UNIVERSITY OF NAIROBI

School of Engineering

Department of Geospatial and space technology

GIS based Multi Criteria Analysis in Mapping

Potential for Irrigated Agriculture.

Case study: Machakos County

BY

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DECLARATION

I, Victor Muema, hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a project in any other university.

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

Mr. B.M Okumu	**……………….........**	**...**
	Signature	Date

DEDICATION

I dedicate this work to my dear wife Naomi Wambua and my lovely daughter Eliana Mueni Wambua for making this journey worthwhile.

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ABSTRACT

Agriculture in Kenya is fundamental in economic development, it contributes 35% of the gross domestic product and such remains the backbone of the economy, it's growth is important for alleviation of poverty and stimulation of economic growth and development. Economic growth and development envisioned in the Kenya Vision 2030 can only be achieved by investing and transforming this sector of the economy which ensures constant food supply and food security for the population. Through all this multiplier effects agriculture is perceived to be an engine of economic growth and development. It's the main economic activity in rural areas.
However this sector has suffered a setback as a result of over reliance to rainfall which is insufficient in most areas. Kenya's dry land areas, Arid and semi-arid makeup more than 80% of the country (Umar 1997).

As a result there has been an imbalance between food demand and supply. Increasing population numbers intensify the pressure on agricultural resources and to meet the nutritional demands of the growing population, an increased food supply is required. It's on this backdrop that irrigated agriculture should be developed in this country to complement rain fed agriculture especially in arid and semi arid areas with rivers and other water bodies.

Geographic Information Systems (GIS) based Multi criteria analysis can be employed to map areas with potential for irrigation. Focusing on Machakos County as the case study, this project explored how GIS can be used to identify areas with potential for irrigated agriculture thus expanding area under crop production in this County.

Multi criteria analysis is concerned with the allocation of land to suit a specific objective on the basis of a variety of attributes that the selected areas should possess (JR Eastman,1999).
The Project focused on different variables including soil fertility (soil texture, depth and Ph), drainage (perennial rivers), land use land cover, topography and road infrastructure.
GIS tools; the model builder, was used to analyze the data sets and result were presented using Suitability maps, tables and graphs.
SRTM 30m was used to extract slope data and Google earth images used for validation.

Results from this work showed that 2602Km² accounting for 41.9% of the total area was highly suitable for agriculture. 3355Km² accounting for 54.03% was moderately suitable for irrigation, 78km² accounting for 1.26% was found to be marginally suitable for irrigation whereas 175Km² accounting for 2.81% was found to be unsuitable for irrigated agriculture.
The results also illustrate how GIS as a tool can be used in exploration of water resources in a scientific approach hence making decision making easier and accurate.

The findings from the study will help in developing policies and strategies to address the perennial food shortage in Machakos County by among others the County Government of Machakos, Ministry of Agriculture and Non – Governmental Organisations.

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LIST OF ABBREVIATIONS AND ACRONYMS

AHP – Analytical Hierarchy Process.

ASAL – Arid and Semi Arid Lands.

DEM – Digital Elevation Model

FAO – Food and Agriculture Organization of the United Nations.

GDP – Gross Domestic Product.

GIS – Geographic Information System.

GLCN – Global Land Cover Network.

HA – Hectare.

IDMPS – Irrigation Drainage and Management of Problem Soils.

ILRI – International Livestock Research Institute.

IWMI – International Water Management Institute.

KARLO – Kenya Agricultural Research and Livestock Organisation.

KNBS – Kenya National Bureau of Statistics.

KVDA – Kerio Valley Development Authority.

LBDA – Lake Basin Development Authority.

LULC – Land Use Land Cover.

MCDA – Multi Criteria Decision Analysis.

MCDM – Multi Criteria Decision Making.

MCE – Multi Criteria Evaluation.

NGOs – Non Governmental Organizations.

NIB – National Irrigation Board.

RCMRD – Regional Centre for Mapping of Resource for Development.

SISO – Smallholder Irrigation Schemes Organizations.

SRTM – Shuttle Radar Topography Mission.

TARDA – Tana and Athi River Development Authority.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study.

In a crowded world with population still rising and consumption patterns changing, humankind has not done enough to plan and manage the future development of land and water resources. After decades of underinvestment, poor management and lack of governance, the evidence is widely apparent. There is no doubt that access to and management of land and water resources need to improve remarkably.

Projected demands for food and agriculture production have to be met, malnutrition and rural poverty still have to be addressed, and competing demands for land and water must be reconciled with concerns over rapid degradation of natural systems.

Agriculture continues to be the number one economic activity in Kenya and Machakos County in particular; it provides not only food but remains the main economic activity especially in rural areas. However Agriculture in Machakos County which is a Semi arid area continues to suffer a setback as a result of over reliance on rainfall which is hardly sufficient. Machakos County is endowed with large tracts of fertile land mainly in Mwala, Yatta and Masinga. Farmers however rely on unreliable rain fed agriculture, predisposing them to low economic returns and food insecurity. Great opportunities exist in irrigation by tapping water from rivers Tana, Athi, Thika and the numerous streams.

This study will map areas suitable for irrigated agriculture in the county through evaluation of specific attributes ranging from soil, topography, drainage, land use and land cover, and road infrastructure.

Irrigation is the artificial application of water to the land or soil, it is used to assist in the growing of agricultural crops, maintenance of landscapes, and revegetation of disturbed soils in dry areas and during periods of inadequate rainfall.Irrigation is essentially the artificial application of water to overcome deficiencies in rainfall for growing crops (Cantor, 1967).

In the next few years world food production will need to double to meet the demands of increased population. Seventy percent of this increased food production will have to come from irrigated land. Without irrigation, farming is very limited and if the rainfall decreases to less than 300mm, agriculture becomes impossible without irrigation (King, 1953).

1.2 Problem Statement

Machakos County and other Arid and semi arid areas continue to encounter perennial drought and as a result food scarcity, this has led to malnutrition and even deaths in some cases. Food security in these areas has been a challenge despite the presence of major river in some of these areas (Tana, Athi and Thika rivers in Machakos County). This is the greatest paradox of all time, that a County blessed with natural resources like water and viable soil resources cannot feed its population. The County Government of Machakos and Non Governmental Organizations have continued to support feeding programmes in the county popularly known as “mwolyo” which is not sustainable instead of focusing on creating sustainable solutions like investing in irrigated agriculture. It’s on this backdrop that this project will be based.

Attempts by the County Government of Machakos as envisioned in the County’s master plan to improve food security by setting up irrigation schemes must be carefully analysed so as to establish the viability of the irrigation scheme in the proposed areas to ensure maximum benefits are achieved from the project and to avoid cases of spending inadequate County resources only for projects to stall due to unsustainability.

1.3 Objectives

The principal objective of this study is to demonstrate how GIS based multi criteria analysis can be used to map potential areas for irrigated agriculture. Machakos County has been used chosen as the area of study.

The specific objectives are:-

i) Identify criteria for suitable site selection.
ii) To recommend areas suitable for irrigated agriculture in Machakos County.

1.4 Justification for the Study

Populations in ASALs served by perennial rivers have continued to languish in poverty and hunger out of absolute dependence on inadequate and unreliable rain fed agriculture. It is fundamental to set up irrigation projects in these areas where maximum returns from available resources (rivers and land) can be exploited and attained to change livelihoods, hence this project.

Findings from this project will go a long way in providing answers to policy makers and other stakeholders who as a fact need to refocus their energy from unsustainable programs like free feeding programmes popularly known as "mwolyo" to sustainable projects like supporting irrigation programs which can liberate populations in these marginalized but endowed areas.

1.5 Scope of work

This project is limited to Machakos County, Kenya and the hydrological analysis is limited to surface drainage only and specifically perennial rivers. The study will analyse how the perennial rivers in the County of Machakos can be exploited for irrigated agriculture. The study mainly focuses on large scale irrigation, and because of magnitude of investment, constructing canals, investing in generators and pumps, the study focuses on perennial/permanent rivers. Variables to be considered will include Topography (slope), Soil fertility (PH,texture and depth), land use land cover, drainage (perennial rivers) – and in this case Tana, Athi and Thika rivers.

1.6Limitation of the Study

Although much remains to be done, this work will generate important findings in the field of irrigated agriculture potential mapping. However this study has some limitations:

1.7 Organization of the report

The report is organised into five chapters.

Chapter 1 of this study introduces the problem statement and describes the specific problem addressed in the study as well as design components.

Chapter 2 presents a review of literature and relevant research associated with the problem addressed in this study.

Chapter 3 presents the methodology and procedures used for data collection and analysis.

Chapter 4 contains an analysis of the data and presentation of the results

Chapter 5 offers a summary and discussion of the researcher's findings, implications for practice, and recommendations for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Irrigation

2.1.1 Definition

Irrigation is the artificial application of water to the land or soil. It is used to assist in the growing of agricultural crops, maintenance of landscapes, and revegetation of disturbed soils in dry areas and during periods of inadequate rainfall.

Additionally, irrigation also has a few other uses in crop production, which include protecting plants against frost,suppressing weed growth in grain fields and preventing soil consolidation. In contrast, agriculture that relies only on direct rainfall is referred to as rain-fed or dry land farming (Cantor,1967).

2.1.2 Types of Irrigation methods Irrigation is described as the artificial application of water to the land or soil. It is the substitute or supplement of rainwater with another source of water. It is used in dry areas and during periods of insufficient rainfall. It is considered as basic infrastructure and vital input required for agricultural production (Mamata, 1999).

Irrigation water may be applied to the crops using two broad methods; Surface irrigation and Micro-irrigation/ Localised irrigation (Punmia, 2009).

2.1.2.1 Surface Irrigation

In this technique, water flows and spreads over the surface of the land. Varied quantities of water are allowed on the fields at different times. Therefore, flow of water under surface irrigation comes under wobbly flow. Different factors are considered in surface irrigation

- Surface slope of the field
- Roughness of the field surface
- Depth of water to be applied
- Length of run and time required
- Size and shape of water-course
- Discharge of the water-course
- Field resistance to erosion

If the surface irrigation method is perfectly selected, it fulfils following requirements:

- It assists in storing required amount of water in the root-zone-depth.
- It reduces the wastage of irrigation water from the field in the form of run-off water.
- It reduces the soil erosion to minimum.
- It helps applying uniform application of water to the fields.
- Amount of manual labour required is less.
- It is suitable to the size of the field and at the same time it uses minimum land for making ditches, furrows, strips, etc.
- It does not avert use of machinery for land preparation, cultivation, harvesting.

Surface irrigation technique is broadly classified as *basin irrigation; border irrigation; furrow irrigation and uncontrolled flooding.*

Basin irrigation: Basin irrigation is common practice of surface irrigation. This method is employed for watering orchards (Basak, 1999). It is useful especially in regions with layouts of small fields (Shah et al., 2002).

If a field is level in all directions, is encompassed by a dyke to prevent runoff, and provides an undirected flow of water onto the field, it is herein called a basin. A basin is typically square in shape but exists in all sorts of irregular and rectangular configurations. It may be furrowed or ridged, have raised beds for the benefit of certain crops, but as long as the inflow is undirected and uncontrolled into these field modifications, it remains a basin.

Furrow Irrigation: In furrow irrigation technique, trenches or "furrows" are dug between crop rows in a field. Farmers flow water down the furrows (often using only gravity) and it seeps vertically and horizontally to refill the soil reservoir. Flow to each furrow is individually controlled. Furrow irrigation is suitable for row crops, tree crops and, because water does not directly contact the plants, crops that would be damaged by direct inundation by water such as tomatoes, vegetables, potatoes and beans. It is one of the oldest system of irrigation. It is economical and low-tech making it particularly attractive.

In different situations, different furrow methods are used (Surajbhan 1978). They are mainly of five types:

- Sloppy Furrow
- Levelled Furrow
- Contour Furrow
- Serial Furrow
- Corrugated Furrow

*Free Flooding:*This flooding system of irrigation is used from ancient times. Flooding method consists in applying the water by flooding the land of rather smooth and flat topography. In free flooding method, water is applied to the land from field ditches without any check or guidance to the flow. The land is divided into plots or kiaries of suitable size depending on porosity of soil. Water is spread over the field from watercourse. The irrigation operation begins at the higher area and proceeds towards the lower levels. The flow is stopped when the lower end of the field has received the desired depth of water. The field watercourse is properly spaced; the spacing depends on the topography, oil texture, depth of soil and size of stream.

This technique is beneficial for newly established farms where making furrows is very expensive. This method is economical and can be effectively used where water supply is in plenty. This method is suitable for the fields with irregular surface in which other techniques are difficult to apply. Major drawback of this method is that there is no perfect control over the flow of water to attain high efficiency. Sometimes the flow of water over the soil is too rapid to fulfil soil moisture deficiency. On the other hand, sometimes water is retained on the field for a very long time and consequently the water is lost in infiltration or deep percolation.

*Border Strip Method:*In this technique of irrigation, a field is divided into number of strips. The width of strip varies from 10 to 15 metres and length varies from 90 m to 400 m. Strips are separated by low embankments or levees. The water is diverted from the field channel into the strips. The water flows gradually towards lower end, wetting the soil as it advances. The surface between two embankments should essentially be level. It assists in covering the entire width of the strip. There is a general surface slope from opening to the lower end. The surface slope from

2 to 4 m/1000 m is best suited. When the slope is steeper, special arrangement is made to prevent erosion of soil.

Canal Irrigation: Canals are most important source of irrigation. Canals are most effective techniques of irrigation in areas of low level relief, deep fertile soils, perennial source of water and extensive command area

Most of the canals provide perennial irrigation and supply water as and when required. This saves the crops from drought conditions and helps in increasing the farm production. Canals carry a lot of residue brought down by the rivers. This sediment is deposited in the agricultural fields which make soil more fertile. Some of the canals are parts of multipurpose projects and, therefore, provide inexpensive source of irrigation. Although the initial cost involved in canal irrigation is more, it is quite cheap in the long run.

2.1.2.2 Micro-Irrigation or Localized irrigation

In this technique, water is controlled as compared to surface irrigation.

Drip irrigation: In the area of irrigation process, drip irrigation is modern technique. It is also called trickle irrigation, which was originally developed in Israel in the early 1960s and became popular in areas of water scarcity. The drip irrigation is the most competent and it can be practised in array of crops, especially in vegetables, orchard crops, flowers and plantation crops (Mamata, 1999).

Sprinkler Irrigation:In the sprinkler technique of irrigation, water is sprinkled into the air and allowed to fall on the ground surface just like rainfall. The spray is done by the flow of water under pressure through small orifices or nozzles. The pressure is generally obtained by pumping.

Through proper selection of nozzle sizes, operating pressure and sprinkler spacing the amount of irrigation water required to refill the crop root zone can be applied almost uniform at the rate to suit the infiltration rate of soil. In agriculture, almost all crops are suitable for sprinkler irrigation system except crops such as paddy and jute. The dry crops, vegetables, flowering crops, orchards, plantation crops like tea, coffee are all suitable and can be irrigated through sprinklers techniques of irrigation

Surge Irrigation: Surge Irrigation is an alternative of furrow irrigation where the water supply is pulsed on and off in planned time periods (e.g. on for 1 hour off for 1½ hour). The wetting and drying cycles reduce infiltration rates resulting in faster advance rates and higher uniformities than constant flow.

Ditch Irrigation: Ditch Irrigation is type of traditional method, where ditches are dug out and seedlings are planted in rows. The plantings are watered by placing canals or furrows in between the rows of plants. Siphon tubes are used to move the water from the main ditch to the canals.

2.1.3 Irrigation in Kenya

The land area of Kenya is 582,646 km², 17 percent of which is defined as medium to high potential land with more than 700mm of rainfall per year, which is suitable for rain fed agriculture. The remaining land (83 percent) is classified as arid and semi arid lands (ASALs) and cannot reliably support rain-fed agriculture unless other technologies such as irrigation and water harvesting are used to augment water for crop production.

The Government recognises the important role that the agricultural sector plays as the backbone of Kenya's economy. The sector (including the agro-based industries) contribute approximately 55 percent of the gross domestic product GDP, provides about 80 percent of employment directly or indirectly, accounts for 60 percent of exports and generates about 45 percent of government revenue (Ragwa et al., 1998).
Supporting the rapidly increasing population and ensuring the economic growth in the dwindling landholdings of high to medium potential lands will require the use of technologies which will ensure the intensification of production in such potential lands in the ASAL areas. This is possible only with the use of irrigation technologies.

Food shortages are a recurrent problem, which cannot be solved through rain-fed agricultural production alone, without irrigation development. In Kenya food insecurity continues to loom, not to mention the existing water crisis. As demand for food increases, more and more water will continue to be used in an attempt to alleviate persistent food shortages. Available water resources are diminishing, leading to conflicts over water uses and among water users.

The increasing demand for water for the domestic and industrial sectors is expected to continue. This means that the water use by the agricultural sector must be efficient and used sustainably. (Seckler et al., 1998).

2.1.4 Role of Irrigation

For the last two decades, agricultural production has not been able to keep pace with the increasing population, to address this challenge, Kenya must seek ways to improve and stabilise agricultural production to cater to the needs of its increasing population. The biggest potential for increasing agricultural production lies in the development of the ASALs, especially through the development of irrigation and water harvesting technologies.

