University of Nairobi

School of Engineering

Department of Geospatial and Space Technology

Site Suitability Mapping of Water Harvesting Structures Using GIS and Remote Sensing.

Case Study: Machakos County

BY:

Livingstone Asala

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June, 2017

Declaration

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

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Name of student Signature Date

This project proposal has been submitted for review with our approval as university supervisor(s).

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Abstract

Machakos County receives an average annual rainfall of 650 mm. It is therefore a region with limited water resources. According to an abstract on the Geology Departments' website University of Nairobi the main source of water in Machakos County is ground water, accessed through boreholes, since most of the rivers are seasonal, however there is a high likelihood that the boreholes that are constructed in Machakos County will suffer from borehole failure due to over exploitation of the underground water resource (http://geology.uonbi.ac.ke/node/1109 accessed on 25/4/2017). There is need therefore to augment the ground water potential in Machakos County by artificial infiltration of water to the underground chambers in order to recharge the depleted reservoirs/ aquifers in a systematic way (Harish et al 2014). Water harvesting principle entails, appropriate management of all the precipitation through proper collection, storage and efficient utilization of runoff water and to recharge the ground water. This study aims to identify suitable zones for water harvesting structures in Machakos County by geospatial technologies for normal use but also for recharging ground water. The different layers taken into account for evaluation were; Soil texture, slope, land use/cover, geomorphology, and lithology, lineaments, and drainage network.

Multicreteria analysis was then carried out on the different layers in order to come up with a site suitability map for water harvesting structures, each layer characteristics were assigned weights as given by experts in passed research reviews. The different layers were then overlaid according to their influence and their various class weights.

The suitability map produced helped in the choice of water harvesting structures such as percolation tanks, storage tank, check dams and stop dams to be constructed in the various sites identified.

Fifteen WH structures' zones, were identified – from the WH suitability map - for the various water harvesting structures; five zones for percolating tanks, five zones for stop dams and another five zones for storage tanks.

GIS and remote sensing can therefore be used in exploration of water harvesting structures in a scientific approach hence making decision making easier and accurate.

Acknowledgement

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Finally I thank God almighty for life, good health and sound mind to study and fathom new knowledge and ideas.

List of Abbreviations

AfDB: African Development Bank

CIM: Christian Impact Mission

DEM: Digital Elevation Model

GIS: Geographic Information System

GNSS: Global Navigation Satellite System

LULC: Land Use Land Cover

MCA: Multicreteria Analysis

RCMRD: Regional Centre for Mapping of Resources for Development

RWH: Rain Water Harvesting

SoK: Survey of Kenya

UNEP: United Nations Environment Programme

WOP: Weighted Overlay Process

ASTER: Advanced Space borne Thermal Emission and Reflection Radiometer

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CHAPTER 1

1.0 Introduction

This chapter deals with the background to the study, it then explains the problem that the study seeks to address, the main and specific objectives of the study, justification of study and finally the scope of the study.

1.1 Background

Ground water is one of the most important water sources in the Arid and Semi-Arid Lands (ASAL) regions of Kenya such as Machakos County in Eastern Kenya where surface water sources are scarce. However, the level of groundwater in most parts of Machakos County is gradually dropping due to over-exploitation and insufficient natural replenishment, resulting from erratic rainfall (annual average of 650mm) in the region and frequent drought conditions. According to an abstract from the Department of Geology, University of Nairobi (http://geology.uonbi.ac.ke/node/1109 accesses on 25/4/2017), the boreholes being constructed in the larger Machakos County face one major problem of borehole failure which is caused by several factors, among them; over- extraction and un supporting geology of the area which causes obstructions and imbalance.

To provide a solution to this problem of disparity between exploitation and groundwater resources, it is necessary to boost the groundwater potential by artificial replenishment of the exhausted aquifers via a methodical and well-researched approach and hence this project.

The primary source of water is rainfall, rain water harvesting is consequently necessary to guarantee the storage while avoiding wastage. Rain Water Harvesting (RWH) entails collection and storage of rainwater for farming in arid and semi-arid areas (Hatibu and Mahoo 2000). Groundwater recharge usually requires directing the water in surface and near-surface dispersal basins, trenches and pits, by means of the unsaturated permeable and porous zones and the cracked planes to provide passage and store water. The unsaturated zones' hydrogeology, mainly the vertical hydraulic conductivity of the land-cover materials, including the soils and the sub-soil sediments, lineaments, frequency of fractures and fault zones etc., play a critical role in the passage and storage the recharged water (Joshi & Kundal (2004). Hence, the study and evaluation of these zones and their underground soil layers, drainage, the general topography and land-cover characteristics are essential and indispensable in the choice of regions or places for groundwater recharge/ replenishment.

Rain Water Harvesting and Management in this project can therefore be defined as, the activity of collecting and storing rain water for use or to be applied into the Groundwater, a process known in this project as ground water re-charge. "Identification of suitable sites for water harvesting structures needs a large volume of multi-disciplinary data from various sources for which the applications of modern remote sensing and geographic information system techniques have gained much attention in recent years". (Jabbori 1988).

The multi-displinary data used in this process includes; soil data, lithology data, geomorphology data, land use land cover data and slope data. Each data used is prepared as a layer and is a factor that influences the site suitability for water harvesting structures.

The various layers are then overlaid considering their various weights - as derived from different literature reviews by geology experts - through multicreteria analysis and the required site suitability map is then generated. The site suitability map is then overlaid with the drainage map to determine the exact location of the specific water harvesting structures. Three divisions in the county were then visited to compare the results with the existing situation.

GIS and geospatial technologies have been used for mapping suitable sites for water harvesting in various places of the world. Harish et al 2014, did a site suitability analysis for water harvesting using Remote Sensing and GIS for Pisangan watershed In Ajmer District, Rajasthan, India. Ishtiyaq Ahmad and Dr. M.K Verma in 2016, did site suitability mapping for water storage structures using Remote Sensing and GIS for Sheonath Basin in Chhattisgarh State, India. Here in Kenya GIS techniques and remote sensing are being adopted in site suitability mapping for rail route determination, suitable area for dam site location among others.

1.2 Problem Statement

The groundwater table in most parts of Machakos County is progressively lowering due to over-exploitation and insufficient replenishment. According to an abstract from the Department of Geology, University of Nairobi (http://geology.uonbi.ac.ke/node/1109 accessed on 25/4/2017), the boreholes being constructed in the larger Machakos County face one major problem of borehole failure which is caused by several factors such as the geology of the area and frequent drought condition and over-extraction.

Most parts of Machakos County face a serious problem of water deficiency (UNEP 2002). The County is projected to become even drier owing to climatic changes, erraticism and harsh weather conditions. Even as all these happens the population of Machakos county continues to grow due to its proximity to the City of Nairobi and the proposed Konza Techno City that will be built within the County.

As a solution to this problem of disparity between abstraction and ground water resources, it is vital to supplement the potential of groundwater by artificial replenishment of the exhausted underground reservoirs in a scientific and well-researched manner.

This project therefore seeks to map suitable sites to establish rain water harvesting structure so as to facilitate artificial recharge of underground water reservoirs by facilitating infiltration of rain into the aquifers using the unsaturated permeable and porous zones and the fracture planes to provide passage and store water during rainy seasons for use when it's dry.

1.3 Objectives

The main objective of this study is to develop a site suitability map of water harvesting structures using GIS and Remote Sensing techniques. The specific objectives are;

i) To identify the criteria for selecting a suitable rain water harvesting site and establish respective weights.
ii) To produce a suitability map for each criterion.
iii) To carry out multi criteria analysis resulting in the production of a map showing the suitable sites for water harvesting structures.
iv) To analyse the results and draw appropriate conclusions and recommendations

1.4 Justification for the Study

The results of this study will aid the residents of Machakos County in constructing simple water harvesting structures for their domestic use while facilitating artificial recharge of the depleted aquifers.

The site suitability map will facilitate planning and prioritizing which areas to start with and which structures to begin with in the process of implementation.

A scientific study on suitable areas for water harvesting in Machakos County will enhance effective and efficient water harvesting that will result in improved livelihoods due to constant access to water in wet and dry seasons.

The results of this study once implemented will eliminate borehole failure because the aquifers in Machakos County will be replenished fully every rainy season.

1.5 Scope of Study

This study will be limited to the development of site suitability map for water harvesting structures using GIS and Remote Sensing in Machakos County. The study therefore relies on the availability of data from other professions dealing with water such as geology and meteorology. The study will therefore entail preparation of criterion maps based on available data and the final site suitability map after weighting.

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

In this chapter an overview of previous researches is undertaken. A background about water harvesting is introduced, the techniques and structures highlighted, ground water and aquifers explained and an overview of GIS application in suitability mapping for water harvesting structures.

2.1 Water Harvesting

2.1.1 Definition and Classification of Water Harvesting

According to Critchley and Siegert, (1991), Water harvesting is the collection and managing of precipitation runoff to enhance accessibility to water for domestic use and farming as well as sustenance of the ecosystem.

Rainwater harvesting methods can be categorized by the runoff breeding process, the extent of catchment and the kind of storage features. Runoff is generated from; rivers, lakes and rainfall. According to the Greater Horn of Africa Rainwater Partnership (2010), the storage categories could be; storage within a soil profile, a cistern or a tank and the extent or measure of the system determines whether it is considered a micro or macro scheme. Five classes exist as suggested by African Development Bank (AfDB) manual 2008; Domestic rain water harvesting, which entails individual or institutional harvesting of water like roof catchment system for domestic purposes. Surface Catchment, this entails use of concrete, rock, treated ground surfaces, plastic sheets or other appropriate surfaces for home, livestock consumption and small scale irrigation. The third class is the small scale dams which include; check dams, sand dams, water pans, ponds or pits and earth dams, for home use, livestock consumption and small-scale irrigation and the fourth class is the micro catchment which entails in situ rain water harvesting/ on the field water conservation e.g. contour bunds, fanya juu and demi-lunes. And the last class is the External catchment which entails run-off directed to the field e.g. delineated stone bunds, trapezoidal bunds among others

Machakos County has all these classes of water harvesting, it only lack a scientific guide in order to leverage on the various efforts so far.

Figure 1: Water Pan: Source AfDB RWH Manual 2008

Figure 2: Sand Dam: Source AfDB RWH Manual 2008

Figure 3: Rock Catchment: Source: AfDB RWH Manual 2008

2.1.2 Objectives of Water Harvesting

The purpose of water harvesting is to divert runoff from areas of excess or where it is unused, store it and avail it, where and when there is need. This leads to increased water availability by way of trapping and catching runoff and hence increasing runoff storage.

Water harvesting efforts undertaken in Machakos County and Kenya in general are all geared towards domestic use, livestock use, and small scale irrigation and erosion prevention. However, Harish Chand et al. 2014, has observed that, the principle of water harvesting and management is the appropriate control of all the rainfall runoff by way of collection, storage and resourceful consumption of runoff water and to replenish the aquifers. This principal is well illustrated by figure 4. This principle informs this study, i.e. the determination of suitable sites for water harvesting structures, for water utilization and recharge of the depleted aquifers. The aspect of ground water recharge has not been well studied in the efforts towards rain water harvesting. This study will therefore seek to establish a mechanism that yield sites that store rain water and prevent runoff to wastage while at the same time feeding ground water reservoirs.

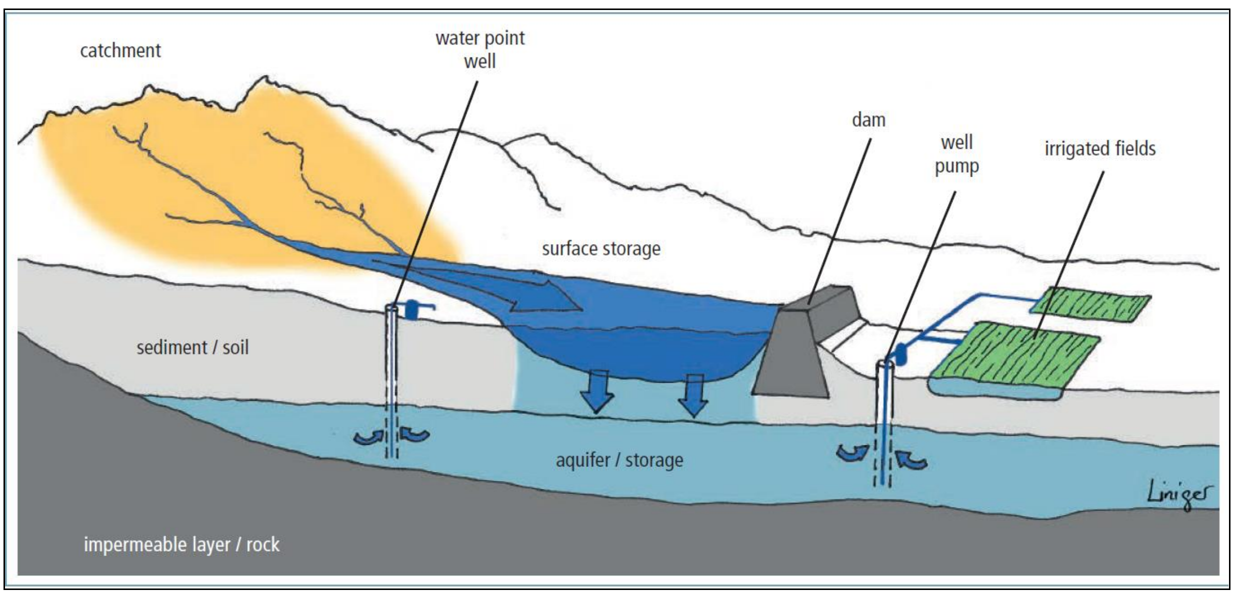

Figure 4: Watershed Principle: Source – AfDB RWH manual 2008

2.2 Ground Water and Aquifers

An aquifer may be broadly described as saturated fractured rock or sand from which usable volumes of groundwater can be pumped. An aquitard on the other hand restricts the flow of water from one aquifer to another, for example a clay layer or solid rock. An unconfined aquifer is a section of rock or sand that does not have a confining layer e.g. clay aquitard on top of it, such an aquifer is often shallow (Goulburn Murray Water 2015).

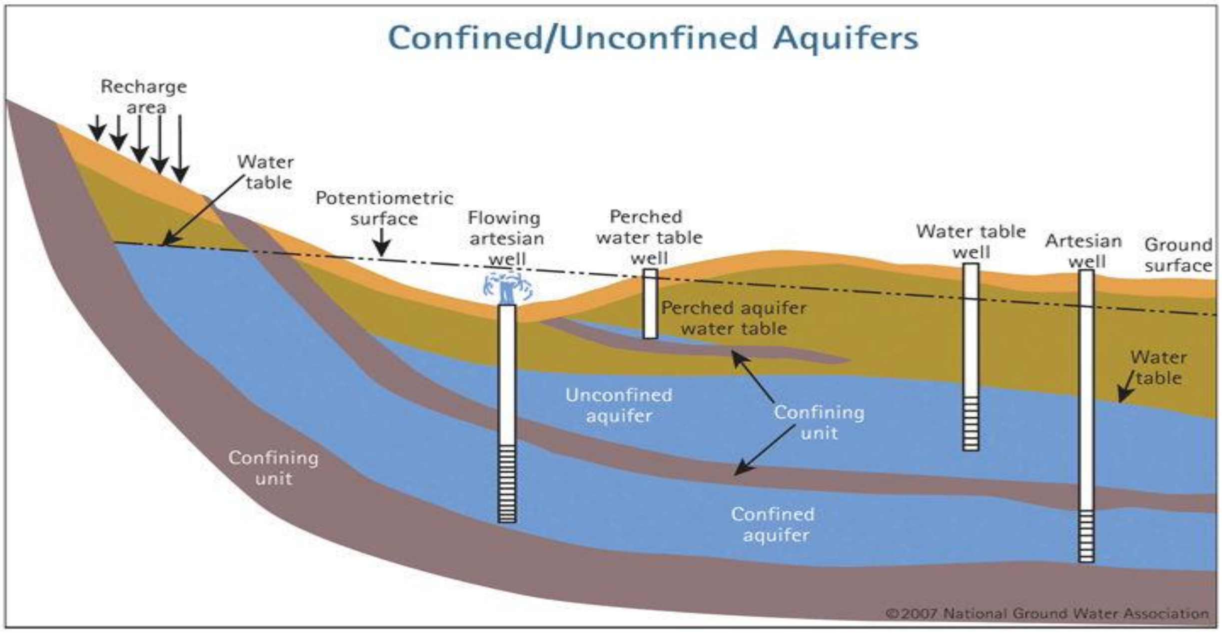

Figure 5: Aquifer Types (National Groundwater Association 2007)

According to Edugreen (2007), ground water generally occupies large areas under the earth's surface and will often supply other water sources such as streams, rivers and springs. Most of the time, runoff harvested is stored in aquifers especially when facilitated to infiltrate into the underground chambers. Lately, consciousness of depleted aquifers has prompted a rise in rain water harvesting methods whose purpose is to directly recharge these quickly draining resources. Numerous practises of rain water harvesting collects water and stores it in underground chambers for future use. This does not only recharge the depleted aquifers, but it also raises the diminishing water table and can help supplement water supply

2.3 Ground Water Recharge.

According to R. K. Parghane et al 2006, non-natural replenishment to aquifers is a procedure where the ground water reservoir is boosted at a frequency above the natural conditions of replenishing. Overally therefore, any man-made scheme or effort that enhances infiltration of water to an aquifer is an artificial recharge to ground water.

