Focussed Engineers (Feng) Uganda Ltd

Application of Remote Sensing and GIS in Ground Water Prospecting

Case Study: Busitema Sub County, Busia District

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ABSTRACT

Since last decade, the value per barrel of potable ground water has outpaced the value of a barrel of oil in many areas of the world. Hence proper assessment of groundwater potential and management practices are the needs of the day. Establishing relationship between Remotely Sensed data and hydrologic phenomenon can maximize the efficiency of water resources development projects.

Present study focuses on ground water potential assessment in Busitema Sub county of Busia District and its field verification. For the same, all the basic factors determining the existence and movement of ground were identified and their thematic layers were formulated, digitized and integrated in the GIS environment using Weighted Index Overlay Analysis (WIOA) method. The weights of different parameters/ themes were computed using Analytic Hierarchy process (AHP) Multi-Criteria Evaluation (MCE) technique. Through this integrated GIS analysis, ground water prospects map of the study area was prepared qualitatively.

Field verification at existing wells was used to verify identified potential zones and depth of water measured at observation wells. Ground water flow nets (Ground water table contours) were generated using the water levels of the existing wells.

Generated map from weighted overlay using AHP performed very well in predicting the groundwater potential zones since the existing wells were found in the most promising zones and hence this methodology proves to be a promising tool for future.

LIST OF ACRONYMS

AHP – Analytical hierarchy process

DEM – Digital Elevation Model

DGSM – Directorate of Geological Survey and Mines

DWD – Directorate of Water Development

DWRM – Directorate of Water Resources Management

ETM – Enhanced Thematic Mapper

GIS – Geographical Information System

MWE – Ministry Of Water and Environment

NARO – National Agricultural Research Organization

NASA – National Aeronautics and Space Administration

NFA – National Forestry Authority

NRSA – National Remote Sensing Agency

RS – Remote Sensing

UNMA – Uganda National Meteorological Authority

USGS – United States Geological Survey

UTM – Universal Transverse Mercator

WGS – World Geodetic System

WIOA – Weighted Index Overlay Analysis

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CHAPTER ONE

1. INTRODUCTION

1.1. Preamble

This chapter includes the following; back ground to the study, problem statement, purpose of the study, justification, objectives of the study, scope as well as a brief description of Busitema sub-county's topography, climate and the land use.

1.2. Back ground information

Water is the most essential natural resource on the planet earth. It is categorized into saline water which is ocean water and fresh water which is a finite resource essential for life, development and the environment. According to ***UN annual report, 2010,*** saline water (oceans) cover about 97% of earth's waters and fresh water is only a small proportion of the total water (3%) and mainly stored in the ice and glacier form. Fresh water resources are majorly ground water and surface water resources. According to ***UN annual report, 2010,*** Ice caps and glaciers contribute 68.7% of fresh water, ground water 30.1, surface water 0.3% and others 0.9%.

According to ***Banks, D., Robins, N., (2002),*** Groundwater is a form of water held under the ground in the saturated zone that fills all the pore space of soils and geologic formations. It is formed by rainwater or snowmelt water that seeps down through the soil and into the underlying rocks (aquifers). It is the major resource of water supply as provides more than half of humanity's freshwater for everyday uses such as drinking, cooking, and hygiene, as well as thirty percent of irrigated agriculture and industrial development **(Zuppi, G.M,2007).**

According to ***MWE; 2011***, the average sustainable available groundwater resources in the Uganda are 5,670 million cubic meters per year while the domestic water demand up to the year 2030 is estimated to be 326 million cubic meters per year which there is an indication that, there is enough sustainable ground water in the country. Groundwater will continue to be the main source of water supply in Uganda with domestic water supply expected to use less than 15% of the available groundwater resources up to the year 2030. ***(Tindimugaya et al, 2011).***

Due to increased pollution of surface water sources as a result of population growth, the uncertainties related to climate change and consequent economic and agricultural development, it has become more expensive to treat surface water to potable water standards and therefore, ground water sources are the only option especially for rural water supply systems in Uganda due to its high quality and low operation and maintenance costs although its initial investment costs are relatively high due to the long time taken in the field and high costs incurred in the survey to locate the sites for its exploration using the geophysical methods that require robust machinery for drilling. More so, ground water can be accessed even in areas where surface water sources such as rivers and lakes do not exist.

Currently, the conventional methods used in ground water exploration are the geophysical methods such as carrying out vertical electrical sounding (VES) by applying Schlumberger configuration on the locations using Terrameters, and then interpreting the data in form of VES curves, geo-electric sections and geophysical maps which is time consuming and expensive. Therefore, sustainable and cost effective methods such as interpolation of remote sensed data in the GIS environment are needed to identify ground water potential sites and exploit ground water resources especially in rural areas and in areas where the surface water resources are few or not available in order to significantly reduce the costs of groundwater development and increase sustainability of groundwater based water supply systems.

According to ***(ESRI, 2011),*** **GIS** is a computer system designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data. In a general sense, the term describes any information system that integrates, stores, edits, analyzes, shares, and displays geographic information and according to ***Schowengerdt and Robert A, (2007),*** **Remote sensing** is the acquisition of information about an object or phenomenon without making physical contact with the object and thus in contrast to in situ observation.

Jawad T. Al-Bakri1and Yahya Y. Al-Jahmany ***(2013)*** in their Journal of Water Resource and Protection, applied GIS and Remote Sensing to Groundwater Exploration in Al-Wala Basin in Jordan and the ground water prospecting areas were obtained by interpolating and analyzing remote sensed ground data (maps) using GIS tools.

Remote sensing and GIS provide important data and tools for groundwater exploration. Remotely sensed data of medium resolution are valuable sources for creating maps of geological structures. Maps of basic factors that determine the existence ground water in an area such as lithology, slope, land use, soil type, rainfall, lineament density and drainage patterns can also be extracted from remote sensing data of aerial photography and medium to high resolution satellite imagery, depending on the scale of the study and the available resources. Conversion of maps into digital layers will enable the analysis of these maps by GIS tools.

Implementation of spatial functions, query and intersection will produce maps of potential locations for groundwater exploration, based on different criteria that integrate maps of lineaments density, topography (slope), drainage density, land use, lithology, and soil and rain fall distribution. The approach for identifying potential sites for groundwater exploration is based on analyzing length density and frequency of lineaments and drainage lines, geological features (lithology), topography (slope), land use, soil type and rainfall distribution to reflect different probabilities of groundwater potential in various parts of the area under consideration.

This approach will be used in Busitema Sub County, Busia district to identify promising sites with high potential for groundwater exploration.

1.3. Problem statement

Despite the existence of surface water resources in Uganda, Ground water has been exploited for rural water supply sources especially in Busitema Sub County where the major source of water for domestic uses is got from boreholes. This is because of its better quality and less investment costs during exploitation and development as compared to surface water resources but investments are always made without knowing the extent of the aquifer. This is due to the conventional approach of groundwater exploration using geological, hydrogeological, and geophysical methods such as vertical electrical sounding (VES) which are expensive due to high cost of drilling and time consuming during investigation. Furthermore, these methods of surveys destabilize the geological structure of soils and rocks in areas where surveys are made and they do not always account for the different factors that control the occurrence and movement of groundwater.

1.4. Purpose of the study

The purpose of the study is to identify different factors that determine the existence of ground water in the study area, investigate their effect and integrate their GIS layers with remotely sensed data in ArcGIS software environment to delineate ground water potential sites for exploitation. The factors will be based on hydrological, geologic and hydrogeological data and surveys

1.5. Justification

If the study is successfully carried out and implemented, it is hoped that the findings will specifically help in the ground water assessment, investigation, management, exploration and siting. It will also help in policy and decision making regarding whether to invest in ground water as a source of water supply since its exploitation will be easy, cheap and time saving.

More so, the available data will be put to more use and this will lead to increased strictness in data collection as well as the efficiency and the effectiveness in water resources management and climate change intervention programmes since the responsible authorities will recognize the economic use of such data.

The final findings will also enable the responsible authorities to manage ground water effectively and efficiently as the cost and time of ground water management, assessment and exploration will be less.

1.6. Objectives

1.6.1. Main objective

To ascertain the availability of ground water in the study area using remote sensing and GIS

1.6.2. Specific objectives

- To ascertain the basic factors determining the existence and quantity of ground water in the study area.
- To formulate the GIS layers of the basic factors.
- To analyze and interpolate GIS layers of the study area.

1.7. Scope of the study

The study will focus on the identification of the basic factors that determine the existence and quantity of ground water, their effect on ground water, analysis of their effect. It will include the identification of GIS maps/layers of the identified factors and any other remote sensed data that will be deemed necessary for interpolation and analysis using ArcGIS software package to delineate ground water potential areas/sites in the study area.

1.8. Project Area

The study will cover Busitema Sub County in northern parts of Busia district found in eastern Uganda (Uganda – Kenya boarder) as shown in figure 1.1 below. The total area of the study area is **98.25 km².** The major source of water in the area is Ground water as there are many existing boreholes.

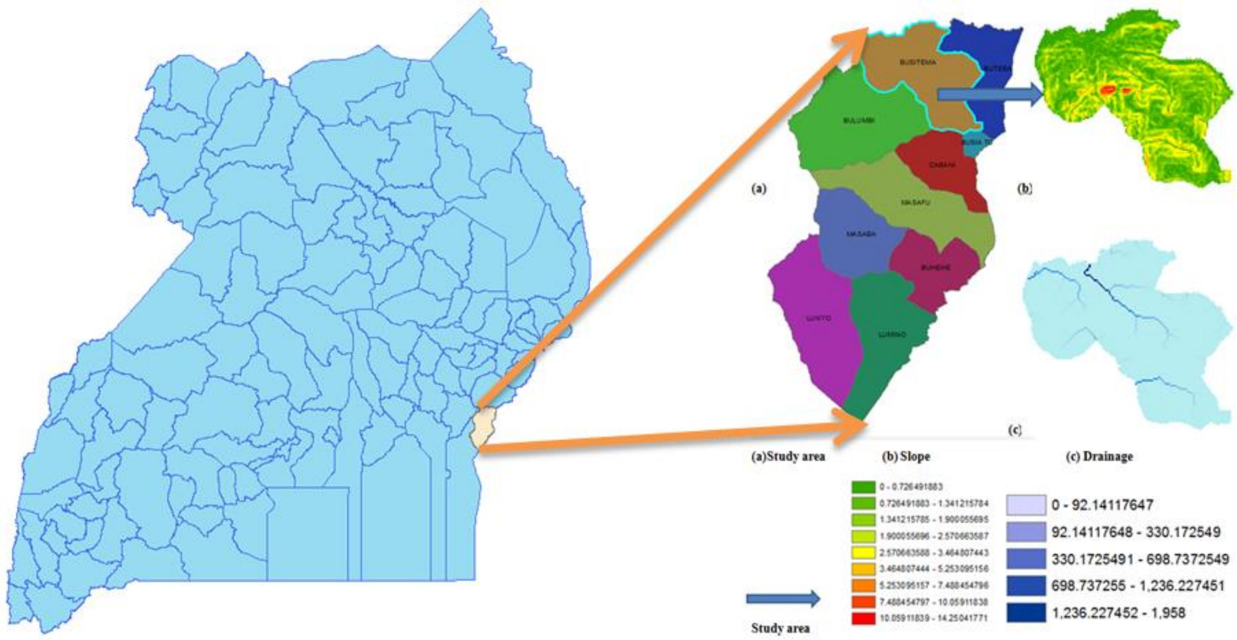

Figure 1.1: (a) The location of the study area (b) Its slope (c) Its drainage.