If 50 percent of the irrigated potential is exploited, Kenya would not only be self sufficient in food but also a producer and exporter of a wide variety of agricultural products.
Irrigation and rain-fed agriculture are complementary and not mutually exclusive. Irrigation can assist in agricultural diversification, enhance food self-sufficiency, increase rural income, generate foreign exchange and provide employment opportunities when and where water is a constraint. The major contribution of irrigation to the national economy includes food security, employment creation, settlements and foreign exchange.

In the ASALs, smallholder irrigation schemes have been used to supplement fodder. However contributions to food security are more pronounced in group based irrigation and National Irrigation Board - NIB schemes (Kimani & Otieno, 1992).
Irrigation is labour intensive and is able to generate 730 person days of labour per irrigated hectare. Hence, irrigation makes a substantial contribution to job creation.

2.1.5 Irrigation Development

Kenya has a relatively limited irrigation tradition and the majority of existing irrigated areas were developed between 1960 and 1980. Since then, the rate of irrigation development has unfortunately declined.
The area under irrigation is far less than the potential irrigable area estimated between 244,700 and 539,500 hectares in Kenya.

Nevertheless, irrigation has been making a substantial contribution towards national agricultural goals: food self-sufficiency, raising of rural incomes and generating employment. Currently, there is a notable contribution of irrigation to the horticultural export industry – the third highest foreign exchange earner of the country. (Ngigi 2000)

2.2 Categorization of Irrigation development in Kenya

According to (Kimani & Otieno ,1992), Irrigation development in Kenya can be in any of the following categories:-

2.2.1 Public Irrigation Schemes

This category includes the settlement schemes managed by the National Irrigation Board – NIB. The schemes are based on a tenant farmer system where each tenant is generally allocated 0.4 – 1.0 hectare. The other schemes in this category are managed by regional authorities and are operated as commercial estates. These include Yala Irrigation Scheme under the Lake Basin Development Authority (LBDA), Sigor Irrigation Scheme under Kerio Valley Development Authority (KVDA), Kibwezi and Tana Deltas under Tana and Athi River Development Authority (TARDA).

2.2.2 Small Holder Irrigation Schemes

These schemes can be further grouped into two types:-

i. Schemes where the irrigation infrastructure and water distribution system are operated and maintained by a water undertaker.
   Example of this type includes the Yatta Furrow and Njoro Kubwa Furrow where the Ministry in charge of water resource is the water undertaker. Southwest Kano Irrigation Scheme Organization where an NGO called Small Holder Irrigation Scheme Organization (SISO) is the water undertaker.

ii. Schemes where the Water User Association (WUA) has full responsibility for operating and maintaining the irrigation infrastructure and for distributing the water to all its members. Most of the schemes supported by the irrigation and drainage branch of the Ministry of Agriculture fall in this category, they include:- Mitunguu, Kibirigwi, Eldume, Ishiara, Kwa Kyai and Ngaare Ndare.

2.2.3 Private commercial farms

These are commercial farms or estates that produce high-value crops, such as floricultural and horticultural crops mainly for export market – often these farms are highly specialised in their production of technology such as drip sprinkler and even centre pivots.

2.3 Historical Development of Irrigation in Kenya.

Irrigation is an age old technology involving the artificial application of water to supplement rainfall for the purpose of crop production. In Kenya, there is evidence that local communities especially Marakwet, Illchamus (Jemp Maasais), Turkana and the Pokomo may have practiced some form of irrigation for the last 500 years (Njokah, 1992). Formal irrigation started between 1901 and 1905 during the construction of the Kenya Uganda railway around Kibwezi and Makindu. Large scale irrigation commenced in the mid 1950s with the development of Mwea - Tebere, Hola and Perkerra Irrigation Schemes.

The efforts of the Government of Kenya in irrigation development after independence focused mainly on establishment of large scale tenant based irrigation schemes. The Ministry of Agriculture took over the management of the three initial schemes:- Mwea, Hola and Perkerra. In July 1966 the NIB was enacted with the mandate to develop, improve and manage national irrigation schemes in Kenya.

By the mid 1970s three more schemes were constructed:- Ahero, Bunyala and West Kano Irrigation Schemes. This brought the number of schemes under NIB to six. The Bura Irrigation Scheme constructed between 1978 – 1983 is however no longer functional.

2.4 Developmental aspects of irrigation

Irrigation is practiced to maintain the different developmental parameters.
These are: -

- To make up for the soil moisture deficit.
- To ensure a proper & sustained growth of crops.
- To make harvest safe.

- To colonize the cultivable wasteland for horizontal expansion of cultivation.
- To shift from seasonal cultivation.
- To promote more intensive cultivation by multiple cropping.
- To improve the level of agricultural productivity by acting as an agent for adoption of modern technology
- To lessen the regional & size class inequalities in agricultural productivity that will reduce in turn socioeconomic imbalances.

2.5 Overview of GIS Application

A GIS is computer software for capturing, storing, querying, analyzing and displaying geographically referenced data (Goodchild, 2001).

2.5.1 Remote Sensing and GIS in Multi Criteria Decision Analysis.

Many spatial decision problems have lead to the integration of Geographic Information Systems (GIS) and Multi – Criteria Decision Analysis(MCDA), as these two techniques can interact with each other.

GIS techniques have an important role in analyzing decision problems and are decision support systems that integrate spatially referenced data into a problem-solving environment.

MCDA provides many techniques and procedures for structuring decision problems and for evaluating and prioritizing alternative decisions. The integration of GIS and multi-criteria decision-making can be thought of as a process that combines geographical data and value judgements of decision-makers to obtain information for decision-making (Malczewski, 2006).

GIS is used as a decision making tool for the site suitability analysis and for development activities. Land use suitability mapping and its analysis is one of the most useful applications of the GIS(Javadian et al.,2011)

Integration of GIS with Multi criteria evaluation methods reveals its extreme applicability in site suitability analysis. GIS technology is used to formulate different criteria maps which are used to construct the site suitability model (Xu et al.,2012).

In the context of GIS, two procedures are common for the Multi-Criteria Evaluation (MCE) the Boolean overlay and the weighted linear combination (WLC). In a Boolean approach, all criteria are assessed by thresholds of suitability to produce Boolean maps, which are then combined by logical operators such as intersection (AND) and union (OR). With the use of WLC, continuous criteria (factors) are standardized to a common numeric range and then combined by weighted averaging. The result is a continuous mapping of the suitability (Jiang & Eastman, 2000).

2.5.2 Weighted overlay analysis

Weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. Geographic problems often require theanalysis of many different factors using GIS.

For instance, finding optimal site for irrigation requires weighting of factors such as land cover, slope, soil and distance from water supply (Yang Yi, 2003).

To prioritize the influence of these factor values, weighted overlay analysis uses evaluation scale from 1 to 9 by 1. For example, a value of 1 represents the least suitable factor in evaluation while, a value of 9 representsthe most suitable factor in evaluation. Weighted overlay only accepts integer rasters as input, such as a raster of land cover/use, soil types, slope, and Euclidean distance output to findsuitable land for irrigation

Euclidean distance is the straight-line from the center of the source cell to the center of each of the surrounding cells. (Janssen &Rietveld, 1990).

2.6Irrigation Land Suitability Classification

Land suitability is the fitness of a given type of land for a defined use. The land may be classified in its present condition or after improvements for its specified use. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO,1976).

Land suitability classes reflect degrees of suitability. The classes are numbered consecutively in sequence of decreasing degrees of suitability within the order.

Within the order suitable the number of classes is not specified however number should be kept to the minimum necessary to meet interpretative aims, utmost five classes should be used.
They classes are:-

i) S1 – Highly suitable (>**80%)**
ii) S2 – Moderately suitable (**60% - 80%)**
iii) S3 – Marginally suitable (**40% - 60%)**
iv) N1 – Marginally not suitable (**20% - 40%)**
v) N2 – Permanently not suitable (<**20%)**

Highly suitable – Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits.
Moderately Suitable – Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, though still attractive, will be appreciably inferior to that expected on Class S1 land.
Marginally suitable – land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity of benefits, or increase required inputs, that this expenditure will be only marginally justified.
Marginally not suitable – Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner.
Permanently not suitable– Land having limitations which appear so severe as to preclude any possibilities of successful use of the land in the given manner. (FAO 1993)

2.7 Irrigation criteria

2.7.1 Slope

Slope is the incline or gradient of a surface and is commonly expressed as a percent. Slope is important for soil formation and management becauseof its influence on runoff, drainage, erosion and choice of irrigation types. The slope gradient of the land has great influence on selection of the irrigation methods. According to FAO standard guidelines for the evaluation of slope gradient, slopes which are less than 2%, are very suitable for surface irrigation. But slopes, which are greater than 8%, are not generally recommended (FAO, 1999)

Legend	Slope (%)	Factor Rating
1	0 – 2	S1
2	2 – 5	S2
3	5 – 8	S3
4	>8	N

Table2.1 Slope suitability classification for surface irrigation *(Source: FAO 1996)*

2.7.2. Soils

The assessment of soils for irrigation involves using properties that are permanent in nature that cannot be changed or modified. Such propertiesinclude drainage, texture, depth, salinity, and alkalinity (Fasina et al, 2008). Even though salinity and alkalinity hazards possibly improved by soil amendments or management practices, they could be considered as limiting factors in evaluating the soils for irrigation (FAO, 1997). Accordingly, some soils considered not suitable for surface irrigation could be suitable for sprinkler irrigation or micro-irrigation and selected land utilization types.

2.7.3 Land use/Land cover

Land use/Land cover is often used interchangeably. However, they are actually quite different. The Global Land Cover Network - GLCN (2006) defines Land cover as the observed bio/physical cover, as seen from the ground or through remote sensing, including vegetation and man made features (buildings, roads, etc.) which cover the earth’s surface. Water, bare rock or sand surfaces also count as land cover. However, the definition of land use establishes a direct link between land cover and the actions of people in their environment.

Thus, a land use can be defined as a series of activities undertaken to produce one or more goods or services. A given land use may take place on one, or more than one, pieces of land and several land uses may occur on the same piece of land. Definitions of land cover of land use in this way provide a basis for identifying the possible land suitability for irrigation with precise and quantitative economic evaluation.

Therefore, matching of existing land cover/use with topographic and soil characteristics to evaluate land suitability for irrigation with land suitability classes, present possible lands for new agricultural production (Jaruntorn et al.,2004)

2.7.4 Water availability

It is important to make sure that there will be no lack of irrigation water (thus the focus on Perennial Rivers in this study).

If water is in short supply during some part of the irrigation season, crop production will suffer, returns will decline and part of the scheme's investment will lay idle (FAO, 2011).

Therefore, water supply (water quantity and seasonality) is the important factor to evaluate the land suitability for irrigation according to the volume of water during the period of year which it is available (FAO, 2001).

Therefore, water supply (water quantity and seasonality) is the important factor to evaluate the land suitability for irrigation according to the volume of water during the period of year which it is available (FAO, 1985).

Quantifying the amount of water available for irrigation and determining the exact locations to which water can be economically transported are important in the decision to expand its use. Where possible, the water source preferred to be located above the command area so that the entire field can be irrigated by gravity. It is also desirable that the water source be near the centre of the irrigated area to minimize the size of the delivery channels and pipelines. Therefore, distance from water sources to command area, nearness to rivers, is useful to reduce the conveyance system (irrigation canal length) and thereby develop the irrigation system economical (Silesh, 2000).

2.8 Crop viability in Machakos County

Drought resistant crops basically do well in Machakos County,but generally the following are the most viable:- Maize, Sorghum, beans, millet, cowpeas, green grams, pigeon peas, mangoes, onions, pawpaw and cassava.

Fig. 2.1 Onion plantation (Irrigated agriculture) at Ikalaasa, Machakos County

Fig 2.2 French bean (irrigated agriculture) Machakos County

CHAPTER 3: MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location, size, economy and population

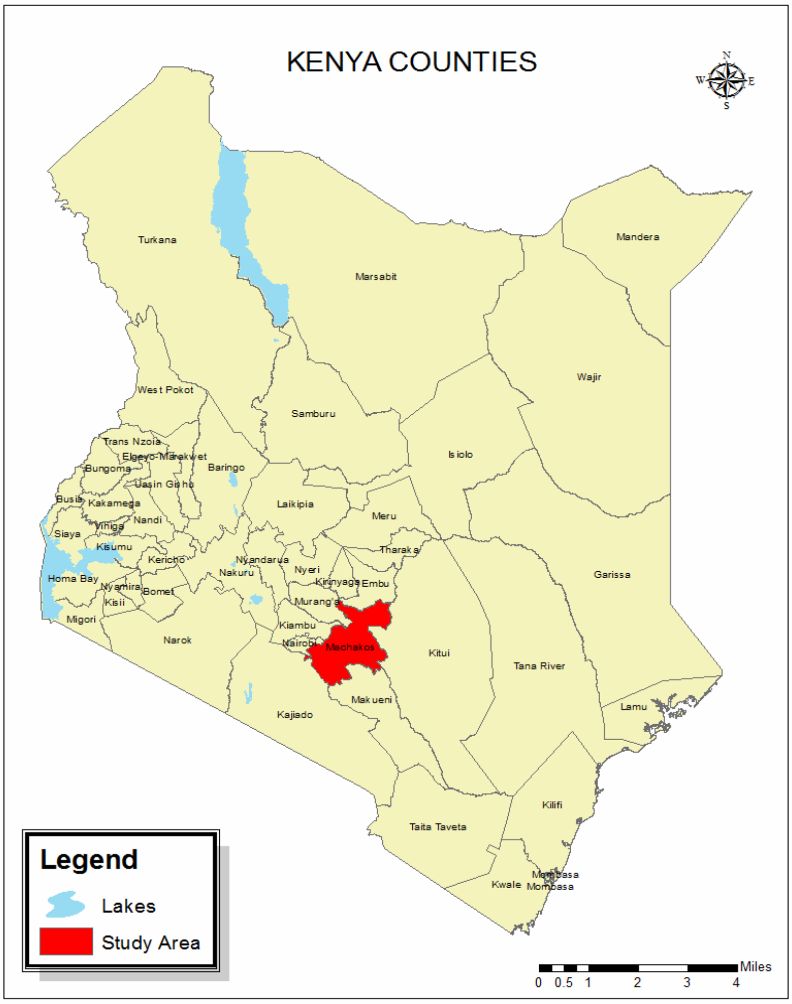

Fig. 3.1 Figure showing area of study within Kenya

Machakos County is one of the 47 counties in Kenya. The County borders Embu, Murang'a and Kiambu to the North, Nairobi and Kajiado counties to the West, Makueni County to the South and Kitui County to the East. It lies between latitude $0^{0}45'$ South and $1^{0}31'$ South and longitudes $36^{0}45'$ East and covers an area of 6,208.20 Km^{2}. The prevailing local climate is semi-arid and the landscape is hilly, rising from an altitude of 1,000 to 1,600metres above sea level.

It experiences erratic and unpredictable rains of less than 500mm annually, with short rainsin October through to December and the long rains in late March to May.Administratively, Machakos County is divided into eight sub-counties*; Machakos, Masinga*, *Yatta*, *Kangundo, Matungulu, Kathiani, Athi River* and *Mwala.* The sub-counties are further subdivided into twenty two divisions, seventy one locations and two hundred and thirty three sub-locations.

Machakos County has a population of 1,098,583 as per 2009 Kenya Population and Housing census (male– 49 percent, female– 51 percent); with an age distribution of 0-14 years at 39 percent, 15-29 years 28 percent, 30-64 years 27.7 percent and 5 percent above 64 years. Its population annual growth rate is 1.7 percent. The population is projected to increase to 1,238,650 and 1,289,200 by 2015 and 2017 respectively.

The County has a population density of 188 per KM^2 with Kangundo Constituency having the highest density of 565 per KM^2. Masinga constituency is the least densely populated with 95 persons per KM^2 mainly due to unfavorable weather conditions.

The poverty level in the County is at 59.6 percent against a national average of 47.2 percent based on KNBS (2009). This positions the County at 33 out of the 47 counties. About 52 percent of the population lives in the urban centers, way above the national average of 29.9 percent.

Land has been generally under-exploited for agricultural production. Only 31 percent of land in the high and medium potential area is under production which represents only 5 percent of the land in the county. Arid and Semi-Arid Lands (ASALs) represent 84 percent of the land and also remains largely underutilized. Optimal utilization of the land both for livestock and crop production can be achieved through expansion of existing and introduction of new irrigation schemes in the County.

Absence of the national land use policy has led to the proliferation of informal settlement, inadequate infrastructure services, environmental degradation, unplanned urban centers, pressure on agricultural land and conflicts. The high population growth rate has led to a continuous decrease in average farm sizes. The average farm size under small scale farming is 0.756 Ha while that under large scale farm is 10 Ha.

Agriculture is the predominant economic activity in the county. It is leading in terms of employment, food security and income earnings. Therefore growth in the agricultural sector contributes proportionally more to poverty reduction than growth in any other economic sector. The sector is made up of four major subsectors, namely industrial crops; food crops; horticulture; and livestock & fisheries. Agricultural productivity is generally constrained by a number of factors; including high cost of inputs especially price of fertilizer and seeds, poor livestock husbandry, limited extension services, over dependence on rain fed agriculture, lack of markets, and limited application of agricultural technology and innovation.