The rate of abstraction of ground water has increased in the recent past largely due to increase in population. Natural recharge of the aquifers does not match this rate of abstraction, since the increase in population has also come with impediments to natural recharge like concrete structures, tarmac among other surfaces that prevent natural percolation of water into the aquifers. This has led to the ground water levels going down and in adverse circumstances borehole failure. Artificial ground water recharge is therefore a solution to this challenge since it complements the natural recharge.

Three methods of ground water recharge are suggested by R.K. Parghane et al 2006; Recharge-well method, Spreading method, and Induced infiltration method. Spreading method entails spreading the water over the surfaces of permeable open land and pits, from where it directly infiltrates to rather shallow aquifers. In this method, the water is temporarily stored in shallow ditches or is spread over an open area by constructing low earth dykes called percolating bunds. The stored water will slowly and steadily, percolate downwards to the nearby aquifers.

Recharge-well method on the other hand entail injecting the water into boreholes called recharge wells. This method yields high recharge rates as it may inject water directly into the aquifers, this method is used in Israel. The water used for recharging wells should be free from suspended impurities to avoid clogging of the well screens.

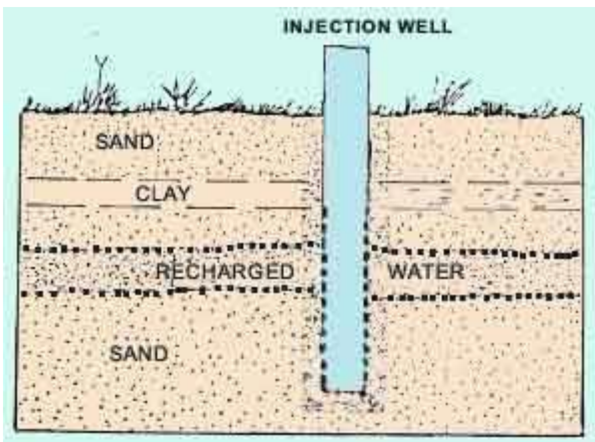

Figure 6: Recharge Well Method - Injection Well: Source - Kavuri et al. 2011

And induced infiltration Method, in this method the gradient of the water table is increased compared to that of the source of recharge. Radial collectors are fixed on a well which is constructed near the river banks, the water will then percolate through the collectors and get discharged into a lower level reservoirs to be stored.

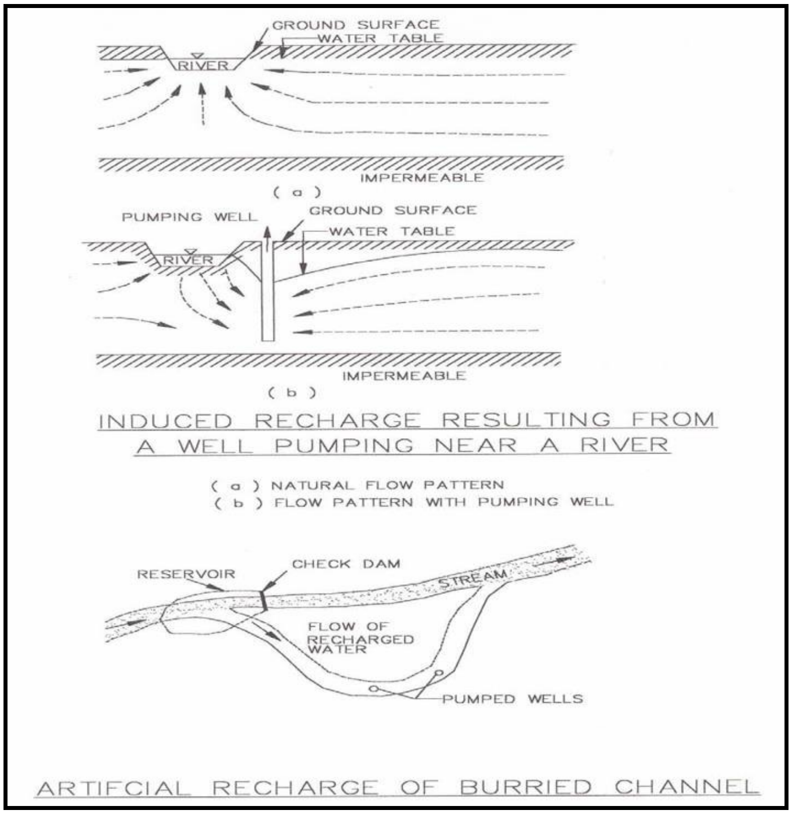

Figure 7: Induced Recharge: Source: http://megphed.gov.in/knowledge/RWHManual.htm- accessed 3/5/2017.

2.4 Water Harvesting Structures

Based on the ground truthing undertaken in parts of Machakos County water pans and Concrete Check dams are the majority of water harvesting structures in Machakos County. This project proposes four more water harvesting structures; the Check Dams, Stop Dams, Storage tanks and Percolating Tanks, this is based on a research by Harish et al. 2014 in India, these structures are good for water harvesting for domestic use but also for recharging ground water. Table depicts the structures and the drainage order requirements.

Table 1: Water harvesting structures

S. No	**Type of Structure**	**Drainage**
1	Storage Tank	1st order
2	Percolating Tanks	1st and 2nd order
3	Stop Dams	3rd order
4	Check Dam	4th order

Storage tank is a structure for surface water storage. It is used for harvesting rain water. They are cylindrical in shape and are constructed so that they are flat at the bottom and are at right angle to the ground. They usually have a roof fixed on them.

In Machakos County, the most suitable areas for storage tanks are areas within the identified very high and extremely high suitability areas where streams develop i.e.1st order streams and valleys.

Percolating tanks on the other hand, are for replenishing ground water. They are usually built across watercourses and larger channels so as to trap a part of the water flowing in the streams and gullies. Suitable areas for installing Percolating Tanks in this study, are those regions identified as very high and Extremely High suitable areas and on order one and order two steams.

The Stop dam is barrier made of concrete built across the gullies and on shallow tributaries and streams for purposes of harvesting water for home use and for farming. In this project considering Machakos county Stop dams should be installed in areas identified as very high suitability areas and extremely high suitability areas and on 3rd order streams.

Finally Check dams are small barriers constructed using rock residues, rolls of retention fibers, bags of gravel and sand or any other materials positioned crossways of natural or man-made channel. A well-built check dam will decrease scour and erosion in gullies and channels by decreasing the velocity of flow v and boosting the settlement of sediment. In this Study of Machakos county Check Dams should be installed in the regions identified as very high suitable areas and extremely high suitable areas and on 4th order streams.

2.5 Application of GIS in Suitability Mapping for Water Harvesting Structures

Application of Geographic Information System (GIS) has been done in numerous disciplines like environmental studies, urban planning, geography, geology and forestry. Likewise suitability mapping has been a matter of interest to conservational planners in determining most suitable areas for solid wastes, City planners in determining best route for a highway, farmers in determining most suitable area for growing a certain type of crop. As such the potential for GIS application in suitability analysis and mapping is very important. According to Bualhamam, (2009), GIS is now known extensively as a means for management, analysis and display of large capacities of various data related to numerous local and regional planning issues. The impact of its use in planning the environment and related issues has been increasing rapidly.

Suitability analysis/mapping is a process depended on large volumes of data from different sources and GIS provides the best environment for assessing all these data and making judgement after comparing the usefulness of each data set. This process is known as Multicreteria Analysis, denoted as (MCA). MCA aids in decision making process by facilitating the analysing of various options in a GIS, Mendoza et al. (1999) defines MCA as a tool used in approximating the significance of the various elements involved in a project and the criteria is relied upon in the final decision making process.

The purpose of MCA is mainly to help in the decision making process and not making a final and definite decision itself (Atila G. et al 2006). Voogd, (1983) argues that the objective of MCA entails an exploration of alternative choices in light of numerous, often incompatible intentions and to come up with an inclusive ranking of these varieties according to Janssen & Rietveld, (1990).

To come up with multicreteria centred ranking, weighted overlay process (WOP) is used. WOP is a part of GIS using two indices: Suitability level Index (SL) and Standardized Compound Weight Index. The last rating for criteria constraint is gotten via compound suitability index.

CHAPTER 3: MATERIALS AND METHODS

3.0 Introduction

This chapter deals with a depiction and explanation of the area of study, the data and their sources, conceptual methodology, weighting of the various layers and allocation of their respective influence in the multicreteria analysis and the analysis process.

3.1 Description of Study Area

Machakos County is found in Eastern part of Kenya. The County borders Nairobi and Kiambu Counties to the West, Embu to the North, Kitui to the East, and Makueni to the south, Kajiado to the South west and Murang'a and Kirinyaga to the North West. It has an area of 5,952.9 Square KM (Machakos 2013), Bounds: (36.878296, -1.777822 and -37.8681130,-0.774464).

It has a population of 1,098,584 people according to the 2009 census - the high population could be associated to its proximity to The City of Nairobi where City dwellers prefer to stay in Machakos and work in the City. Due to such a high population, the necessity for water in the County is very high. Actually, the demand for water surpasses the supply of the water resource available by far. The County goes through severe climatic conditions and thus has little vegetation cover. Hence the volume of surficial water in the County has significantly decreased. The residents of Machakos County therefore depend mainly on ground water. Figure 8 shows the map of Machakos County depicting constituencies, main drainage and road network features.

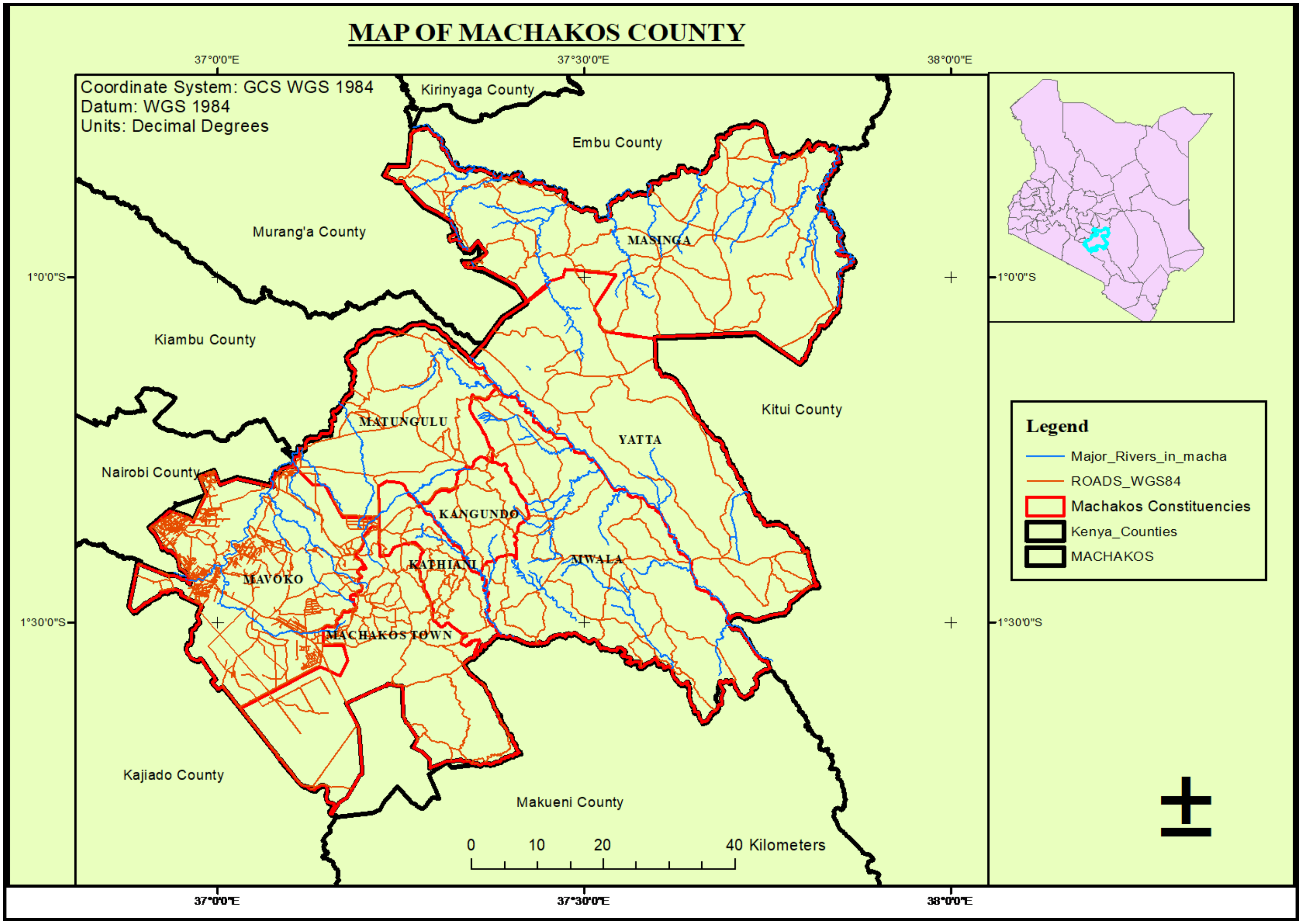

Figure 8: A Map Showing Machakos County and its Constituencies

3.2 Data Types and Sources

Data from mainly Secondary sources were used to meet the objectives for the study. The sources included mapping agencies like Survey of Kenya (SoK) and Regional Centre for Mapping of Resources for Development (RCMRD). International Livestock Research Institute - ILRI provided the platform of access for most of the data .i.e. they host a portal that allows downloading of the various datasets in their possession. Aster Data was obtained from Open Source Resources online. Table 1 shows all the datasets used in the project and the place they were obtained from.

Table 2: Dataset Types and places obtained from

No.	Dataset	Location/Access	Source	Last Update
1	Soils	ILRI	Kenya Soils Surveys/SoK	1997
2	Lithology	ILRI	Kenya Soils Surveys/SoK	1997
3	Geomorphology	ILRI	Kenya Soils Surveys/SoK	1997
4	Drainage	JICA	Survey of Kenya/JICA	2005
5	Land Cover	RCMRD	RCMRD/SoK	2010
6	Roads	MoTIH&UD	SoK,KURA,KeNHA,KeRRA	2010
7	DEM	WEB	ASTER	2016
8.	Administrative Boundaries	RCMRD	RCMRD/SoK	2010

Different layers were formed based on the mentioned data assigned weights. These layers were then overlaid via a multicreteria evaluation technique to produce the site suitability map of the study area.

3.3 Data Collection Methods

Because of the varied nature of the datasets required to facilitate the multicreteria analysis, collecting the data involved data mining from online data warehouses and already established Spatial Data Infrastructure Clearing houses.

Most data sets were obtained online as shapefiles, and Digital Elevation Model (DEM) by downloading from portals like ILRI or by sharing over emails.

