro-BW1 during the 2002/2003 cropping seasons. The results in the initial season were so encouraging. However, the seed demand was so huge that it could not be maintained. Other factors such as limited resources to support adequate seed bulking. This gap existed up to the first year of the seed bulking project and farmers were still enthusiastic to participate in the trials. There was need for immediate intervention since a persistent lack of seeds would certainly threaten the successful implementation of this noble idea. Consequently, KARI-Njoro station wanted its breeding station to fill the gap through a Community-Based Seed (CBO) Bulking and

Distribution Initiative that would guarantee seed availability in the selected districts in the long term. Gradually, and through deliberate sensitization efforts, wheat production was expected to spread to the other semi-arid districts of Kenya. The overall objective of this project was to therefore to promote wheat farming in the semi-arid districts of Kenya through support to wheat seed production, bulking and distribution in the selected districts of Makueni and Machakos. (Ooro *et al.*,2007)

2.5: Role of GIS in Land Suitability Analysis

Land can best be used if we logically match the characteristics of the land to the crop that best fits the profile. This study aims to establish the parts of Makueni County that will be suitable for the growth of wheat and to what degree they are favorable. Besides increasing output, this method can be incorporated to prevent land degradation by establishing crops that are planted where they should not be planted. Geographic Information Systems incorporate different land attributes for analysis purposes. We will utilize the decision-making power and the very capable location/spatial data capabilities of GIS to realize our objective of Wheat suitability in Makueni.

2.6: Suitability Classification

Classes will assist in visualizing the variability of the favorability of the land to wheat across its extents. Classes aren't meant to be many as it becomes complex to visualize them. The Food and Agricultural Organization recommended four levels of land suitability (FAO 1976) which are as shown in Table 2.1.

Table 2.1: FAO levels of land suitability

S1	Highly suitable	No significant limitation to agricultural productivity
S2	Moderately suitable	The land has some limitations that are limitations that are severe for agricultural productivity.
S3	Marginally suitable	Land with major limitations for sustained agricultural productivity
N	Unsuitable	Land with extreme limitations for sustained agricultural productivity.

2.7: Standardization of Criteria

The criteria have to be transformed to the same scale since each criterion has a different scale of measurement. This is simply the modelling of criteria to fit a standard that can be uniformly used to analyze them. In order for the decision matrix to be formed their needs a uniform data set. Standardization of criteria can be done in two ways:

a. Classification of the criteria into beneficial and non-beneficial; with high values going to the beneficial category and vice versa.
b. A standardized scale is used to show the significance of each criterion value based on expert recommendations

2.8: Multi Criteria Decision Making (MCDM) concept

MCDM was developed in the 1960s in order for decision-makers to find the most suitable method to integrate different suggestions/proposals into a potential framework that would make the final decision.(Ahmed et al., 2016)

In the past and also presently, considering multiple criteria when ranking or choosing between alternatives is a natural approach for making decisions. However, 'traditional' intuitive decision-making – how most people make their everyday decisions – typically involves evaluating the criteria and the trade-offs between them in an intuitive or holistic fashion. In contrast, MCDM, a sub-discipline of operations research with foundations in economics, psychology and mathematics, is concerned with formally structuring and solving decision problems. Most MCDA methods, which are increasingly supported by specialized software such as ArcGIS, involve the explicit weighting of criteria and the trade-offs between them.

Overall, MCDA is intended to reduce biases from decision-makers relying on their intuition which may lead to undesirable outputs, and also group decision-making failures (e.g., 'groupthink'), that almost inevitably afflict intuitive approaches .Logical solutions might be required and that's when MCDM/MCDA comes in.

Multicriteria Decision making will involve the selection of the alternatives/places in Makueni County that best suit the growth of wheat based on several unrelated criteria- which are the conditions that favor the growth of wheat. The physical conditions will be compared to the physical conditions that exist in Makueni. Their level of ‘matching’ determines if the place is suited for wheat.

2.8.1: Analytical Hierarchy Process

Analytic Hierarchy Process (AHP) is a Multi-Criteria Decision Making (MCDM) that is composed of techniques that are suitable for ranking critical management problems. A hierarchy is a system of ranking different options against each other based on importance.

Thomas Saaty developed the AHP in 1980. It uses pairwise comparison questions to elicit a matrix of judgments of the relative preference between each pair of alternatives with respect to each attribute and a matrix of judgments of the relative importance of each pair of attributes can be used as a consensus-building in tool in a situation involving a committee or group decision making (Saaty, 1988)AHP is particularly helpful when you are undecided on what choice alone will bring out the best output. AHP is a procedure that seeks to consider the context of a spatial planning decision, identifying and arranging the criteria into different groups (Vogel, 2008). AHP is based on three principles: **decomposition, comparative judgment, and synthesis of priorities (**C. J. Dawsen, Ed. ,2011)

The AHP uses linear algebra to assess the results of each pairwise comparison. Each criterion receives its own importance weight. The higher the weight, the more important the criterion is to the overall decision. In any AHP process, it is possible to disintegrate or simplify a decision involving numerous criteria through a four-step process *(*Russo and Camanho,2015). AHP consists of four steps:

a. Identify the decision, options, and criteria (hierarchy construction)
b. Conduct pairwise comparisons.
c. Calculate the importance weight of each criterion.
d. Identify the best option by calculating the numerical representation of how useful your to-be decision is.

Elements of one level in the hierarchy are related to the other level which is below them. Then comparisons of the criteria and alternatives and their relative rankings are calculated. Firstly, the criteria in the hierarchy construction must be determined and this can be done through different stages from the top level, middle level, and bottom level.

This process or function is vital to group decision-making as it presents important top elements for target achievement. AHP is simple peer-to-peer differences that can be tweaked to what best fits the objective and to determine the best criteria and/or alternatives there should be a focus on the weight of the factors. The criterion with the most weight overally 'adds the most' to the output. More also, the comparison matrix will have to be expanded by calculating the weights of the criteria and the local weight of the alternatives to obtain the matrix weight.

Table 2.2: Important evaluation scales of pair-wise comparison.

1	Equal Importance
3	Moderate
5	Strong
7	Very Strong
9	Extreme
2.4,6,8	Intermediate Values
1/3,1/5,1/7,1/9	Values for Inverse comparison

The value in the square matrix depends on the decision maker and its dimensions depend on the number of criteria. In our case this will be taken under advice from Kenya Seeds Company. The pairwise comparisons are arranged in the square matrix. The primary diagonal usually has the same elements since comparisons are made of the same criteria across the alternatives. The computation of the Eigenvector is then carried out in which the values are referred to as principal eigenvalues. It is out of the eigenvalues that the weights of criteria and sub-criteria are obtained.

2.8.2. Decision Rules in Multi-Criteria Decision Making

A decision rule is the ranking of the alternatives from the most to least desirable based on how the criteria and sub-criteria aggregation match the objective.

The use of decision rule facilitates:

a. Selection of the most desirable alternative
b. Sorting the alternatives (Makueni County raster subdivided into pixels) based on their performance ranking in the priority order from best to worst.

Decision rules provide the basis for selection, sorting, and ranking by integrating the data on alternatives and decision makers into an overall assessment of the alternatives. The assessment is usually expressed by the overall appraisal score**:** the value of a function that aggregates the outcome of a decision alternative overall evaluation criteria with the decision maker's preferences.

2.8.3: Overlaying Map Layers

The weighted overlay is a technique for applying a common scale of values to diverse and dissimilar input data to create an integrated analysis. After weighing the criteria, all the criteria maps were overlaid using a suitability index. The criteria that will be overlaid will be from the variety that has been selected.

2.9: Case Study

(Fekadu and Negese, 2020) conducted research on GIS assisted suitability analysis for wheat and barley crops through AHP approach at Yikalo sub-watershed, Ethiopia. The most important climatic, topographic and soil parameters were selected. Each parameter was subjected to pair-wise comparison following Analytical Hierarchy Process (AHP). The suitability of each factor for wheat and barley was generated and the overall suitability of the land was developed using the weighted overlay tool of GIS software. The land suitability procedure followed the guideline of the Food and Agricultural organizations [FAO], (1976), where the crop requirements were assessed and used to determine the suitability of the area

Then, land characteristics such as climate, erosion hazard, wetness, soil physical properties, soil fertility and chemical properties, and topographical data were compared with wheat and barley crops requirements as described by Sys et al. (1991, 1993). The raster format in GIS environment was employed to analyze land suitability due to its simplicity in the overall weightage process. Raster suitability maps for each parameter for wheat and barley crops were developed by interpolation with a pixel size of 30 m, then reclassified to a common suitability level using ArcGIS 10.4 software for the weighted overlay to derive final suitability maps for the crops. and was developed using weighted overlay tool of GIS software.