The district lies within the drainage basins of River Athi and Tana, which, together with River Thika, a tributary of the Tana are the only perennial rivers. The hills in the central part of the county namely Kanzalu Range, Mango, Kangundo, Iveti, Mua and Kiima Kimwe are a source of a few permanent springs and streams, whose flow is intermittent at low attitude.

3.1.2 Irrigation Schemes Development

The County is endowed with large tracts of fertile land mainly in Mwala, Yatta, Kangundo and Masinga, however farmers mainly rely on unreliable rain fed agriculture predisposing them to low economic returns and food insecurity.

Great opportunities exist in irrigation for floriculture and horticulture for local and international markets by tapping water from rivers Tana, Athi, Thika and the numerous streams.

A number of irrigation projects have been developed in the County on a small scale basis and these include:- Mutuyu Irrigation project, Kondo Irrigation Project, Kamuthambya Irrigation project, Kalama clusters (Lumbwa water pan), Kayatta Irrigation project, Kwa Kiluli irrigation project and Kivaa irrigation project. These minor irrigation projects are prove that the key to development of the agriculture industry lies in irrigation, exploiting available water resources for gainful farming.

3.2.1 Multi Criteria Decision Making/Analysis

MCDA provides a rich collection of technologies and procedures for structuring decision problems, and designing, evaluating and prioritizing alternative decisions.

GIS MCDA – can be thought of as a process that transforms and combines geographical data and value judgements to obtain information for decision making.

MCDA supports complex decision making when multiple, conflicting factors are involved. It provides support for decision making at any stage of a decision process, such as design, choice and visualization (Malczewski, 2006).

Decision is a choice between alternatives.
Criteria are a set of guidelines or requirements used as basis for a decision and are of two types:-
A factor – a criterion that enhances or detracts from the suitability of a specific alternative for activity under consideration.
A constraint – serves to limit the alternatives under consideration. Element or features that represent limitations or restrictions.

Multi Criteria Evaluation– criteria evaluated as fully continuous variable. Such criteria are called factors and express varying degree of suitability for the decision under consideration. The process of converting data to such numeric scales is called standardization (Voogd, 1983). Standardized factors will be combined by means of weighted linear combination, that is each factor will be multiplied by a weight, and results summed.

3.2.2 Process of Multi Criteria Analysis

This process involves a number of steps:-

i. Set the goal/define problem
ii. Data collection
iii. Determine the criteria (factors/constraint)
iv. Generation of Criteria maps
v. Determine the weight of each factor - AHP
vi. Standardize the factors/criterion scores
vii. Aggregate the criteria (weighted overlay)
viii. Validate/verify results

ix. Suitable map for potential irrigation area

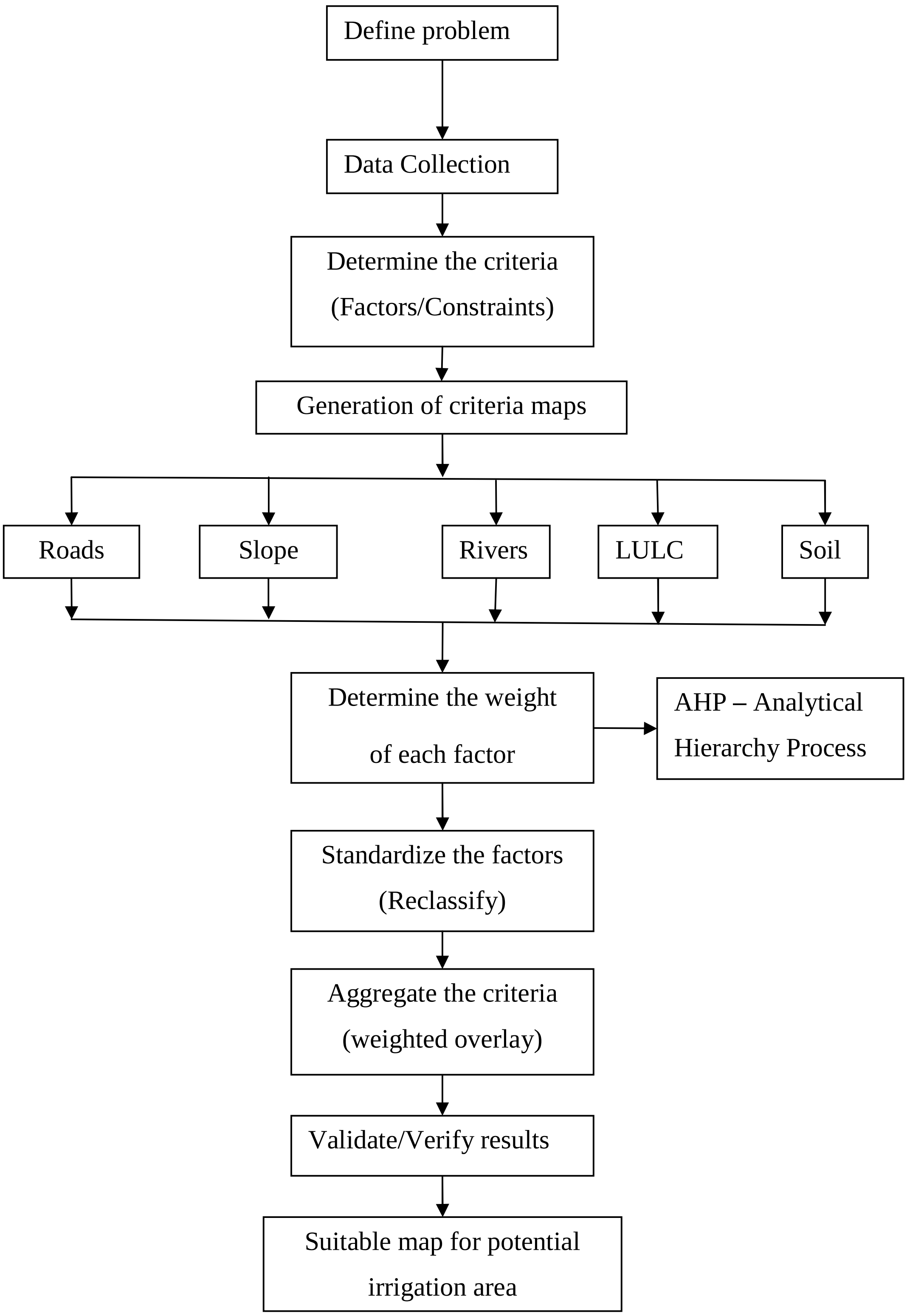

Fig. 3.2 Schematic representation of the methodology*(Adopted from Eastman et al.,1995)*

AHP - Analytical Hierarchy Process

The AHP will be used to determine the weights. The method was introduced by Saaty and is constructed of different hierarchy levels. It places the goal on the top, the criteria in the middle and alternatives at the bottom. The input of experts is a pair-wise comparison of the criteria values, which multiplied by the performances of the alternatives will result in the choice of the best scoring solution (Saaty, 1980).

Fuzzy set applications -There are two sources of uncertainty in GIS-based multi-criteria decision making; database and decision rule uncertainty since fuzzy theory was designed to handle uncertainties; methods derived from the theory are very useful to deal with non-statistical, qualitative or unquantifiable information. In case of an MCDA problem, these data can be linguistic quantifiers, such as categories like “good”, “fair”, or “poor”. (Eastman et al.,1995).

3.3 Data and data sources

- *Soil map* – KARLO GIS Laboratory
- *Vector data* – Roads, Rivers, County boundary obtained from ILRI website (www.ilri.org) and RCMRD Geo database – www.rcmrd.org
- *Land use land cover* layers (2014) were obtained from ILRI website (www.ilri.org) and RCMRD geo-portal (geoportal.rcmrd.org)
- *Elevation data* - SRTM 30m (Geo-referenced tagged image file format - GeoTiff) – to determine the slope (source www.rcmrd.org)
- Google earth was used for accuracy assessment and validation

3.4 Software

ArcGis 10.2.1 was used for analysis and map production. The ArcGis spatial analyst extension provided a rich set of spatial analysis and modelling tools for both raster and vector data.

3.5 Methodology

In this study multi criteria site suitability analysis was done to identify locations with potential for irrigated agriculture based on a group of criteria and constraints. Based on their importance and significance five different criteria and constrains were chosen which include Soil (depth, PH, and Texture), Rivers (permanent/perennial), Slope, Roads and Land use /land cover (LULC) Weights for each criterion were calculated using AHP and after that weighted overlay was done to generate the suitability map.