3.4 Conceptual Methodology

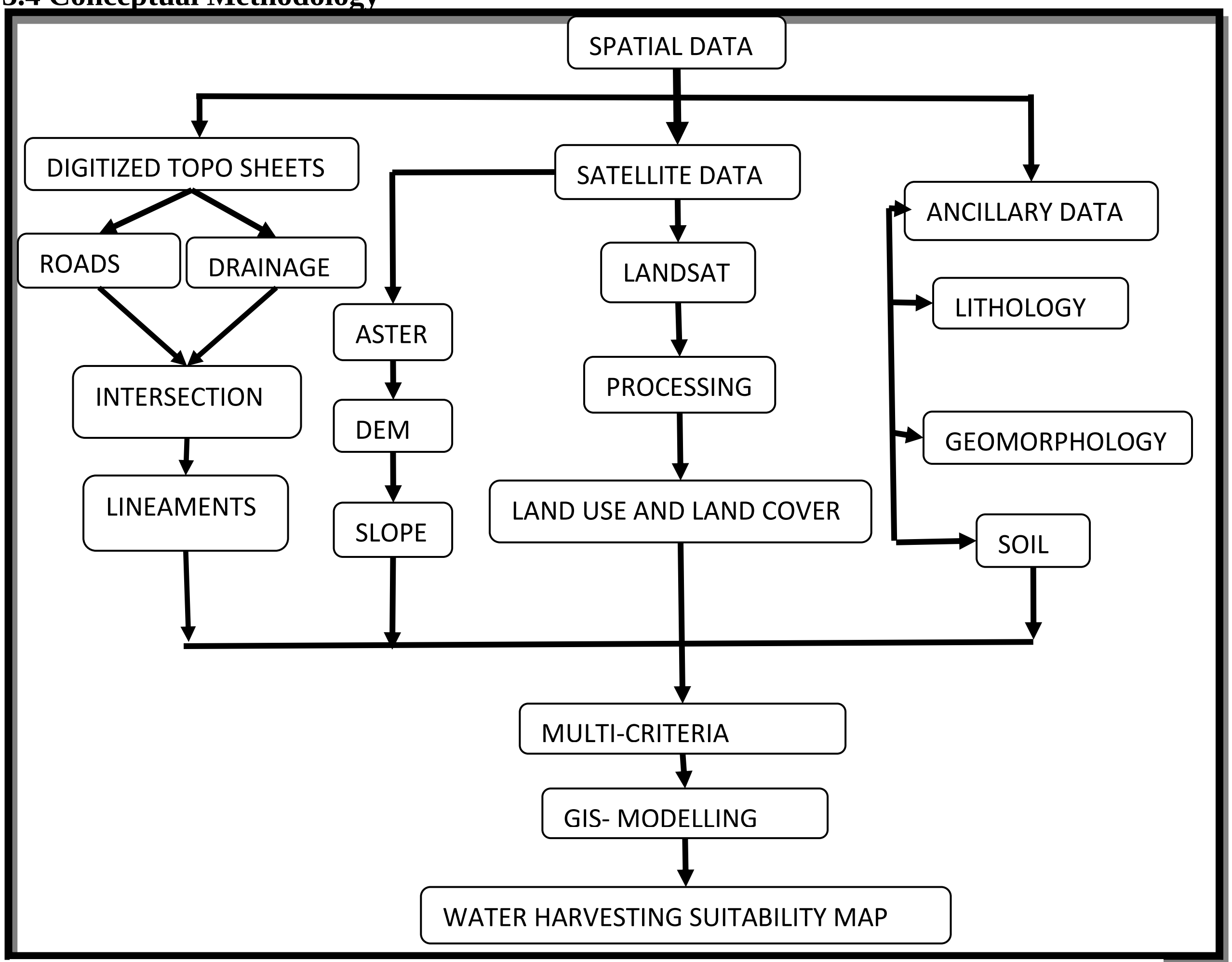

Figure 9: Conceptual Model

3.5 Layers and Themes.

As stated earlier, various layers/ themes are created and overlaid in order to produce the required suitable areas for water harvesting structures. The layers are formed from the various factors that influence site suitability for water harvesting structures. The factors include; drainage network, soils, land use/cover (agriculture, forest), road network, lithology, geomorphology and lineaments.

The layers form constraints on which to evaluate the suitable areas. This section gives a brief overview of these layers/ themes.

3.5.1 Lithological Data

According to Harish et al. (2014), Lithology entails the study of landforms, structures and the subsurface so as to appreciate the physical processes forming and altering the earth's crust. To appreciate lithology in Machakos County, an overall lithology map was used. Andesite, Basalt, Gneiss, Granite Igneous rock, Quartzite and Clastic sediments were the rock types as given in the general lithology map of Machakos County. Granite and Gneiss are the common rock material in the study area. They are a tough kind of material, they are compact with virtually no intergranular (primary) porosity. However, these impervious and non-porous rocks develop secondary porosity which means they can hold water in the cracks, joints, fractures, or faults or along contact zones between various rock types. When these rocks are subjected to adverse weather climatic conditions they undergo weathering resulting in conditions favourable for the infiltration and storage of groundwater.

The Lithology data obtained for analysis in this project comprised of; Acid metamorphic rocks, Andesite/Trachyte/phonolite, Basalt, Basic igneous rock, Clastic sediments, Eolian unconsolidated rock, Fluvial, Gneiss rich in ferromagnesian minerals, Gneiss/Migmatite, Granite, Igneous rock, Intermediate igneous rock, Pyroclastic unconsolidated rock, quartzite and water. All these rock types were classified and weighted according to scales in table 2 and a suitability map generated.

3.5.2 Geomorphology

The Geomorphological units available in Machakos County are; hills and mountain foot ridges, plateaux, plains and foot slopes as obtained from the attributes of the geomorphology data used. The plains and plateaux are the most suitable for water harvesting structures since the runoff speeds are low and therefore it is relatively easier to trap the water for use and infiltration into the aquifers.

The various landforms were then classified and weighted as per table 2 and the geomorphology criteria map generated.

3.5.3 Digital Elevation Model (DEM) and Slope

A DEM for Machakos was generated from ASTER data, this helped in determining the average slope of Machakos County which provided general information about the Machakos watershed topography. Machakos DEM depicts zones of elevation in groups of; 722-1,143m, 1143-1349m, 1349-1543m, 1543-1726m, 1726-2162m, respectively. Slope is a very significant variable since, the average slope of a watershed influences radically the value of time of concentration and directly the runoff generated by rainfall.

The DEM was used to generate the slope map using ArcGIS 10.5 software. The slope map was then classified and weighted as per table 2 and a slope map generated.

Preparation of the slope data from the DEM entailed the preparation of percentage rise in slope via the 3D analyst tool of ArcGIS. The slope ranges from 0% to 71%.

3.5.4 Soil

The porosity of the soil will determine its water holding capacity. Porosity is a measure of the open spaces within the soil and is a function of the various sizes of particles in the soil. The texture of the soil indicate the comparative content of various particles sizes, such as clay, silt and sand in the soil. When suggesting water harvesting structures to consider, the texture of the soil is an indispensable characteristic to consider. Clay soils will generally hold water hence are good for water harvesting structures that allow retention of water e.g. water pans. On the other hand sand soils are good in facilitating infiltration of runoff into the underground chambers to recharge the aquifers.

The Soils data obtained for use in this project comprised of the following types as obtained from the attributes; Heavy clay, light clay, loamy sand, Sandy clay loam, Sandy clay and Sandy loam, these soils were classified and weighted according to table 2 and a soils suitability map generated.

3.5.5 Lineaments

For purposes of this study, lineaments will be taken as linear features of a surface, which are placed in a straight or slightly curved connection and which are different from the design of nearby features and are assumed to reflect some surface occurrence. A buffer map for lineaments was then produced, due to their ability to accumulate and stored high volumes of water when it rains. In this project the drainage data and roads data were used as the lineaments. And hence a buffer map was generated on the rivers and roads which had been intersected. Multiple buffers were generated around all the roads and rivers, i.e. nine buffers at an interval of 100m from 100m to 700m, where 100m buffer was taken as the most suitable area for water harvesting structures while 700m buffer as the least suitable area.

3.5.6 Drainage

Harish et al. (2014) defines drainage pattern as a plan, which stream courses put together form. It entails both the general pattern made by the individual drainage lines and the spatial relations of each steam. Machakos County's drainage pattern is composed of several streams and sub-streams of River Athi and River Tana in addition to numerous seasonal streams.

Drainage network aids in outlining watersheds in addition to the selection of different structures for water harvesting. The water harvesting structures are constructed on the streams based on the order of stream. The order of drainage represents the number of streams present in each order defined i.e. 1, 2, 3 and 4 stream orders. Order 1 and 2 are suitable for Storage Tank and percolating Tank. 2 and 3 are suitable for check dams while 3 and 4 are suitable for Stop Dams.

3.5.7 Land Use Land Cover (LULC)

The LULC map was generated from the Landsat 8 data. This formed a constraint of the various regions available and not available for water harvesting structures.

The various constraint layers were overlaid systematically via the multicreteria analysis until the required suitable areas are determined. Generally water harvesting structures are located on sites away from settlement and preferably within agricultural lands where the harvested water can be used for farming among other agricultural use. Settlement will therefore form a constraint layer while agricultural areas will form a suitability layer.

3.6 Data Analysis

Analysis carried out on the datasets was carried out using two software ArcGIS and QGIS. Both are systems for working with maps and geographic information. They are used for but not limited to the following;

- Creating and using maps
- Compiling geographic data
- Analysing mapped information
- Sharing and discovering geographic information

- ❖ Converting between different forms of data – Raster to Vector and vice versa among others

The various datasets were therefore prepared, stored and analysed in the said software to come up with the desired results.

3.7 Analysis Procedures and Presentation

Various stages were undertaken in order to fulfil the objectives of the study. The process of suitability analysis using multicreteria method is a concept now quite common in GIS field, and thus, it is relatively standard procedure which can be applied to any suitability model. It is based mainly on spatial analyst tools and partly the conversion tools of ArcGIS and QGIS.

The first stage was to determine the criteria/factor for determining suitability of water harvesting structure and hence obtain datasets to support the criteria. The second stage involved the preparation of maps/ layers for each criteria using the respective datasets obtained. The third stage was, based on literature reviews weight each criterion in a multicreteria analysis using the weighted overlay tool in ArcGIS 10.5 and hence come up with the required suitability map.

A map was generated for each layer/factor prepared and the suitability map too was generated.

3.7.1 Factors/Criteria Considered in the Suitability Mapping

The following define the criteria used in locating the suitable sites for water harvesting structures.

- The site should be about 100m from a lineament
- It should be on level to gently sloping ground
- Should be in an area where the lithology is Alluvium/ sand stone or related rock that allows water to infiltrate
- Should be located where the soils are fine loamy to clayey soil that retain water and allow infiltration
- The geomorphology of the area should generally be alluvium plain or similar land form
- Should be near a water body and near agricultural land

3.7.2 Assigned Weights

Table 2 shows the theme weights and feature weights applied. They are based on expert's opinions in various literature reviews of past studies.

Table 3: Weights and Percentage Influence

Criteria Layer	Weight (% influence)	Class of feature	Feature Weight Class
1. Lineament Buffer	20	Lineament Buffer 100m	7
		Lineament Buffer 200m	6
		Lineament Buffer 300m	5
		Lineament Buffer 400m	4
		Lineament Buffer 500m	3
		Lineament Buffer 600m	2
		Lineament Buffer 700m	1
2. Geomorphology	15	Land forms	
		Plains	7
		Hill and Mountain foot ridges	3
		Foot slopes	4
		Plateaux	7
		Water body	1
3. Lithology	15	Rock type	
		Acid metamorphic	7
		Basalt	6
		Igneous Rock	5
		Classic Sediments	5
		Eolian Unconsolidated rock	4
		Fluvial	7
		Gneiss	5
		Quartzite	3
		Water body	6
4. Soil	10	Soil Type	
		Clayey light	6
		Clayey heavy	7

		Loamy sand	6
		Sandy clay	5
		Sandy clay loam	6
		Sandy Loam	3
5. Gradient/slope	25	Slope Structure	
		Gentle slopping	5
		Level to gentle slopping	7
		Moderate sloping	4
		Others	3
6. Land Use/Cover	15	Classes	
		Agricultural	6
		settlements	1
		Forested	3
		Grass lands	4
		Water body	7
		Others	3

A scale of 1-7 is used to show suitability where 1 is least suitable and 7 is most suitable. As shown in Table 4.

Table 4: Suitability Scale

Scale	Suitability Level
1	Extremely low
2	Very low
3	Low
4	Moderate
5	High
6	Very High
7	Extremely high

3.7.3 Rasterization of all the classified datasets;

Apart from the slope data, which was already in raster form, all the other datasets - lithology, geomorphology, lineament, soil and land use land cover – underwent the process of rasterization so as to make the weighted overlay possible.

3.7.4 Procedure and Presentation

After obtaining the data sets from the various sources as mentioned above, the information was assembled in a GIS environment using ArcGIS 10.5 and QGIS. All the datasets obtained had been georeferenced and were compatible. In ArcGIS, clip tool was used to obtain the required site only from large amounts of data. For instance a data source provided the whole map of Kenya Counties. Clip tool was used to clip Machakos County since it is the area of interest.

In ArcGIS the various datasets were input and their respective criteria maps/ layers generated. The various layers generated included; lithological map, geomorphology map, Soil map, Slope Map, lineament map and land use land cover map all covering Machakos County.

A compact form of analysis was used by building a model to execute the different procedures. In brief, suitability analysis consisted of getting vector data, which was then converted to raster format through classification, compiling the data in a weighted overlay tool. After this the data was then converted back to vector format for final suitable location.

Both lithology, soil, and Geomorphology datasets underwent classification, after rasterization. Lineament data was obtained by intersecting drainage and roads network datasets, nine multi-buffers were then generated on the lineaments, the obtained buffer map was then rasterised awaiting weighting and overlay. Slope data was obtained from the Aster data using 3D analyst tool of ArcGIS 10.5.

Presentation of the final results was in thematic maps and coordinates showing the different suitability maps for each criterion and the final suitability map.

CHAPTER 4: RESULTS AND DISCUSSION

4.0 Introduction

In this chapter results and findings deduced from the methodology are discussed. The deliverables include display of the thematic maps that would enable each criterion to be viewed as an individual factor towards the determination of a suitable site for water harvesting.

4.1 Suitability Maps for Each Criterion

This part entails the display of all the criterion layers/ maps and a brief discussion on each map. Suitability maps for each criterion define the influence that each criterion has on the positioning of the water harvesting structures. It is a raster file that shows a scale of suitability. In this project the scale of suitability ranges from 1 to 7, with 7 as the most suitable while 1 is the least suitable. The criterion suitability maps fulfil a specific objective for this project and are presented below.

4.1.1 Slope Suitability Map

The slope map generated indicates that 73% of the site of study is suitable for water harvesting i.e. has a slope ranging 0-4% i.e. level to gentle sloping. The suitability map and pie chart are as shown in figure 10 and 11.

Figure 10: Pie Chart Representation of Slope Suitability Map in M^2

Figure 11 depicts Machakos County as having a good slope for water harvesting, because the extremely suitable areas according to the scale are distributed in the entire County. The areas indicated as low suitability are those on the hills such as Chulu hills, Mbooni, Oldonyo sabuk, Iveti and Kanzalu ranges

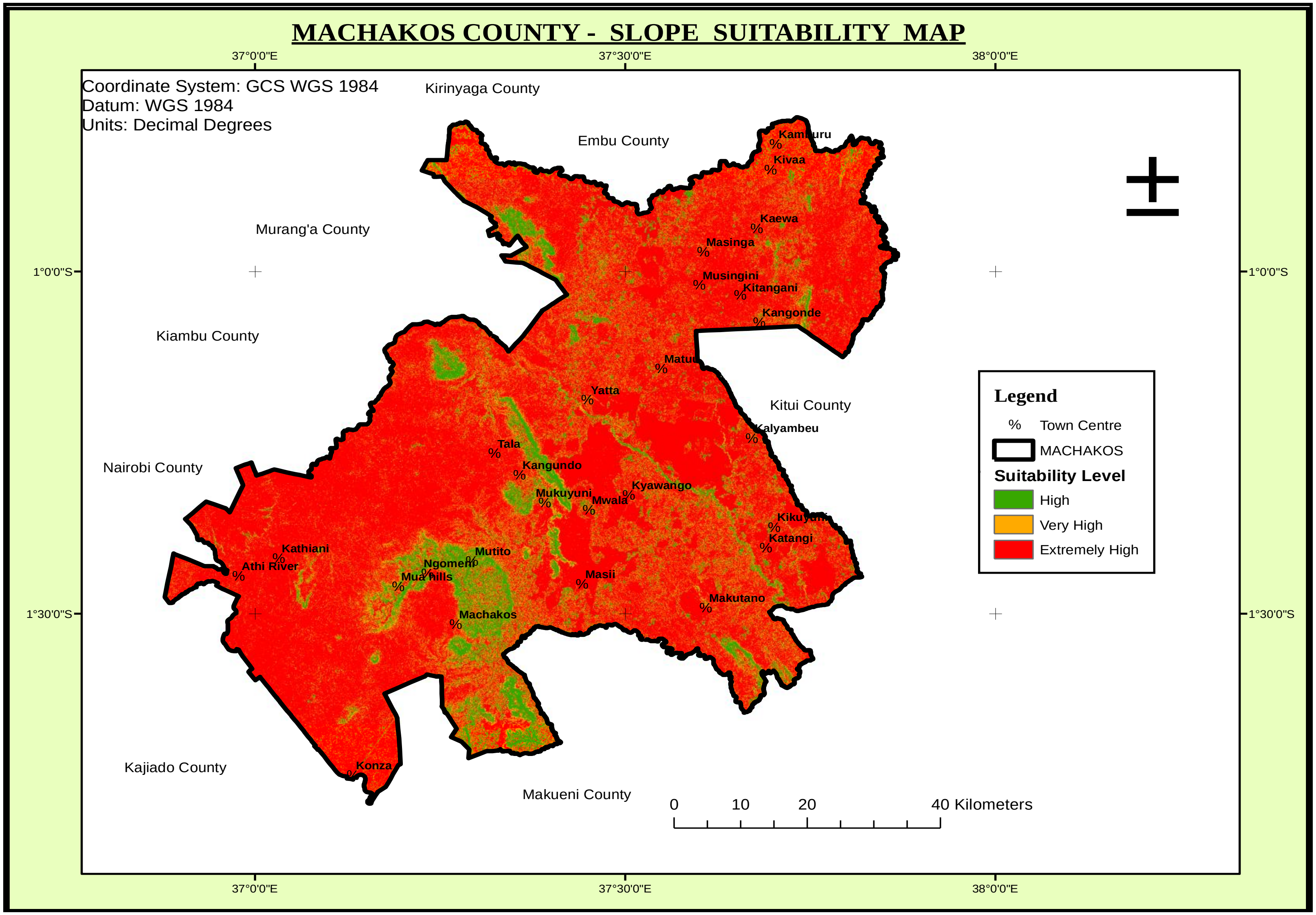

Figure 11: Slope Suitability Map

4.1.2 Lineament Suitability Map

The lineament play a major role in the selection of water harvesting structures because they are collection sites for water when it rains. Most water harvesting structures draw water from lineaments and should therefore be constructed near them. The rasterized buffer map of lineaments is shown in figure 12 and 13.