The final output map showed that 83.21% (1945.17 ha) of the study area is moderately suitable, and 16.79% (392.52 ha) was marginally suitable for wheat cultivation. Likewise, it was observed that 86.14% (2013.61 ha) and 13.86% (324.08 ha) of the watershed was moderately and marginally suitable, respectively, for barley production. MCDM capabilities of GIS using the AHP tool were found to be very beneficial.

The conclusion was that under the existing farming practice, the productivity of cereals is not enough to cater for the people of Ethiopia. Sustainable and immediate land use planning and suitability analysis would help to use the land according to its potential. The study considered climatic, topographic and soil characteristics in Yikalo sub-watershed at Lay-Gayint district to analyze the suitability of the land for wheat and barley production. The result showed the land was not entirely highly suitable for producing these crops. Based on the limiting factors, suitable agricultural practices could be established based on the study.

CHAPTER 3: METHODOLOGY

3.1 Study Area

Makueni county is a former Eastern province county of Kenya. It experiences semi-arid climatic conditions with an average temperature range between 15℃ – 26℃ and annual rainfall ranges between 250mm to 400mm per annum in the lower regions of the county and the higher region receives rainfall ranging from 800mm to 900mm. Its capital is Wote.

The county has a population of 987,653 (2019 census). The county lies between Latitude 1° 35' and 2° 59' South and Longitude 37° 10' and 38° 30' East. It borders Machakos to the North, Kitui to the East, Taita Taveta to the South, and Kajiado to the West and covers an area of 8,008.9 km^2. The county has thirty wards as shown in Figure 3.1:

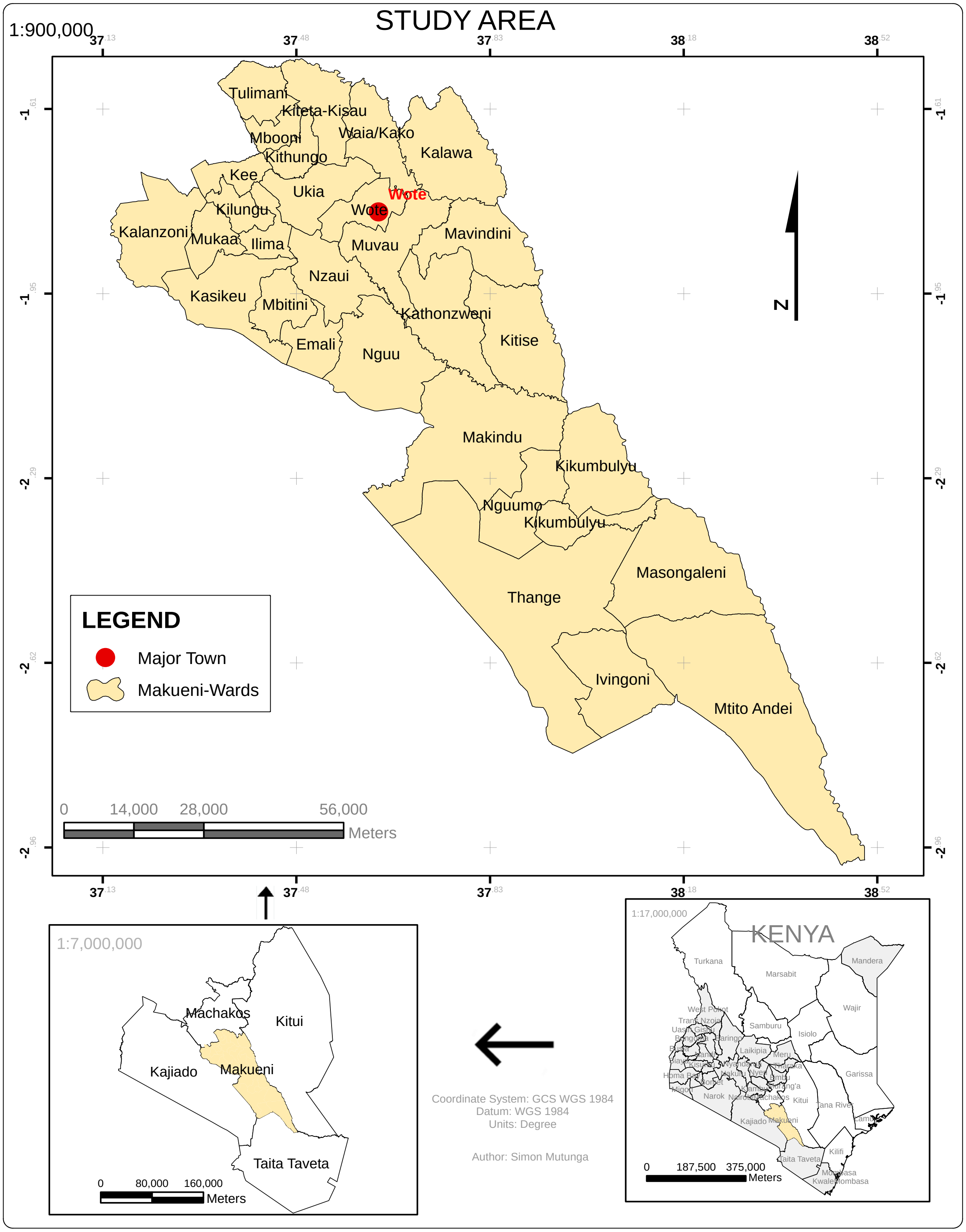

Figure 3.1: Study Area

3.2: Materials and Equipment

SOFTWARE

-ArcGIS Desktop 10.8

-QGIS Desktop 3.28.1

-Microsoft Word 2016

-Microsoft Excel

-Power point

HARDWARE

-Core i5 64-bit Hp computer

-USB flash drive

-Cell phone

3.3: Methodology Overview

Figure 3.2 shows the flow of the project in brief. First, the criteria that would be used at evaluating the overall suitability of Makueni county was identified. These criteria would later be used to guide in the collection of the relevant datasets to be used in the analysis. These criteria were: Altitude, Land Use, Rainfall, Temperature and Soil data. The suitability factors/criteria were then resampled and reclassified to come up with standardized maps that would later be overlaid through the weighted overlay tool in ArcGIS using the weights that were gotten from the pairwise comparison using AHP to come up with a suitability map.