1.8.1. Topography

The area has a flat topography with relatively steep slopes in the middle parts nest to Busitema University. Altitude of study area varies from 138 m sea level at the foothill of Busitema hill to 212 m at the top of the hill above the sea level. (See topographic map).

1.8.2. Climate

Busitema Sub-County experiences tropical climate with both wet and dry seasons in a year. It has a total annual rainfall estimated to be 1,494 mm, two rainfall peaks (March – May and August – November) and the dry season runs from December to February although some seasonal variations have occurred in recent years in form of torrential rains and also long dry spells. The area has a mean annual minimum and maximum temperatures of 16.2^{0}C and 28.6^{0}C respectively, mean annual humidity of 68% and mean annual sunshine duration of 6.9 hours per day (Uganda National Metrological Authority (UNMA), Kampala).

1.9. Geology and Soils

The geologic formations underlying Busitema Sub County are of Neoarchaean era. Masaba Biotite Granitic rocks cover more than half of the sub county extending from the south (Dabani) to central regions roughly north of Tiira

On the other hand, mafic metavolcanic rocks cover the western part, and alluvium,sand , silt and graval in the extreme north.

Chert quartzite and, shale,black shale and mafic metavolcanic rock cover the central part.

The eastern part is covered by quartzite, metagrey wacke.

The area has only three types of soils; clay, clay loam and loam soils. Most parts of Busitema subcounty in the south, east such as Tiira, makina and ndaiga have predominantly poorly drained loamy soils with few areas covered by clay loam which is also poorly drained. The northern extreme of habuleke is covered by clay loam which extends to the central. The western part is covered by moderately drained clay soils.

The loamy soils do support various crops such as cotton, rice, maize and other cereals whereas the clay covered area is covered by a forest

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Preamble

This chapter discusses the opinions, findings from different authors, publications, magazines, websites, journals and all possible sources as a basis of foundation for this research study. It is divided into definition of terms, relationship between ground water, remote sensing (RS) and geographical information system (GIS), the basic factors that determines the existence and quantity of ground water in an area.

2.2. Definitions of terms

2.2.1. Ground water

Groundwater is a form of water held under the ground in the saturated zone that fills all the pore space of soils and geologic formations. It is formed by rainwater or snowmelt water that seeps down through the soil and into the underlying rocks ***(Banks, D. et al, 2002)***. It is the major resource of water supply for about half of the nations. It plays a key role in Nature by providing more than half of humanity's freshwater for everyday uses such as drinking, cooking, and hygiene, as well as thirty percent of irrigated agriculture and industrial developments. ***(Zuppi, G.M., 2007)***

Groundwater potential zones can be said to be water bearing formations of the earth's crust that act as conduits for transmission and as reservoirs for storing water. Its identification and location is based on indirect analysis of some observable terrain features such as geologic, geomorphic, landforms and their hydrologic characteristics.

Groundwater recharge refers to the entry of water from the unsaturated zone into the saturated zone below the water table surface, together with the associated flow away from the water table within the saturated zone ***(Hsin-Fu Yeh, 2008).*** Recharge occurs when water flows past the groundwater level and infiltrates into the saturated zone. It directly affects the existence of ground water in an area.

2.2.2. Remote sensing

Remote Sensing is the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in physical contact with the object, area or phenomenon under investigation. **Remote sensing** is the acquisition of information about an object or phenomenon without making physical contact with the object and thus in contrast to in situ observation. ***(Schowengerdt and Robert A, 2007)***

In modern usage, the term generally refers to the use of aerial sensor technologies to detect and classify objects on Earth (both on the surface, and in the atmosphere and oceans) by means of propagated signals such as electromagnetic radiations).

Human beings perceive the surrounding world using five senses. Some senses (touch and taste) require contact of our sensing organs with the objects. However, much information about our surrounding is acquired through the senses of sight and hearing which do not require close contact between the sensing organs and the external objects. In another word, human beings perform ***Remote Sensing*** all the time.

It may be split into active remote sensing; when a signal is first emitted from the aircraft/satellites ***(Schott and John Robert, 2007)*** or passive; when information is merely recorded. ***(Liu et al, 2009)***

A further step of image analysis and interpretation is required in order to extract useful information from the image. The output of a remote sensing system is usually an image representing the scene being observed.

2.2.3. Geographical information system

Geographic Information System (GIS) is a computer system capable of assembling, storing, manipulating, displaying geographically referenced information, such as data identified according to their locations ***(USGS, 1997).*** According to ***(ESRI, 2011),*** **GIS** is a computer system designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data. In a general sense, the term describes any information system that integrates, stores, edits, analyzes, shares, and displays geographic information.

GIS applications are tools that allow users to create interactive queries (user-created searches), analyze spatial information, edit data in maps, and present the results of all these operations.

(Maliene V et al, 2011). Geographic information science is the science underlying geographic concepts, applications, and systems ***(Goodchild and Michael F, 2010).***

GIS is a broad term that can refer to a number of different technologies, processes, and methods. It is attached to many operations and has many applications related to engineering, planning, management, transport/logistics, insurance, telecommunications, and business ***(Maliene V et al, 2011).*** GIS can relate unrelated information by using location as the key index variable. Locations or extents in the Earth space-time may be recorded as dates/times of occurrence, and x, y, and z coordinates representing, ***longitude***, ***latitude***, and ***elevation***, respectively. All Earth-based spatial–temporal location and extent references should, ideally, be relatable to one another and ultimately to a "real" physical location or extent. This key characteristic of GIS has begun to open new avenues of scientific inquiry.

2.2.4. History of development

The first known use of the term "*geographic information system*" was by Roger Tomlinson in the year 1968 in his paper "A Geographic Information System for Regional Planning". Tomlinson is also acknowledged as the "father of GIS" ***(ESRI, 2013)***

2.3. Relationship between ground water, remote sensing and GIS

On-site hydrogeology experiments and geophysics surveys help to explain the process of groundwater exploration and evaluate the spatial–temporal difference in the study region. However, these surveys often focus on a single affecting factor or an indirect site-specific experiment for groundwater recharge, reducing the reliability of the explanation.

The conventional approach of groundwater exploration using geological, hydrogeological, and geophysical methods such as vertical electrical sounding (VES) are expensive due to high cost of drilling and time consuming during investigation ***(Singh, A.K.et al, 2003 and Sander, P.et al, 1996)***. Furthermore, these methods of surveys do not always account for the different factors that control the occurrence and movement of groundwater ***(Oh, H.J. et al, 2001).***

Recently, remote sensing has been increasingly employed to replace on-site exploration or experiments. Remote sensing not only provides a wide range scale of the space–time distribution of observations, but also saves time and money ***(Murthy 2000; Leblanc et al. 2003; Tweed et al. 2007).***

Sener et al. (2005) pointed out that remote sensing can effectively identify the characteristics of the surface of the earth (such as lineaments and geology) and can also be used to examine groundwater recharge. ***Bierwirth and Welsh (2000)*** applied remote sensing to determine the preferential path of groundwater recharge in an area.

Remote sensing techniques play an important role in terrain evaluation surveys for natural/physical resources inventorying and mapping as remotely sensed data provides synoptic view, multispectral and unbiased information with receptivity for change detection studies. ***(Chaudhary B.S et al, 1996)***

Remotely sensed indicators of ground water may provide important data where practical alternatives are not available. The potential for remote sensing of ground water is explored here in the context of active and planned satellite-based sensors. Satellite technology is reviewed with respect to its ability to measure ground water potential, storage, and fluxes. It is argued here that satellite data can be used if ancillary analysis is used to infer ground water behavior from surface expressions. Remotely sensed data are most useful where they are combined with numerical modeling, geographic information systems, and ground-based information. ***(Matthew W. Becker, 2006).***

The National Remote Sensing Agency ***(NRSA 1987)*** in India was the first to integrate information from remote sensing and the technology of the geographical information system (GIS) for delineating the groundwater recharge potential zone.

GIS is used to manage, utilize, and classify the results of remote sensing, to explore sites, to combine the factors of groundwater recharge potential, and to provide appropriate weight relationships ***(Krishnamurthy et al, 1996; Saraf and Choudhury, 1998; Sener et al, 2005).***

M.P. Sharma et al, (2012) pointed out that Remote Sensing and Geographic Information System (GIS) is a rapid and cost effective techniques, it provides information of large and inaccessible area within short span for assessing, monitoring and management of groundwater resources. The interpretation of the remote sensing data with conventional data and sufficient ground truth information makes possible to identify and delineate the various ground features such as geological structures, geomorphological features and their characters that may cater direct or indirect presence of ground and surface water.

Salama et al, (1994) used aerial photos and information from a satellite to derive the lithology, topography, and geological characteristics of the Salt River in Western Australia. These properties can be used to determine the mechanism of groundwater flow and the groundwater recharge zone. Their analytical results demonstrate that the sandy plain is the major recharge zone.

Chaudhary B.S et al, 1996 applied remote sensing and GIS in ground water investigation in Sohna Block, Gurgaon District, Haryana (India) by visual interpretation of satellite data using various thematic maps, stereoscopic interpretation of panchromatic aerial photographs and information extracted digital image processing of satellite data. These maps were digitized and integrated in GIS environment to prepare a final map showing ground water prospective areas.

Sharma M.P.et al, (2012) attempted to delineate the groundwater potential zones in and around Gola block of Ramgargh district, Jharkhand, India, using integrated approach of Remote Sensing and GIS techniques. The groundwater prospect map was prepared considering major controlling factors, such as geology, geomorphology, drainage pattern, drainage density, lineaments, and slopes which influence the occurrence, movement, yield and quality of groundwater. The map presented hydro geomorphological aspect, which are essential for planning, development, management and extraction of groundwater. The present information depicted is very useful for planner and local authority in respect of site selection of well types, depth of well, water quality, success rate of wells and as well as groundwater development and management.

Edet et al. (1998) classified groundwater recharge potential zones in southeast Nigeria as high, medium, or low. They found that linear features, drainage, lithology, temperature of groundwater, vertical hydraulic conductivity, yield, and transmissivity closely control the recharge potential zones.

Singh and Prakash (2002) plotted a groundwater recharge potential map of a sub-watershed from the geology, lineament maps, drainage, slope, and the thickness of the soil covered. Their results show that the well-yield data in India is closely related to the groundwater recharge potential zone.

Shaban et al. (2006) explored the recharge potential map of the Occidental Lebanon, and found that the regions of hard, fractured, and karstified limestone were excellent potential areas for groundwater recharge, while the least effective recharge potential was in high-populated areas and in relatively flat areas covered by soft materials. The diffusion of pollutants in groundwater is fastest in the most efficient recharge zones.

Tweed et al. (2007) verified that the integration of remote sensing and GIS reduces the uncertainty of hydro-geological data in terms of both macroscopic (climate, change of land utilization) and microscopic (preferential flow) factors. Their data can be used to analyze groundwater numerical models or water balance.

Jaiswal et al. (2003) concluded that there is a need to adjust the information of satellites and GIS to agree with the on-site geology, particularly in typical hard rock terrain, where groundwater occurrence is complex and restricted.

2.4. Factors that affect the existence of ground water in an area

Many factors affect the occurrence and movement of groundwater in a region including topography, lithology, geological structures, and depth of weathering, extent of fractures, primary porosity, secondary porosity, slope, drainage patterns, landform, land use / land cover, and climate ***(Mukherjee 1996; Jaiswal et al. 2003)***

The factors influencing groundwater recharge as well as existence, and their relative importance, are compiled from previous literature. Duplicate factors were combined and only representative factors were extracted. This study uses **lithology, land use/cover, lineaments, drainage, soil, rainfall and slope as the seven significant factors affecting groundwater recharge potential**. The factors influencing groundwater potential include;

Table 2.1: The multi-influencing factors of ground water existence and movement

Factor	**Basis of categorization**
Lithology	Rock type, weathering character, joints, fractures

Land cover/land use	Type, areal extent, associated vegetation cover
Lineaments	Lineament – density value
Drainage	Drainage – density value
Slope	Slope gradient
Soil	Porosity, type and mineral composition
Rainfall	Depth

2.4.1. Lithology

Shaban et al. (2006) pointed out that the type of rock exposed to the surface significantly affects groundwater recharge. Lithology affects the groundwater recharge by controlling the percolation of water flow ***(El-Baz and Himida 1995).*** Although some investigations have ignored this factor by regarding the lineaments and drainage characters as a function of primary and secondary porosity, this study will include lithology to reduce uncertainty in determining lineaments and drainage.