Figure 12 depicts the Lineament buffers zoomed, this is because they are not shown as to such detail in Figure 13.

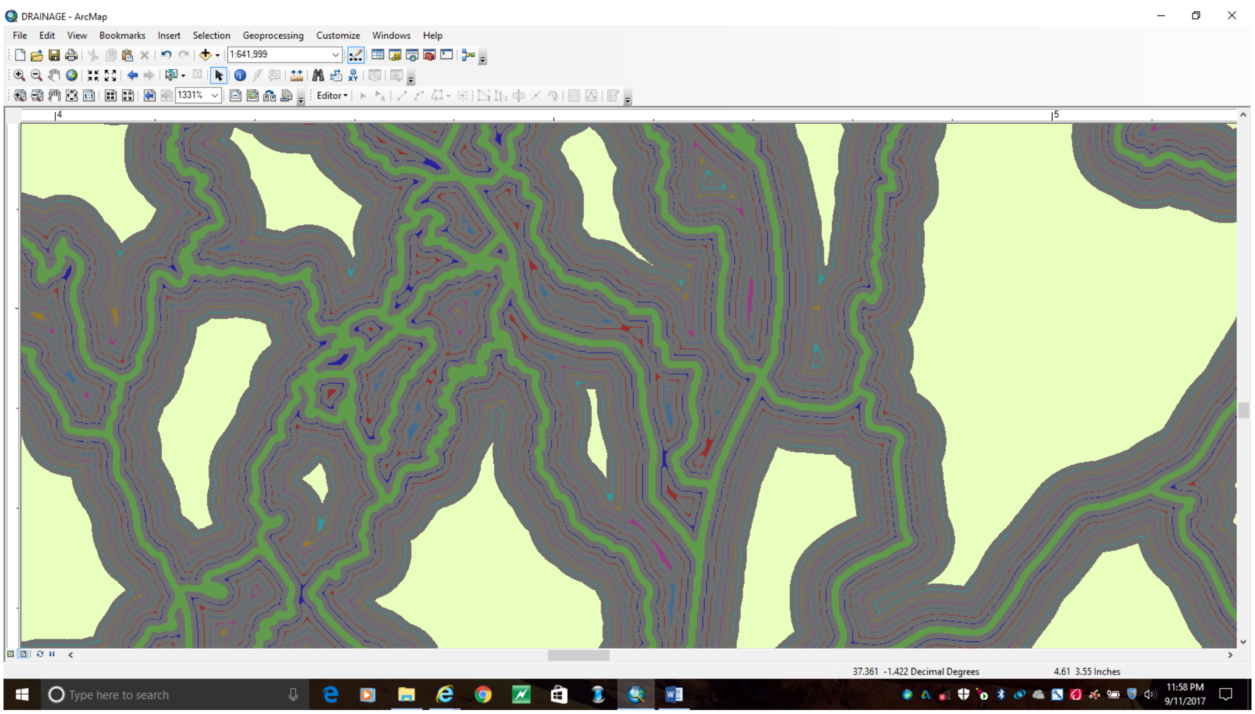

Figure 12: Lineament Buffers zoomed for clarity

Lineament suitable areas generally follow the drainage and road features. Dense road network and drainage network can therefore provide better results.

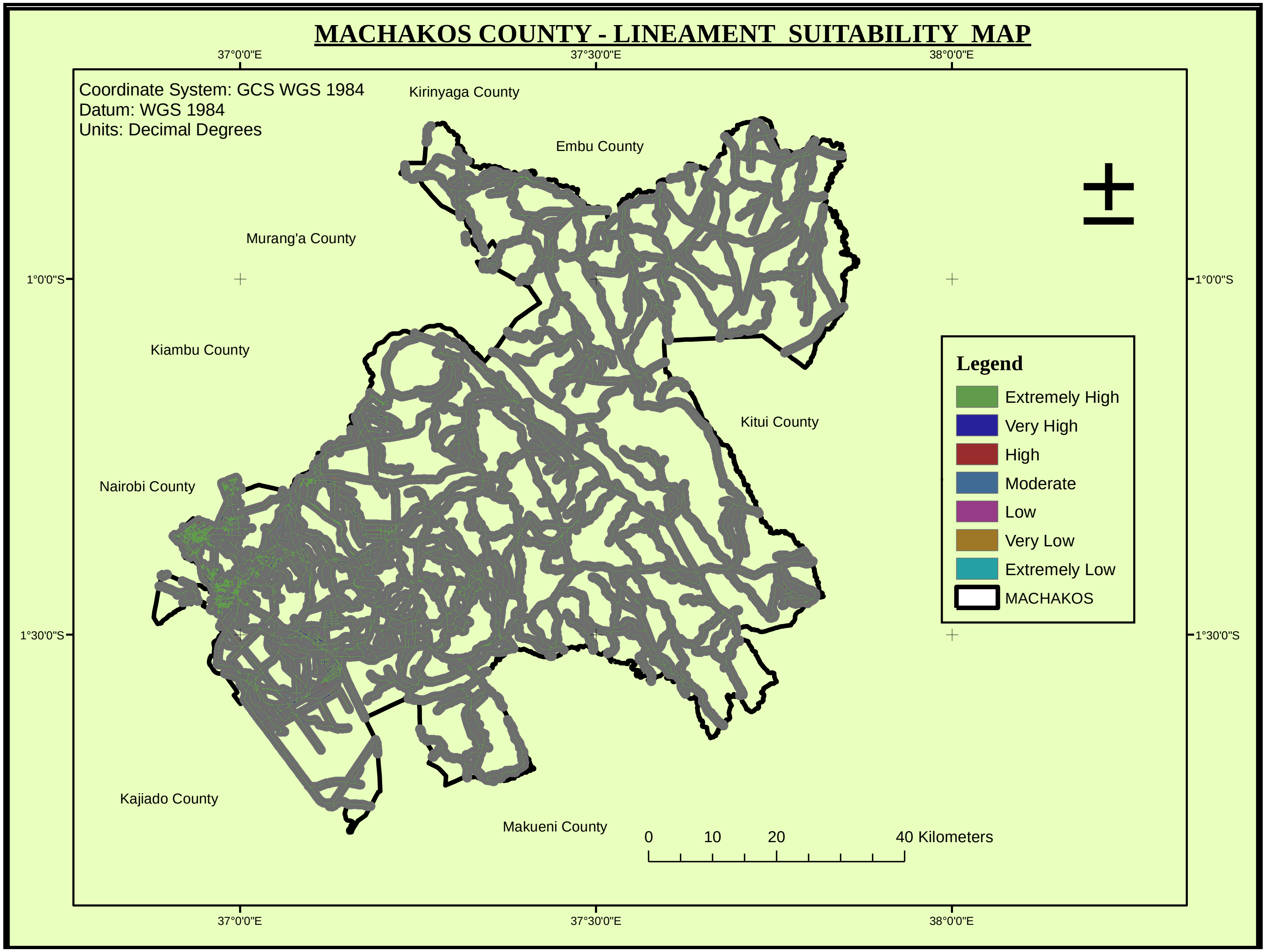

Figure 13: Lineament Suitability Map

4.1.3 LULC Suitability Map

The Land use land cover map is both a constraint and a factor layer. The settlement sites are the constraint part of the layer and are therefore given the least suitability of 1 while crop lands are given the most suitability scale of 8. The LULC map indicates that 80% of the site of study is suitable for water harvesting structures as shown by the pie chart and map in figure 14 and 15 below.

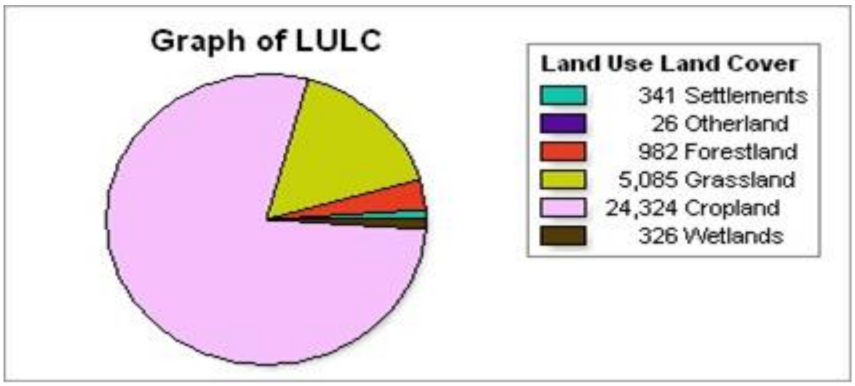

Figure 14: Pie Chart Percentage area Representation of LULC Suitability in KM^2

Most of the analysed land mass in Machakos County is composed of Cropland, this is an indication of great potential in water harvesting since the location of the structures agree with cropland land use. The settlements cover only a small percentage of the analysed land mass and hence the constraint is small.

The areas indicated low to moderate suitability as from Figure 15 are mainly settlements in urban areas within Machakos County.

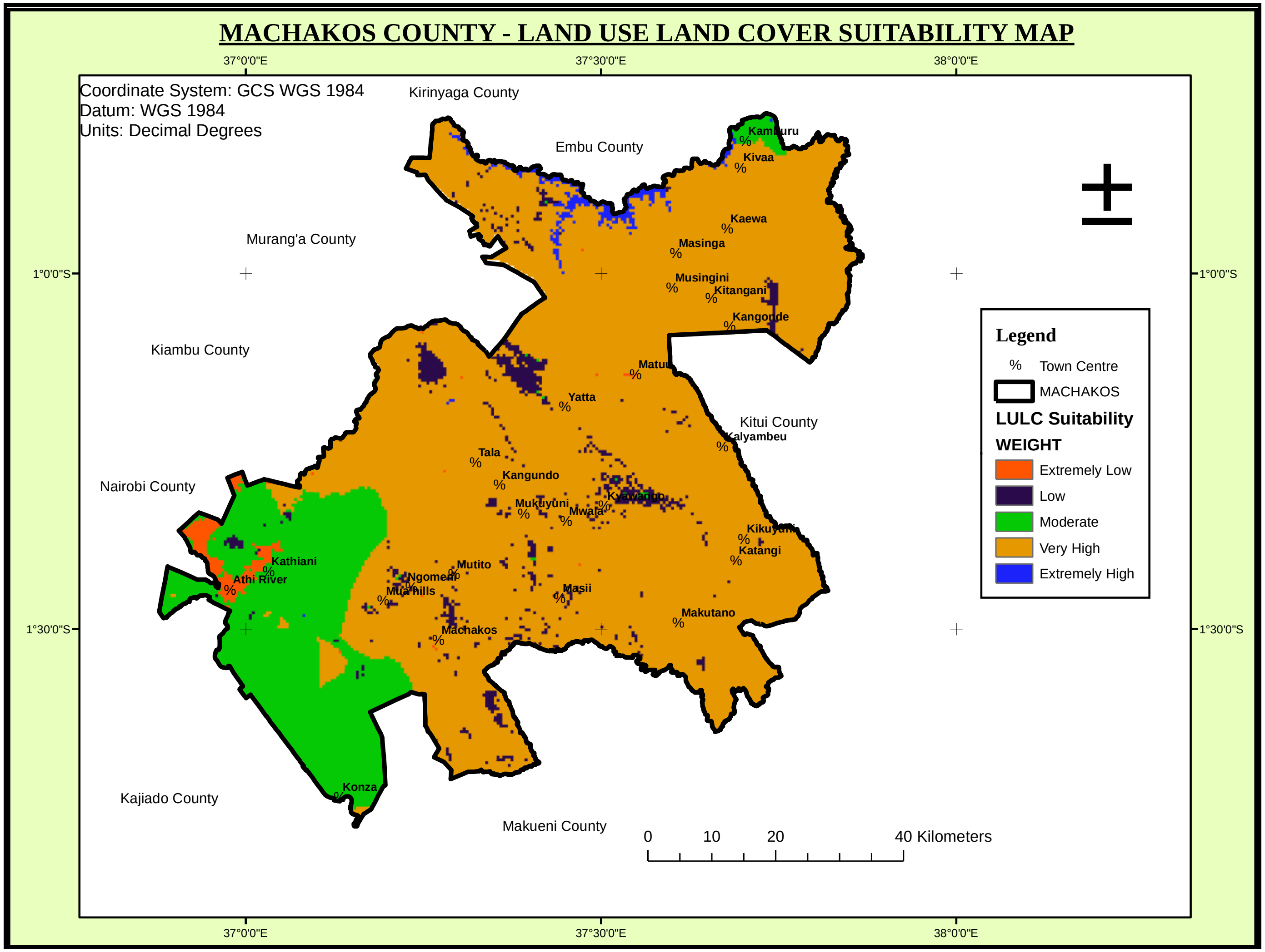

Figure 15: LULC Suitability Map

4.1.4 Lithology Suitability Map

Lithology plays a critical role in the choice of the water harvesting structure as far as the water retention capacity is concerned. Impervious rocks are good for check dams while well drained sand stones will be good for storage tanks whose main objective is infiltration to fill the aquifers. The suitability map is shown in figure 16.

Good rocks for water harvesting are not readily available in Machakos County however there are alternatives such as gneiss which are available and which provide a good base for water storage.

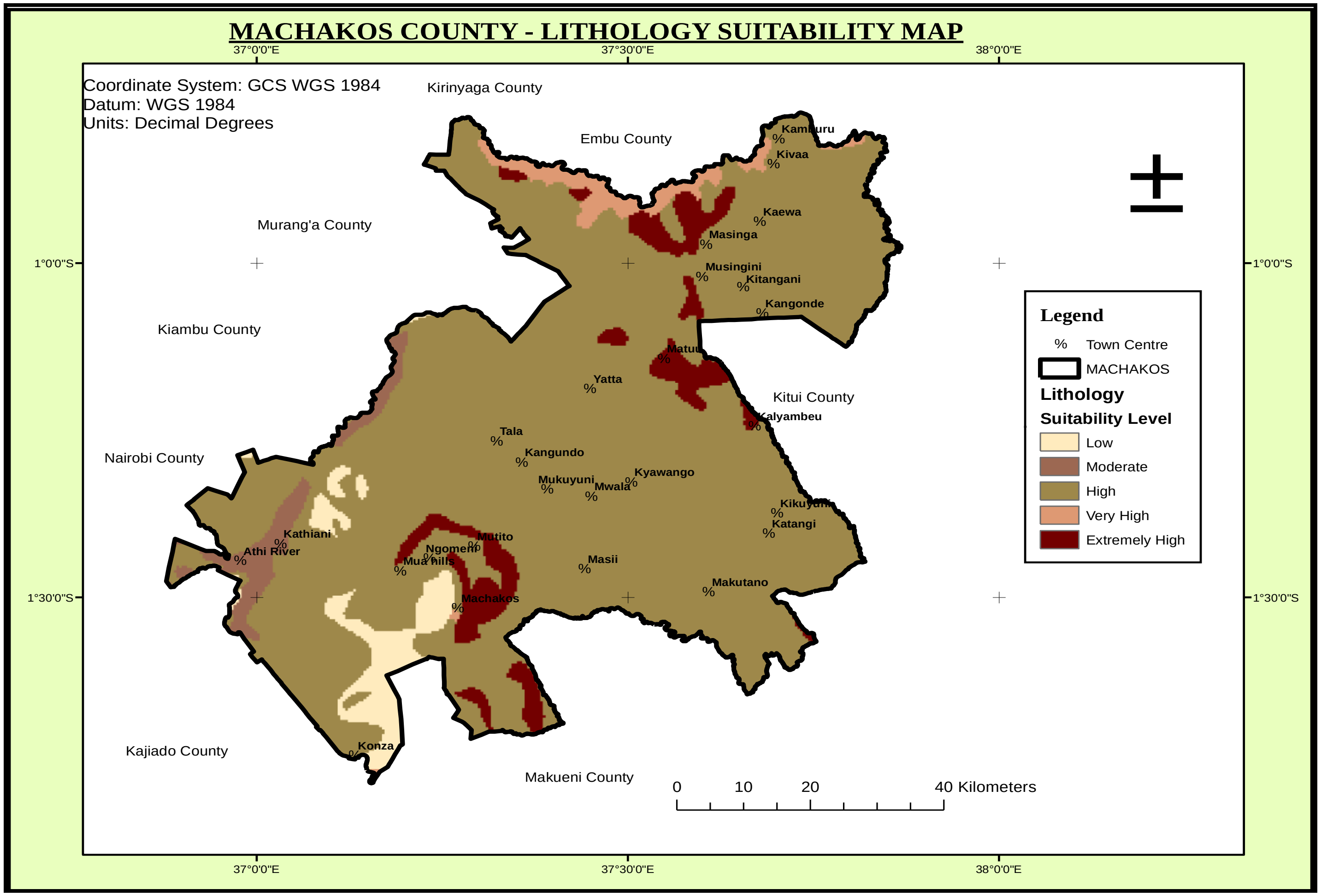

Figure 16: Lithology Suitability Map

4.1.5 Geomorphology Suitability Map

The general geomorphological features in the area of study include; plains, plateaux, hills and hill slopes and water bodies. Plains and plateaux are the most suitable sites for water harvesting structure because the level ground allows for infiltration of water to refill the aquifers and there is minimal runoff speed when it rains.