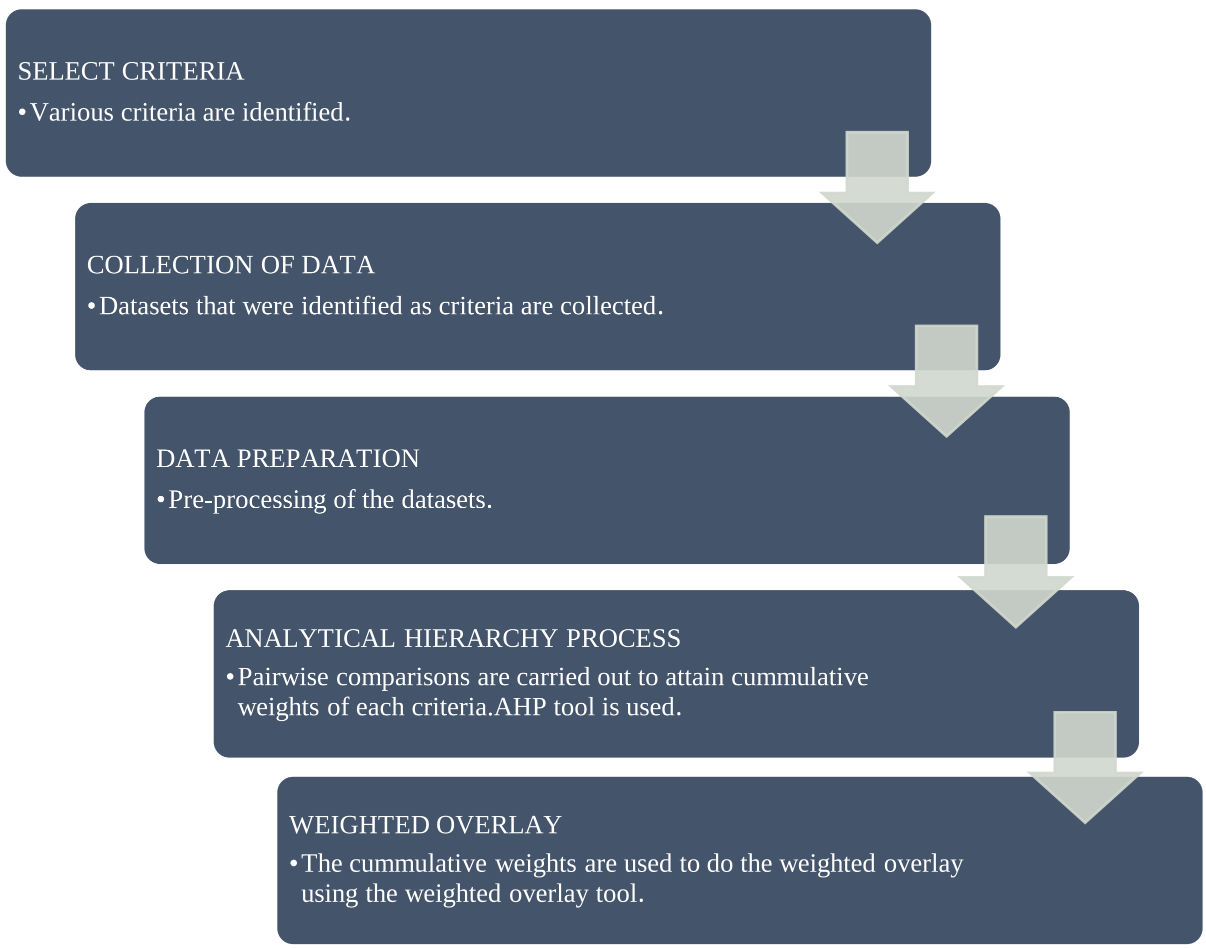

Figure 3.2: General process of suitable areas in Makueni County that favor the growth of Duma Wheat variety

3.3.1: Identification of relevant decision criteria

In order to come up with a suitability of Makueni County for Duma variety, several factors determine if it suitable or unsuitable. Based on research from Kenya Seeds Company website and KALRO website, the factors that were found to be crucial in the growth and development of wheat were:

- Altitude
- Rain
- Temperature
- Soil drainage
- The level of acidity of soil/Soil pH

These are the factors that were afterwards considered as criteria in the determination of the suitability of the county to the growth and development of Duma wheat.

The land use land cover map also needed to be considered as a criterion since it had to be considered that some places couldn’t be considered as suitable if they were either built up or protected areas.

3.3.2: Data Sources and Use

Table 2.3: Data Sources and Use

DATA	**SOURCE**	**USE**
Administrative Boundaries.	Open Africa Website.	Clipping the study area.
Temperature (Minimum and Maximum)	Kenya Meteorological Department	Temperature as factor rating and ranking.
Rainfall	Kenya Meteorological Department	For rainfall rating and ranking
Soil pH and Soil drainage.	KENSOTER	For the rating of soil characteristics and ranking.
Protected areas	World Resource Institute website	

3.4.2: Collection of data

Administrative boundaries and Makueni Roads data was gotten from the Open Africa Website.

The following datasets were obtained from the Kenya Meteorological Department.

- Daily Minimum Temperature within 2010-2021
- Daily Maximum Temperature within 2010-2021
- Rainfall 2010-2021

They were all in point form from twenty points across Makueni county. They had a spatial resolution of 600 meters.

Soil Drainage and Soil pH data were obtained from a zipped shapefile from KENSOTER. The zipped shapefile had a resolution of 600 meters.

Insights into the factors that favor the growth of wheat were gotten from Kenya Seeds Company. Advice on the soil datasets to use was gotten from KALRO.

The Land Use Land Cover data was gotten from ESRI Website application. It was an already classified Sentinel-2 10-metre resolution GeoTIFF file. The protected areas in the county were obtained from the World Resource Institute website.

3.5 Data Processing

3.5.1 Graphical Data Display: Thematic Maps

a. **Land Use Land Cover Data**

This data included a classified raster data from ESRI using Sentinel 2 imagery at 10-metre spatial resolution and roads and protected areas shapefiles. The objective here was to note areas that were non farmable for example towns, roads, areas that were very suited for farming (for example, areas that have been cultivated in the past and areas that had a possibility of being farms. The data that was obtained from ESRI had the conventional classes used to classify land use across the globe. Some classes that would be crucial in the determination of suitability of Makueni to Duma wheat growth were not present. The raster datasets for LULC and the roads and protected areas raster datasets were therefore merged and reclassified to come up with a raster showing different land uses including the main roads and protected areas within Makueni County. This was later reclassified into four classes indicating least to most suitable areas to farm. The final thematic map is shown in the Figure 3.3. The spatial resolution was resampled to 30 meters.

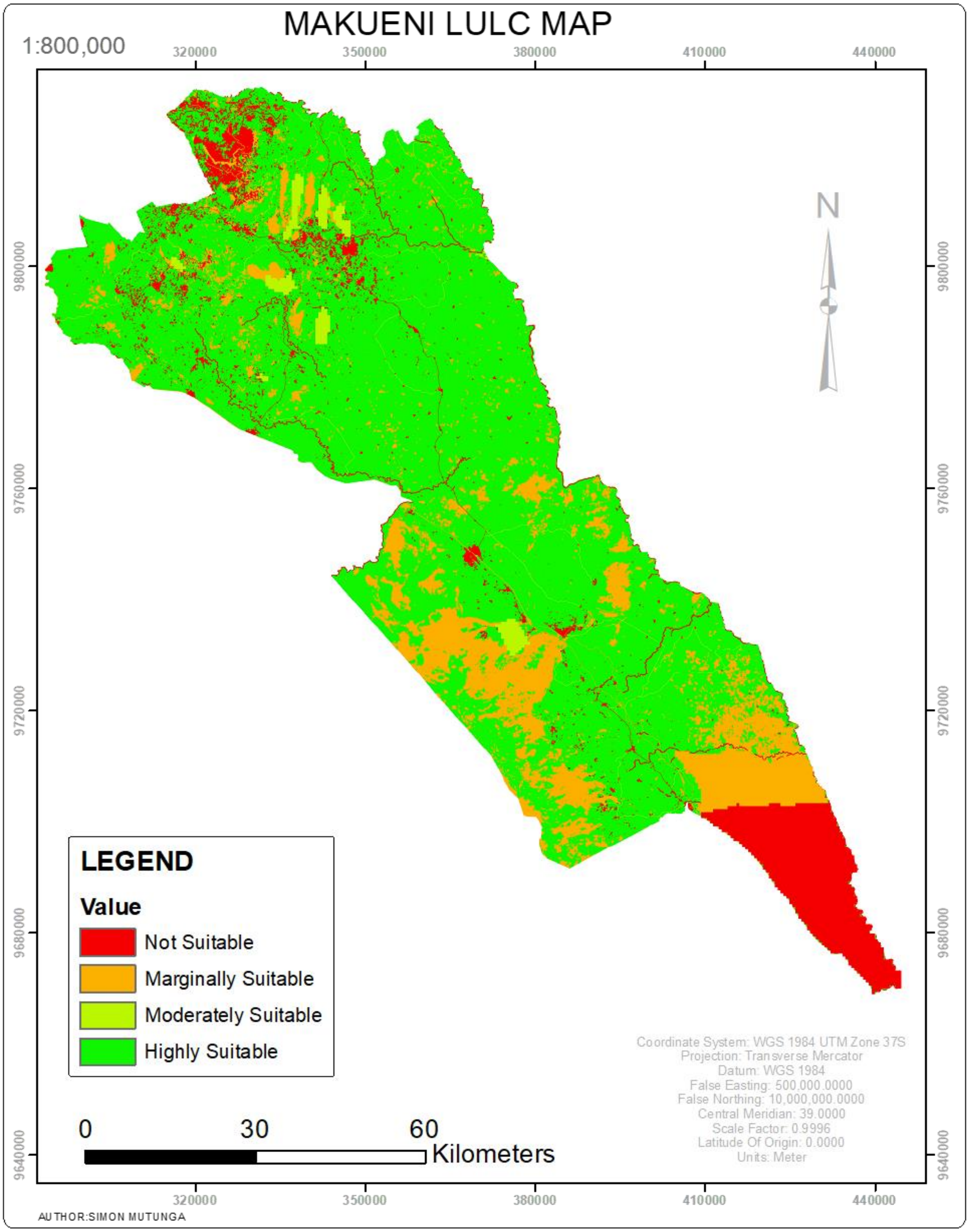

Figure 3.3: Land Use Land Cover Map

b. Rainfall Data

Rainfall data was acquired from the Kenya Meteorological Department. This was the daily rainfall the whole year round from the year 2010 to 2021.Cummulative 2021 rainfall was used. The data was in point form so a shapefile was created and then interpolated using the Inverse Distance Weighted Method in ArcGIS Desktop. The raster was then resampled to 30 meters and reclassified into four classes of suitability according to Figure 3.4