3.6 Generation of criteria maps using GIS

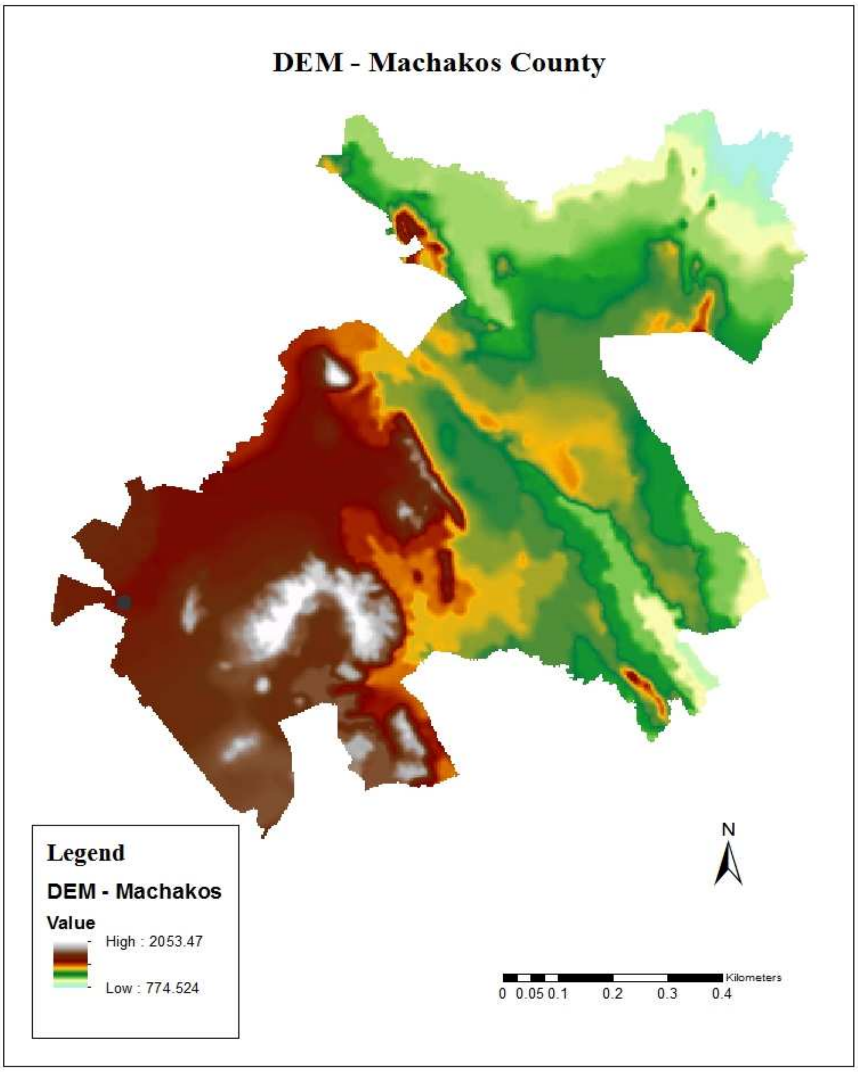

Fig 3.3 Digital elevation map of the study area

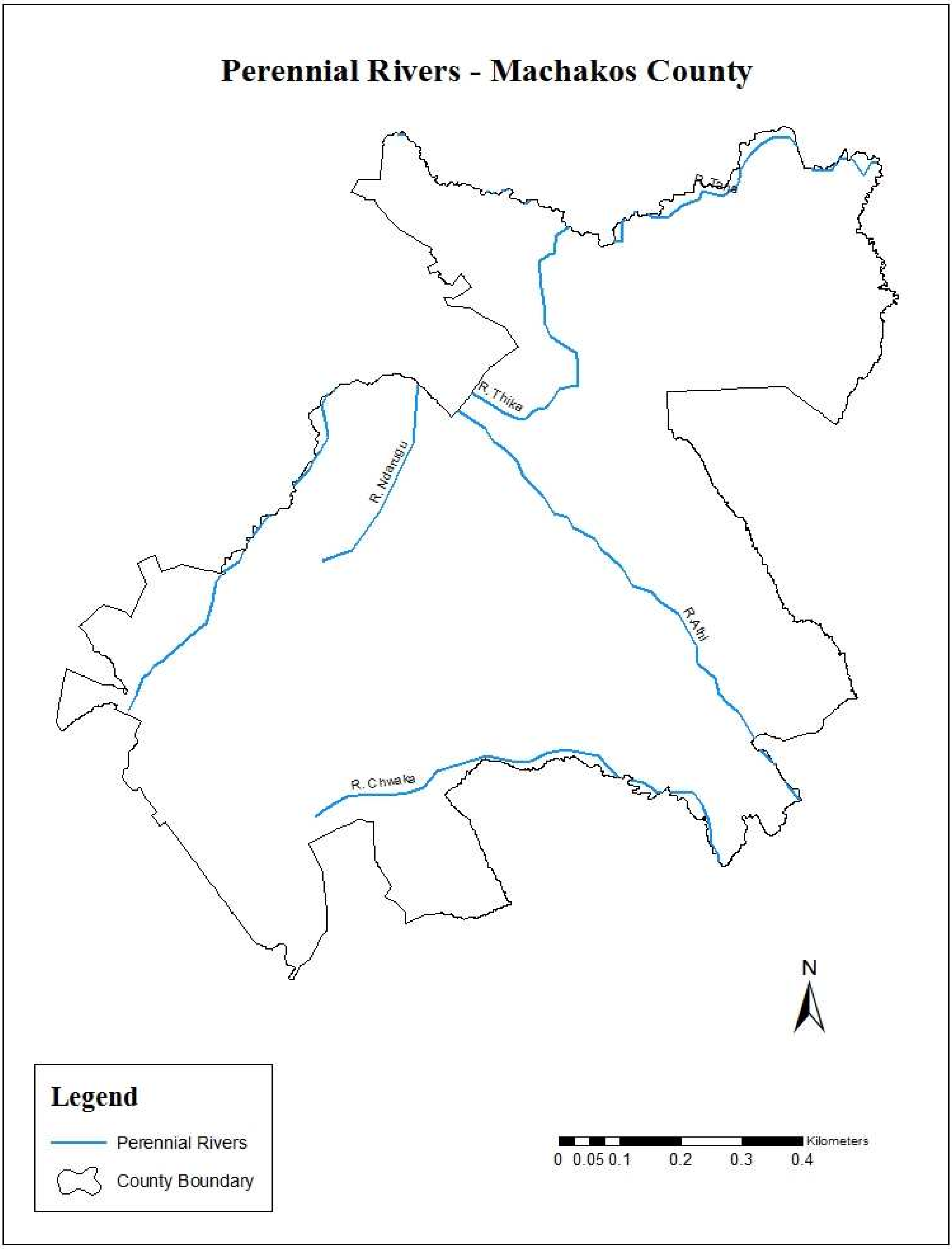

Fig 3.4 Drainage network (perennial rivers) Machakos County

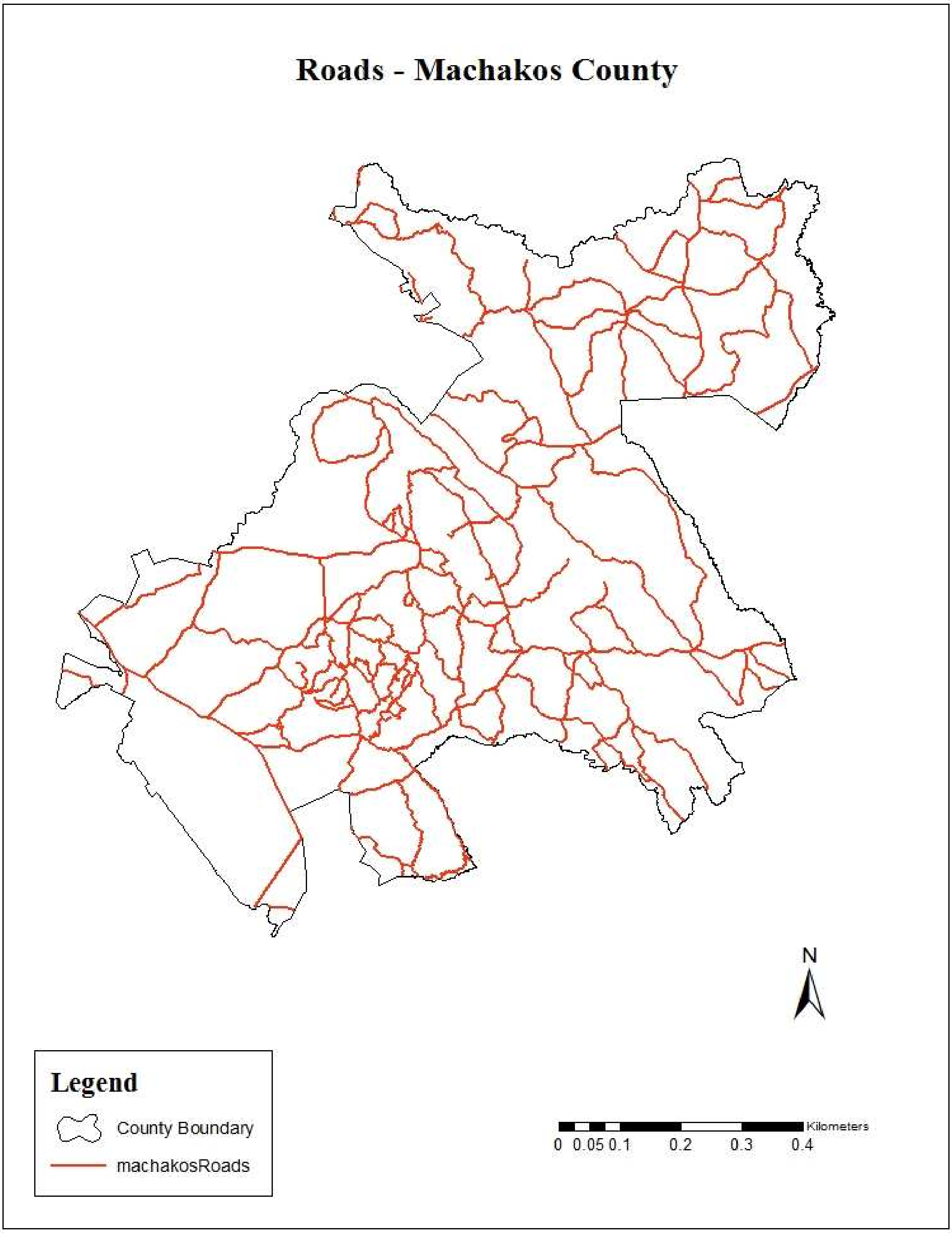

Fig 3.5 Road network Machakos County

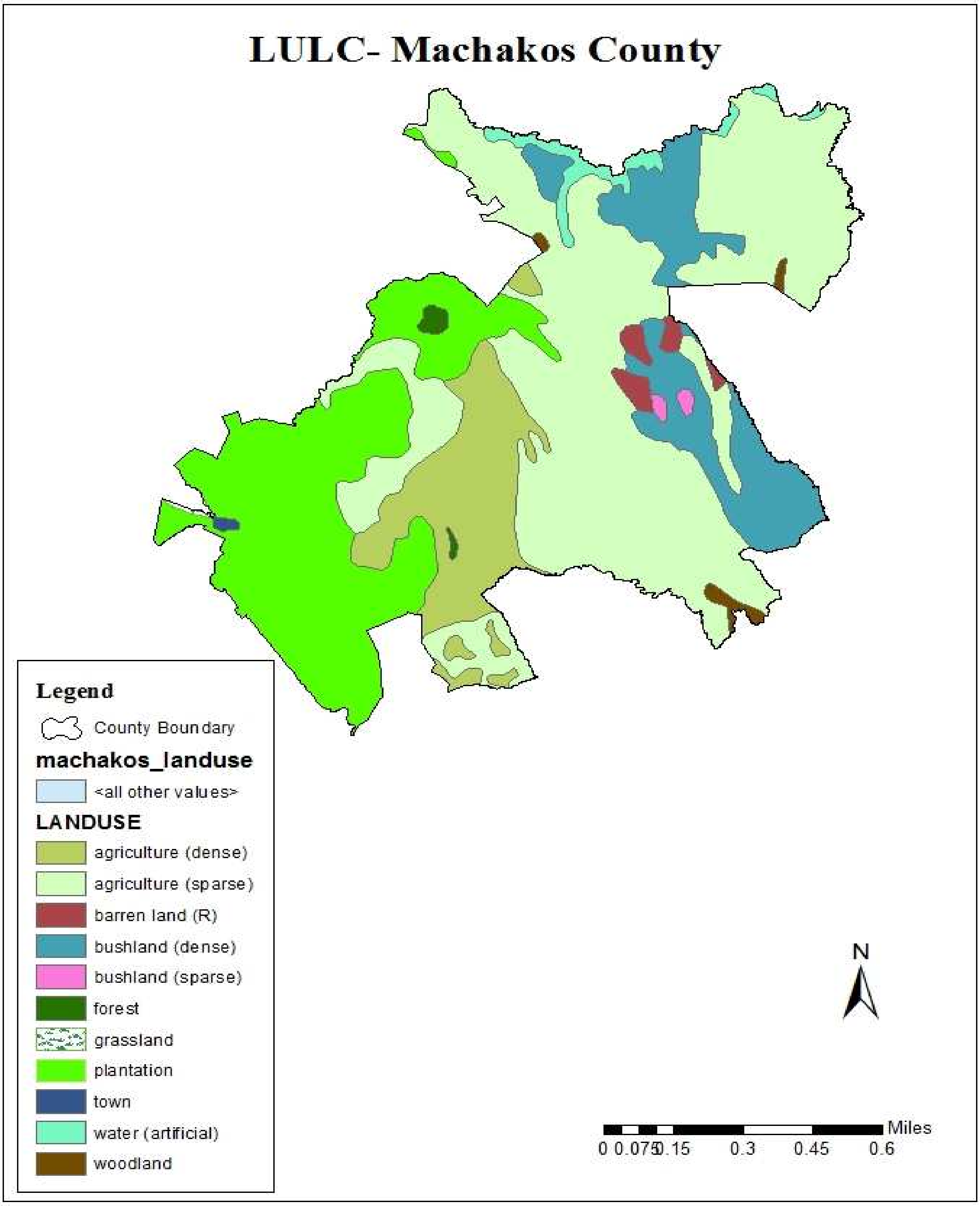

Fig 3.6Figure showing Land use Land cover (LULC) map Machakos County

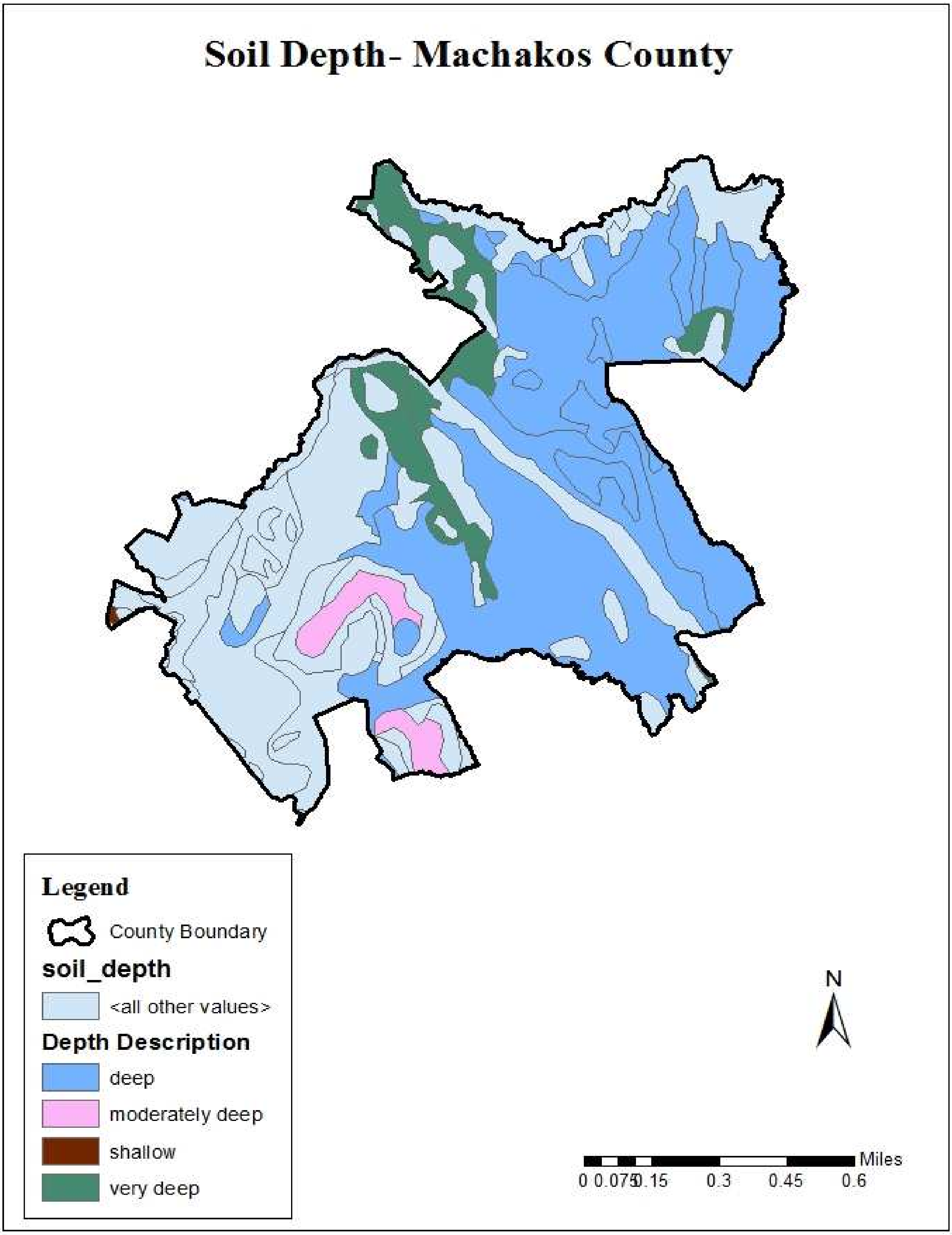

Fig 3.7 Soil depth map Machakos County

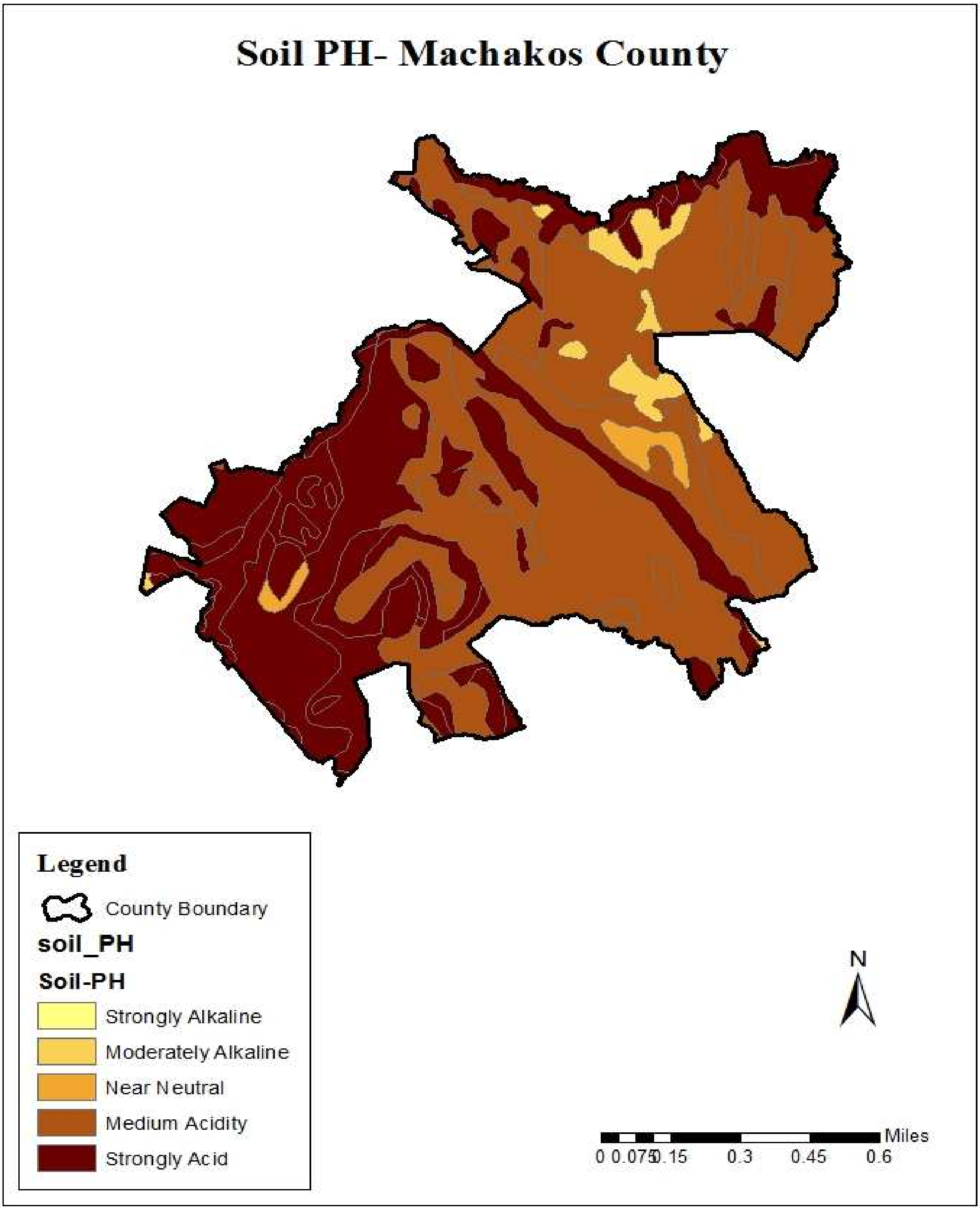

Fig 3.8 Figure showing Soil PH Machakos County

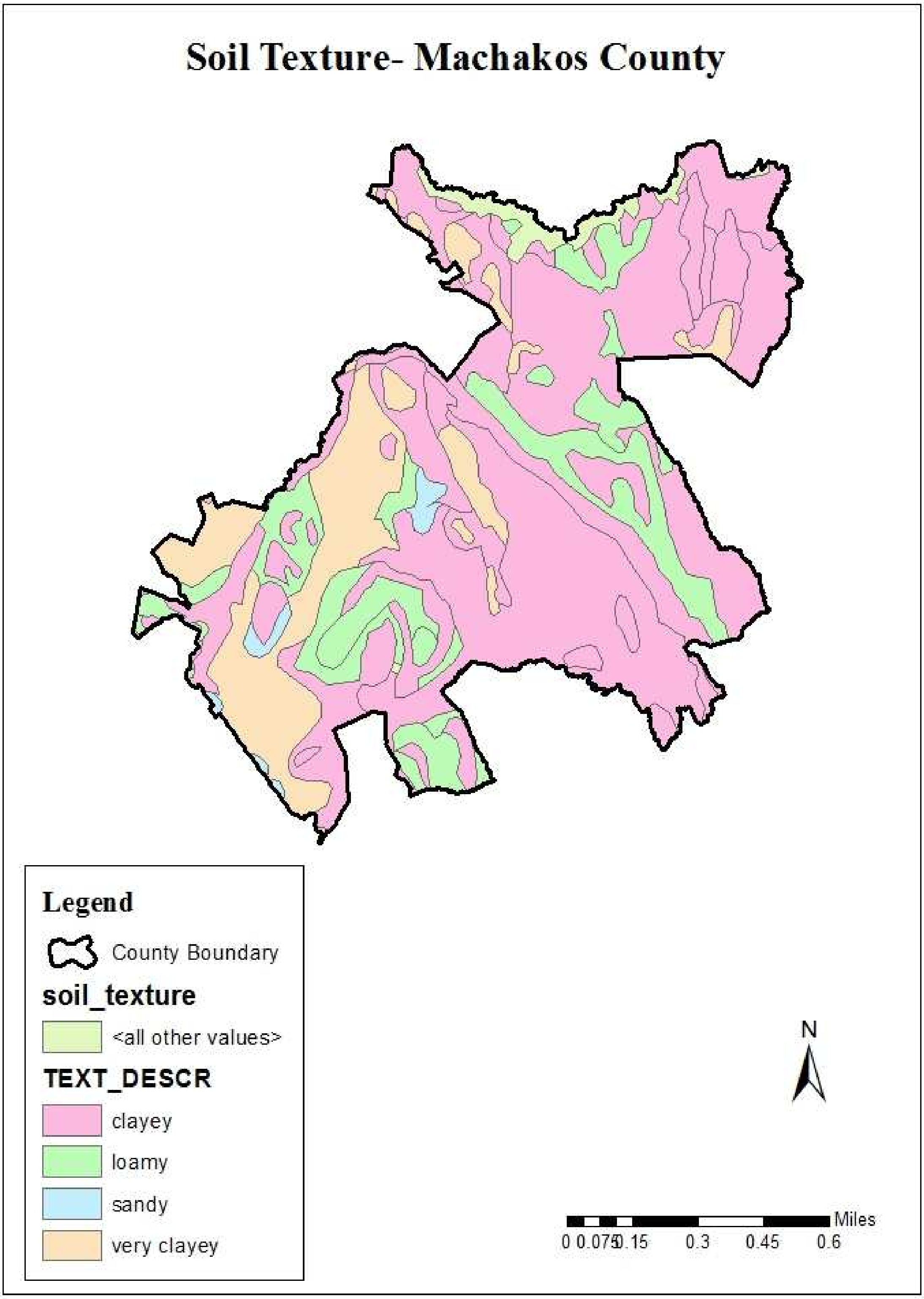

Fig 3.9Figure showing Soil texture Machakos County

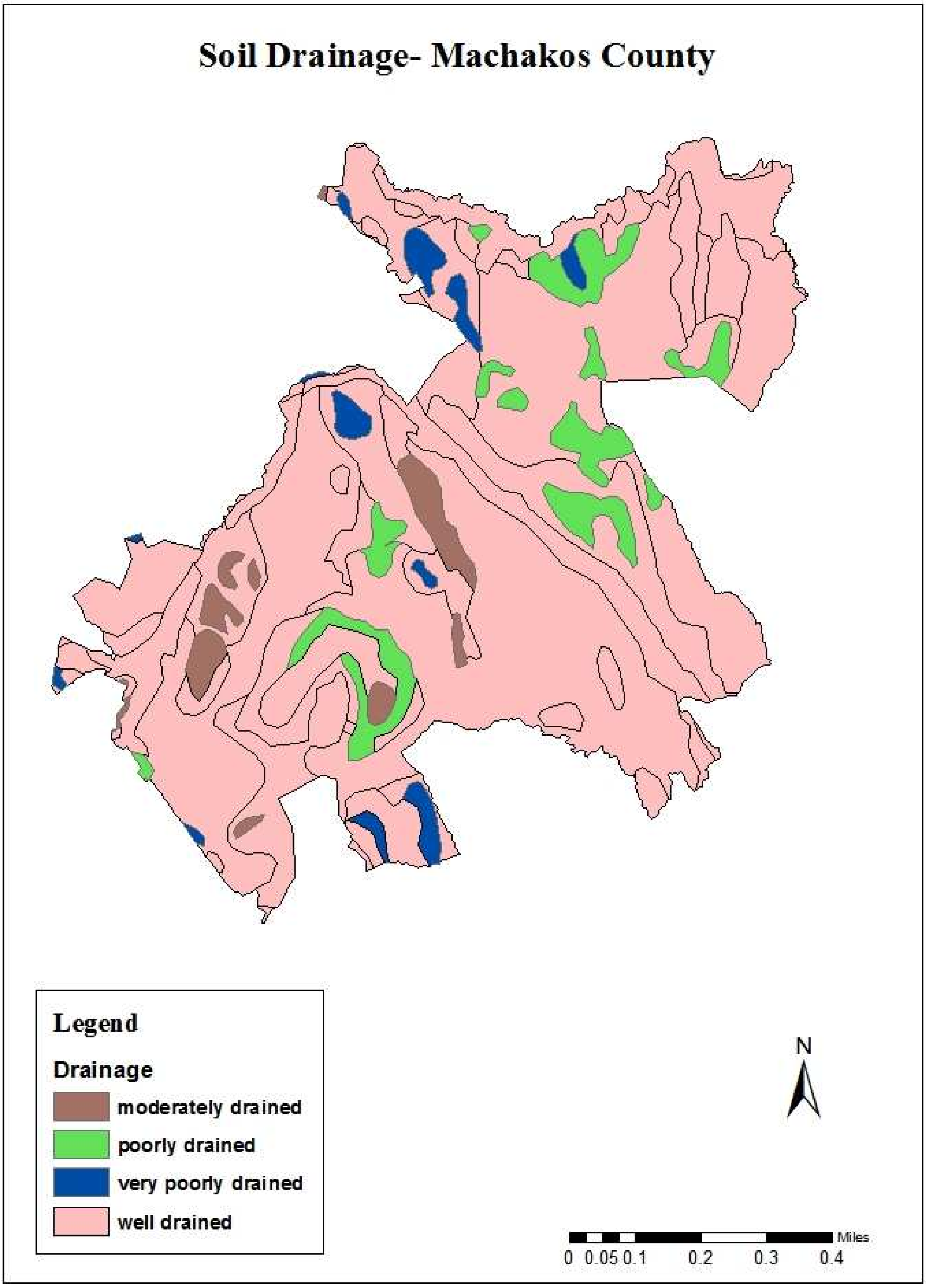

Fig 3.10 Figure showing Soil Drainage Machakos Count

3.7 Determination of weights using AHP

Ahp is used for a group of criteria, sub-criteria to set up the hierarchical structure by selecting the weightage of individual criterion in whole decision making process. The weights reflect the relative importance of each criterion and hence to be selected carefully. AHP was applied to make pairwise comparisons between the criteria and thus reduced the complexity (Saaty, 1977)

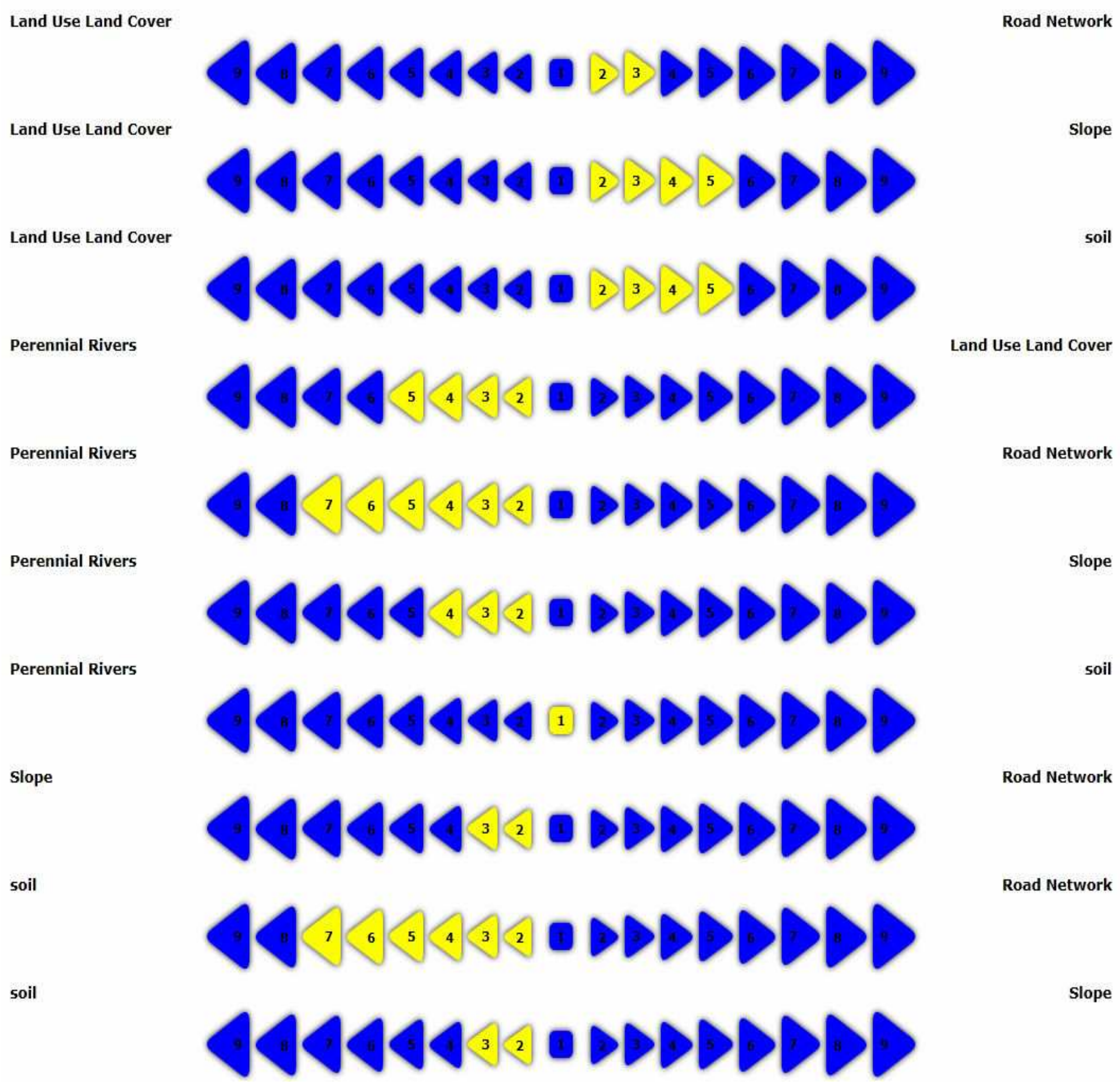

Fig.3.11 Figure showingAHP Pairwise comparison

The pairwise comparison matrix involves pairwise comparisons to create a ratio matrix. As input, it takes the pairwise comparisons of the parameters and produces their relative weights as output. Pairwise generated by using a scale of 1 – 9 in which 1 having equal importance and 9 having extreme importance of in between two criteria (Malczewski,1999).

Once the pairwise matrix is made, Saaty's method of eigen vectors/relative weights is calculated, AHP identifies and takes into account the inconsistencies of the decision makers which is one of the strength (Garcia et al., 2014).

Intensity of importance	**Definition**
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extremely importance

Source: (Saaty, 1980).