2.4.2. Land use/cover

Land use/cover is an important factor in groundwater recharge and thus existence. It includes the type of soil deposits, the distribution of residential areas, and vegetation cover. ***Shaban et al. (2006)*** concluded that vegetation cover benefits groundwater recharge in the following ways.

- ✓ Biological decomposition of the roots helps loosen the rock and soil, so that water can percolate to the surface of the earth easily.
- ✓ Vegetation prevents direct evaporation of water from soil.
- ✓ The roots of a plant can absorb water, thus preventing water loss.

Leduc et al. (2001) estimated the difference in the amount of groundwater recharge due to changes of land utilization and vegetation from changes in the groundwater level. Land use/cover will be included in this study as an important factor affecting the groundwater recharge process.

2.4.3. Lineaments

The analysis of lineaments has been applied extensively to explain geological status since geological images were first utilized in the 1930s. Lineaments are generally referred to in the analysis of remote sensing of fractures or structures. Lineament photos from satellites and aerial photos have similar characteristics but the results of the explanation in on-site may be different. Lineaments are currently not fully defined.

O'Leary et al. (1976) has defined lineaments as the simple and complex linear properties of geological structures such as faults, cleavages, fractures, and various surfaces of discontinuity, that are arranged in a straight line or a slight curve, as detected by remote sensing. Many non-geological structures, such as roads and channels, cause errors in the analysis of lineaments. Therefore, geologic maps and on-site investigations must be used to eliminate possible errors.

Lineaments may be used to infer groundwater movement, existence and storage.

Lattman and Parizek (1964) were the first to adopt a lineaments map to exploit groundwater. Thereafter, many scholars have applied this approach in complicated geological regions ***(Solomon and Quiel, 2006).***

This study will use lineament – length density (L_d, L^{-1}) ***(Greenbaum 1985),*** which represents the total length of lineaments in a unit area, as:

$$L_d = \frac{\sum_{i=1}^{i=n} L_i}{A} \quad \text{..} 2.1$$

Where $\sum_{i=1}^{i=n} L_i$ denotes the total length of lineaments (L), n dentes the number of lineaments and A denotes the unit area (L^2). A high lineament – length density infers high secondary porosity, thus indicating a zone with high ground water recharge potential as well as existence.

2.4.4. Drainage

The structural analysis of a drainage network helps assess the characteristics of the groundwater recharge zone. The quality of a drainage network depends on lithology, which provides an important index of the percolation rate. This study will use drainage – length density (D_d, L^{-1}), as defined by ***Greenbaum (1985)***, indicates the total drainage – length in a unit area, and is determined by:

$$D_d = \frac{\sum_{i=1}^{i=n} S_i}{A} \text{...} 2.2$$

Where $\sum_{i=1}^{i=n} S_i$ denotes the total length of drainage (L) and A denotes the unit area (L^2). The drainage – length density is significantly correlated with the groundwater recharge; a zone with a high drainage – length density has a high level of groundwater recharge. Many studies have integrated lineaments and drainage maps to infer the groundwater recharge potential zone ***(Edet et al. 1998; Shaban et al, 2006).***

2.4.5. Rain fall

Rainfall is the main source of groundwater recharge in tropic and sub-tropic regions. Long duration and low intensity rain fall allows more water to infiltrate into the soil and percolate to the deeper layers of the aquifer because less run off is generated as compared to short duration and high intensity rainfall that allow enough time for runoff collection and flow most especially if the slope is steep.

2.4.5.1 Determination of rainfall intensity

The intensity of rainfall is important for the analysis of the infiltration rate. It is determined by developing the IDF Curve. From this curve and using a given Return Period and Time of Concentration for the catchment, the intensity of design can be determined. Depth of the daily rainfall data is extracted and normally effective rainfall duration of 1.5 hours is assumed. The maximum rainfall depth in every month is considered from which the maximum in every year is selected. Maximum daily rainfall data for the selected years are ranked in descending order and the Return Period obtained from the formula:

$$T = \frac{n+1}{r} \quad \text{..} 2.3$$

Where n is the number of years of rainfall record, r the rank and T the return period.

A graph of rainfall against Return period is plotted.

From the graph, maximum rainfall depths at desired return periods are obtained. The maximum 24-hr intensity and coefficient a^T are then computed for each selected return period using the formulae below (Chin, 2006);

$${i_{24}}^T = \frac{{R_{24}}^T}{24} \text{..} 2.4$$

$$a^T = i_{24}{}^T x\ (b+24)^n \text{ ……………………………………………2.5}$$

$$n = \frac{In\left(\frac{14.4}{t_{eff}}\right)}{In\left(\frac{b+24}{b+t_{eff}}\right)} \text{ ……………………………………………………2.6}$$

Where;

$i_{24}{}^T$ = Maximum 24-hour intensity

$R_{24}{}^T$ = Maximum 24-hour rainfall

b = constant and is $^1/_3$

t_{eff} = Effective duration of rainfall =1.5

The values of i and R are obtained and the IDF Curve is then developed using the formula below to obtain the intensity in mm/hr.

$$i = \frac{a}{(T_c+b)^n} \text{ ……………………………………………..………2.7}$$

Where T_c = time of concentration in minutes.

$$\boldsymbol{T_c = 0.0195L^{0.77}S^{-0.385}} \text{ ……………………………………………....2.8}$$

Where L is maximum length of flow (m), S is the difference in elevation between the outlet and the most remote point of the catchment divided by the length L.

Using the obtained time of concentration and a given return period, the intensity for analysis is obtained from the IDF curve.

2.4.6. Soil

Different soil types have different properties that affect ground water recharge such as porosity which is a measure by the ration of the contained voids in a solid mass to its total volume. It is given by;

$$\theta = \frac{V_V}{V} \text{ ………………………………………………………………}2.9$$

Where θ is the porosity, V_V is the volume of voids and V is the total volume.

The spaces where groundwater occupies are known as voids, interstices, pores or pore spaces. They are fundamentally important to the study of groundwater because they serve as water conduits. It is dependent on geology of the parent rock; shape; size, packing and degree of cementation. Uniformly graded sand has a higher porosity than a less uniform, fine and coarse mixture, because in the latter, the fines occupy the voids in the coarse material. In square packing for example, the porosity is as high as 48% while in rhombic packing, it is as low as 26%. Angularity tends to increase porosity while cementation decreases porosity. Thus, the higher the porosity of the soil, the higher the ground water recharge potential and vice versa.

Table 2.2: Different soil types and their respective porosity.

Soil type	**Porosity, n**
Peat soil	60 – 80%
Clay	45- 60%
Silt	40-50%
Sand	30-40%
Gravel	25-35%
Sand stone	10-20%
Shale	0-10%
Lime Stone	0-10%
Lime stone dissolved	10-50%
Hard rock	0-5%

Source: Ontario

2.4.7. Slope

The slope gradient directly influences the infiltration of rainfall. Larger slopes produce a smaller recharge because water runs rapidly off the surface of a steep slope during rainfall, not having sufficient time to infiltrate the surface and recharge the saturated zone.

Table 2.3: Soil infiltration rates

Soil texture type	0 – 4.9%	5 – 7.9%	8 – 11.9%	12 – 15.9%	16 and above
Coarse sand	1.25	1	0.75	0.5	0.31
Medium sand	1.06	0.85	0.64	0.42	0.27
Fine sand	0.94	0.75	0.56	0.38	0.24
Loamy sand	0.88	0.70	0.53	0.35	0.22
Sandy loam	0.75	0.6	0.45	0.30	0.19
Fine sandy loam	0.63	0.50	0.38	0.25	0.16
Very fine sandy loam	0.59	0.47	0.35	0.24	0.15
Loam	0.54	0.43	0.33	0.22	0.14
Silt loam	0.50	0.40	0.30	0.20	0.13
Silt	0.44	0.35	0.26	0.18	0.11
Sandy clay	0.31	0.25	0.19	0.12	0.08
Clay loam	0.25	0.20	0.15	0.10	0.06
Silty clay	0.19	0.15	0.11	0.08	0.05
Clay	0.13	0.10	0.08	0.05	0.03

Source: USDA, (Agriculture and water use)

According to **Magesh, N.S.,(**2012), Seven influencing factors, such as lithology, slope, land-use, lineament, drainage, soil, and rainfall were identified to delineate the groundwater potential zones in Theni district, Tamil Nadu, India using remote sensing and GIS techniques. Interrelationship between these factors and their effect is shown in the flow chart in **figure 2.1.** Each relationship was weighted according to its strength. The representative weight of a factor of the potential zone was the sum of all weights from each factor. A factor with a higher weight value shows a larger impact and a factor with a lower weight value shows a smaller impact on groundwater potential zones. Integration of these factors with their potential weights is computed through weighted overlay analysis in ArcGIS.

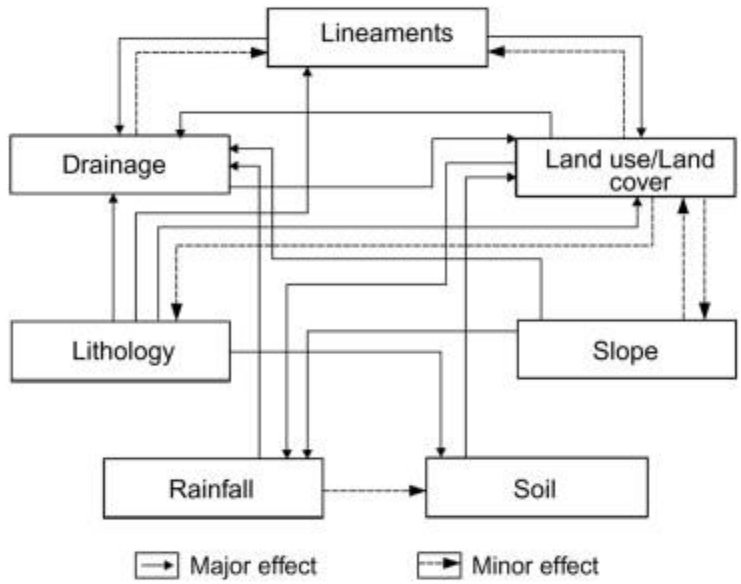

Figure 2.1: Interrelationship between the multi influencing factors concerning the groundwater potential zone.

According to Shaban et al., (2006), groundwater potential zones are obtained by overlaying all the thematic maps in terms of weighted overlay methods using the spatial analysis tool in ArcGIS environment. During weighted overlay analysis, the ranking are given to each individual parameter of each thematic map, and weights are assigned according to the multi influencing factor (MIF) of that particular feature on the hydro-geological environment of the study area.

2.5. Digital terrain models/Digital Elevation models (DEM)

Digital Elevation Model (DEM) is the digital representation of the land surface elevation with respect to any reference datum. DEMs are used to determine terrain attributes such as elevation at any point, slope and aspect. Terrain features like drainage basins and channel networks can also be identified from the DEMs. DEMs are widely used in hydrologic and geologic analyses, hazard monitoring, natural resources exploration, agricultural management.