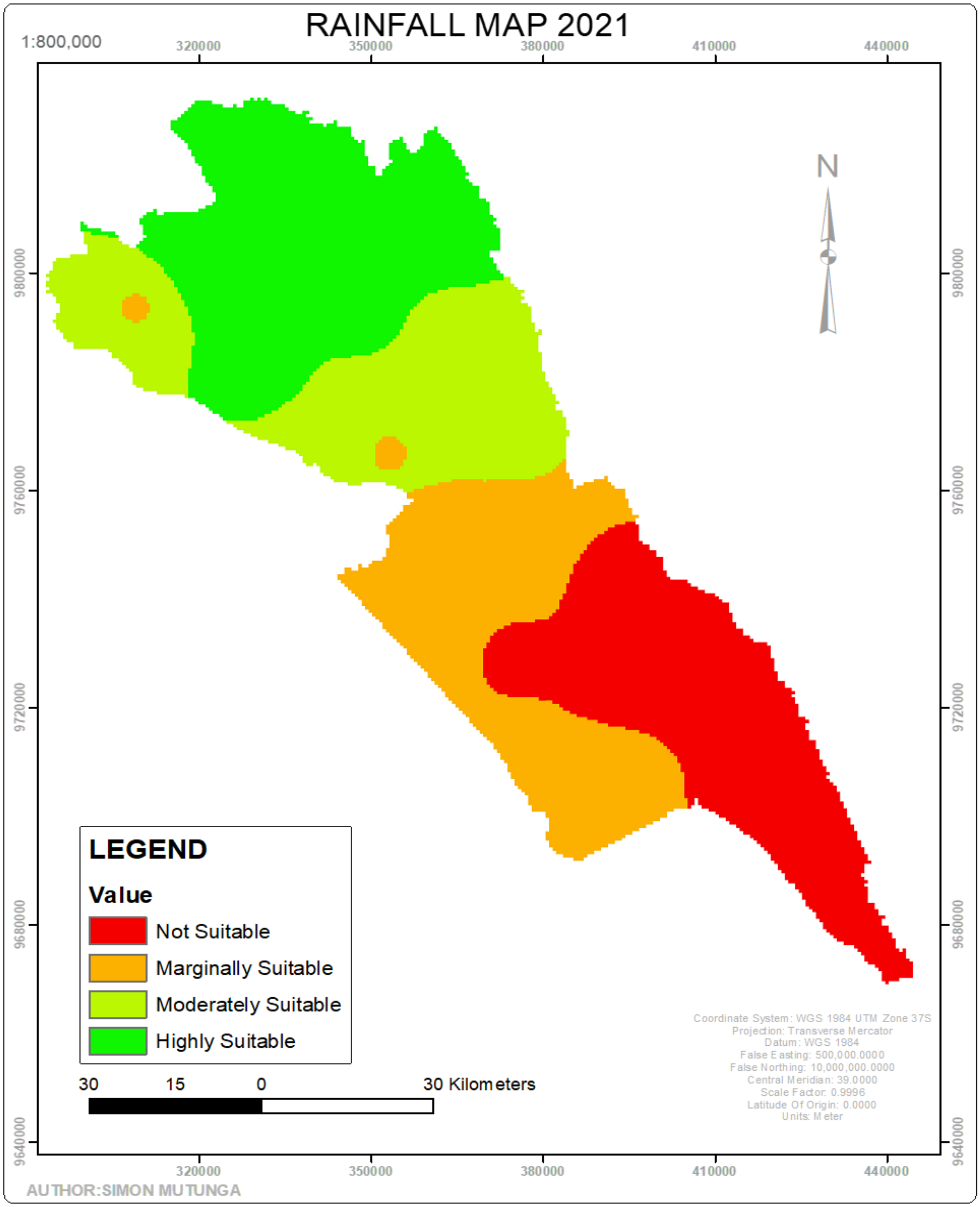

Figure 3.4: Rainfall Map 2022

c. Temperature

Temperature data-both minimum and maximum temperature, were acquired from the Kenya Mereological Department. They were both point data covering the 2010-2021-year range. Average 2021 temperature was used in both cases of minimum and maximum temperatures. The data was used to create shapefiles that were later interpolated using the IDW method to raster. The resulting raster was then resampled to 30 meters and reclassified to four classes in terms of suitability as shown in Figure 3.5 and Figure 3.6:

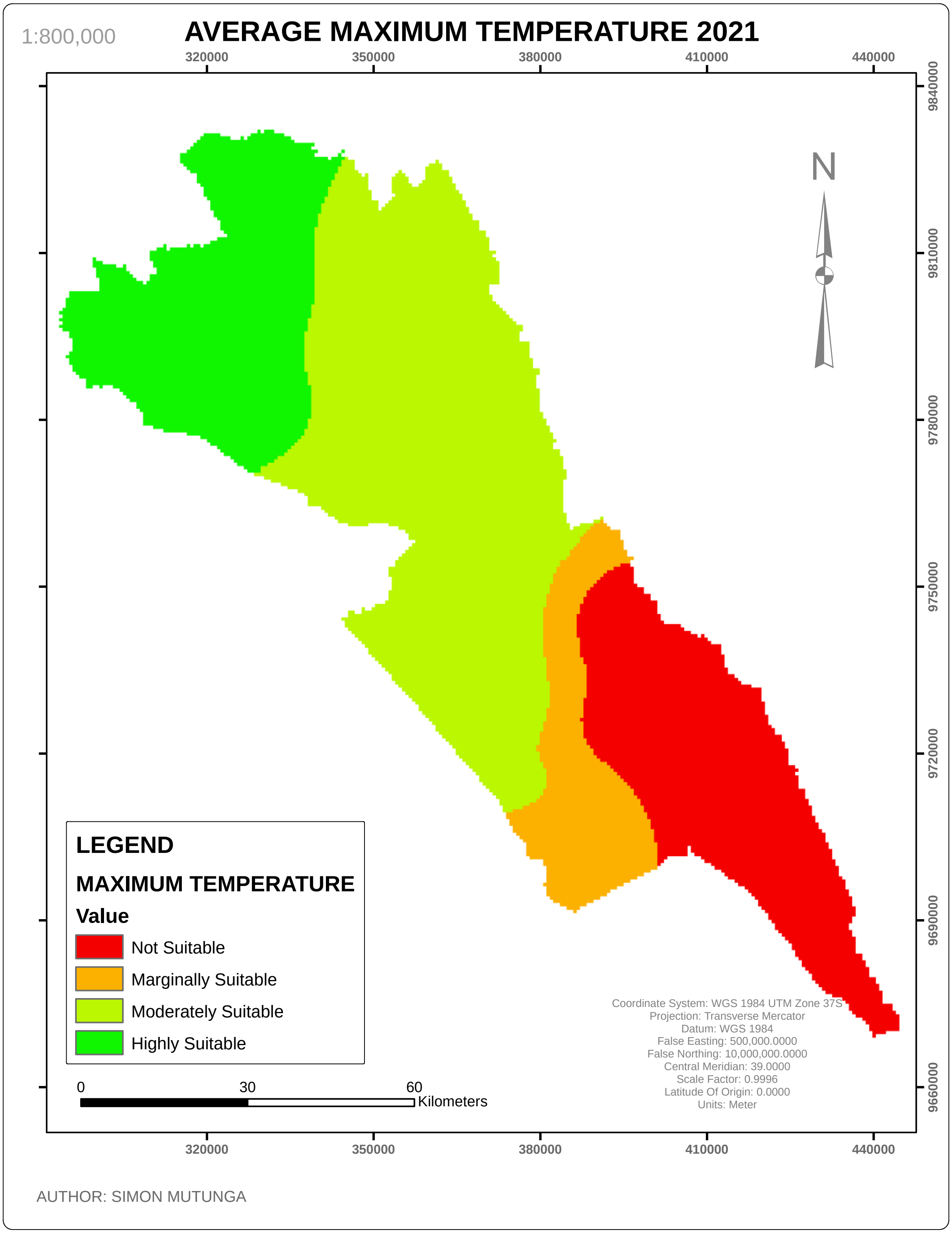

Figure 3.5: Average Maximum Temperature 2021

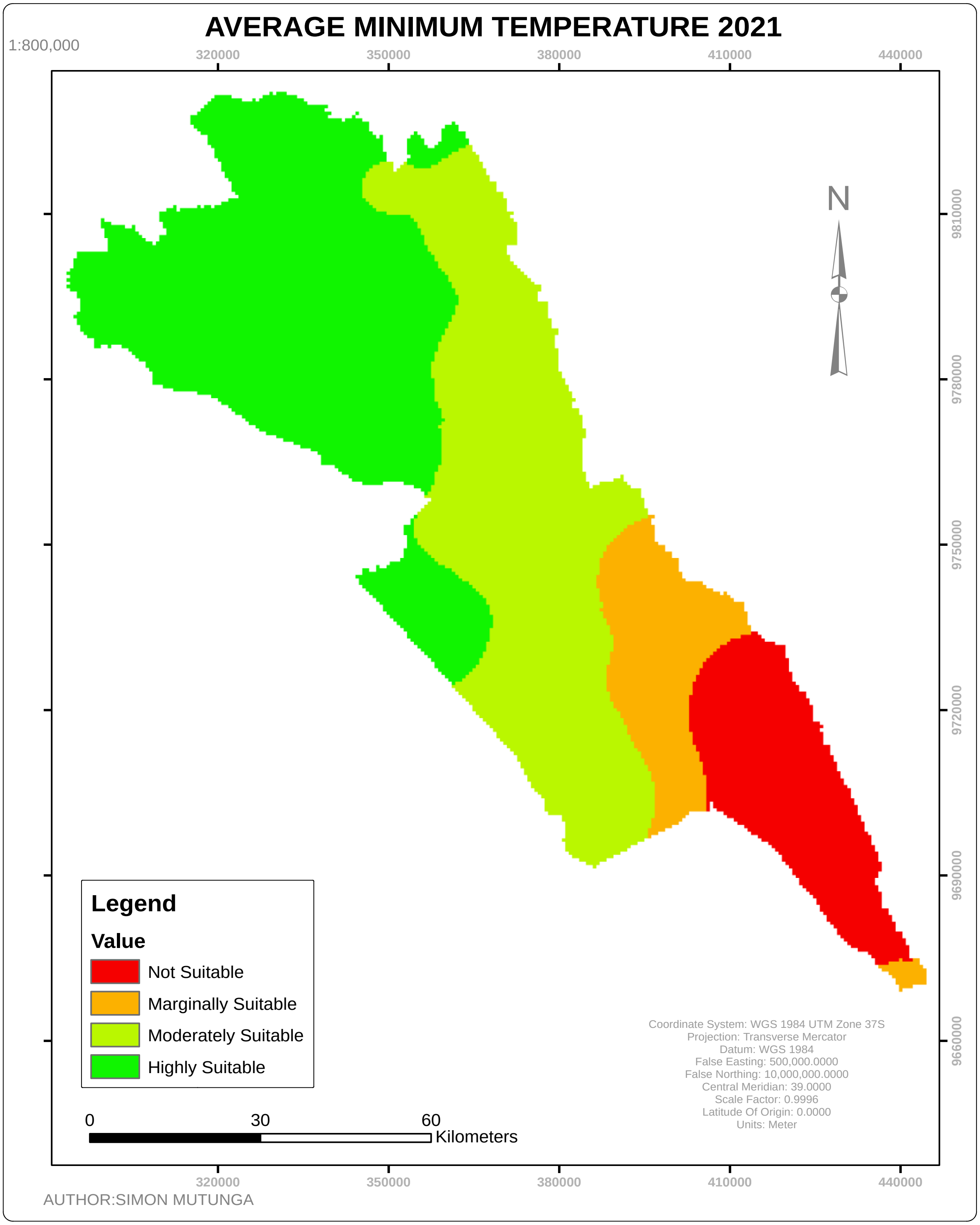

Figure 3.6: Average Minimum Temperature 2021

d. Soil

Soil was considered as one of the factors that affect wheat growth and yields hence it was considered in the checking for the suitable areas. Soil pH and drainage were considered. Soil pH was gotten from the Soil and Terrain Database for Kenya (KENSOTER). The 600-meter resolution dataset was converted to raster, resampled to 30 meters each and reclassified into four classes.

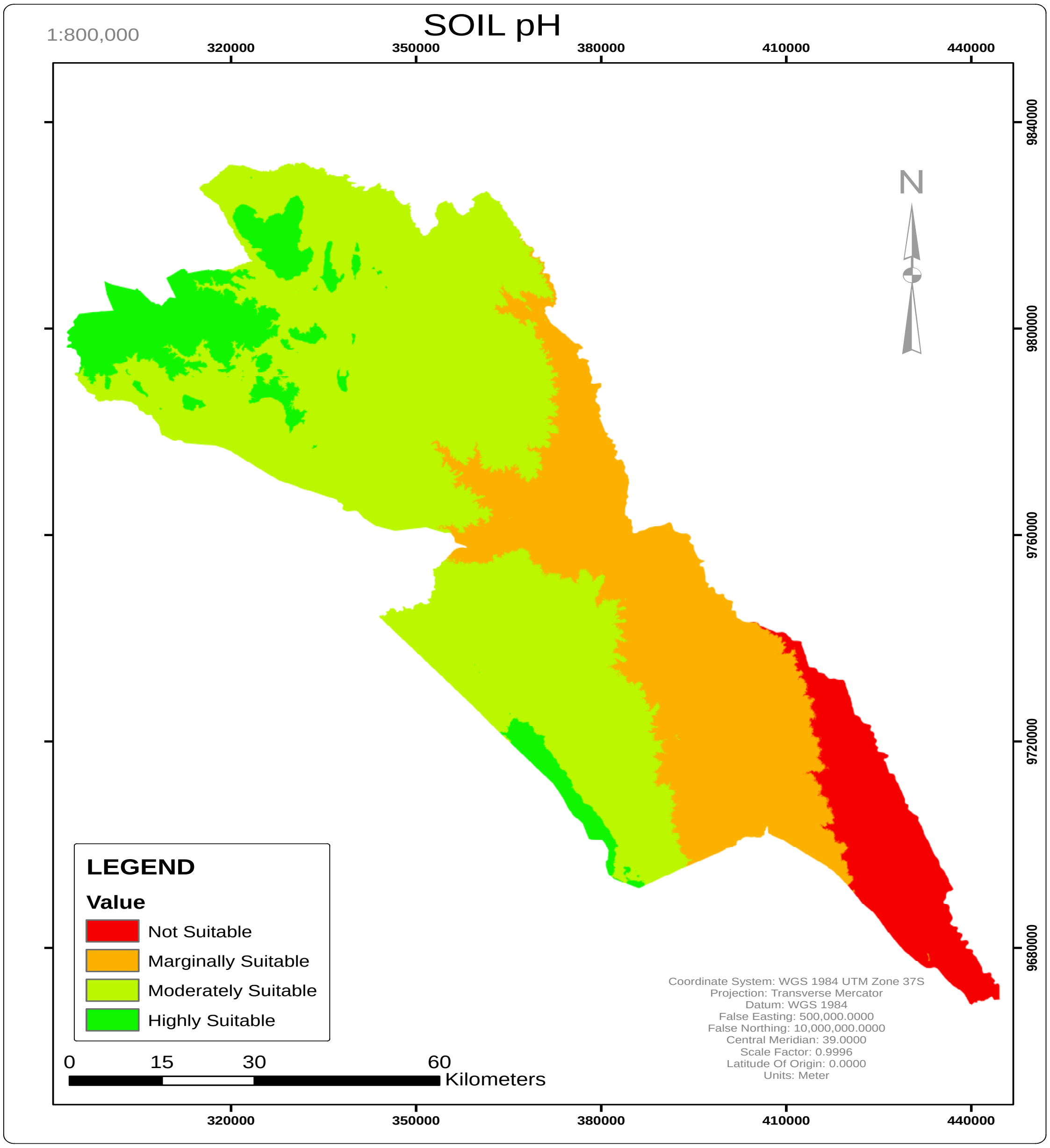

Figure 3.7: Soil pH Map

The Soil drainage for Makueni was clipped from the Kenya Soil drainage from the Soil terrain Database for Kenya. It was then rasterized, resampled and reclassified to four classes The thematic map that was gotten is as shown in Figure 3.8