The Geomorphological characteristics of Machakos County are highly favourable for water harvesting. The entire county is extremely suitable for water harvesting according to the chosen scale. The few regions indicated as of low suitability are hill tops which indeed may not support water harvesting.

The geomorphology suitability map is shown figure 17.

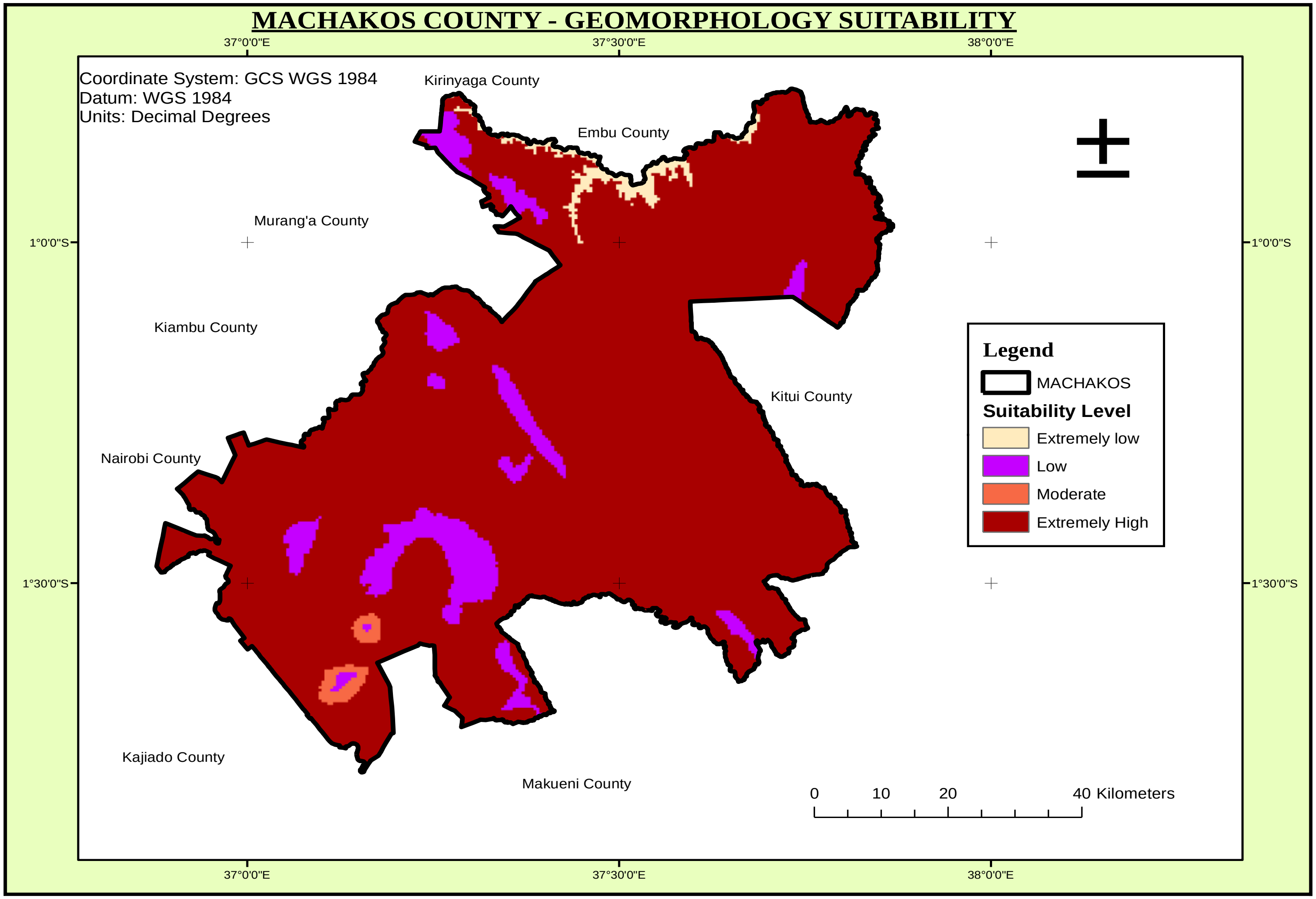

Figure 17: Geomorphology Suitability Map

4.1.6 Soils Suitability Map

Soil texture plays a critical role in the selection of water harvesting structures. Clay soils are the best for water retention while sandy loams are good at allowing infiltration to the aquifers. The soil suitability map is shown figure 18.

The regions covered by clay soils are highly suitable due to the water retention capacity of clay soil that make it good for structures that hold water such as water pans. Most of the analysed soil land mass of Machakos County is highly suitable for water harvesting depicting great potential for water harvesting.

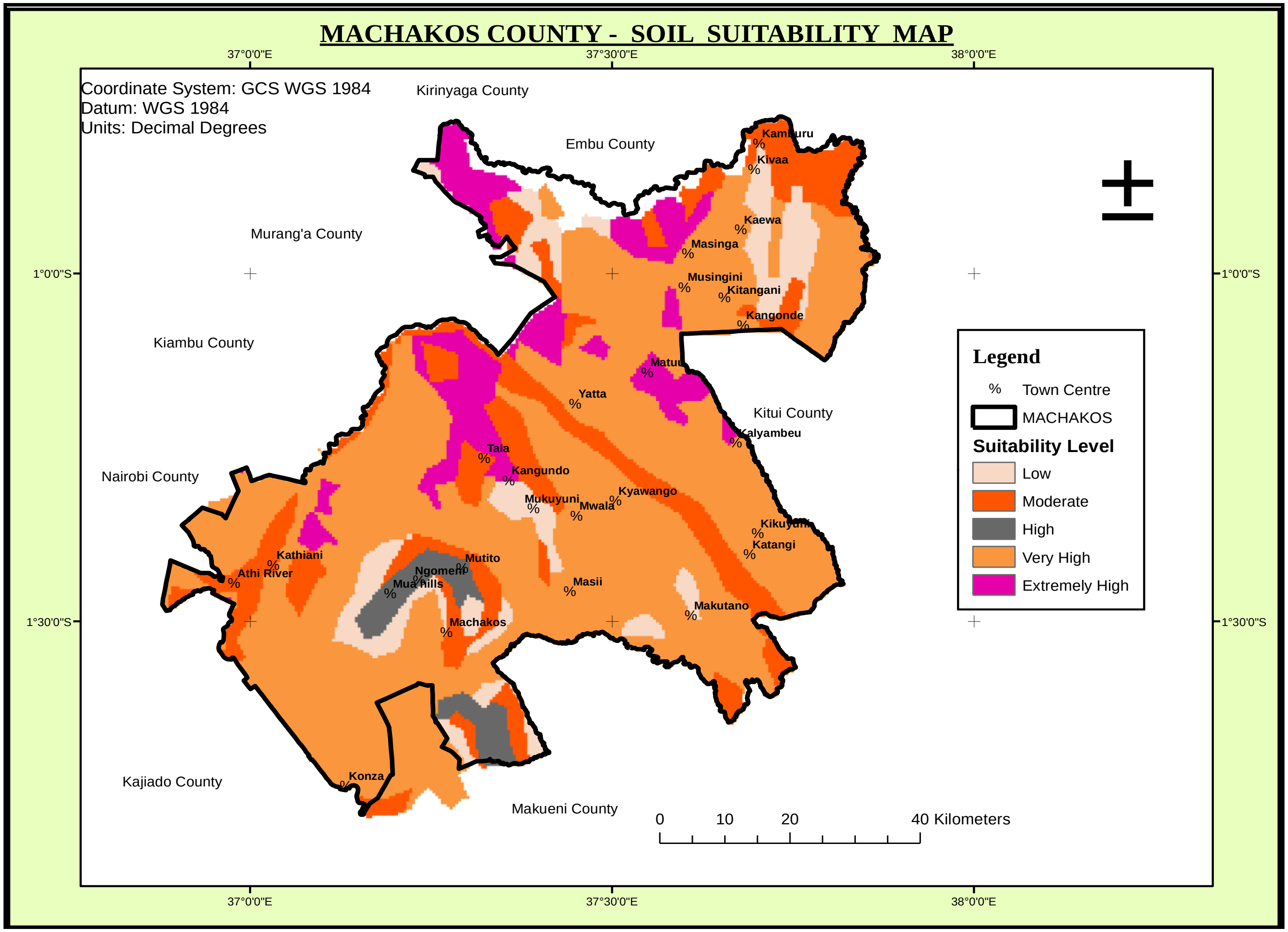

Figure 18: Soil Suitability Map

4.2 Weighted Overlay

The weighted overlay tool was used in combining the influence of each criterion into one map. This involved the assigning of weights/ scale values to each criterion and its respective influence in the overall suitability model.

Print screen of the weighted overlay window is shown in figure 19.

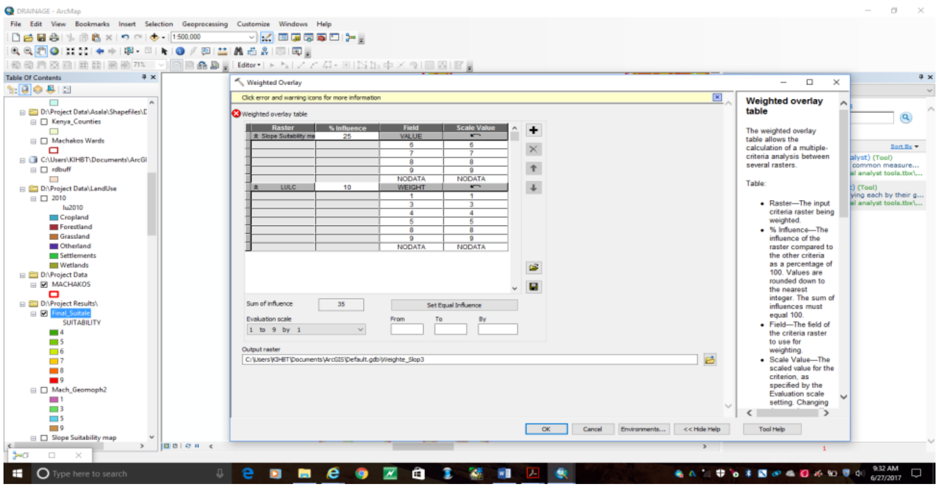

Figure 19: Weighted Overlay

4.3 Final Results

The integration of thematic suitability maps resulted in the production of water harvesting Suitability map of the study area as shown in Figure 20. The map depicts clear zones that met all the set criteria of suitability and in the various suitability levels, the zones that met all the very high suitability criteria constituted 1% of the analysed land mass of Machakos County. A map of these identified zones was then plotted against the Constituencies map of Machakos County as shown in Figure 21, most suitable areas for water harvesting are mainly in Matungulu, Masinga, Yatta, Kangundo and Kathiani Constituencies.

For purposes of selecting specific zones for the various water harvesting structures, the Suitability map was then plotted against drainage map, with streams depicted in the various orders as shown in Figure 22. An analysis of the location of zones for specific WH structures was then undertaken as per the specification in Table 1. One point per zone was then chosen in the various zones identified as a representation of the Zone location for a particular WH structure. Five zones for storage tanks were identified, similarly five zones for percolating tanks and five zones for stop dams were also identified as depicted by Figure 23.

Table 5: Water Harvesting Structures Zones and Location

WH Structure	Number of Zones	Zone Location
Storage Tanks	2	Matungulu
	1	Kangundo
	1	Yatta
	1	Masinga
Percolating Tanks	3	Masinga
	1	Matungulu
	1	Kathiani
Stop Dams	2	Matungulu
	2	Yatta
	1	Masinga

Table 5 depicts a summary of the various zones identified and the constituency in which they are found. Most of the Zones for WH structures are in Matungulu constituency.