Table 3.1Table showing pairwise comparison matrix

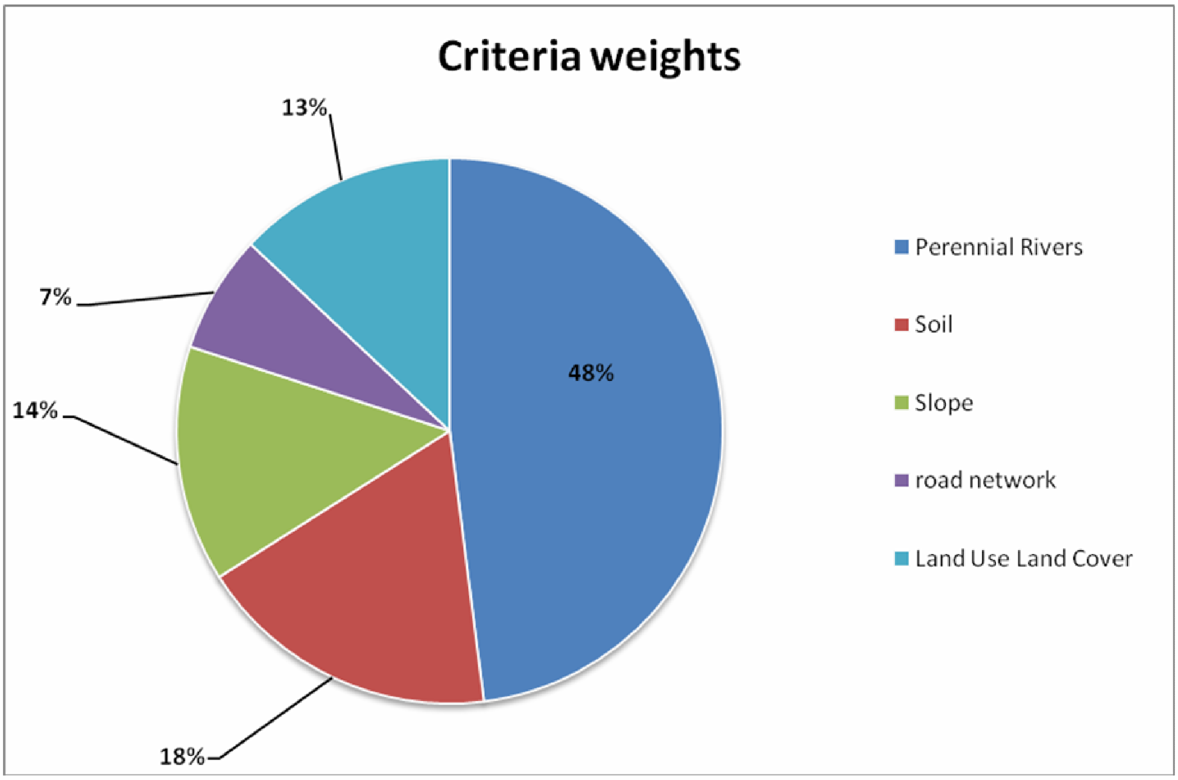

Fig 3.12 Pie chart showing criteria weights

CRITERIA	WEIGHT
Perennial Rivers	**48%**
Slope	**14%**
Road Network	**7%**
Land use Land cover	**13%**
Soils PH - 4% Texture - 4% Depth -4% Drainage -6%	**18%**

Table 3.2 Criteria weights - AHP

3.8 Standardization

All the criteria are in different units so to perform weighted overlay they need to be in same units and hence needed to be standardized. Standardization makes the measurement units uniform, and the scores lose their dimension along with their measurement unit (Effat & Hassan, 2013).

Vector layers were converted to raster further which were reclassified for the input to the weighted overlay which finally gave the suitability map. Reclassify tool in spatial analyst in ArcGIS standardizes the value of all criteria for comparison.

Weighing of irrigation suitability factorsto find potential irrigable sites

To find suitable site for surface irrigation, a suitability model was created using model builder in Arc tools box and tools from spatial analysis tool sets. Then, after their individual Suitability was assessed, the irrigation suitability factors which were considered in this study, such as slope factor, soil factor, land cover /use factor and distance factor were used as the input for irrigation suitability model to find the most suitable land for surface irrigation

Creating a new model

A toolbox (suitabilitanalysistoolbox.tbx) was initially created to hold the model, after which a model was created to perform spatial analyst tasks. A model was built by stringing tools together in model builder.

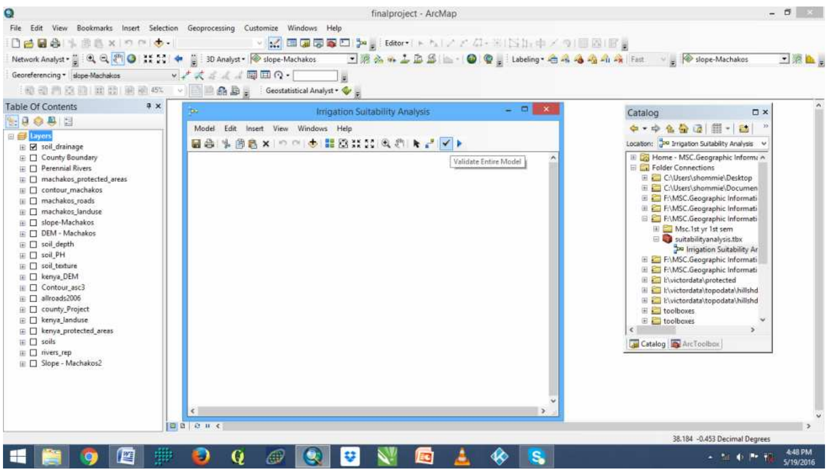

Fig 3.13 Creating a toolbox and suitability model

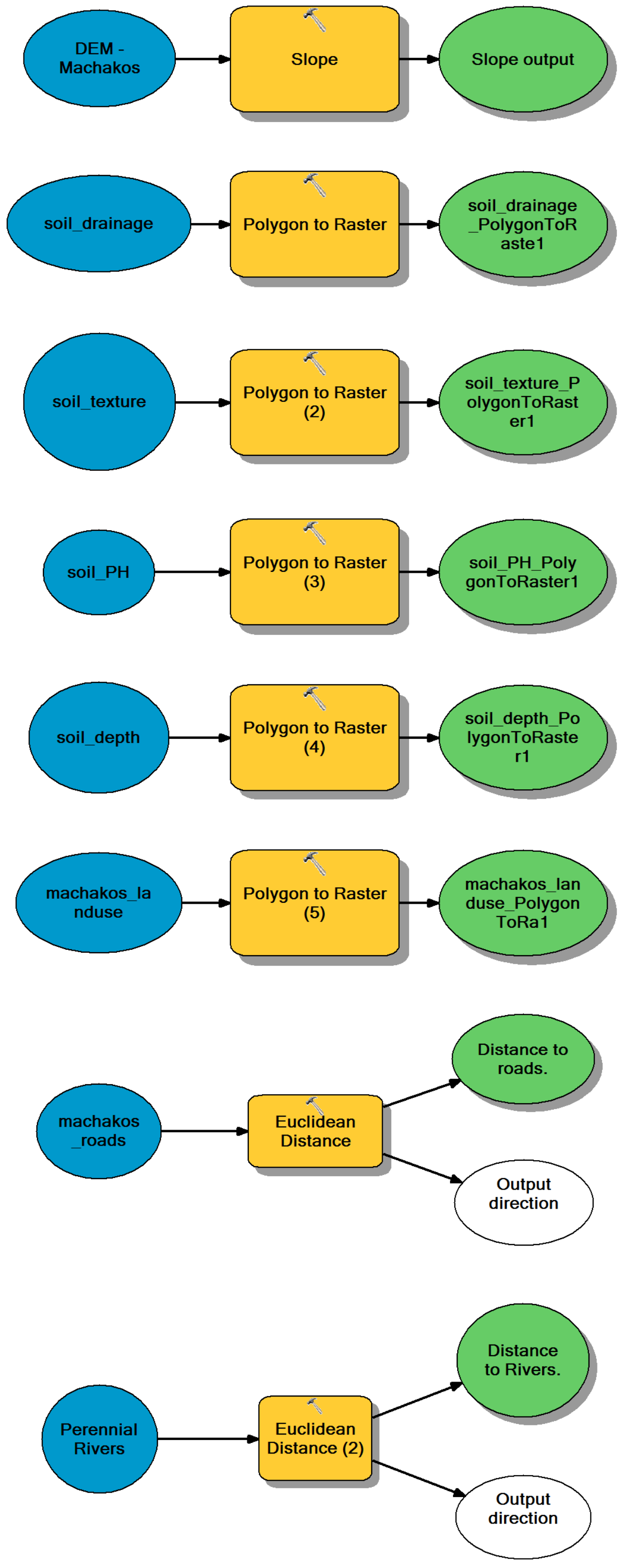

Fig. 3.14 Model Builder

3.9 Euclidean Distance

Euclidean distance is the straight line distance between two points on a plane, also known as *'distance as the crow flies'*. Euclidean distance describes each cell's relationship to a source or a set of sources.