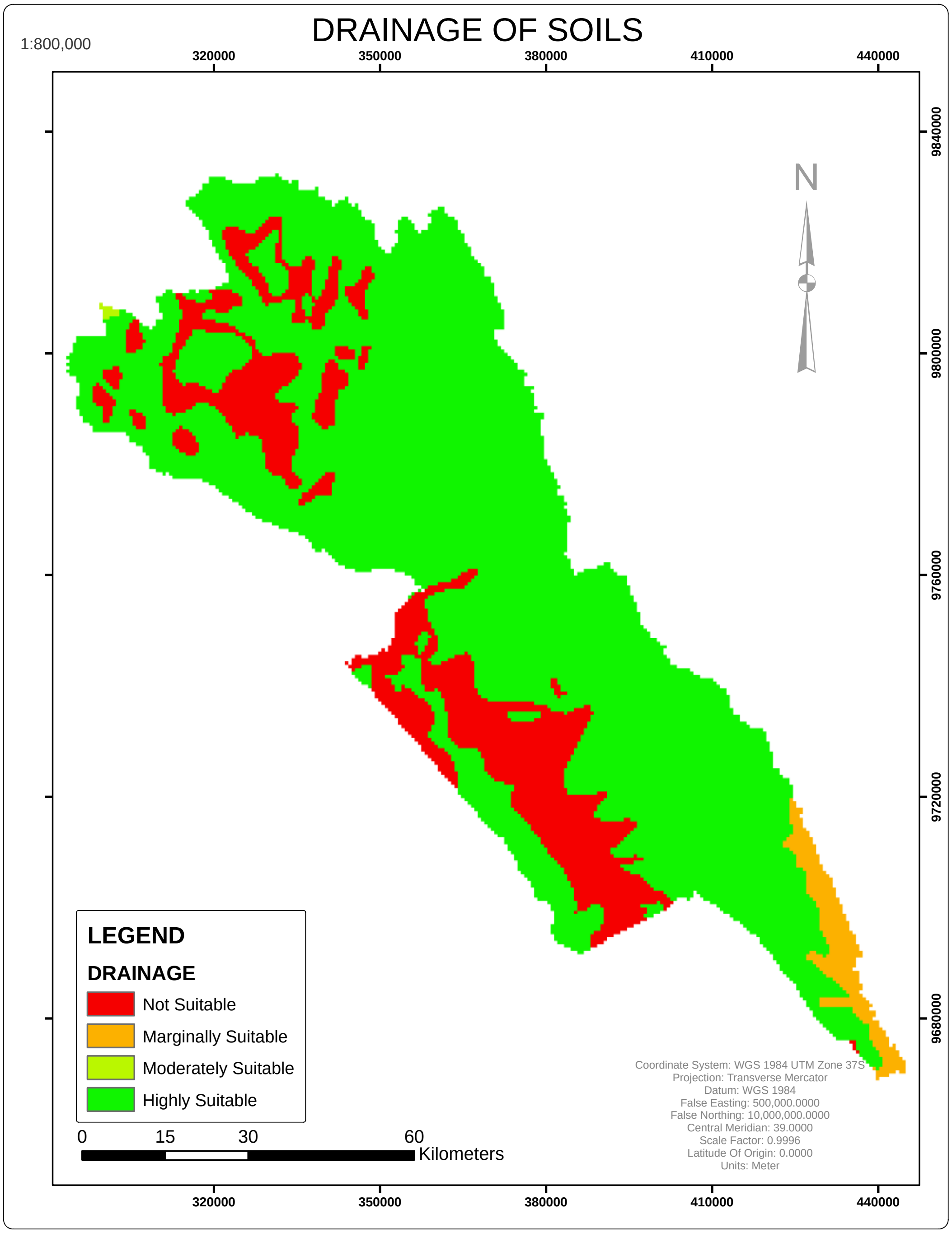

Figure 3.8: Soil Drainage Map

e. Altitude

The altitude data was Kenya SRTM obtained from RCMRD portal. The area of study was clipped from the raster image and reclassified into values ranging from 1 to 4 with 4 being the areas in the Digital Elevation Model having the best altitude suited for growing wheat comfortably.

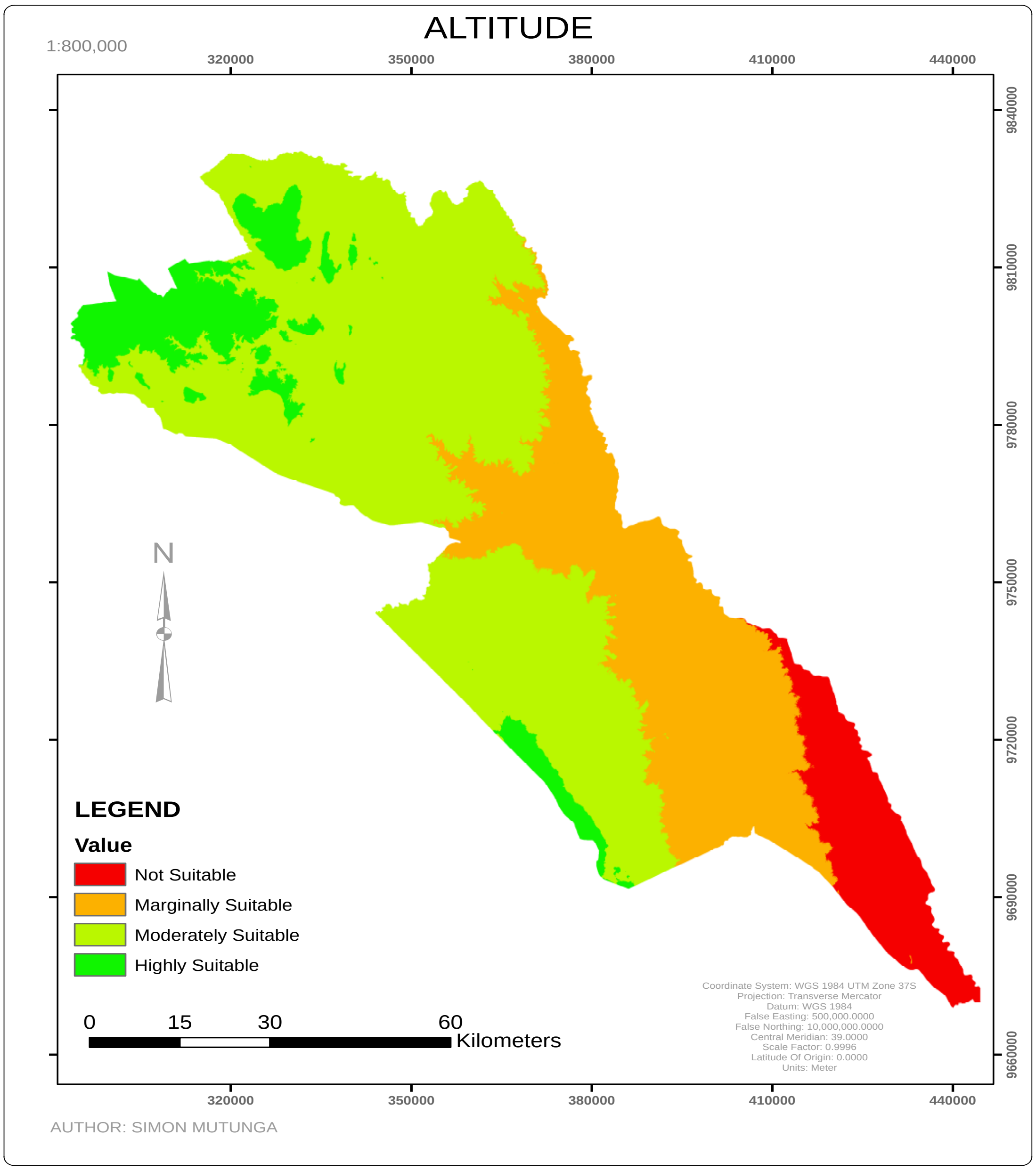

Figure 3.9: Altitude Map

3.5.2: Rating

The rating was done on the datasets for use in the dataset's reclassification and weighting in Analytical Hierarchy Process. The AHP tool was used as the calculator for weights. The weights were gotten based on what was input in the matrix during the pairwise comparisons on the scales of 1 to 9.

The rating scale was based on judgment from research conducted on the most prevalent factors to be considered by the Kenya Seeds Company website. Since Duma is able to do well in lowlands as well as highlands, the altitude had the least weight. Land Use land cover had the most weight since areas that can't be cultivated had to be considered as the one with the most weight.

The FAO levels of land suitability were used:

S1- Highly Suitable

S2- Moderately Suitable

S3- Marginally suitable

Ns- Not Suitable

Tables 3.1-3.7 show the ratings and suitability criteria as shown in the thematic maps.