Hydrologic applications of the DEM include ***groundwater modeling***, estimation of the volume of proposed reservoirs, determining landslide probability and flood prone area mapping.

DEM is generated from the elevation information from several points, which may be regular or irregular over the space. In the initial days, DEMs were used to be developed from the contours mapped in the topographic maps or stereoscopic areal images. With the advancement of technology, today high resolution DEMs for a large part of the globe is available from the radars onboard the space shuttle. .

2.5.1. Definition of a DEM

A DEM is defined as "any digital representation of the continuous variation of relief over space," ***(Burrough, 1986),*** where relief refers to the height of earth‘s surface with respect to the datum considered. It can also be considered as regularly spaced grids of the elevation information, used for the continuous spatial representation of any terrain.

Digital Terrain Model (DTM) and Digital Surface Model (DSM) are often used as synonyms of the DEM. Technically a DEM contains only the elevation information of the surface, free of vegetation, buildings and other non-ground objects with reference to a datum such as Mean Sea Level (MSL). The DSM differs from a DEM as it includes the tops of buildings, power lines, trees and all objects as seen in a synoptic view. On the other hand, in a DTM, in addition to the elevation information, several other information is included such as slope, aspect, curvature and skeleton. It thus gives a continuous representation of the smoothed surface.

2.5.2. Types of DEMs

DEMs are generated by using the elevation information from several points spaced at regular or irregular intervals. The elevation information may be obtained from different sources like field survey, topographic contours etc. DEMs use different structures to acquire or store the elevation information from various sources. Three main type of structures used are the following.

- ✓ Regular square grids
- ✓ Triangulated irregular networks (TIN)
- ✓ Contours

2.5.3. Sources of digital elevation data

Elevation information for a DEM may be acquired through filed surveys, from topographic contours, aerial photographs or satellite imageries using the photogrammetric techniques. Recently radar interferometric techniques and Laser altimetry have also been used to generate a DEM. Field surveys give the point elevation information at various locations. The points can be selected based on the topographic variations. Contours are the lines joining points of equal elevation. Therefore, contours give elevation at infinite numbers of points, however only along the lines.

A digital elevation model can be generated from the points or contours using various interpolation techniques like linear interpolation, kriging, TIN etc. Accuracy of the resulting DEM depends on the density of data points available depicting the contour interval, and precision of the input data.

On the other hand, photogrammetric techniques provides continuous elevation data using pairs of stereo photographs or imageries taken by instruments onboard an aircraft or space shuttle. Radar interferometry uses a pair of radar images for the same location, from two different points. The difference observed between the two images is used to interpret the height of the location. Lidar altimetry also uses a similar principle to generate the elevation information.

Today very fine resolution DEMs at near global scale are readily available from various sources. The following are some of the sources of global elevation data set.

- ✓ GTOPO30
- ✓ NOAA GLOBE project
- ✓ SRTM
- ✓ ASTER Global Elevation Model
- ✓ Lidar DEM

2.5.4. Estimation of attributes from raster DEM

Terrain attributes derived from the DEM are broadly classified as primary attributes and secondary attributes. Primary attributes are those derived directly from the DEM, whereas secondary attributes are derived using one or more of the primary attributes. Some of the primary attributes, which are important in the hydrologic analysis, derived from the DEM include slope, aspect, flow-path length, and upslope contributing area. Topographic wetness index is an example of the secondary attribute derived from the DEM. Topographic wetness index represents the extent of the zone of saturation as a function of the upslope contributing area, soil transmissivity and slope.

Gridded DEM represents the surface as a matrix of regularly spaced grids carrying the elevation information. Most of the terrain analysis algorithms using the gridded DEM assume uniform spacing of grids throughout the DEM. Topographic attributes are derived based on the changes in the surface elevation with respect to the distance.

2.5.5. Calculation of slope from the DEM

Slope is defined as the rate of change of elevation, expressed as gradient (in percentage) or in degrees.

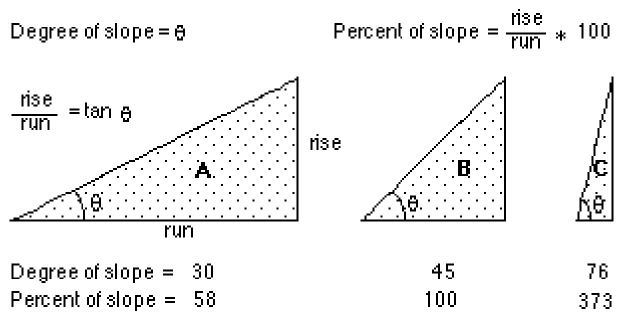

Figure 2.2: Calculating slope from DEM

Using the finite difference approach, slope in any direction is expressed as the first derivative of the elevation in that direction.

$$\text{Slope in the x direction } S_x = \frac{\partial h_x}{\partial x}$$

$$\text{Slope in the y direction } S_y = \frac{\partial h_y}{\partial y} \qquad \ldots\ldots 2.10$$

In general, slope of any point is given as follows;

$$S = \sqrt{\left(\frac{\partial h_x}{\partial x}\right)^2 + \left(\frac{\partial h_y}{\partial y}\right)^2} \qquad \ldots\ldots 2.11$$

2.5.6. Determination of flow direction

In watershed analysis using raster based DEM, water from each cell is assumed to flow or drain into one of its eight neighboring cells which are towards left, right, up, down, and the four diagonal directions. The flow vector algorithm scans each cell of the DEM, and determines the direction of the steepest downward slope to an adjacent cell.

The most common method used for identifying the flow direction is the D8 (deterministic eight-neighbors) method. The method was first proposed by O'Callaghan and Mark (1984). In this method, a flow vector indicating the steepest slope is assigned to one of the eight neighboring cells.

2.5.7. Drainage Pattern Extraction from DEM

Gridded DEM has been widely used in the hydrologic modeling to extract drainage patterns of a basin required for flow routing in the hydrologic models. The gridded DEM provides elevation information at regularly spaced grids over the area. The algorithm used must be capable of identifying the slope variation and possible direction of flow of water using the DEM.

While using the gridded DEM, inadequate elevation difference between the grids often creates difficulty in tracing the drainage pattern. Also, gridded DEM may contain depressions, which are grids surrounded by higher elevations in all directions. Such depressions may be natural or sometimes interpolation errors. These depressions also create problems in tracing the continuous flow path.

Prior to the application of the DEM in the hydrologic studies, preprocessing of the DEM is therefore carried out to correct for the depressions and flat areas.

2.6. Groundwater Flow Nets

Water table contour lines are similar to topographic lines on a map. They essentially represent "elevations" in the subsurface. These elevations are the hydraulic head mentioned above.

Water table contour lines can be used to determine the direction groundwater will flow in a given region. Many wells are drilled and hydraulic head is measured in each one. Water table contours (called equipotential lines) are constructed to join areas of equal head. Groundwater flow lines, which represent the paths of groundwater downslope, are drawn perpendicular to the contour lines.

A map of groundwater contour lines with groundwater flow lines is called a ***flow net***.

Ground water always moves from an area of higher hydraulic head to an area of lower hydraulic head, and perpendicular to equipotential lines. Groundwater Flow Nets (Water table contours) in drainage basins roughly follow the surface topography, but depend greatly on the properties of rock and soil that compose the aquifer:

- ✓ Variations in mineralogy and texture
- ✓ Fractures and cavities
- ✓ Impervious layers
- ✓ Climate

2.7. Suitability analysis

The concept of ***Suitability analysis*** describes the search for locations or areas that are characterized by a combination of certain properties. Often, the result of a suitability analysis is a suitability map. It shows which locations or areas are suitable for a specific use in form of a thematic map such as a ground water suitability map.

Suitability analysis is often used to support decision making in planning processes, such as environmental planning. Frequently, the goal is to find the most suitable spot for a certain object. In the simplest case of decision support with GIS, locations or areas can be found that meet or optimize multiple criteria for one objective. If there are more than one criterion but only one objective, as in this case, it is called a multi-criteria evaluation (MCE).

2.7.1. Standard procedure for MCE

i. Define the problem: the first step of an MCE is the definition of the problem.

ii. Select the criteria: the next step is to select the criteria. The chosen criteria should reflect the characteristics of the desired location or area as closely as possible. Criteria can be both spatial (geometry, topology) as well as factual (attributes).

iii. Operationalization of the criteria: when the criteria are determined, they must be translated to precise, measurable indicators.

iv. Creation of a common reference – data integration: Data integration creates comparability through a common measurement scale, the same data type (raster / vector), and the same resolution and reference system.

v. Intersection: identification of the most suitable areas. Now the different criteria are allocated to find the desired location. There are several possible approaches;

   - ✓ ***Logical (Boolean) overlay Logical (Boolean) overlay***: in each layer there is only binary true/false information such as forest / non forest. By logically intersecting this information, the desired locations and areas wanted are determined
   - ✓ ***Weighted overlay:*** rarely is the simple distinction between true and false possible in the complexity of reality. A significant improvement of the results can be achieved by providing the individual data layers with weights.
   - ✓ ***Fuzzy overlay***: erroneous input data and the wrong choice of criteria can lead to evaluation errors. In a multi-criteria evaluation, appropriate areas could be ignored and unsuitable areas could be falsely classified as suitable. A solution to this problem is the cancelation of sharp boundaries. For the spatial data, this means that boundaries are not

represented as sharp lines but as transition zones. With attributes, fuzzy ranges of values replace sharp class limits.

vi. Verification / evaluation: the final step involves comparing the results with a reference. This is possible if reference data, collected in the field, are available ("ground truthing"). This last step is often neglected.

2.7.2. Weighted overlay

This is the principle of assigning weights to influencing factors used for suitability analysis in GIS. In this approach, a numerical weighting factor is assigned to each thematic layer according to its relative importance compared to all other layers. After that, the weighted layers are overlaid on to one thematic layer. This approach of weighted overlay is possible with raster and vector data sets.

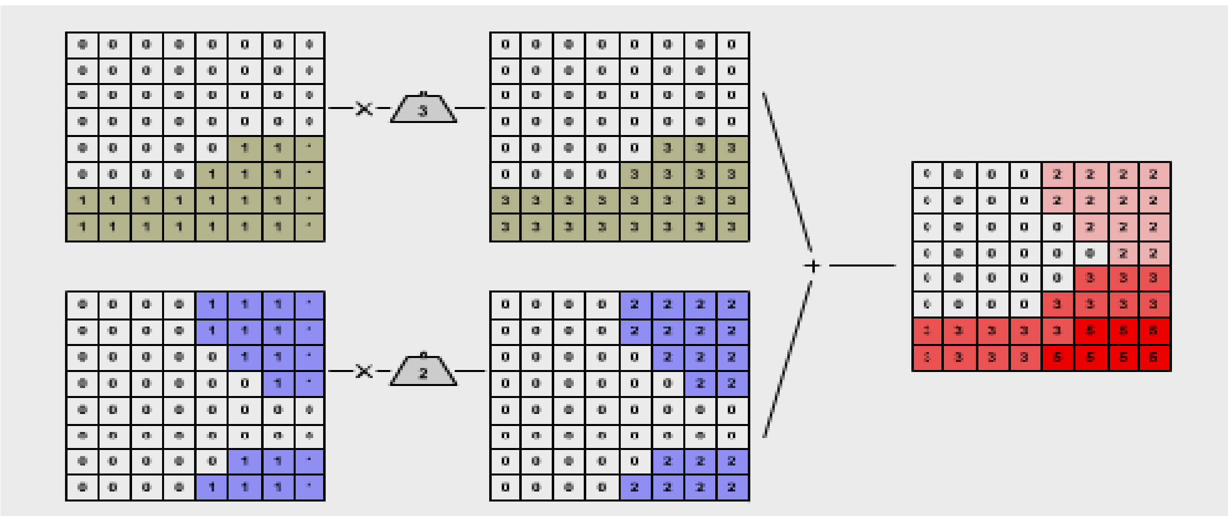

Figure 2.3: The principal of Weighted overlay of raster datasets

2.7.3. Determining weights

The determination of weights in a suitability analysis with weighted overlay is important as it reduces bias. There are three approaches to determine weights for WIOA.