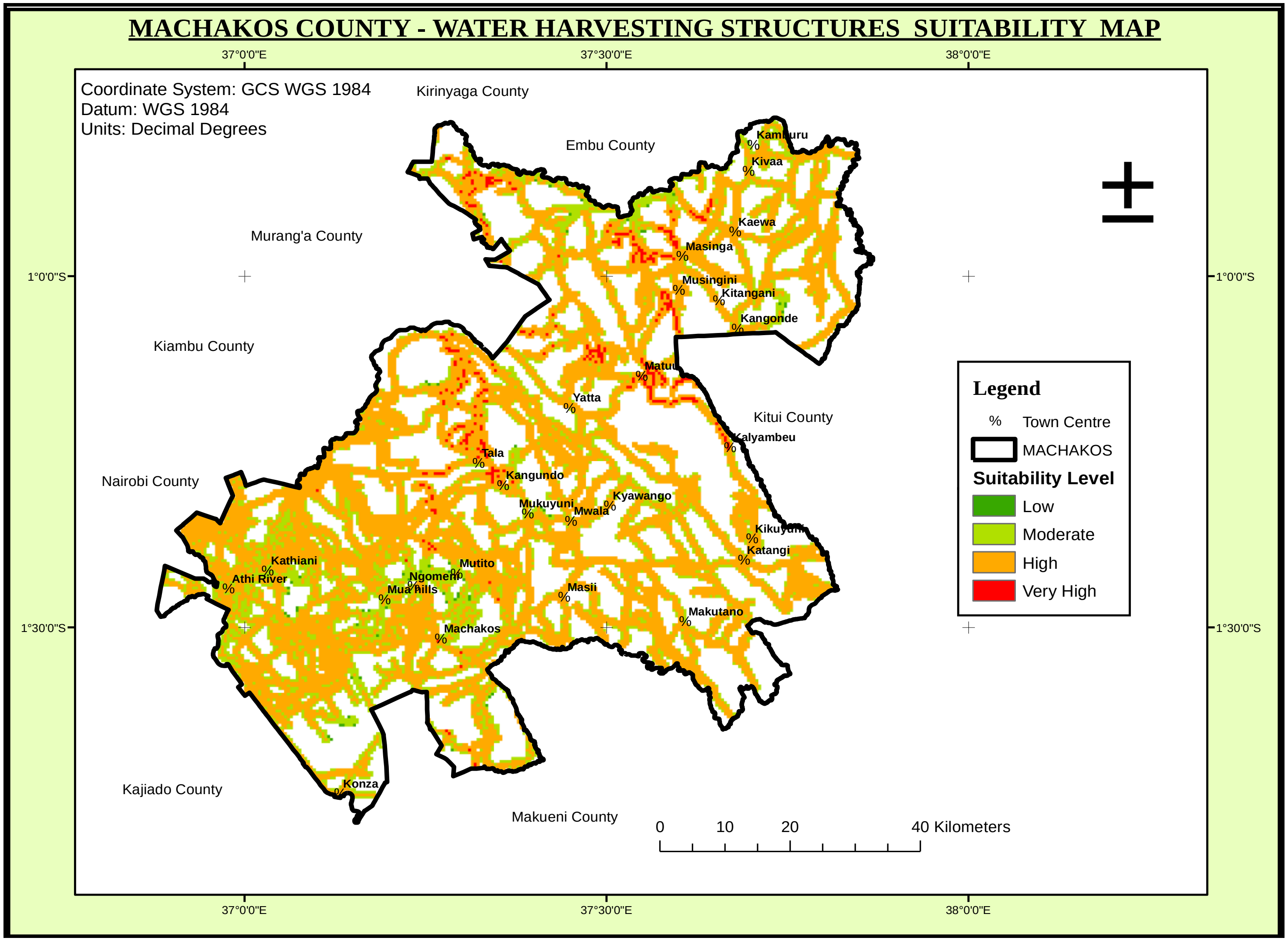

Figure 20: Final Water Harvesting Suitability Map

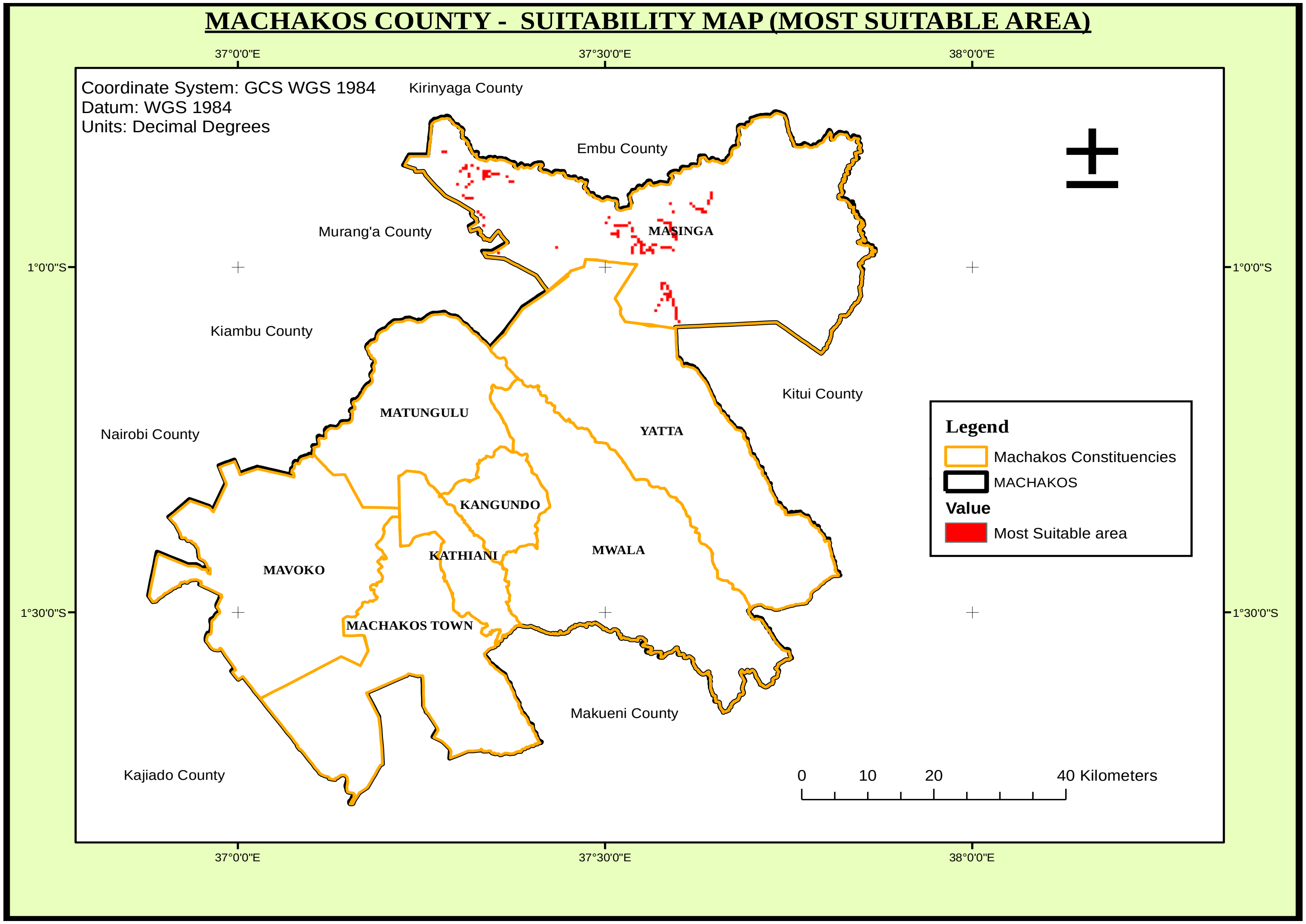

Figure 21: Map of Machakos County Depicting Highly Suitable Area only

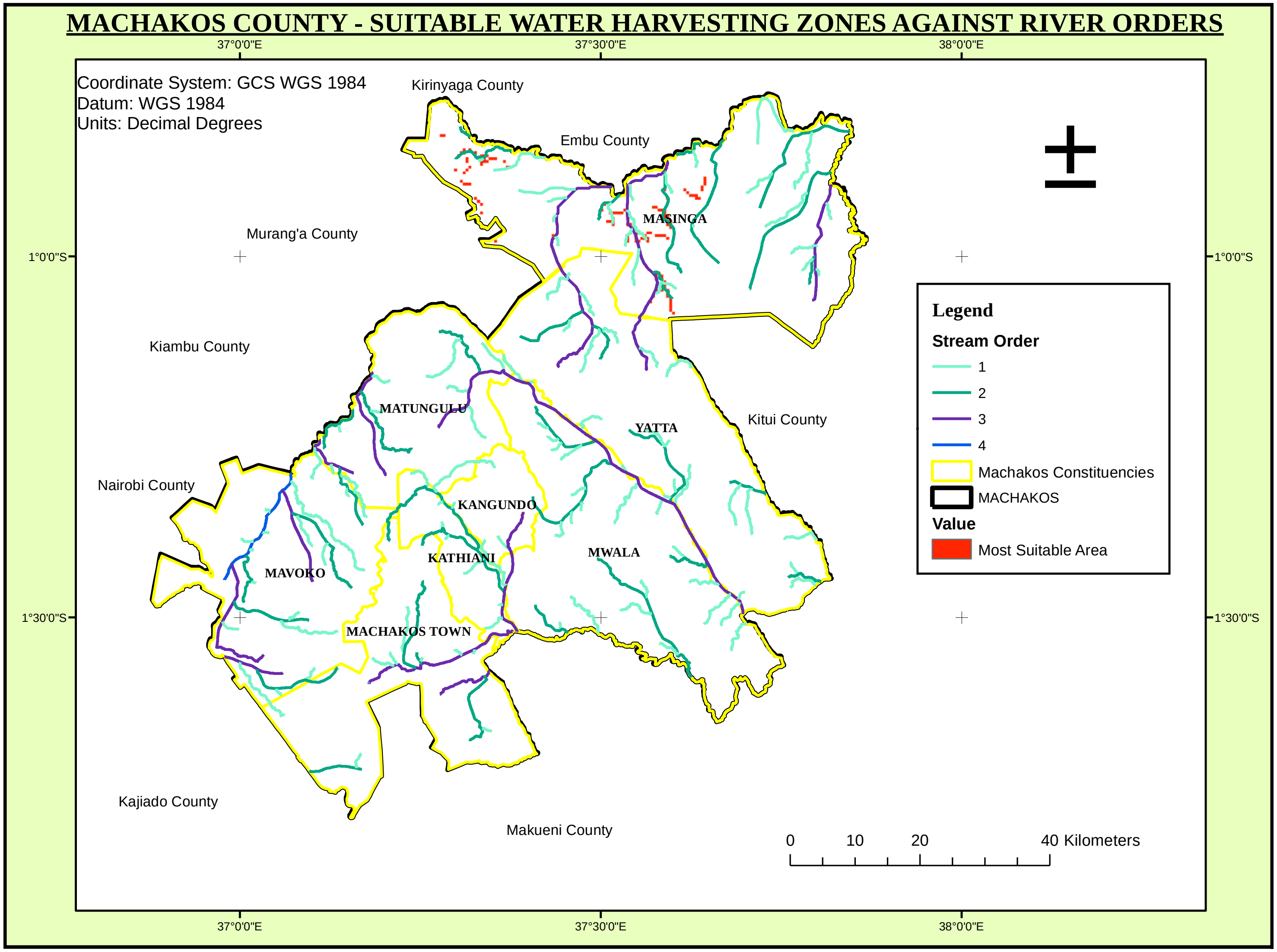

Figure 22: Drainage and Water Harvesting Suitability Map

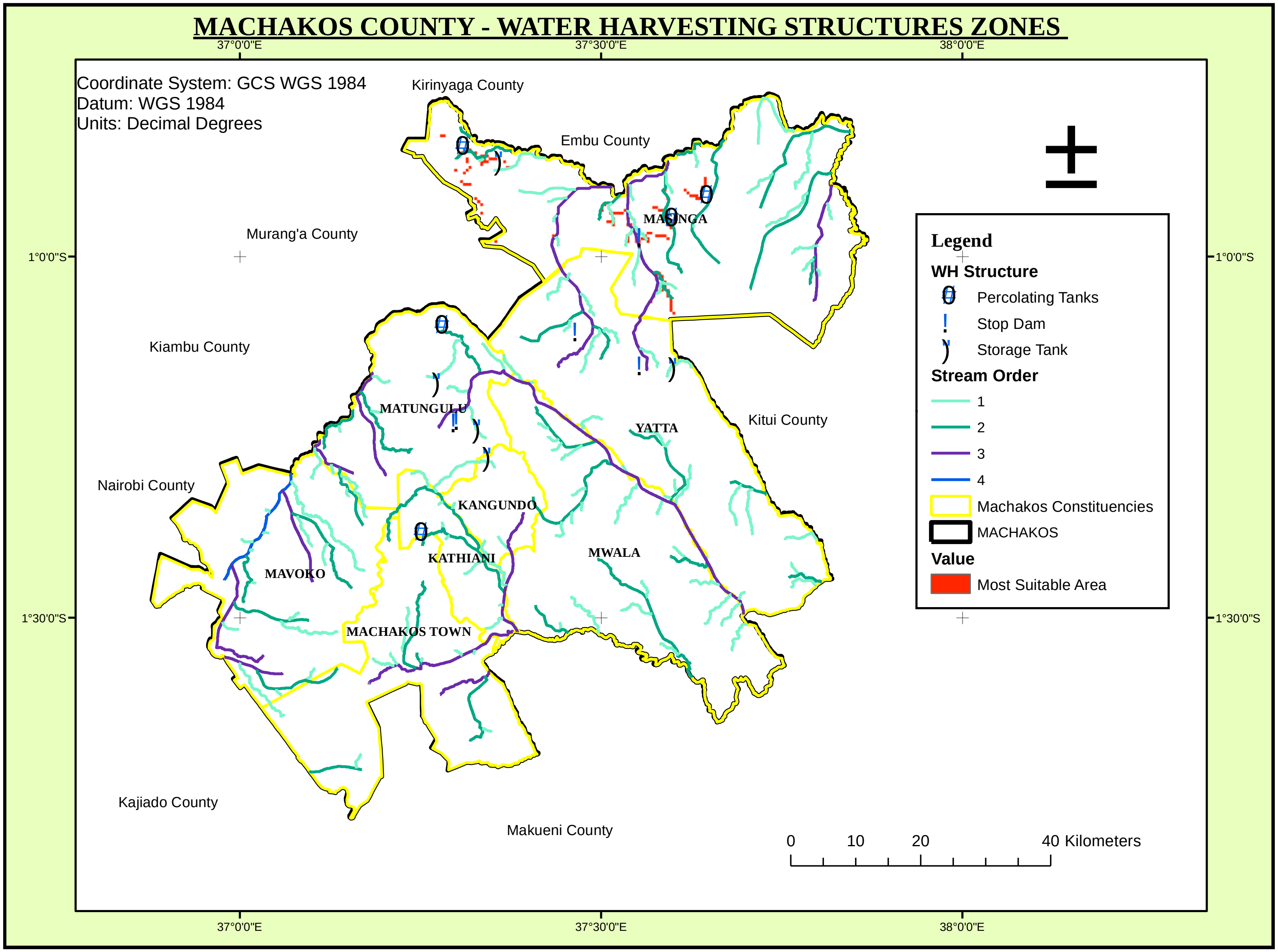

Figure 23: Water harvesting structures Zones Identified

4.5 Results Validation

Validation of results was done by Ground truthing which was conducted by picking some of the existing water harvesting structures.

A few water harvesting structures were picked using a hand held GNSS receiver in Kithimani area, Makutano and at Masii, In Kithimani, water pans were picked. The water pans were constructed through the Initiative of Christian Impact Mission (CIM) led by Bishop Titus Masika. The positions of the water pans agreed with the areas classified as highly suitable.

Two check dams were picked near Masii town and their positions too agreed with the suitable areas as classified. The positions of all the picked points were then plotted against the suitability map and are as shown in figure 24.

The positions of all the picked features fell in the areas determined as high suitable on the suitability map hence making the study credible.

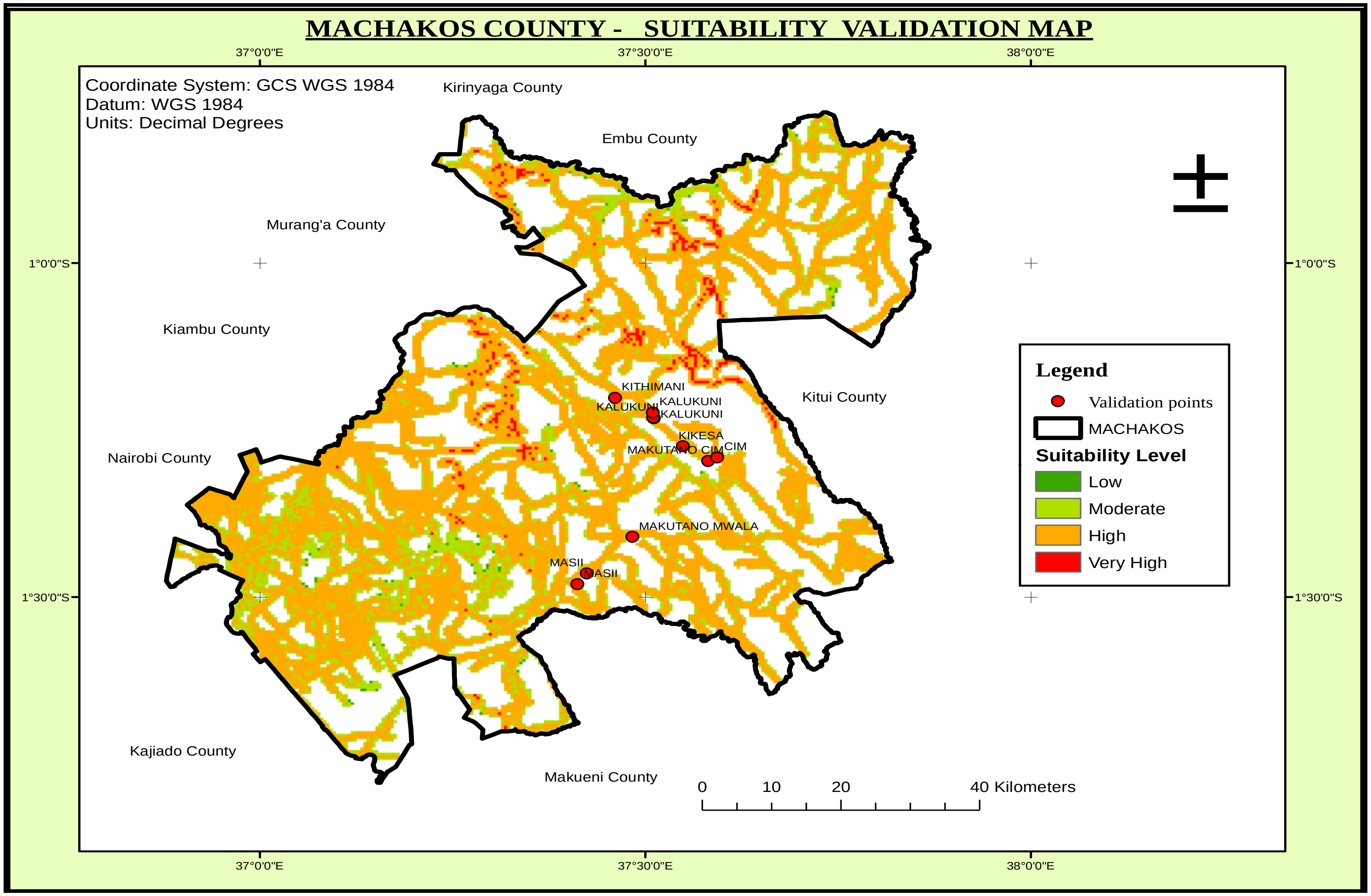

Figure 24: Validation of Suitability Map

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter highlights the conclusions and recommendations of the projects based on the objectives set out at the beginning of study. The main objective of this study was to generate a site suitability map for water harvesting in Machakos County. From the analysis carried out this objective was met. The other objectives too were met, i.e., determination of the suitability criteria, and generating a suitability map for each criterion/ factor.

5.1 Conclusions

This study applied GIS and remote sensing to produce a suitability map for water harvesting structures in Machakos County. This was enabled through application of various spatial analysis tools. The tools were applied on six layers, land use land cove, lineament, geomorphology, soils, slope, and lithology

Six criteria were selected to enable selection of suitable zones for water harvesting structures; gentle to level Slope, Well drained soils, Zones 100m from lineaments, well drained rocks/ Lithology, plateau land formation/geomorphology and Land use land cover.