Table 3.1: Land Use Land Cover rating

36% Weight		
Land Use	Rating	Suitability Class
Crops/Bare Ground	4	S1
Flooded Vegetation	3	S2
Trees	2	S3
Water/Built Area	1	Ns

Table 3.2: Cumulative rainfall 2021

25% Weight		
Annual Rainfall(mm)	Rating	Suitability Class
874 - 1067	4	S1
747 - 874	3	S2
544 - 747	2	S3
444 - 544	1	Ns

Table 3.3: Average Maximum Temperature

17% Weight		
Average Maximum Temperature	Rating	Suitability Class
25.6 – 27.2	4	S1
27.2 – 28.4	3	S2
28.4 – 30.4	2	S3
30.4 – 31.6	1	Ns

Table 3.4: Average Minimum Temperature

11% Weight		
Average Minimum Temperature	Rating	Suitability Class
14.5 – 15.9	4	S1
15.9 – 16.8	3	S2
16.8 – 18.4	2	S3
18.4 – 19.5	1	Ns

Table 3.5: Soil pH

6% Weight		
Soil pH	Rating	Suitability Class
5.5 - 7.5	4	S1
7.5 – 9.2	3	S2
0 – 5.5	2	S3
0	1	Ns

Table 3.6: Soil Drainage

3% Weight		
Soil Drainage	Rating	Suitability Class
W	4	S1
M	3	S2
I	2	S3
P/V/E/S	1	Ns

Where;

W=Well drained, M=Moderately Well drained; I= Imperfectly drained; P= Poorly drained; V= Very poorly drained; E = Excessively drained; S =Somewhat excessively drained

Table 3.7: Altitude

2% Weight		
Altitude (meters)	Rating	Suitability Class
874 - 1067	4	S1
747 - 874	3	S2
544 - 747	2	S3
444 - 544	1	Ns

CHAPTER 4: RESULTS AND ANALYSIS

4.1: Results

The final suitability map was gotten from overlaying the layers which were:

i. Makueni LULC
ii. Cumulative Rain Makueni 2021
iii. Average Maximum Temperature 2021
iv. Average Minimum Temperature 2021,
v. Soil pH,
vi. Soil Drainage
vii. Altitude of Makueni

This was done.in a manner their weights were considered. The weights in the ratings, gotten from the Analytical Hierarchy Process The color scheme applied show the most suitable areas in green as it fades to orange then red indicating the less suitable areas. Makueni county's ward were overlaid with the result on the same projection to show the general suitability of the 30 wards of Makueni County. Table 4.1 shows the overall suitability of Makueni County at ward level.

Table 4.1: General Suitability of Duma Wheat ward level

CLASS	WARD
Highly Suitable	Muvau/Kikumini.
Moderately Suitable	Kilungu, Kiima Kiu/Kalanzoni , Wote, Kasikeu,Nguu/Masumba, Waia/Kako, Kiteta-Kisau, Kithungo/Kitungu, Mbooni, Tulimani, Kee,Mbitini, Kalawa/Kathulumbi, Ukia, Mukaa, Emali/Mulala, Mavindini.
Marginally Suitable	Nguumo, Makindu, Kitise/Kithuki.
Not Suitable	Mtito Andei, Ivingoni/ Nzambani, Masongaleni, Thange, Kikumbulyu North, Kikumbulyu South

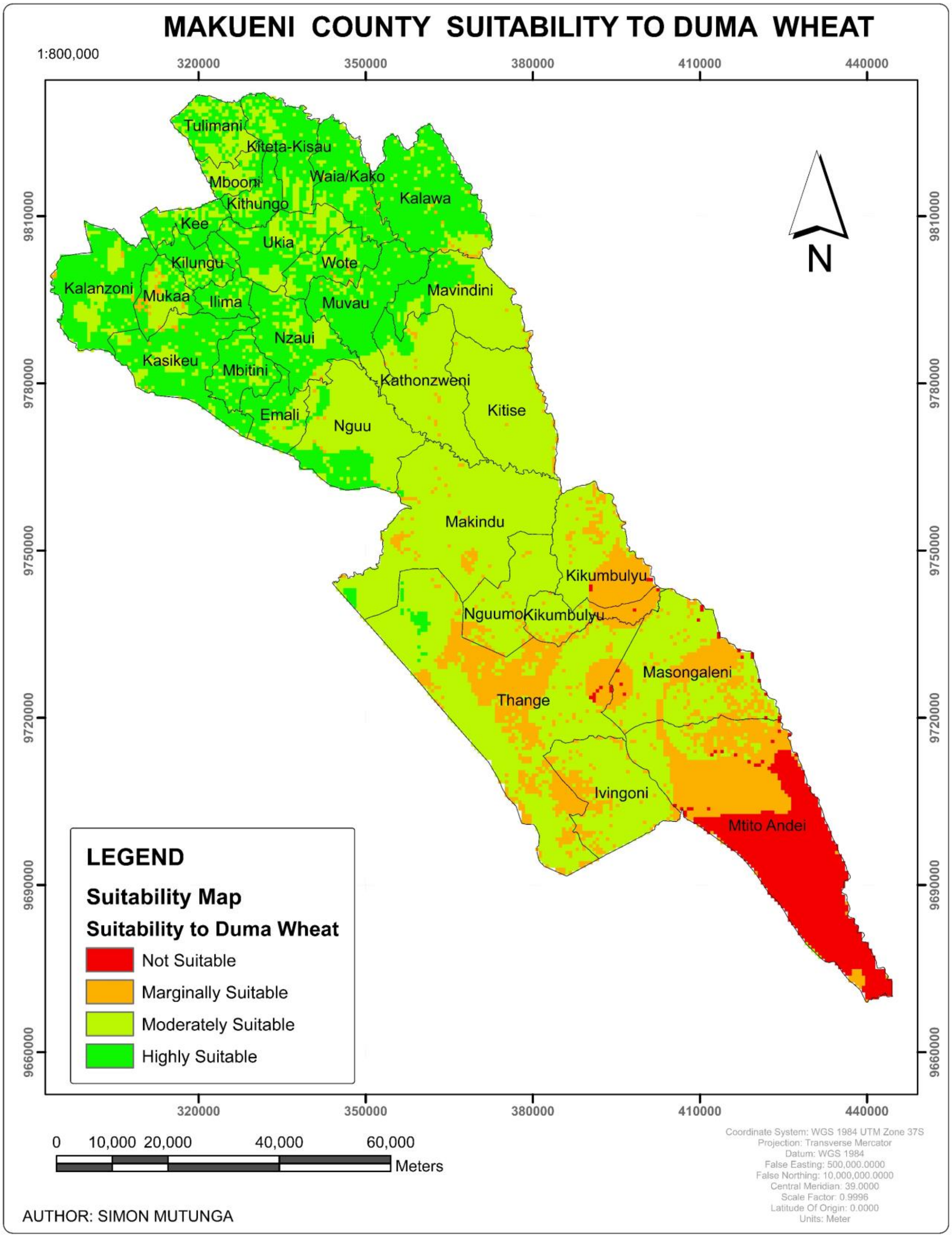

Figure 4.1: Suitability Map

4.2: **Analysis: Overview**

Areas south of Makueni county have minimal chance of supporting wheat growth with their present natural and human conditions. Areas north of the county are suitable and more likely to support wheat growth considering the criteria used are the only ones that would favor wheat farming of the Duma variety. The raster output was converted to vector for the area to be computed. The 30 by 30-meter pixels were now polygon features. They were classified using the grid code field which showed the suitability of each particular pixel.

In terms of area, the four classes have been distributed in Makueni County as shown in Figure 4.2