- ✓ ***Weighting by ranking:*** The easiest way is weighting the criteria by ranks in either ascending or descending order. Ascending means that the most important criterion is given rank 1, the second criterion rank 2…..
- ✓ ***Weighting by rating***: Another common method is rating. Here, the ranked criteria receive a score according to their relative importance.
- ✓ ***Weighting by pairwise comparison:*** Another method for weighting several criteria is the pairwise comparison. It stems from the Analytic Hierarchy Process (AHP), a famous

decision-making framework developed by the American Professor of mathematics (Saaty,1980).

The following three steps lead to the result:

1) Completion of the pairwise comparison matrix; Two criteria are evaluated at a time in terms of their relative importance. Index values from 1 to 9 are used. If criterion A is exactly as important as criterion B, this pair receives an index of 1. If A is much more important than B, the index is 9. All gradations are possible in between. For a "less important" relationship, the fractions 1/1 to 1/9 are available: if A is much less important than B, the rating is 1/9. The values are entered row by row into a cross-matrix. The diagonal of the matrix contains only values of 1. First, the right upper half of the matrix is filled until each criterion has been compared to every other one. If A to B was rated with the relative importance of n, B to A has to be rated with 1/n. If the vegetation cover is a little more important than slope (index 3), the slope is a little less important than vegetation cover (index 1/3). For reasons of consistency, the lower left half of the matrix can thus be filled with the corresponding fractions.
2) Calculating the criteria weights; The weights of the individual criteria are calculated. First, a normalized comparison matrix is created: each value in the matrix is divided by the sum of its column. To get the weights of the individual criteria, the mean of each row of this second matrix is determined. These weights are already normalized; their sum is 1.
3) Assessment of the consistency matrix; A statistically reliable estimate of the consistency of the resulting weights is made.

Table 2.4: Weighting system for AHP

Definition	Index	Definition	Index
Equally important	1	Equally important	1/1
Equally or slightly more Important	2	Equally or slightly less important	½

Slightly more important	3	Slightly less important	1/3
Slightly to much more important	4	Slightly to way less important	¼
Much more important	5	Way less important	1/5
Much to far more important	6	Way to far less important	1/6
Far more important	7	Far less important	1/7
Far more important to extremely more important	8	Far less important to extremely less important	1/8
Extremely more important	9	Extremely less important	1/9

2.7.4. Implementation of the AHP

The AHP can be implemented in three simple consecutive steps;

- ✓ Computing the vector of criteria weights.
- ✓ Computing the matrix of option scores.
- ✓ Ranking the options.

2.7.4.1 Computing the vector of criteria weights

In order to compute the weights for the different criteria, the AHP starts creating a *pairwise comparison matrix* **A**. The matrix **A** is a $m \times m$ real matrix, where m is the number of evaluation criteria considered. Each entry a_{jk} *of* the matrix **A** represents the importance of the j_{th} criterion relative to the k_{th} criterion. If $a_{jk} > 1$, then the j_{th} criterion is more important than the k_{th} criterion, while if $a_{jk} < 1$, then the j_{th} criterion is less important than the k_{th} criterion. If two criteria have the same importance, then the entry a_{jk} is 1. The entries a_{jk} and a_{kj} satisfy the following constraint.

$$a_{jk} \, x \, a_{kj} = 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.12$$

Obviously, $a_{jj} = 1$ for all j. The relative importance between two criteria is measured according to a numerical scale from 1 to 9, as shown in Table 1, where it is assumed that the j_{th} criterion is equally or more important than the k_{th} criterion. The phrases in the “Interpretation” column of Table 1 are only suggestive, and may be used to translate the decision maker’s qualitative evaluations of the relative importance between two criteria into numbers. It is also possible to assign intermediate values which do not correspond to a precise interpretation. The values in the matrix **A** are by construction pairwise consistent. On the other hand, the ratings may in general show slight inconsistencies. However these do not cause serious difficulties for the AHP.

Table 2.5: Relative scores in AHP

Value of a_{jk}	***Interpretation***
1	*j* and *k* are equally important
3	*j* is slightly more important than *k*
5	*j* is more important than *k*
7	*j* is strongly more important than *k*
9	*j* is absolutely more important than *k*

Once the matrix **A** is built, it is possible to derive from **A** the *normalized pairwise comparison matrix,* $\mathbf{A}_{normal}$ by making equal to 1 the sum of the entries on each column. each entry $\bar{a}_{jk}$ of the matrix $\mathbf{A}_{normal}$ is computed as;

$$\bar{a}_{jk} = \frac{a_{jk}}{\sum_{i=1}^{m} a_{ik}} \text{ ....2.13}$$

Finally, the *criteria weight vector* ***w*** (that is an *m*-dimensional column vector) is built by averaging the entries on each row of $\mathbf{A}_{normal}$, as computed.

$$w_j = \frac{\sum_{i=1}^{m} \bar{a}_{ji}}{m} \text{ ....2.14}$$

For a matrix **A**, a_{ij} denotes the entry in the i_{th} row and the j_{th} column of **A**. For a vector **v**, v_i denotes the i_{th} element of **v**.

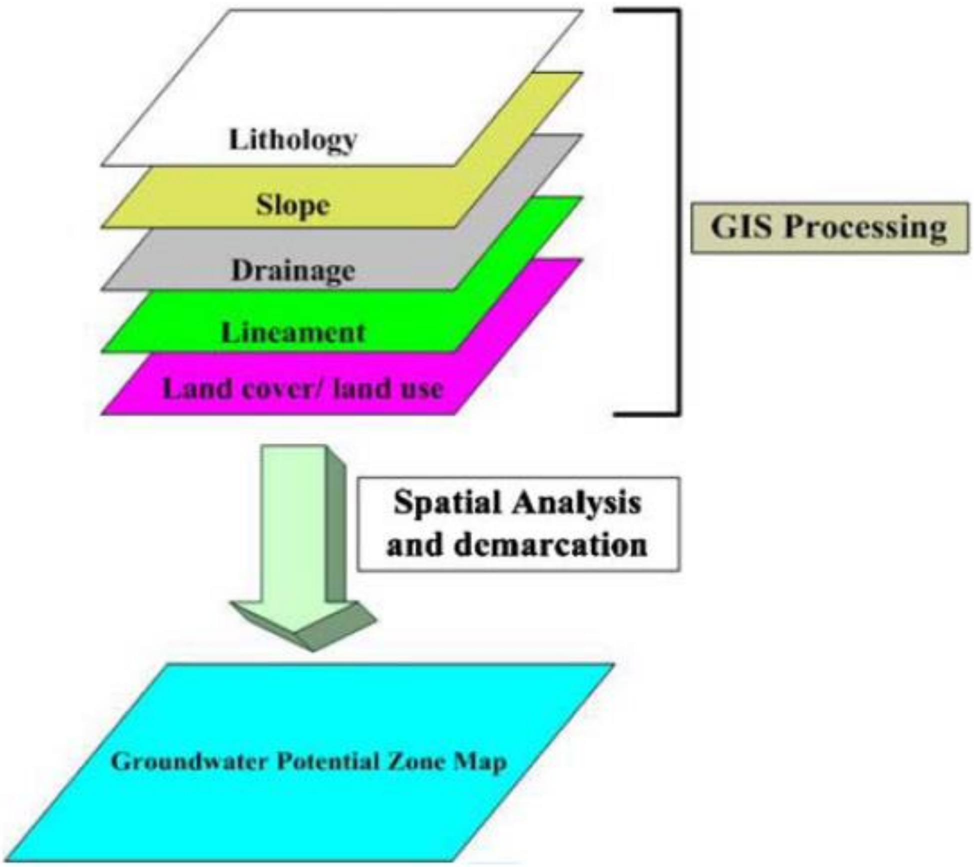

Figure 2.4: GIS technology used in spatial integration and analysis to demarcate basin groundwater recharge potential zone

CHAPTER THREE

3. METHODOLOGY

This chapter consists of the materials and equipment which were used in the study, methods which were used in obtaining the relevant data, different computer softwares that were used in data analysis and the activities carried out to in order to achieve the application of Remote Sensing and GIS in Ground Water prospecting in Busitema Sub county – Busia district.

3.1. Materials and Equipment

The materials that were used in this study include; Digital data such as Uganda Maps, aerial photographs of the study area which were downloaded from http://earthexplorer.usgs.gov, hydrological data from Uganda National Meteorological Authority (UNMA), geological data from the Directorate of Geological Survey and Mines (DGSM), Busitema Sub county boreholes data from Directorate of Water Resources Management (DWRM), satellite image of **Landsat 7 ETM+** covering study area which was downloaded from the **USGS website** and information extracted from field observations such as Land use and location of existing boreholes in the study area as well as the GPS coordinates of the boreholes in Busitema Sub county.

3.1.1. The equipment's used

- ✓ A Global Positioning System (GPS) was used during the survey to locate the geographical coordinates of the existing boreholes in the study area.
- ✓ Computer
- ✓ Field record sheets

3.1.2. Software's employed

Software's used for carrying out the this research work were;

- ✓ Arc Hydro module for drainage extraction
- ✓ Arc SWAT 9.0 for watershed delineation in ArcGIS 9.3
- ✓ Google Earth Pro for validation of data.
- ✓ ArcGIS 10.1 for derivation of thematic layers and Weighted Index Overlay Analysis

- ✓ ERDAS Imagine 9.2 for geo-referencing of LISS-III satellite data and for image classification
- ✓ IDRISI 32 for calculation of weights
- ✓ Micro soft office packages, (word and excel)

3.1.3. Methods employed

The methods that were used in this study include;

- ✓ Digital image processing
- ✓ Thematic map integration
- ✓ Geo-referencing
- ✓ Spatial analysis
- ✓ Weighted Index Overlay Analysis
- ✓ Analytic Hierarchy process (AHP) Multi Criteria Evaluation (MCE)

3.1.4. Thematic layers used

The thematic maps of the identified factors that determine the existence and quantity of ground water in the study area were used. These include the following;

- ✓ Digital elevation model (DEM)
- ✓ Geological map
- ✓ Geomorphological map
- ✓ Lineament map
- ✓ Rain fall map
- ✓ Soil map
- ✓ Land use/cover map
- ✓ Slope map
- ✓ Drainage map
- ✓ Depth to water level map

3.2. Source of data and methods of data collection

The sources of data and methods of data collection that were used in this research include;

3.2.1. Data Types and Sources

The study will use both Primary and Secondary Data.

3.2.1.1 Secondary data collection methods

Secondary data include the information obtained from available published records. Secondary data was obtained from textbooks, journals, articles and the internet and it is majorly used for desk study. This data was used to obtain information about how GIS and Remote Sensing has been used in ground water exploration

3.2.1.2 Primary data collection methods

Primary data include the information collected from the field. The source of this information was Ministry of Water and Environment (MWE); Directorate of Water Resources Management (DWRM), Ministry of energy and mineral development (MEMD), Department of Geological Survey and Mines (DGSM), National Forestry Authority (NFA) and National Agricultural Research Organization (NARO).

The following methods will be used in primary data collection.

- ✓ **Interviews**

Oral interviews concerning the methods of ground water exploration, their limitations as well as advantages were conducted with the staff of DWRM.