Suitability maps for the selected criteria were then generated and further integrated through Multicreteria analysis to produce the required WH suitability map.

Fifteen zones were then identified – from the WH suitability map - for the various water harvesting structures; five zones for percolating tanks, five zones for stop dams and another five zones for storage tanks.

Results of this study illustrate how GIS and remote sensing can be used in exploration of water harvesting structures in a scientific approach hence making decision making easier and accurate.

Information derived from this study can be used to inform government, investors and other stakeholders on best water conservation practises and sustainable use of the water resource.

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 experts from the Geology Department University of Nairobi and past literature reviews were key ingredient to this study.

The suitability map has about 30% of the study area ranked as low suitability. These low ranked areas are highly mountainous such as Chulu and Mbooni, Oldonyo sabuk, iveti hills and Kanzalu ranges

5.2 Recommendations

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

Machakos County has great potential in water harvesting as can be seen from the identified suitable WH zones. The citizens of the county could therefore leverage on the results of this project to avoid over-reliance on rain seasons.

Government and Non-government agencies could investigate further and invest in construction of the water harvesting structures in the identified suitable areas for improved livelihoods through improved food production since water will be available.

The Ministry of Water and Natural Resources should leverage on such a study to invest in the suggested simple structures – stop dams, percolating tanks and storage tanks - that can course impact in a greater way.

More ground truthing should be conducted on the identified suitable WH zones for certainty of the study and for further application in other semi-arid areas. An analysis of the identified zones should also be undertaken to determine the specific location of the WH structures within the zones.

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APPENDICES

Appendix 1: Coordinates of Ground Truthing Points

S.No.	Longitude	Latitude.	Elevation	Description
1	-1.19938	37.46025	1337.709	OTITHINI
2	-1.23004	37.51031	1303.105	WP002
3	-1.22895	37.50958	1301.455	WP001
4	-1.27206	37.54824	1307.411	WP003
5	-1.29395	37.58087	1290.383	WP004
6	-1.28828	37.59273	1289.523	WP005
7	-1.22153	37.50871	1291.154	WP006
8	-1.40749	37.48239	1298.752	WP007
9	-1.46208	37.4234	1378.345	WP/CD008 Masii
10	-1.47834	37.41104	1308.952	CD009 Masii

Appendix 2: Pictures Taken during Ground Truthing

Figure 25: Water Pan at Otithini

Figure 26: Water Pan Yatta at CIM

Figure 27: Water Pan at Makutano

Figure 28: Stop Dam in Masii

Appendix 3: Designs of Water Harvesting Structures

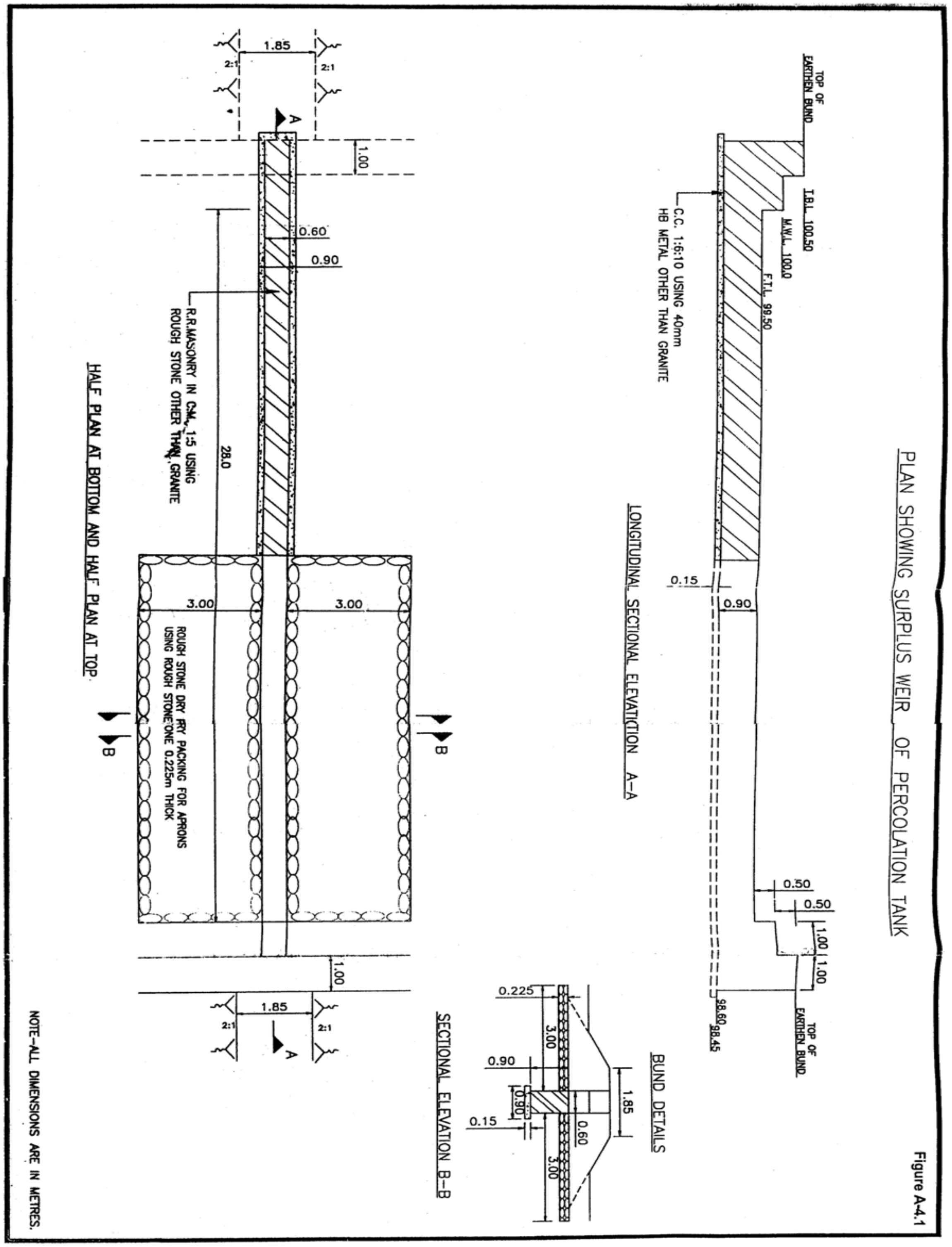

Figure 29: Design Plan for Percolating Tank; Source: Goulburn Murray Water. (2015).

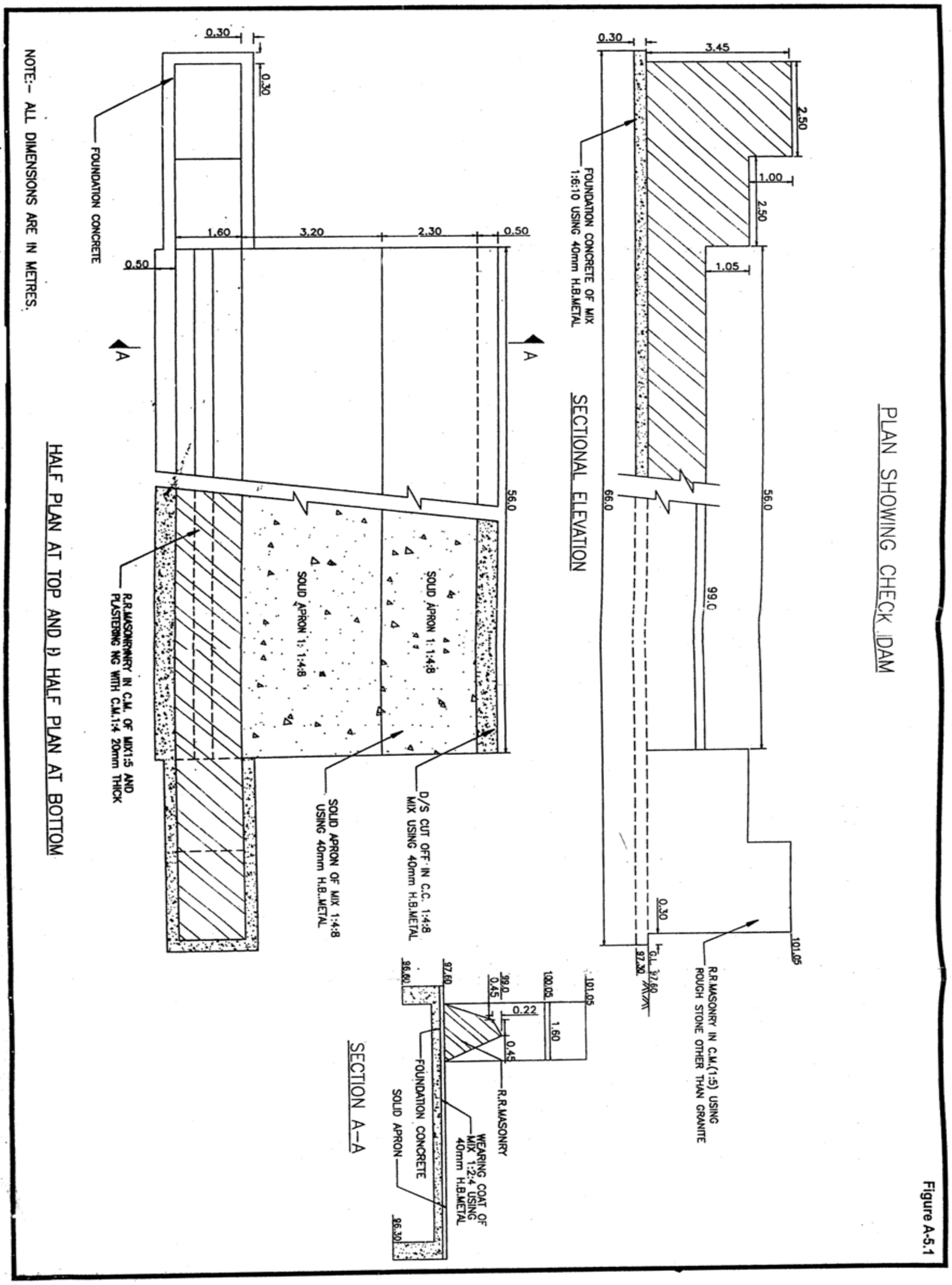

Figure 30: Design Plan for Check Dam; Source: Goulburn Murray Water. (2015).