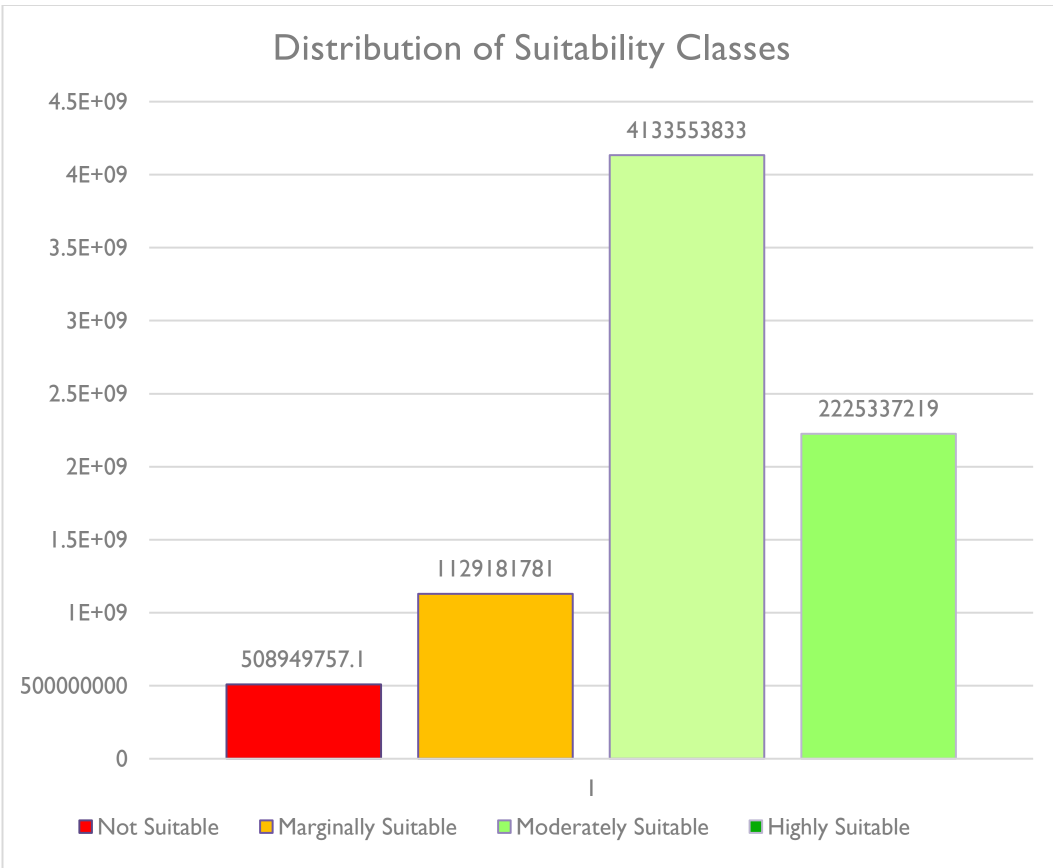

Figure 4.2: Distribution of Suitability classes across Makueni County

4.3: Discussion

From the results, it was established that 28% of Makueni favored the growth of Duma wheat,52% of the area needed some adjustments to favor it, 14% would need major adjustments and 6% of the area was severely limited to its growth and would therefore not be suitable for the growth of Duma wheat variety.

The growth of wheat is influenced by several factors. The favorable conditions that are said to cause high yields were considered. The final result is on assumption that all the factors were exhausted. The suitability map is of the year 2021.This is due to the availability of the datasets. Therefore, the Duma wheat suitability map is for 2021, it can’t be considered presently since the variables have changed, especially the climate.

AHP technique was used in creating the weights to be used in the creation of the final suitability map based on the criteria considered. The pairwise comparisons on AHP were purely biased on a single judgment on the advice from the Kenya Seeds Company website. The relative significance of the factors was the basis for comparison. Land use Land cover was considered as the most significant criterion bearing in mind that the physical and manmade conditions were considered as they are with no expectations of changing what existed.

MCDM involves choosing of the most significant alternative from a group of alternatives, based on some criteria. The alternatives for this study were the pixels representing the whole of Makueni county. Based on the criteria that were provided-several raster datasets were aggregated in order of importance in weighted overlay using the weights from AHP. The result is an aggregate of all the factors with the most favorable land use being the priority.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1: Conclusions

The objectives of the project were to determine the suitability criteria for the growth of Duma wheat variety, based on the criteria collect data and create a GIS database and use GIS Multi Criteria Analysis techniques to determine the suitable areas of Duma wheat.

These have been achieved and it is concluded that;

a. There is need a spatial data infrastructure to enable access to geographic information.
b. Duma is generally moderately suitable in Makueni County.
c. Drought resistant crops can do well in semi -arid areas in Kenya as in Duma wheat in Makueni. Crop engineering these crops should be encouraged to increase agricultural output of the Makueni County.
d. GIS can be applied in crop and management for sustainable farming through its decision-making function among many other functions.
e. With irrigation and application of fertilizers, the county can be better placed to producing wheat.
f. There is urgent need of assessing the land before utilizing in order to put its best use.

5.2 Recommendations

From the study, it is recommended that;

a. The criteria considered in this project don't fully cover the suitability of the land to Duma wheat variety. To increase the accuracy of the result, other criteria need to be factored. In addition, there is no real way to measure the accuracy because in order to do so, all factors would need to be put in.

b. Driving the agenda of having a geo-literate population: Geospatial technologies like GIS need to be taught more to the population since many farms in Makueni are small scale. GIS can help in the advancement of agriculture by introducing logical reasoning when making agricultural decisions.

c. Wheat farming of Duma is moderately suitable in Makueni County. It should be encouraged. The land needs to be put to is best possible use in a sustainable manner. Other drought resistant wheat varieties that have early maturity need to be tried out too in the county. Wheat has higher returns as compares to maize and beans.

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APPENDIX

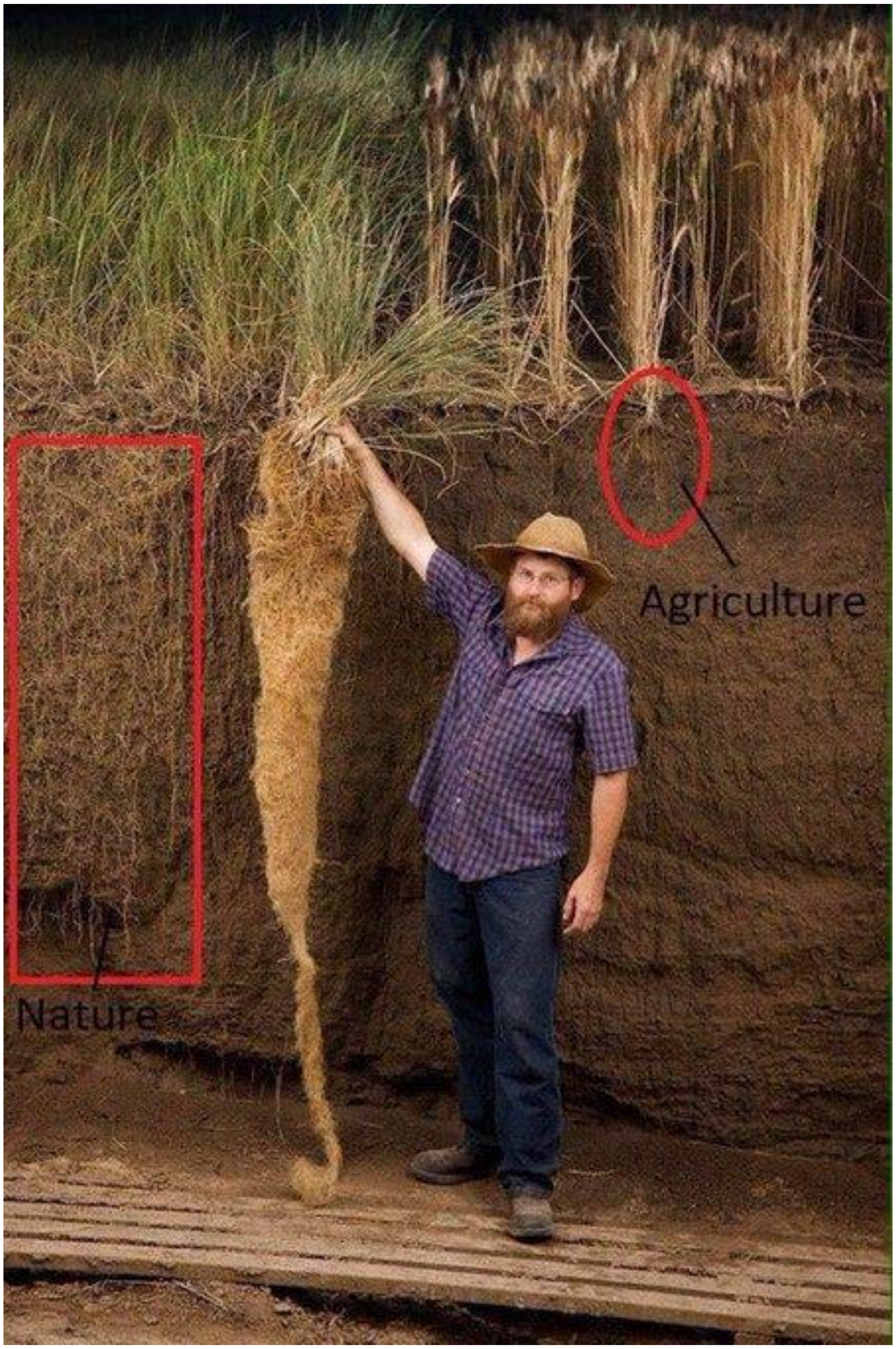

Figure 5.1: Jerry Glover, a soil scientist, shows off a perennial wheatgrass' long roots, which grow deeper than annual plant's roots, improving soil structure and reducing soil erosion.