- ✓ **Consultations**

Some of the data for this research was obtained by consulting individuals such as supervisors, lectures, fellow students, as well as key individuals from the places where data was collected from such as MWE, DWRM, NFA and DGSM.

Discussions concerning the existence of temporal data and remote sensed data as well as its analysis and interpolation were held with them. Discussions concerning the behavior and relationship of different geological formations with ground water were also conducted with geologists in DGSM, remote sensing and GIS specialists were also contacted to give guidance about the interpolation of data in ArcGIS environment.

- ✓ **Field visits**

Field visits were conducted in the study area to ascertain the existence of the geographical features that are reflected on aerial photographs and topographical maps.

A GPS was used in the field survey to locate the coordinates (longitudes and latitudes) as well as elevations of all the existing boreholes in Busitema Sub County. The obtained data was later converted into UTM, fed into Microsoft excel 2013, imported into ArcGIS 10.1 environment and then integrated to geo-reference the aerial photographs of the study area.

3.3. Identification the basic factors determining the existence and quantity of ground water in an area

The factors that determine the existence of ground water in an area are categorized into three;

- ✓ Hydrological factors
- ✓ Geographical factors
- ✓ Geomorphological factors

3.3.1. Hydrological factors

The Hydrological factors that determine the existence and quantity of ground water in an area include; drainage – networks configuration, rainfall (intensity and duration), sub-surface flow, infiltration rate, evaporation and evapotranspiration

The hydrology of the study area was studied and analyzed by relating all the key hydrological processes such as precipitation, runoff, infiltration, subsurface flow and evaporation and evapotranspiration. This was done using the data which was obtained from Uganda National Meteorological Authority (UNMA) such as rainfall data, temperature data and evaporation data. Some datasets were accessed from Tororo meteorological station and DWRM.

The data about the existing boreholes in Busitema Sub County was obtained from DWRM-Entebbe and it included majorly features such as rainfall, temperature, humidity, borehole depth, borehole yield and this data was analyzed to determine the major contributors to ground water.

3.3.2. Geographical factors

The Geographical factors include; vegetation cover/ land use, slope/topography and soil. Field surveys were conducted to ascertain the existence of geographical features such as vegetation cover, land use, topography as well as existence of hills in the study area. GPS coordinates were also obtained to locate the study area.

Additional data such Uganda soil map with all attributes in the table was obtained from the Department of Geological Survey and Mines (DGSM) and then land use map and the Digital Elevation Model (DEM) and borehole data was obtained from the Directorate of Water Resources Management (DWRM)

The data about the geographical features and the vegetation cover and land use that was obtained from the field and the relevant authorities was analyzed and compared with the Google maps of the study area, interpolated with the existing boreholes to identify the major geographical contributors to ground water.

Thus, soil and vegetation were found to be major contributors to ground water existence in the study area.

3.3.3. Geomorphological factors

Geomorphological factors include; slope steepness, lineaments and lithology. The geology of the study area was studied basing on the available data of the existing boreholes which was obtained from DWRM as well as lithology and lineament datasets which were obtained from DGSM.

The data was interpolated an ArcGIS environment to obtain the nature of rocks underlying Busitema Sub county were obtained and their contribution to ground water was obtained basing on their characteristics such as porosity, transimitivity and their ability to hold and transmit water

The lithology and lineaments in the study area were found to be influencing factors in ground water existence.

Therefore, the multi influencing factors that determine the existence of ground water in the study area include; lithology, land use, soil, drainage, lineament and slope.

3.4. Identification the GIS layers, remote sensed data and maps of the basic factors to be used in interpolation

GIS layers of the basic factors that determine the existence of ground water in an area were created using the remote sensed data to create maps which were used for interpolation in ArcGIS environment. Remote sensed data used was obtained from NASA and USGS website and it was for the most recent period (2014).

Different GIS layers were created basing on the factors affecting the existence of ground water in an area such as lithology, lineaments, slope, soil, drainage and land use.

3.4.1. Formulation of Lithology map

Lithology is the branch of geology that studies rocks: their origin and formation and mineral composition and classification. Therefore, a map of the study area showing different rock types underlying Busitema Sub County was created using the lithologies from geo-referenced boreholes in the study area and the further comparison was done with the lithology map which was obtained from DGSM.

Lithology is a very vital aspect in forecasting groundwater potential zones. Extraction of geological information from satellite data depends on the identification of different patterns on an image resulting from the spectral arrangement of different tones and textures. Depending on the rock reflectance properties, satellite images are used and they play important role in rock identifications. A lithology map is prepared using the IRS IC and Landsat TM Digital Data and

Simultaneously ground check verification is done in field

The following procedures were followed;

- ✓ Spatial adjustment; within the editing environment, the spatial adjustment tools were used to align and integrate the lithology map with the sub county map.
- ✓ Extraction; In ArcMap, the map of Busitema Sub County was extracted from the map of Uganda sub counties using Select By Attributes. The Select tool was used with a Structured Query Language (SQL) query to make a new map of Busitema Sub County from Uganda sub counties.
- ✓ Interpolation and overlay; the boreholes were overlaid onto the lithology map to find out whether the geo-referenced borehole lithology were corresponding to the ones on the map.

Then the final lithology map was obtained with the following attributes, ; Alluvium (sand, silt, gravel), Masaba biotite granite, Mafic and intermediate metavolcanic rock, Mafic metavolcanic rock, Quartzite, metagreywacke and Cherty quartzite, shale, black shale and BIF.

3.4.2. Formulation of Lineament density map

The lineament map for Uganda was obtained from DGSM, Busitema Sub County map was then extracted and analyzed using ArcGIS environment.

The lineament density map was derived using “density tool” of spatial analyst extension in ArcGIS is employed for deriving the density of lineament lines in Km/Km^2 using ***equation 2.1***

3.4.3. Formulation of Land use map

Land use map of Busitema Sub County was derived from Google Earth (GE) imagery through supervised classification. Different categories of interpretation were selected from GE Imagery, based on their relative importance towards ground water potential influence.

Finally field verification concluded the land use map with four categories such as forest, farm land, agriculture and wetlands.

GE images covering the study area at a scale of 1:50,000, were acquired from USGS website and geo-referenced in GIS.

3.4.4. Formulation of Slope map

Slope map as percentage rise was derived from SRTM Digital Elevation Model (DEM). For each cell, the Slope tool calculates the maximum rate of change in value from that cell to its neighbors. Basically, the maximum change in elevation over the distance between the cell and its eight neighbors identifies the steepest downhill descent from the cell.

The slope was obtained using the “slope tool” in spatial analyst and five subclasses of thematic layer were assigned through reclassification method.

3.4.5. Formulation of Drainage density map

Drainage map which is layer of streams network in the study area was derived from SRTM DEM of Busitema Sub County using ArcSWAT Tools an ArcGIS-based system; which is a series of tools built on top of the ArcSWAT database, geared to support water resources applications.

Later, a drainage density map was derived using “density tool” of spatial analyst extension in ArcGIS is employed for deriving the density of drainage lines by applying ***equation 2.2.***

3.4.6. Formulation of Soil map

The soil map of Busitema Sub County was obtained from NARO.

Geometric correction was done for the image using ground control points (GCP's) collected by a global positioning system (GPS) using a second order transformation and the nearest neighbor re-sampling method. The layers were overlaid over the geo-referenced topographic maps in GIS to correct the positional shifts.

3.5. Application of GIS

The output thematic layers of lineaments, stream (drainage) network, slope, land use, soil and lithological formations with all attributes associated with each layer were overlaid using WIOA to produce a ground water prospective map. This was done by analysing and interpolating them in ArcGIS environment to obtain the final map of ground water exploration sites. The final map was refined after considering altitudes, derived from the DEM, with maximum occurrence of medium and high yield of groundwater wells. Ground trothing was done to ascertain the accuracy of the produced map by geo – referencing the existing boreholes using ground control points obtained using a GPS.

3.6. Application of Remote Sensing

The ETM+ imagery was transformed into three Principal Components (PC's) known as "Eigen Channels", which accounted for all variations of the selected bands of the ETM+. This was mainly performed to reduce data auto correlation and dimensionality into fewer interpretable bands.

The unsupervised image classification was then applied to the output PC's using the Iterative Self-Organizing Data Analysis Technique (ISODATA) clustering algorithm to group the ETM+ grey levels into fewer classes, which was then identified in relation to lithological units using the existing geological maps and field visits. This was done during the formulation of thematic layers.

The overall accuracy of the classification was assessed through a confusion matrix by comparing a number of random points of classified pixels with existing geological maps and ground data and later, the output layer from the digital classification was intersected with the layer of the promising sites of groundwater wells to identify the class where most of these sites was located.

3.7. Analyzing and interpolating GIS layers and maps of the study area

This was based on GIS, where layers of the basic factors that determine the existence and quantity of water were used to derive a map showing the potential areas for groundwater exploration. The groundwater potential zones were obtained by ***overlaying*** all the thematic maps in terms of ***weighted overlay methods using the spatial analysis tool in ArcGIS 10.1***.

The model building tool was used to come up with a cartographic model that produced a map onto which all the necessary thematic maps were overlaid.

Different thematic maps were imported into the model builder window and the vector data layers were converted into raster data layers using the conversion tool in the toolbox. All the thematic maps were reclassified to the required scales using the reclassification tool in spatial analyst and later, they were overlaid using the weighted overlay tool also in spatial analyst.

In this research, specific weighing scheme has been adopted as ***Analytic Hierarchy process (AHP) Multi Criteria Evaluation (MCE)*** technique to attach scale factors to all the multi influencing factors both in data analysis during layer formulation and weighted index overlay analysis.

Thematic layers identified for weighted index overlay analysis were Drainage Density, Lineament Density, Landuse, Slope, Lithology and Soil. Subclasses in every thematic layer were derived through reclassification method which is based on natural breaks in data. Relative importance of each individual class within the same thematic map was compared with each other by pairwise comparison method (***using continuous rating scale developed by Satty in 1977).*** Formulated pairwise comparison files were used as input in weight module of IDRISI 32 software, to calculate the weights of subclasses in a thematic layer, with a cross check on acceptable consistency levels.

Similarly by pairwise comparison of thematic layers with each other based on their relative importance, weights of individual thematic layers for WIOA were determined.

3.7.1. Weightage calculation

The multi influencing factors for groundwater potential zones such as lineaments, drainage, lithology, slope, land-use, rainfall and soil were examined and assigned an appropriate weight using the AHP approach and the MCE.