It consists in generating a raster from a vector layer or another raster that indicates the existing distances from the figure to the rest of the field in a visual and colourful way. It indicates the space that exists from a certain distance to another distance and so on until a maximum distance is indicated or we have the raster predefined.

The Euclidean distance output raster contains the measured distance form every cell to the nearest source. The distances are measured 'as the crow flies' in the projection unit of the raster and are computed from cell centre to cell centre. This tool was used when creating the irrigation suitability map (Esri, 2016)

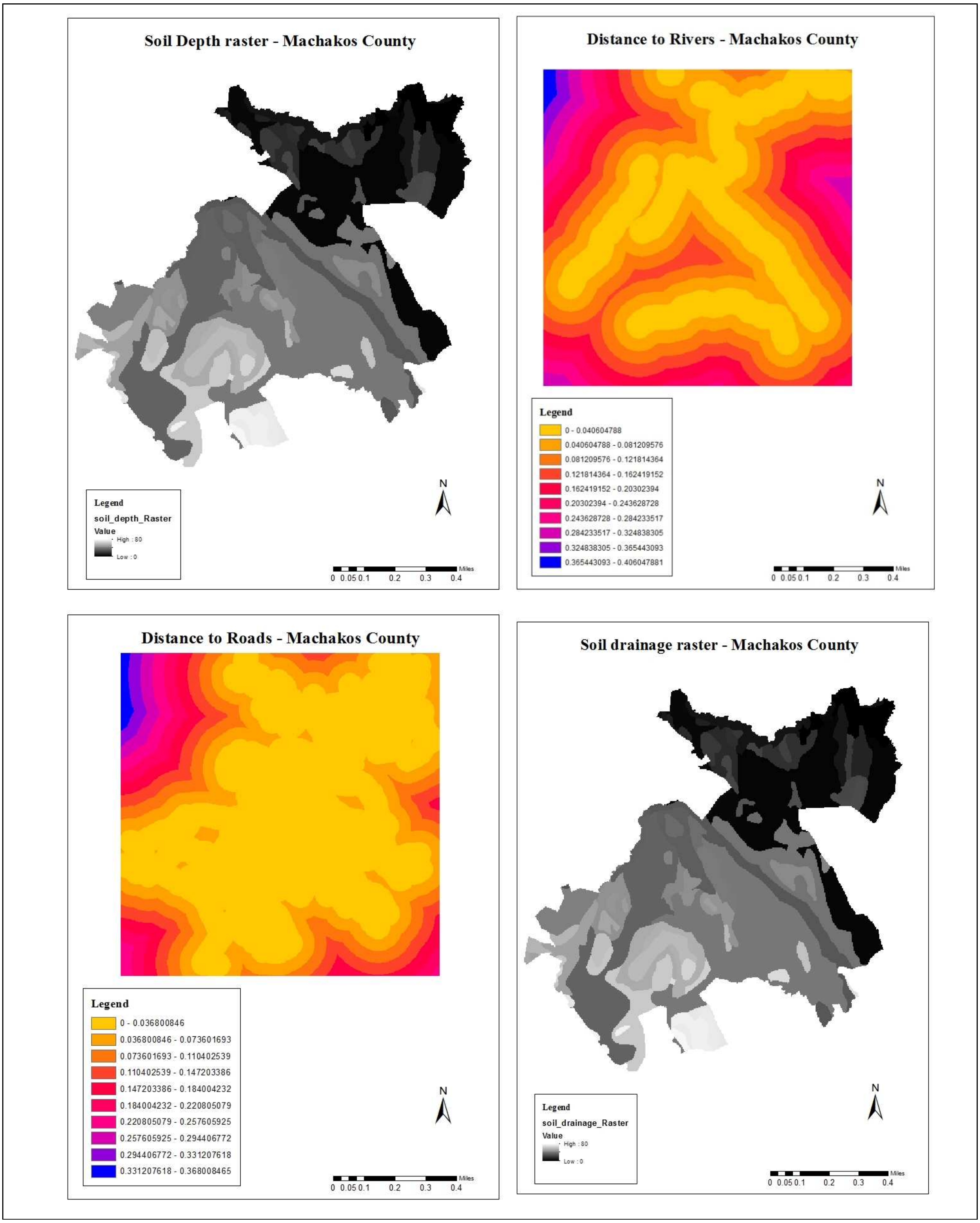

Fig 3.15 Figure Derived Datasets

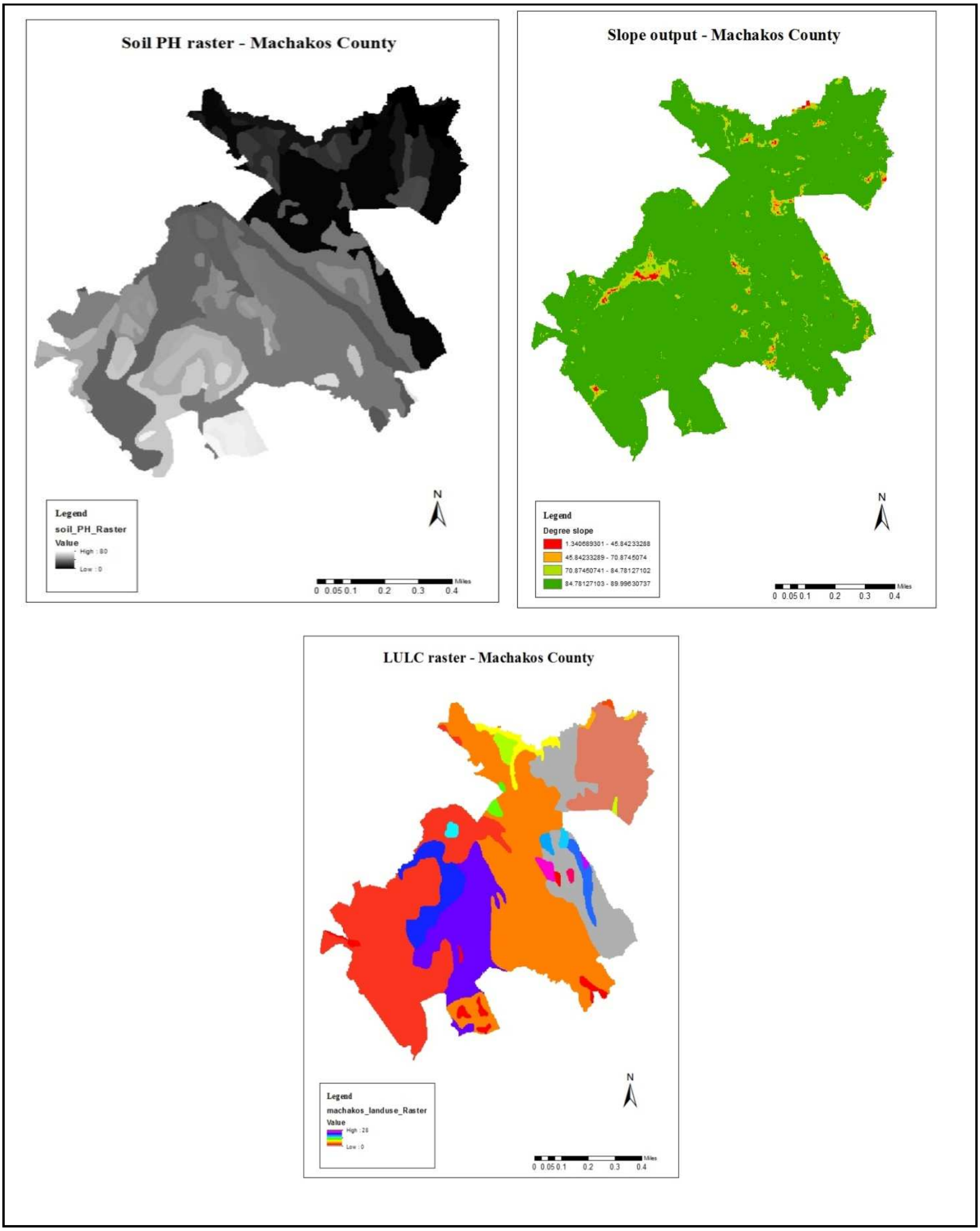

Fig 3.16 Figure Derived datasets

3.10 Reclassifying Datasets.

Deriving datasets, such as slope was the initial step when building the suitability model. The derived datasets were combined to create a suitability map that was used to identify potential areas for irrigated agriculture in Machakos County. However it was not possible to combine them in the present form. For example, combining a cell value in which slope equals 15 degrees with a cell value for land use that equals 3(bush land) – and get a meaningful answer that can be compared to other locations. To combine the datasets, they first need to be set to a common measurement scale, such as 1 to 10. That common measurement scale is what determines how suitable a particular location – each cell – is for irrigated agriculture. Higher values indicate more suitability (Esri, 2016).

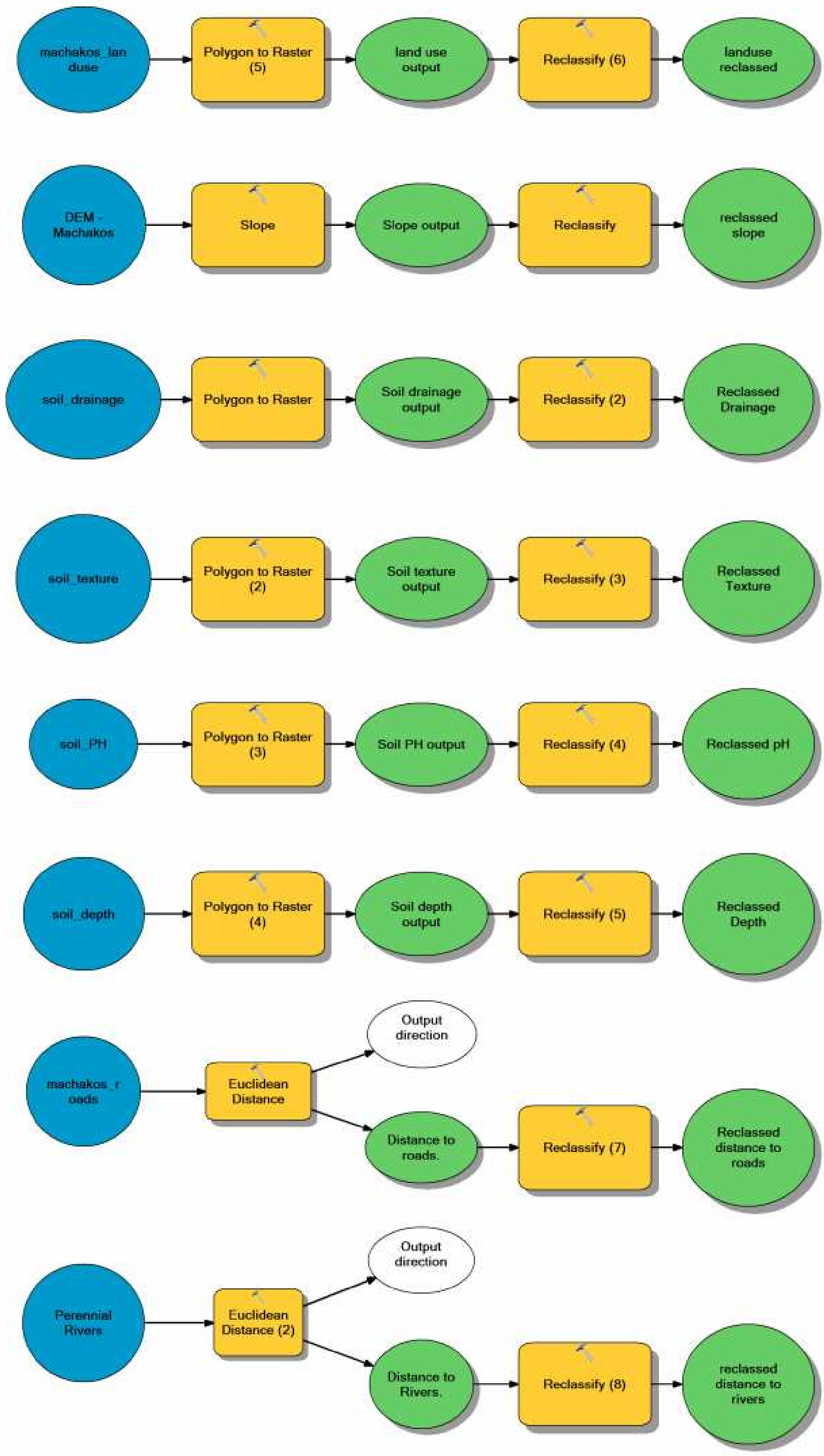

Fig 3.17 Reclassifying datasets Model

Reclassifying Slope

It is preferable that potential irrigation site be located on relatively flat ground. The slope output was reclassified, slicing the values into equal intervals. Value of 4 assigned to the Highly suitable range of slopes (those with the lowest degree of slope) and value of 1 to the least suitable range of slopes (those with the steepest degree of slope) and ranked the values in between linearly.

Class range (°)	Weight	Description
85.0 – 89.9	4	Highly suitable
70.0 – 85.0	3	Moderately suitable
45.0 – 70.0	2	Marginally suitable
<45.0	1	Not suitable

Table3.3Table showing criteria for classification of Slope

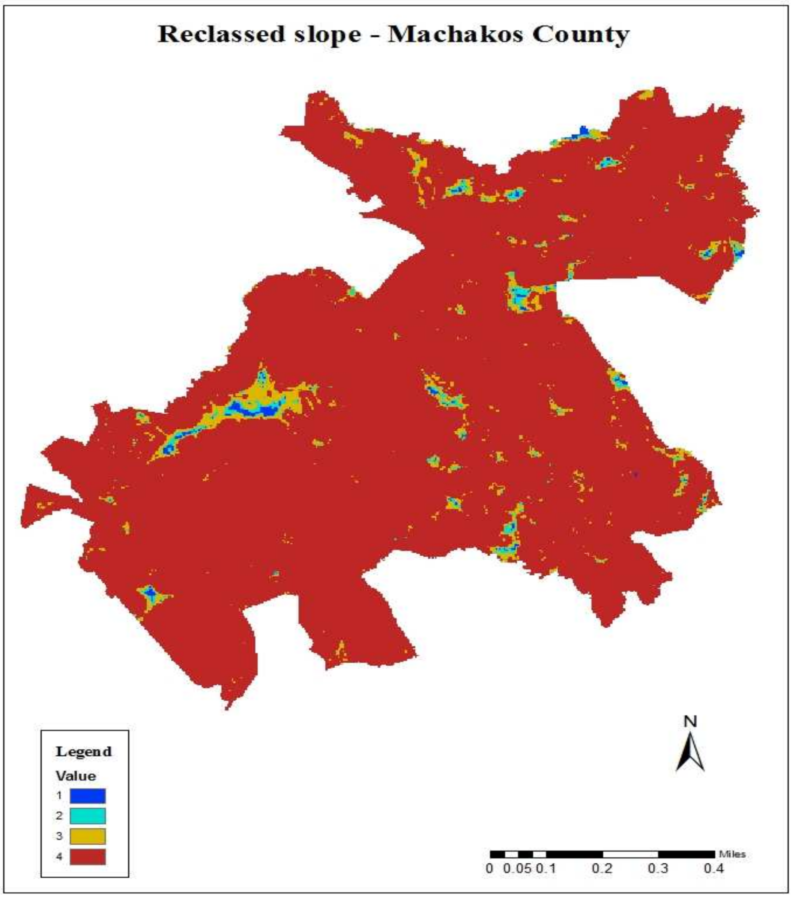

Fig 3.18 Map showing the suitability of study area based on slope

Reclassifying Soil depth

The depth of soil that can be effectively exploited by plant roots is an important criterion in selection of land for irrigated agriculture.