Appendix 4: Original data sets

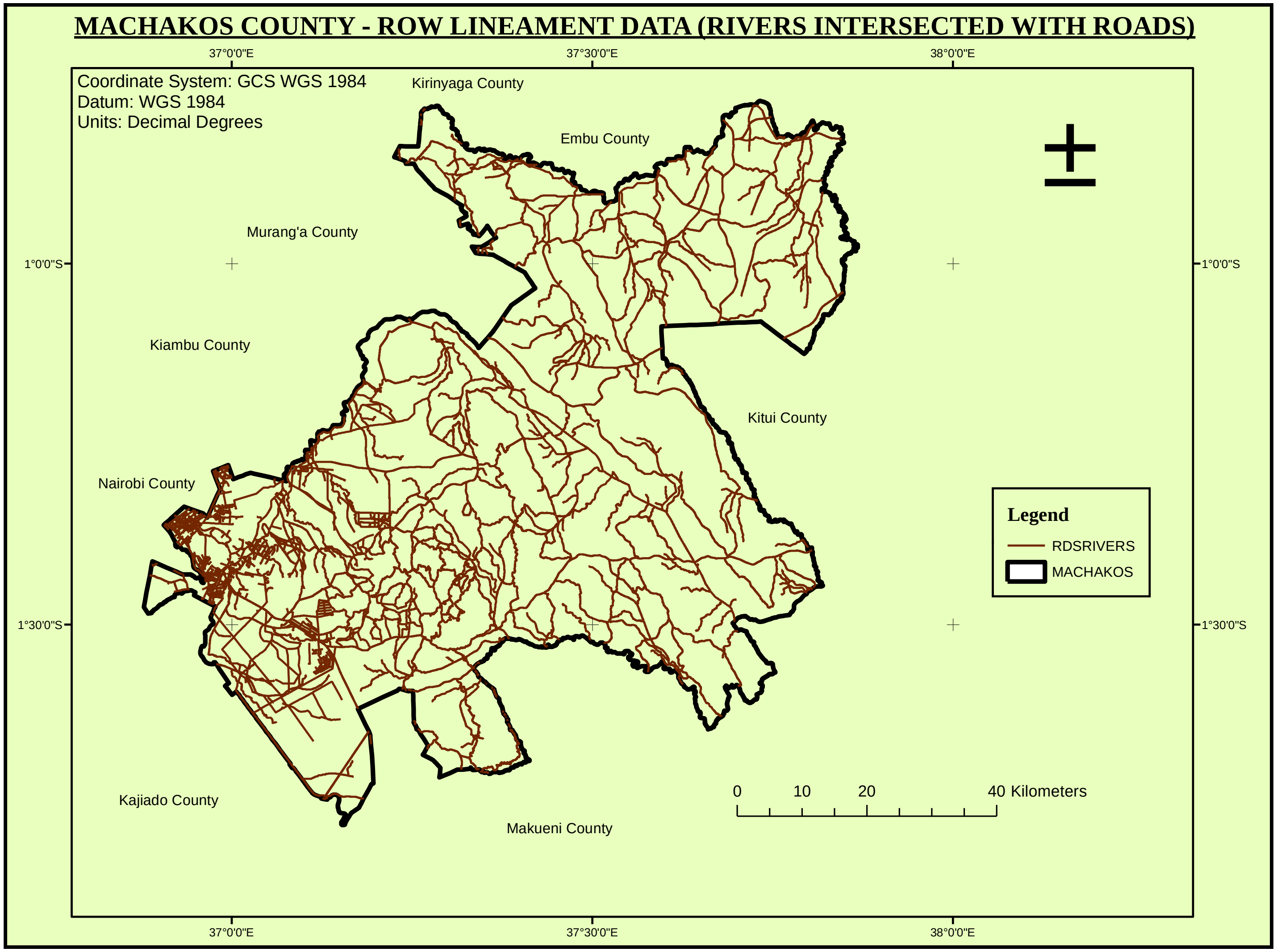

Figure 31: Raw lineament data

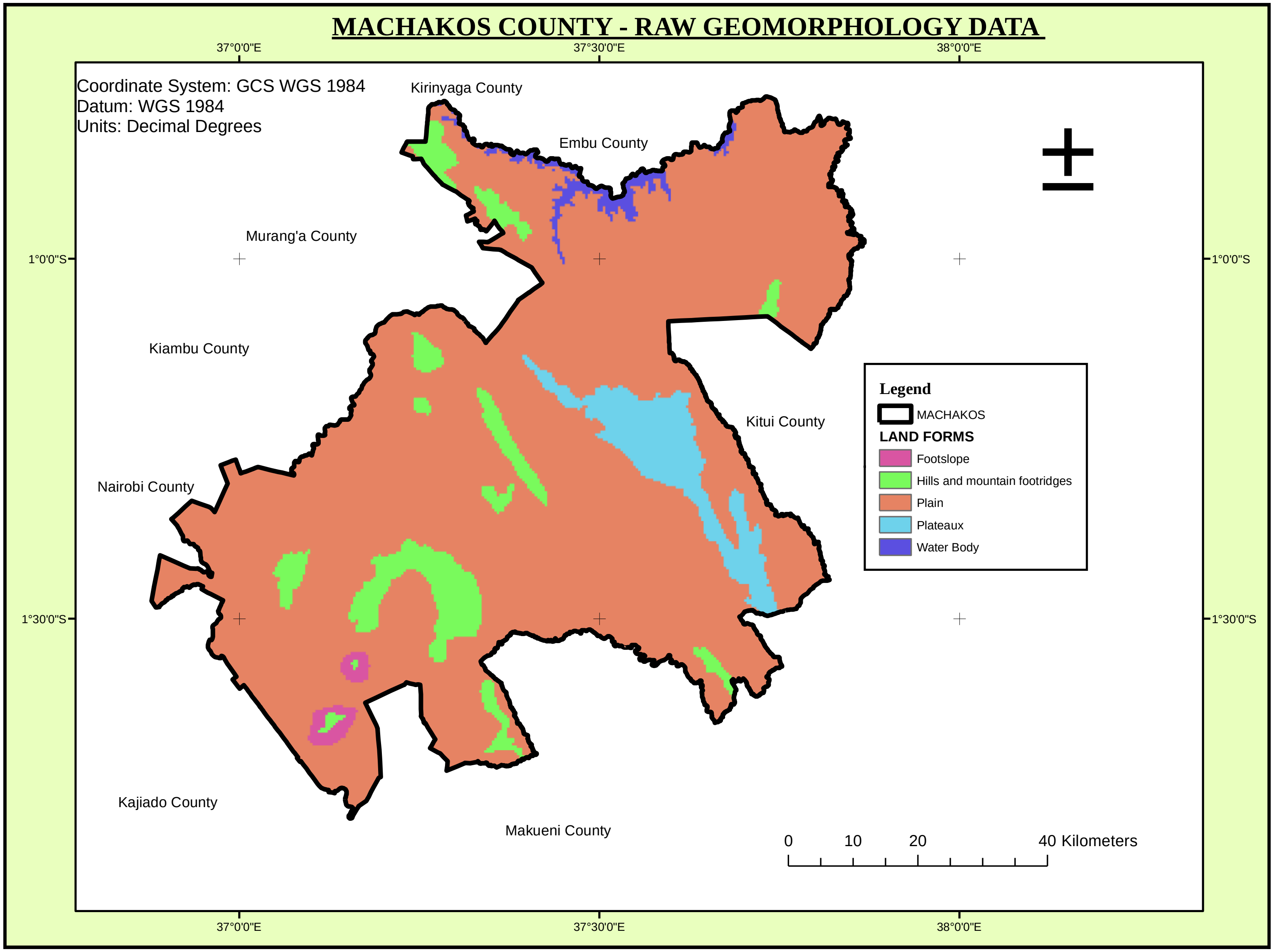

Figure 32: Raw Geomorphology Data

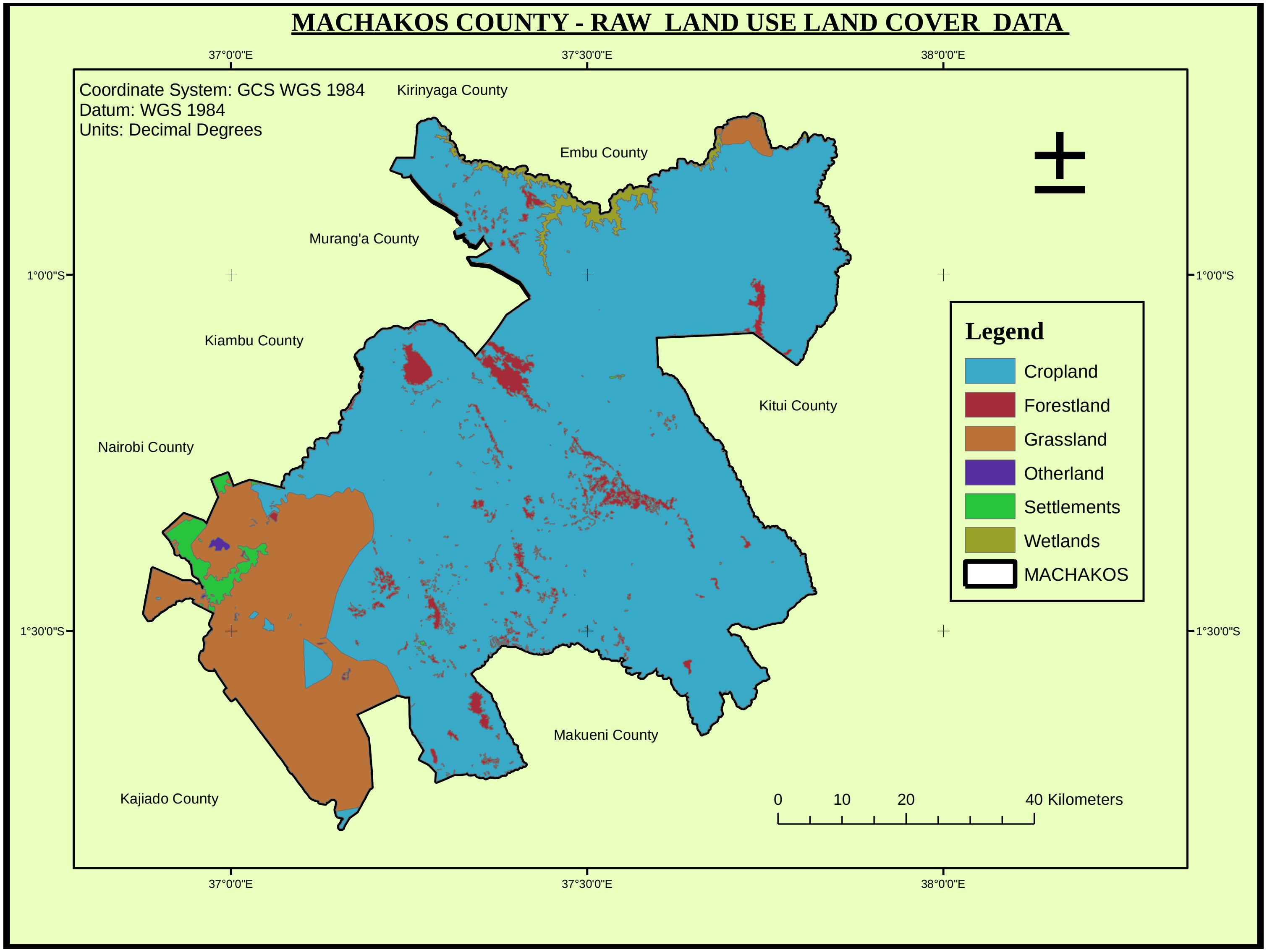

Figure 33: Raw Land use land cover data

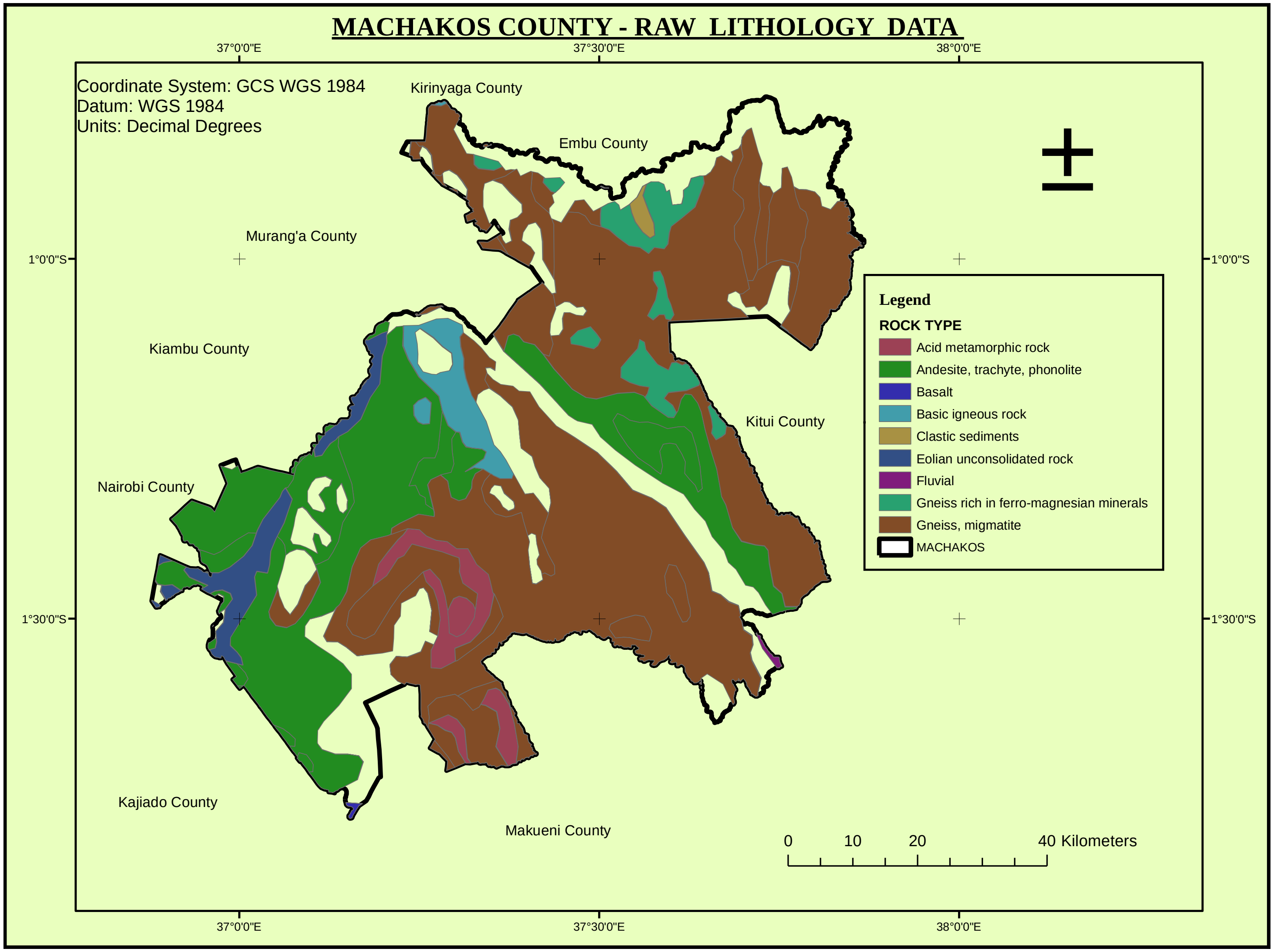

Figure 34: Raw Lithology Data

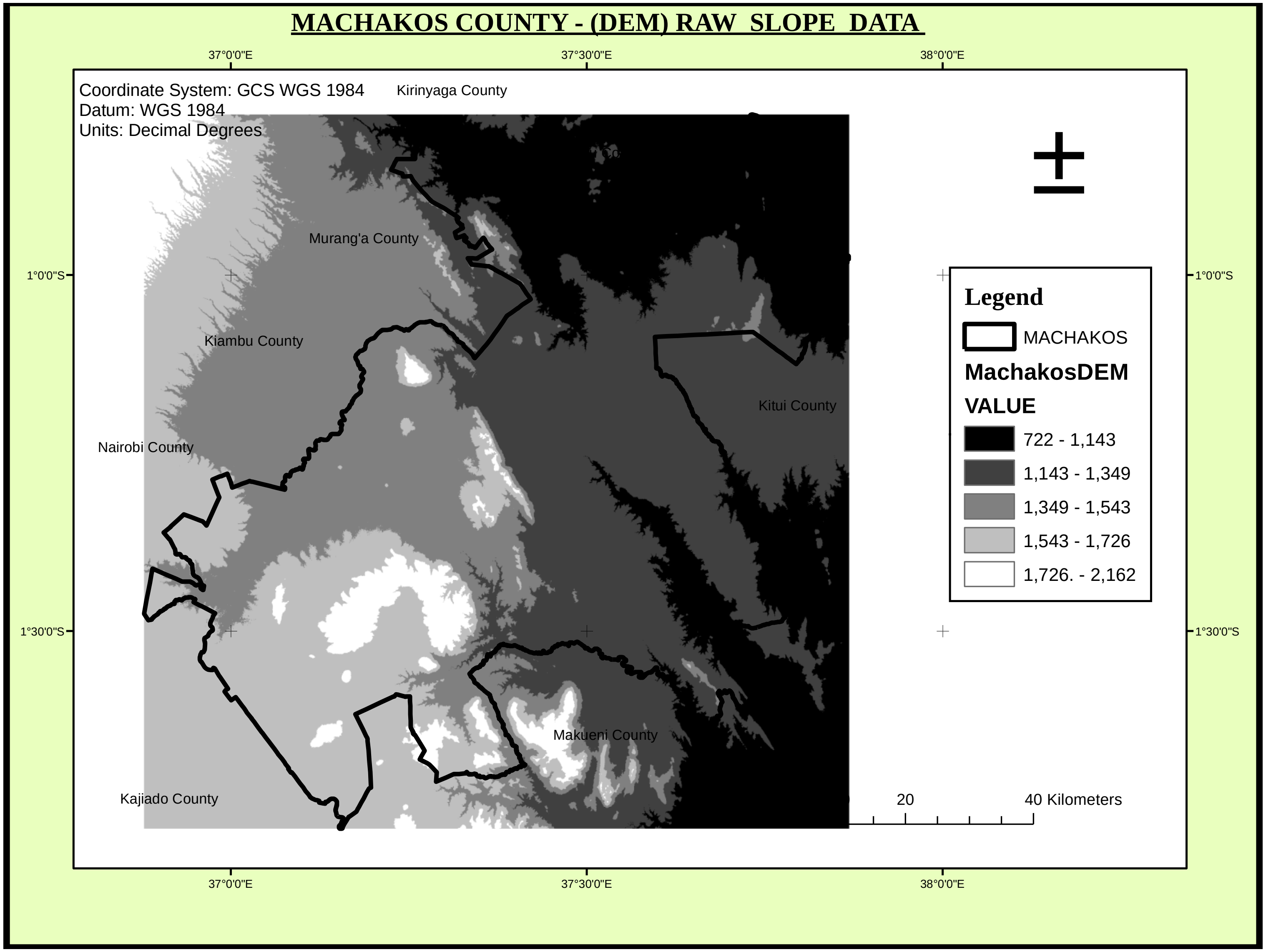

Figure 35: Raw Slope Data (DEM)

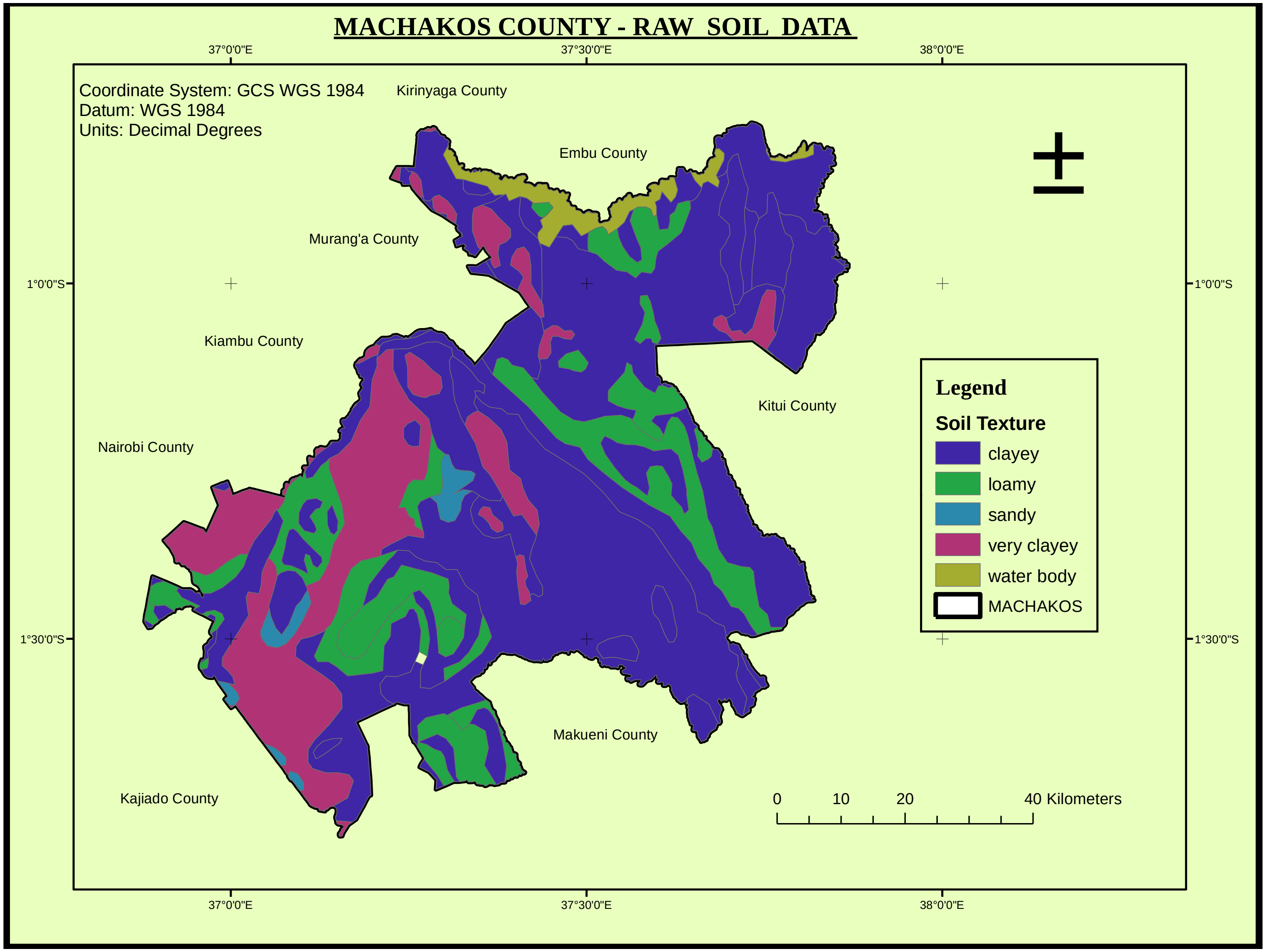

Figure 36: Raw Soils Data