The weights for WIOA, were obtained using the steps for pairwise comparison as they are discussed in ***section 2.7.3.***

The effect of each influencing factor contributes to delineate the groundwater potential zones was calculated using ***equations, 2.12, 2.13 and 2.14***. The obtained data was presented as follows

Table 3.1: Presentation of Relative Weight of influencing factors generated using AHP

S/N	**Classes**	**Raster Value (km/km^2)**	**Weight (Fraction)**	**Weight (Decimal)**	**% influence**	**Relative Weights for WIOA**
1						
2						
3						
4						
5						

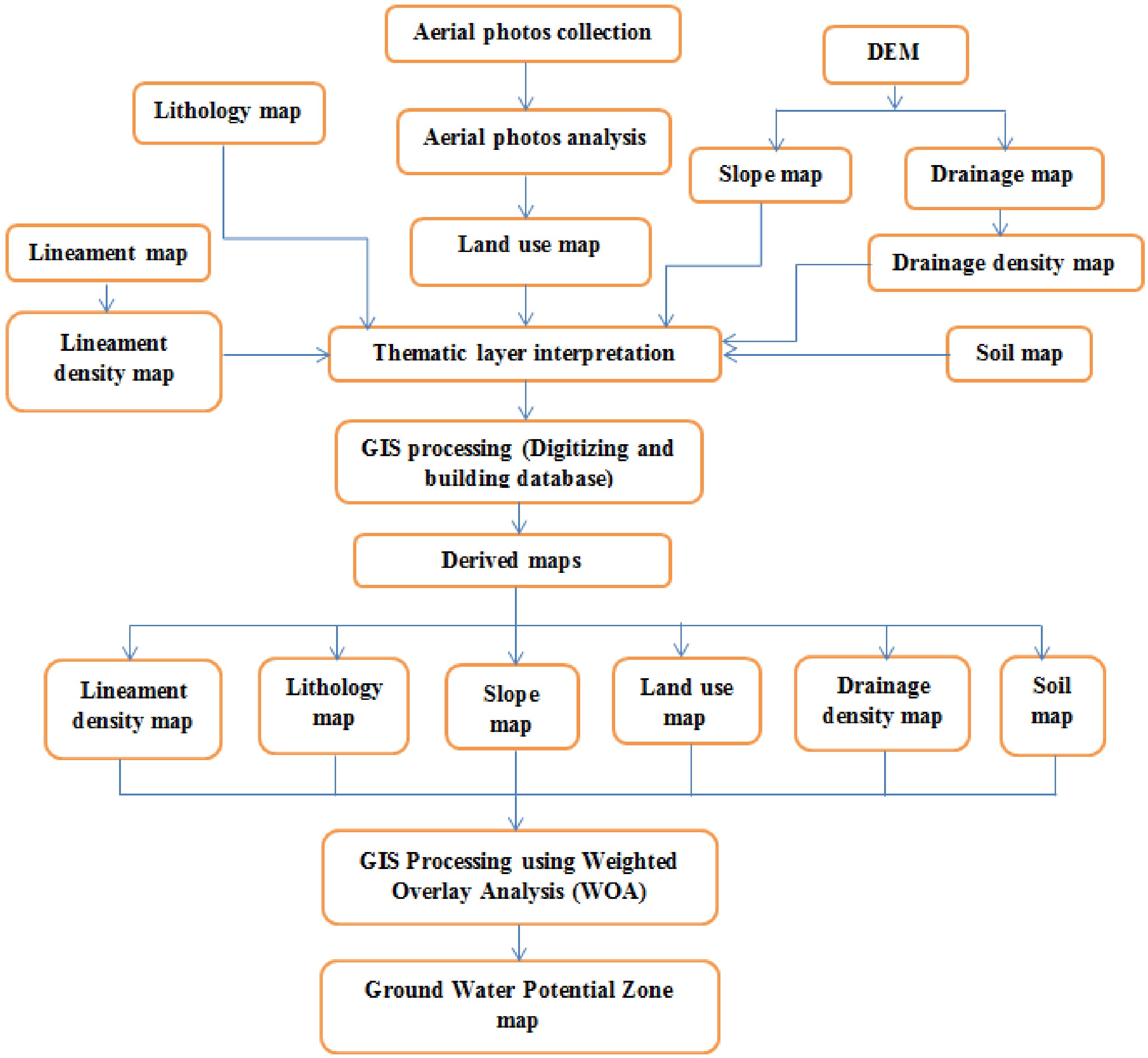

Figure 3.1: Methodology flowchart for the delineation of groundwater potential zones.

CHAPTER FOUR

4. PRESENTATION AND DISCUSSIONS OF RESULTS

4.1. Preamble

This chapter discusses, how the earlier obtained hydrological and geological data as well as the thematic layers developed were critically studied and analyzed to assess their impact on ground water in Busitema Sub County and the results are presented in form of maps, tables and graphs.

4.2. Analysis of hydrological and geological data

Various trips were made to DWD and UNMA where the hydrological data (mean annual rain fall data, mean temperature, humidity) as well data about the existing boreholes was obtained. This data was analyzed using MS Excel 2010.

4.2.1. Hydrological analysis of the rainfall data

The data was obtained in form of daily rainfall records, it was analyzed in excel to obtain the mean monthly and mean annual rain fall. **(see appendix B)**

Single Mass Curve diagram for Tororo metrological station was drawn and Cumulative annual rainfall was generated and used to draw the consistency curve.

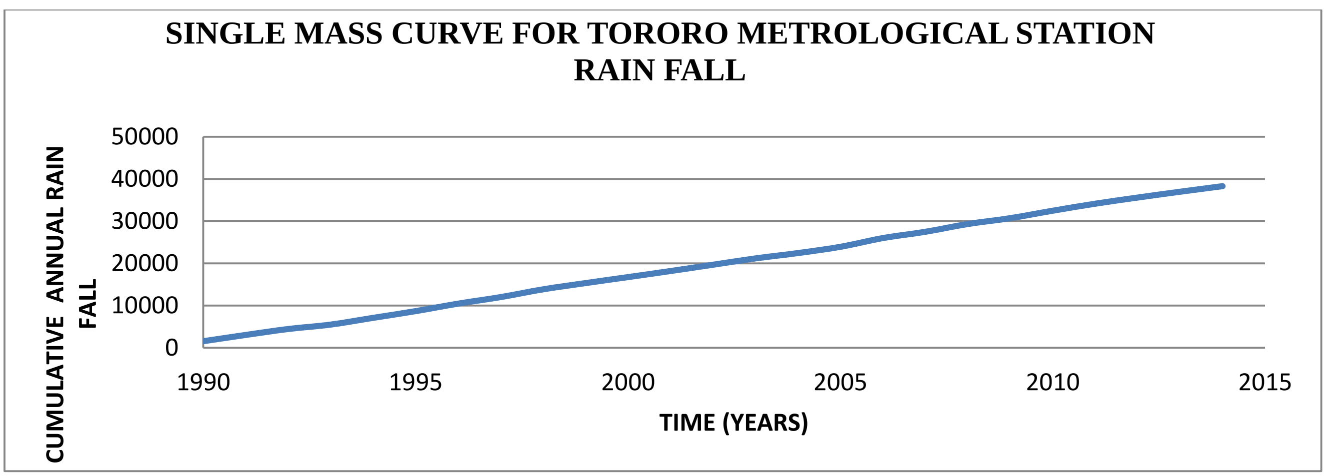

Figure 4.1: a single mass showing the consistency of the rainfall data from Tororo.

From the figure above, the line of regression is linear which indicate a strong degree of consistency. Therefore rainfall data collected was used as input data for subsequent design stages.

4.2.2. Rainfall–runoff relationships

Rainfall–runoff relationships are used primarily for design, forecasting and evaluation. If stream flow data are unavailable or are too limited for reliable interpretation, rainfall–runoff relationships can be very helpful because of their ability to extract stream flow information from the precipitation records. Because of the relative simplicity and inexpensive nature of the collection of rainfall data, they are generally more abundant than are stream flow data.

If a strong relationship can be established between the rainfall and runoff for a catchment of interest, the combination of the rainfall–runoff relationship and the rainfall data may, for example, give more reliable estimates of the frequency of high stream flows than either a regional flood relationship

In general, rainfall–runoff relationships are developed in two distinct steps: the determination of the volume of runoff that results from a given volume of rainfall during a given time period and the distribution of the volume of runoff in time.

4.2.3. Soil Infiltration potential

Different soil textures have different porosities and thus different infiltration rates. Busitema Sub County consist three soil texture types.

From the curve below, the infiltration rate of loam soil is higher, followed by clay loam and then clay with the lowest infiltration rate.

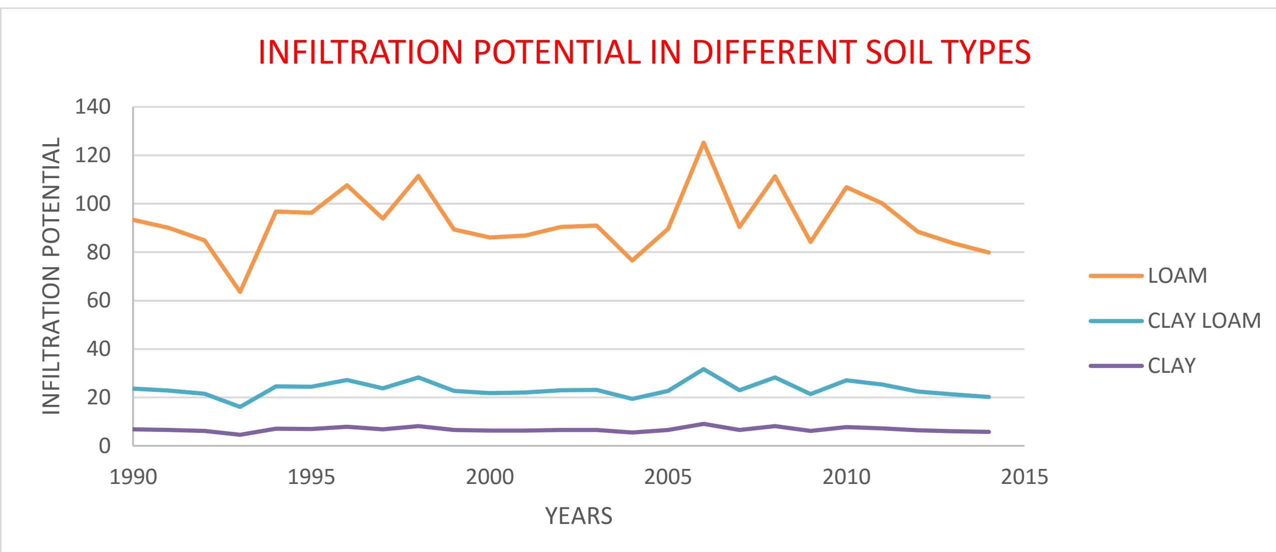

Figure 4.2: The infiltration potential of different soil types in Busitema Sub County

4.3. Thematic layers

Six different thematic layers were derived prior to weighted overlay analysis. These are layers of the major factors that determine the existence and quantity of ground water in an area.

4.3.1. Drainage density map

A watershed map showing all the water streams and the natural drainage canals (Drainage map) was derived from a digital elevation model (SRTM DEM) of Busitema sub county using ArcSwat Tools (version 9.0), an ArcGIS-based system; which is a series of tools built on top of the Arc Swat database, geared to support water and soil resources applications. In deriving a drainage density map, "density tool" of spatial analyst extension in ArcGIS was employed for deriving the density of drainage lines using the application of ***equation 2.2.***

There are three main streams in Busitema Sub County which include; ***River Okame*** in the east after Busitema trading center, ***Namukombi stream*** in the central between Busitema University and Busitema trading center and ***Solo stream*** in the west before the University in Busitema forest. The drainage density ranges from 0 to 7.5 Km/Km^2.

All the drainage canals, streams and rivers in Busitema sub county flow from south to north as shown in the map below.