Class range (cm)	Weight	Description
70 – 100 *(very deep)*	4	Highly suitable
50 – 70 *(Deep)*	3	Moderately suitable
20 – 50 *(Moderately deep)*	2	Marginally suitable
0 – 20 *(Shallow)*	1	Not suitable

Table3.4 Table showing criteria for classification of Soil Depth

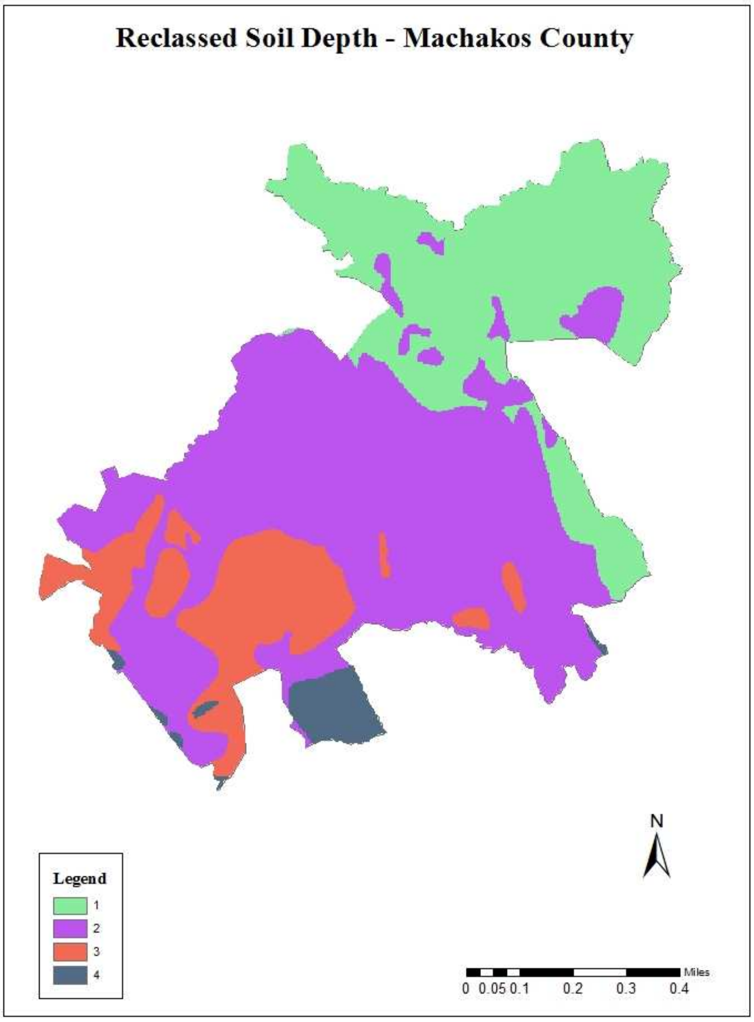

Fig 3.19 Map showing the suitability of study area based on soil depth

Reclassifying Soil drainage

Drainage is the removal of excess surface and subsurface water. Soil drainage refers to the flow of water through the soil, and the frequency and duration of periods when the soil is free of saturation under natural conditions. Soil drainability refers to the ability of soil and substrata to respond to subsurface drains. It enables predictions to be made of soil drainage under project irrigation conditions.

Class range (cm)	Weight	Description
70 – 100	4	Well drained
50 – 70	3	Moderately drained
20 – 50	2	Imperfectly drained
0 – 20	1	Poorly drained

Table3.5 Table showing criteria for classification of Soil Drainage

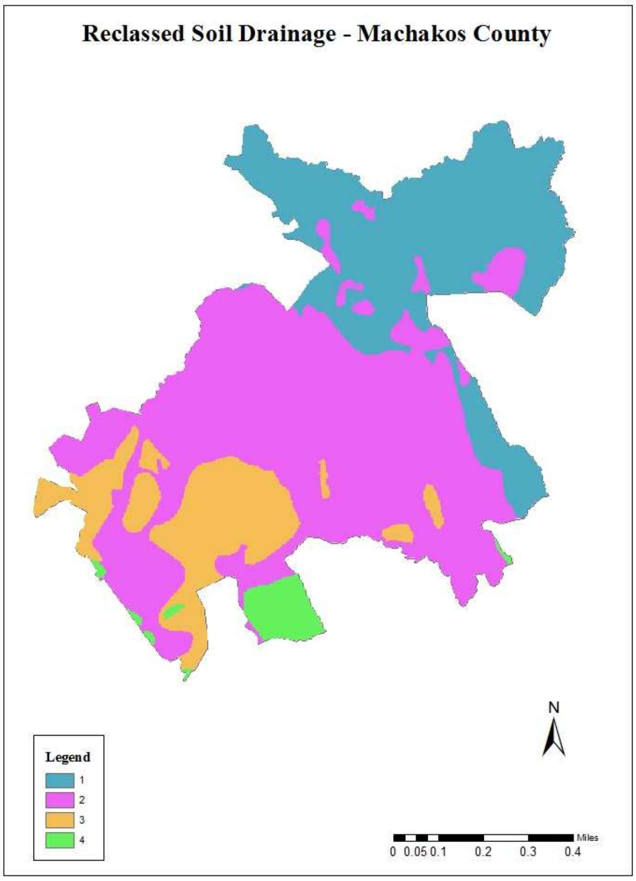

Fig 3.20 Map showing the suitability of study area based on Soil drainage

Reclassifying Soil texture

The proportion of sand, silt and clay are used to determine the textural classes of the soil. Particle size distribution is a function of parent materials and degree of weathering.

Field	Weight	Description
Clayey	4	Well drained
Loamy	3	Moderately drained
Sandy	2	Imperfectly drained
Very Clayey	1	Poorly drained

Table3.6 Table showing criteria for classification of Soil Texture

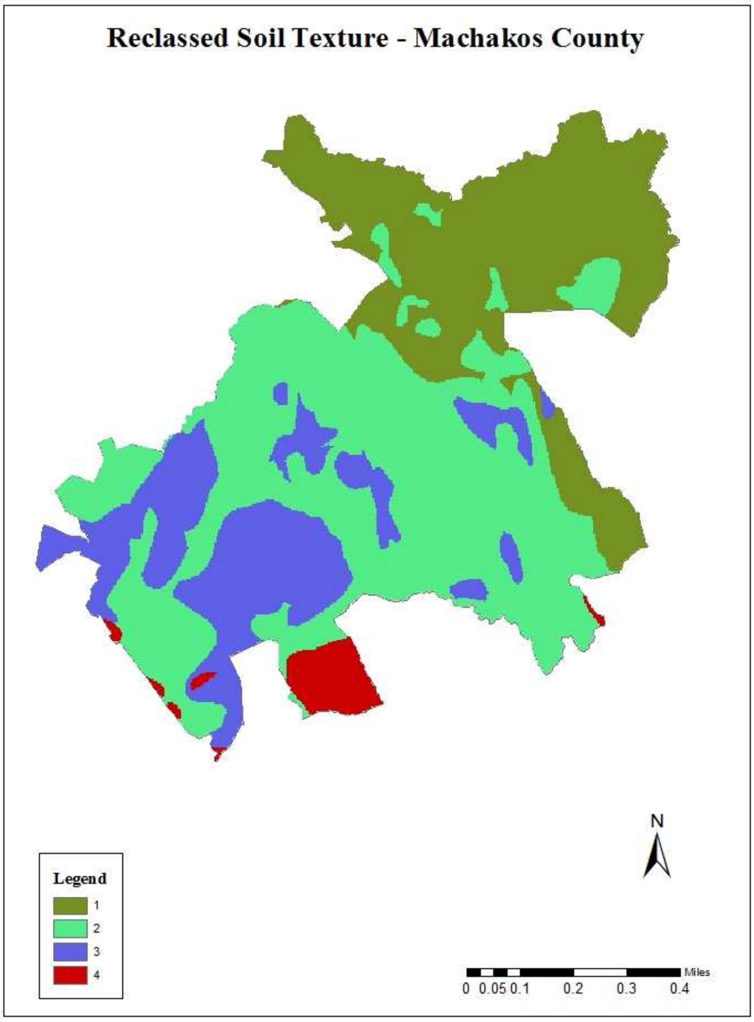

Fig 3.21 Map showing the suitability of study area based on Soil texture

Reclassifying Soil PH

The degree of acidity or alkalinity of a soil is usually expressed as a pH value which is defined as the negative logarithm of the hydrogen ion activity. pH determination on soil samples is made to make some generalizations regarding the availability of nutrients. A suitable range for most crops is between about 6.3 and 7.5Low pH-water (acidic condition) from 4.5 to 5.5, normally decrease crop yields or even prevent it. The same with alkaline soils (pH-water over 8.0)

Class range (pHaq)	Weight	Description
5.5 – 7.0	4	Highly suitable
7.0 – 8.0	3	Moderately suitable
4.5 – 5.5	2	Marginally suitable
<4.5 ; >8.0	1	Not suitable

Table3.7 Table showing criteria for classification of Soil pH

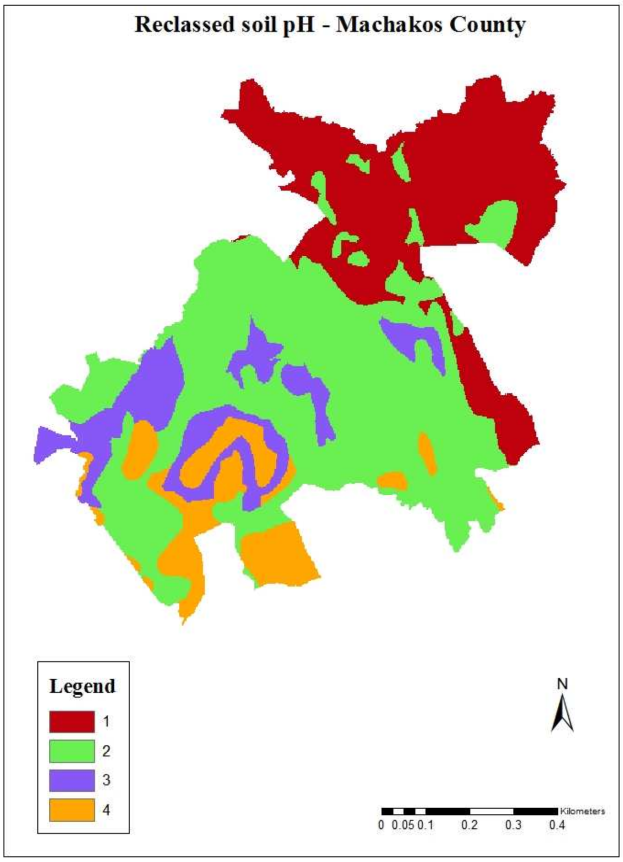

Fig 3.22 Map showing the suitability of study area based on Soil pH

Reclassifying distance to perennial rivers

Irrigated areas should be located as close as possible to rivers (putting into consideration a buffer zone for protection of water resources).

Class range (km)	Weight	Description
0 – 2.5	4	Highly Suitable
2.5 – 5	3	Moderately Suitable
5 - 10	2	Marginally Suitable
0>10	1	Not Suitable

Table3.8 Table showing criteria for classification of Distance to Perennial rivers

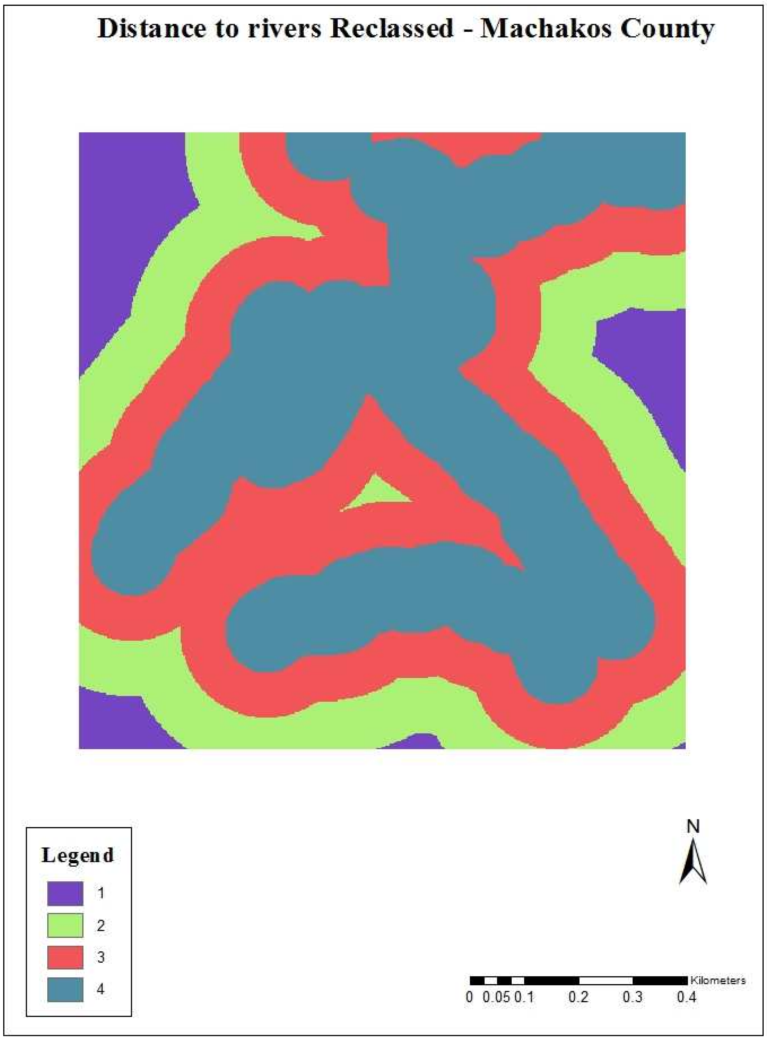

Fig 3.23 Map showing the suitability of study area based on Distance to rivers

Reclassifying distance to Roads

Irrigated areas should be located close to roads for accessibility, interms of labour accessibility, and movement of both farm input and output.

Class range (km)	Weight	Description
0 – 1	4	Highly suitable
1 – 2.5	3	Moderately suitable
2.5 – 5.0	2	Marginally suitable
5.0 – 10.0	1	Not suitable

Table3.9 Table showing criteria for classification of Distance to Roads

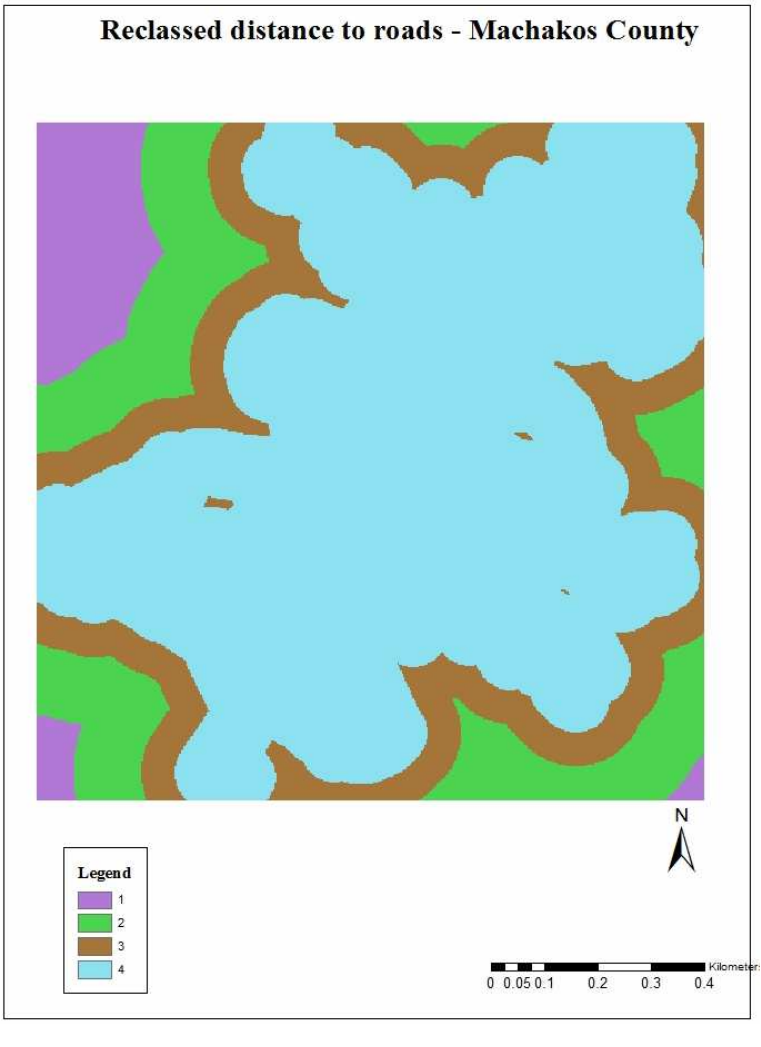

Fig 3.24 Map showing the suitability of study area based on Distance to roads

3.11 Weighting and combining datasets

The reclassified datasets are then combined to find the most suitable location. The values of the reclassification datasets representing slope, distance to rivers, distance to roads, land use land cover, soil texture, pH, drainage and depth have all been reclassified to a common measurement scale (more suitable cells have higher values). Values representing areas of water, forests, National reserves will be restricted, so these values will be excluded. If all datasets were equally important, they could be combined, giving each equal influence. However the different datasets have different influence. All inputs are weighted, assigning each a percentage of influence. The higher the percentage, the more influence a particular input will have in the suitability model.

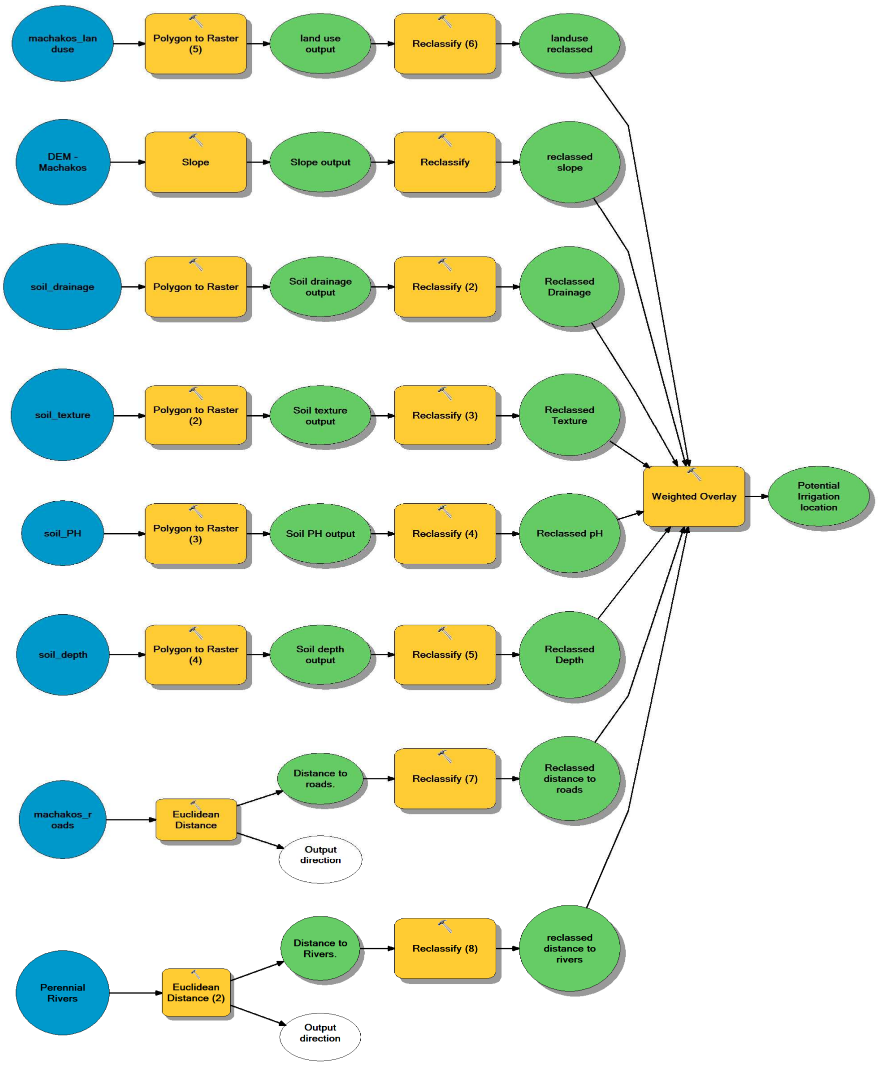

Fig3.25Weighted Overlay Model

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter outlines the major findings of this study, the analysis and discussions on results obtained.

4.2 Results

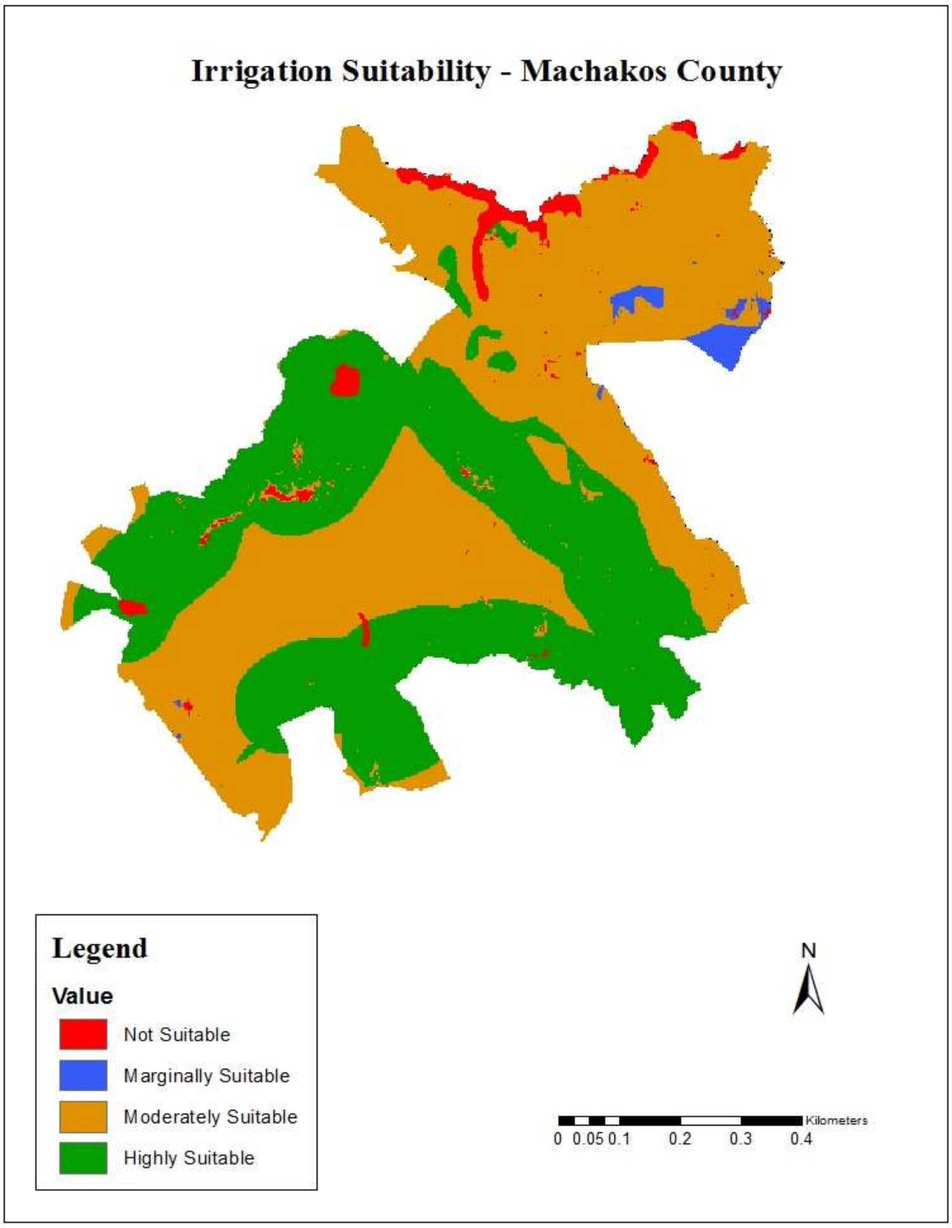

Fig 4.1 Map showing irrigation suitability of study area

CLASS	SUITABILITY	AREA (Km²)
4	Highly Suitable	**2602**
3	Moderately Suitable	**3355**
2	Marginally Suitable	**78**
1	Not Suitable	**175**

Table 4.1 Table showing Area Potential for irrigated agriculture in Km²

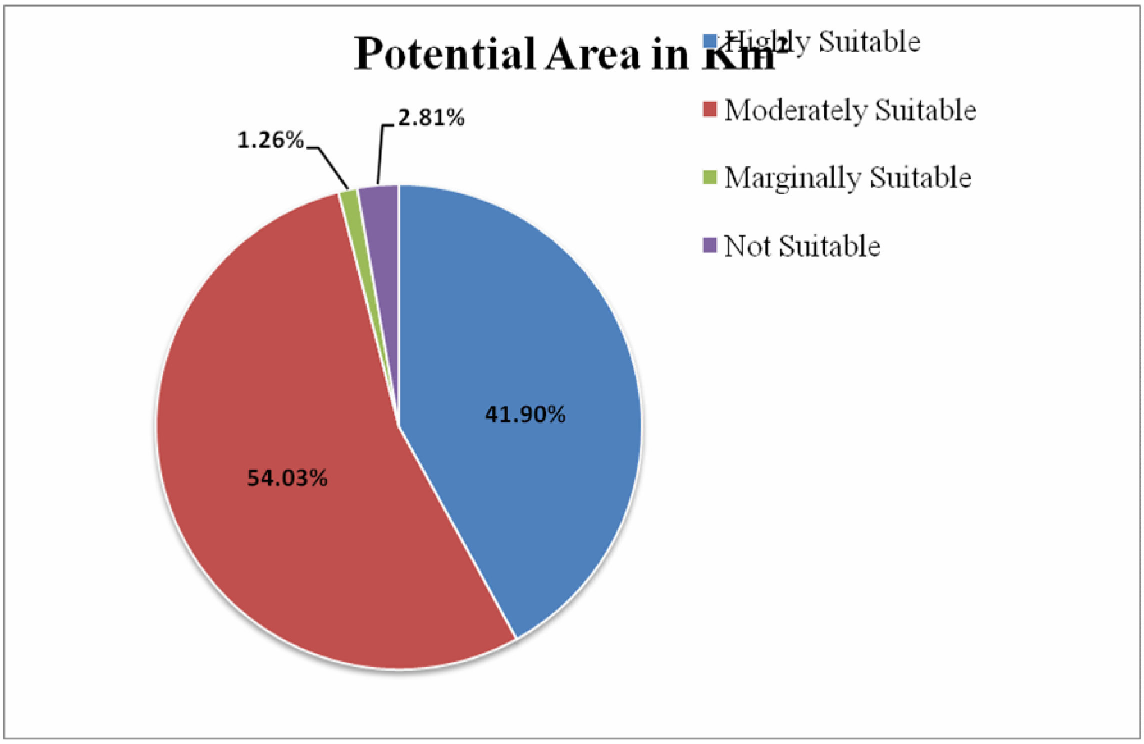

Fig. 4.2 Pie chart showing potential area in Km²

The principal objective of this study was to map potential areas for Irrigated agriculture in Machakos County by use of GIS Multi Criteria Analysis. This was accomplished through use of Suitability analysis model which incorporated various weighted criteria and constraints.

Figure 4.1 shows the resultant map indicating potential Irrigation areas by degree as well as areas not suitable for Irrigated agriculture.

After weighted overlay of eight layers :- Perennial Rivers, Roads, Slope, Land use land cover, Soil Ph, Soil depth, Soil texture and Soil drainage the results were obtained showing potential for irrigated agriculture in Machakos County. The results are shown in a suitability map (Figure 4.1) which assists in quick identification and comparison of suitability level.

2602 Km^2 was found to be highly suitable for irrigation. This accounted for 41.90% of the total area. 3355Km^2 accounting for 54.03% was found to be moderately suitable for irrigation. 78Km^2 accounting for 1.26% was found to be marginally suitable for irrigation and 175Km^2 accounting for 2.81% was found to be unsuitable for irrigation.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS.

5.1 Objectives achieved

The principal objective of this study was to demonstrate how GIS based multi criteria analysis can be used to map potential areas for irrigated agriculture. From the analysis carried out in chapter 4, it can be concluded that this objective was met. Secondary objectives like identifying criteria for mapping and recommending potential irrigation site in Machakos County were achieved .

5.2 Conclusions

This study applied GIS based multi criteria analysis to produce a suitability map for potential irrigation site. This was enabled through application of various spatial analysis tools. The tool were applied on eight layers:- Perennial rivers, roads, slope, land use land cover, soil pH, soil texture, soil drainage and soil depth.

The results of this study illustrate how GIS as a tool can be used in exploration of water resources in a scientific approach hence making the decision making easier and accurate.

Information derived from this study can be used to inform government, investors and other stakeholders on best land use practices.

From the study, it was noted that to define the weights for each criteria, expert opinion in the subject of interest is paramount. In this case, expert input from Irrigation Department KALRO - IDMPS and KALRO - GIS was a key ingredient.

5.3. Recommendations

The following is a set of recommendations based on the findings of this research project:-

i) Machakos County needs to stop over reliance on rain-fed agriculture if she is to achieve sustainability and invest in irrigated agriculture because of it's potential and viability.

ii) Government and Non – Governmental agencies need to invest in the irrigated agriculture because of it's obvious potential and move away from unsustainable programs like the infamous *"relief food"* narrative. Machakos County is able to feed her population and have a surplus.

iii) The National Irrigation Board, the National Government through Line Ministries (Ministry of Agriculture and Ministry of Irrigation and Water Sources) and County Governments adopt GIS based Multi Criteria Analysis approach in identifying potential areas for irrigation and exploitation of water resources generally.

REFERENCES

Blank, H.G 2000 The changing face of Irrigation in Kenya. Opportunities for anticipating change in eastern and southern Africa. A SWIM concept paper. Nairobi: International Water Management Institute.

Barker,R and Van Koppen B. (1999) Water scarcity and poverty. IWMI water Brief3. Colombo,Sri Lanka: International Water Management Institute

Calder, I.R (1994) Water and Sustainability. A summary Report. ODA forestry series No.6 London:Overseas Development Administration. 14p

Carver S.J (1991) Integrating multi-criteria evaluation with Geographical Information Systems. International Journal of Geographical Information Systems 5:321-39

Eastman R.J.;Jin W.;Kyem P.A.; and Toledano J. (1995) Raster procedure for multi-criteria/multi-objective decisions. *Photogrammetric Engineering and Remote Sensing*, 61, 539 – 547.

Eastman R.J (1999) Geographic Information Systems 1, 493 – 502 Multi-criteria evaluation and GIS.

ESRI. (2016, April 20th).Desktop Help.

Herbert.G. B.;Mutero C.M. and Hammond M. The Changing face of Irrigation in Kenya: Opportunities for anticipating change in Eastern and Southern Africa. Colombo, Sri Lanka: International Water Management Institute.

Heyer,J (1976) Achievements, Problems and Prospects in the Agricultural sector. In Agricultural Development in Kenya. An Economic assessment, ed J.Heyer, J.K.Maitha and W.M.Senga. Nairobi: Oxford University Press.

Kimani,J.K and J.O Otieno,eds (1992)*Which way irrigation?Proceeding of a Nationalworkshop, 26-29 May 1992* Nairobi:Irrigation and Drainage Branch.

Kiragu D.K (1992) Assesment of Irrigation potential in Kenya in Which way irrigation? Proceeding of a National workshop,26-29 May 1992 ed J.K Kimani and J.O Otieno 20 – 25 Nyeri,Kenya

Malczewski J (2004) GIS – based land-use suitability analysis: a critical overview.*Progress in planning*,62, 3- 65.

Malczewski J (2006) GIS based multicriteria decision analysis: a survey of the literature. *International journal of Geographic information Science*, 20,703 – 726

Ngigi S.N (2000) *Preliminary evaluation of irrigation development in Kenya*. Paper presented at the Third SWIM workshop on the changing face of smallholder irrigation in Kenya, 19th October 2000, Nairobi, Kenya.

Njokah,J.J (1992) Irrigation research in Which way Irrigation? Proceeding of a National workshop 26-29 may 1992, ed J.K Kimathi and J.O Otieno 82-86 Nyeri,Kenya.

Ragwa,P.K ; N.R Kamau and E.D Mbatia (1998) Irrigation and drainage branch position. Paper Presented during the workshop on promotion of sustainable smallholder irrigation Development in Kenya, 16-20 November 1998,Embu,Kenya.

Saaty, T.L. (1980) *The Analytic Hierarchy Process*. NY: McGraw-Hill.

Saaty, T.L. (1990) How to make a decision; the analytic hierarchy process.Euro. J. Oper. Res. 48 (1), 9–26.

Seckler,D; D Molden and R Barker (1998) *Water scarcity in the twenty first century*.IWMI Water Brief Colombo, Sri Lanka:International Water Management Institute.

Swain M. (1999) Emerging trends and reforms in irrigation in India; A perspective of Orisa. New Delhi.

Torori,C.O.;A.O. Mumma and A.Field –Juma (1995) Governance of water resources in Kenya. Ecopolicy series No.8 Nairobi: ACTS Press

Voogd H (1983) Multi-criteria evaluation for urban and regional planning.London

FAO, 1976. A framework for land evaluation. FAO Soils Bulletin No. 32. FAO, Rome

FAO, 1977b. Crop water requirements. Irrigation andDrainage Paper No. 24. FAO, Rome.

FAO, 1979. Land evaluation criteria for irrigation.Report of an Expert Consultation, 27 February-2 March, 1979. World Soil Resources ReportNo. 50. FAO Rome. 219 p.

FAO, 1983. Guidelines for the preparation of irrigation and drainage projects. Revised version.

FAO, 1984 Guidelines: land evaluation for rainfed agriculture. FAO Soils Bulletin No. 52. FAO Rome. 335 p.

FAO, 1985. Guidelines Land Evaluation for IrrigatedAgriculture.FAO Soils Bull 55, Rome, 290 pp.

FAO, 1987. Irrigation and water resources potentialfor Africa. FAO AGL/MISC/11/87. Rome. 127 p.

FAO, 1990. Guidelines for soil profile description,3rd edition. AGLS, FAO, Rome

FAO, 1997. Irrigation potential in Africa: A basin approach FAO Land and Water Bulletin 4

Goodchild, M. F., 2000. The Current Status of GIS and Spatial Analysis, Geographical Systems, 2:5-10.

Jamshid, Y., 2003. The integration of satellite images, GIS and CROPWAT model to investigation of water balance in irrigated area: Acase study of Salmas and Tassoj plain, Iran, MSc thesis, Enscheda, Netherlands.

Janssen. R., Rietveld, P., 1990. Multi-criteria Analysis and GIS: An Application to Agriculture Land use in the Netherlands.

Jaruntorn, B., Det, W, and Katsutoshi, S., 2004. GIS based land suitability assessment for Musa. Graduate School of Agricultural science, Ethime University, Japan

Negash Wagesho, 2004. GIS based irrigation suitability Analysis: A case study in Abaya-Chamo basin in southern Rift valley of Ethiopia. MSc thesis, Arba-Minch University.

Wilkinson, G.G., 1996. A review of Current Issues in the Integration of GIS and Remote Sensing. International Journal of Geographical Information Systems, 10, 85-101

Yang Yi .D.H.G, 2003. Application of GIS and RemoteSensing for Assessing Watershed Ponds for Aquaculture development in Thai Nguyen, Vietnam. School of Environment, Resources and Development Asian Institute of Technology.