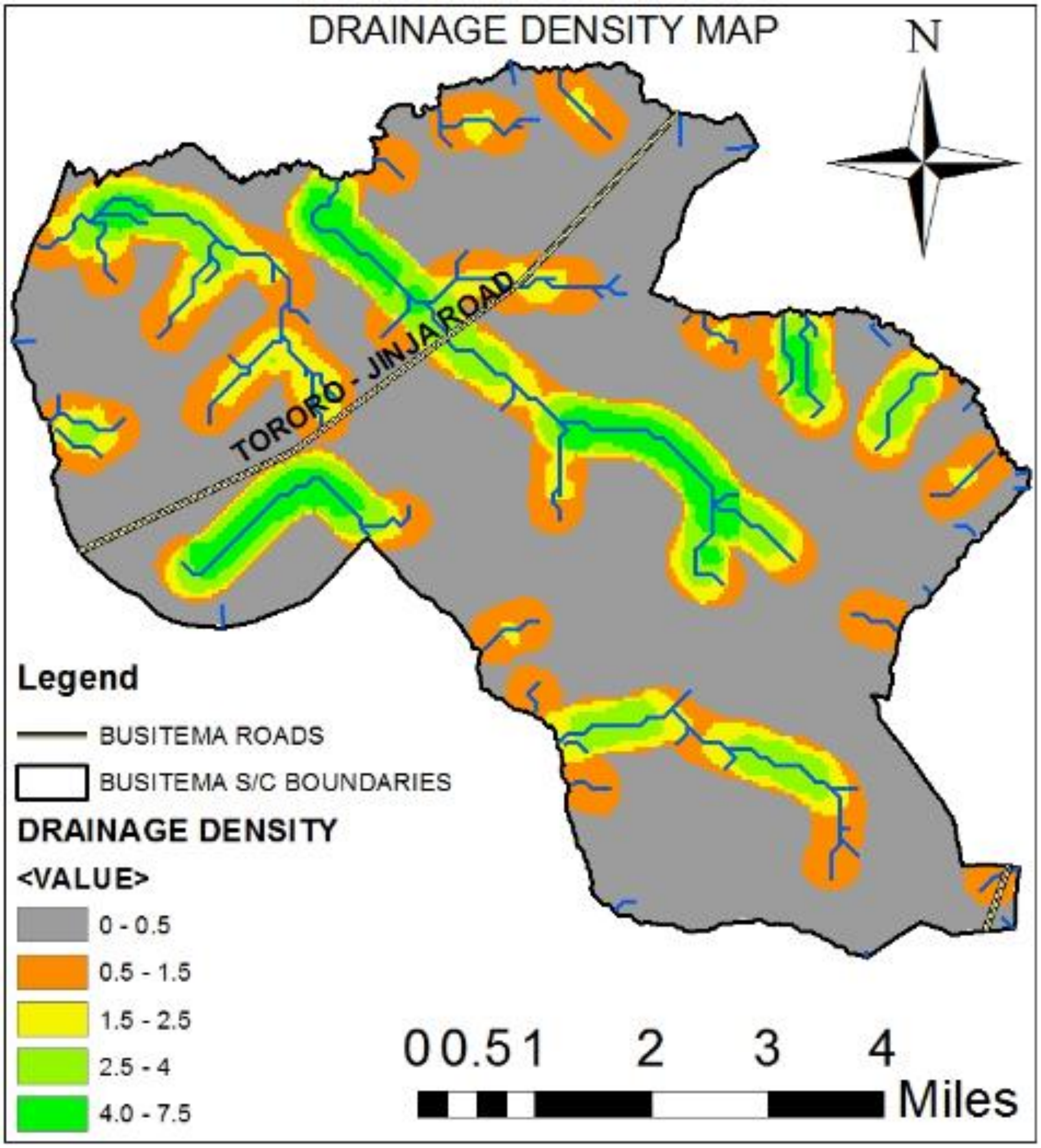

Figure 4.3: A thematic layer showing the drainage density of Busitema Sub County

4.3.2. Lineament density map

Lineaments are underlain by zones of localized weathering and different permeability and porosity. Previous studies have revealed a close relationship between lineaments and groundwater flow and yield. A map of Lineaments was obtained from DGSM, and then it was compared with the lineaments extracted from the satellite imagery using PCI-Geomatica software package for accuracy. The layer of lineaments was then used to obtain lineament density map using the "density tool" of spatial analyst extension in ArcGIS. Most lineaments are in mafic and intermediate metavolcanic rocks and masaba biotite granite rocks.

The lineament density ranges from 0 – 2.3Km/Km^2.

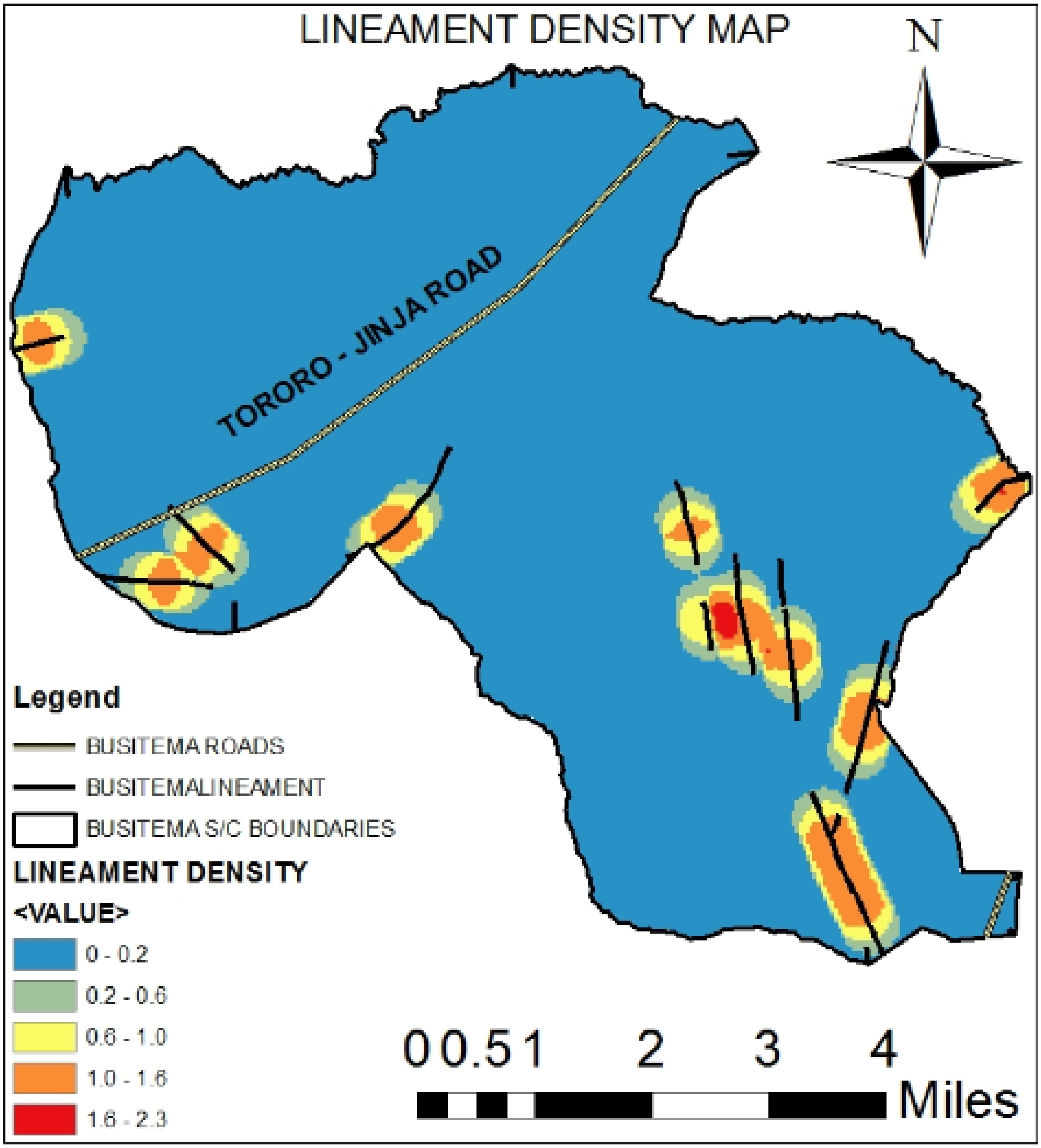

Figure 4.4: A thematic layer showing the lineament density of Busitema Sub County

4.3.3. Land use map

Land use map of Busitema Sub County was derived from USGS imagery through supervised classification where different categories of interpretation were selected from Google Earth Imagery of the study area, based on their relative importance towards ground water potential influence. Finally field verification concluded the land use map with four categories which include agriculture, wetland, forest and farm land.

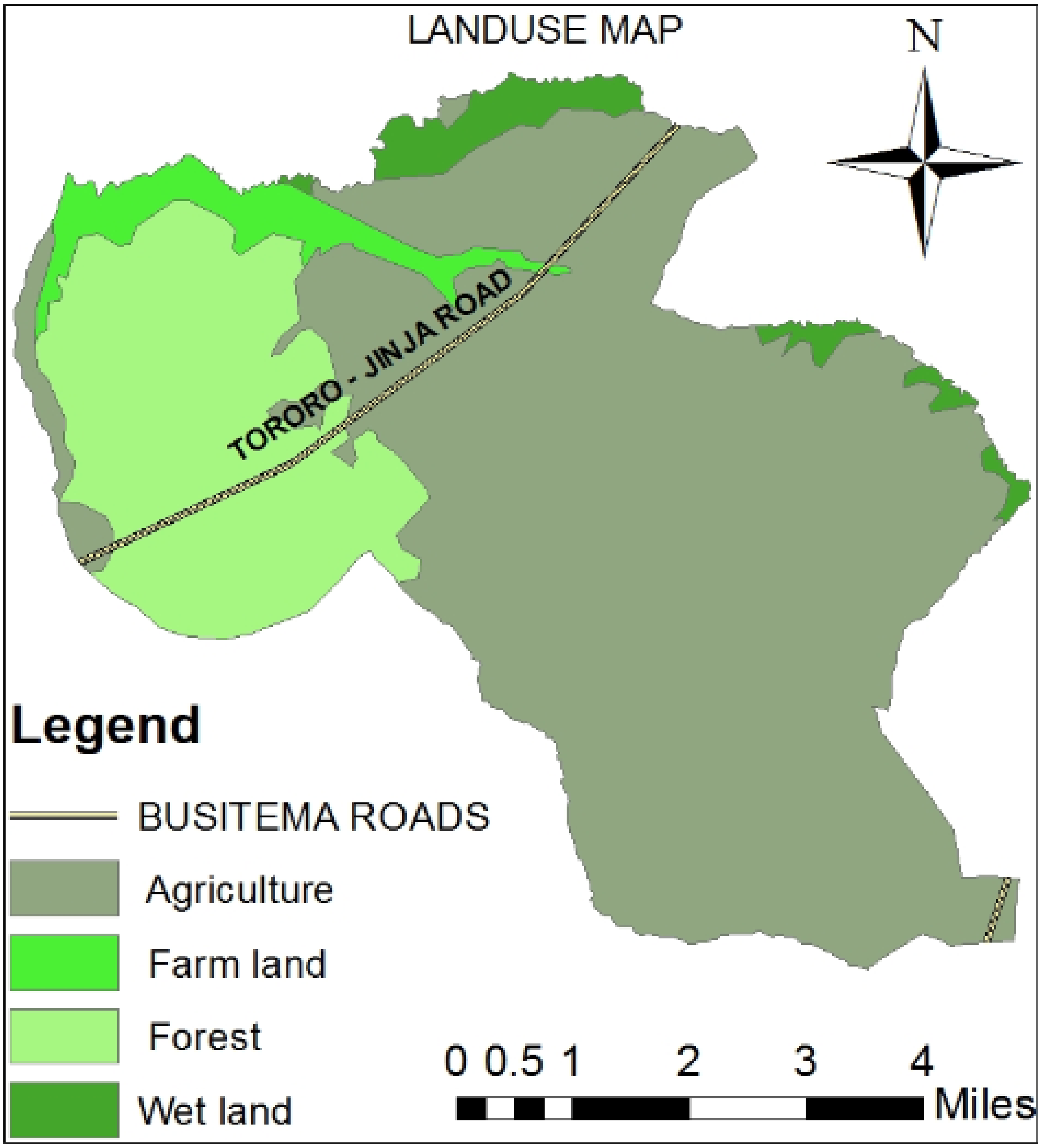

Figure 4.5: A thematic layer showing the land use of Busitema Sub County

4.3.4. Slope map

This was derived from SRTM Digital Elevation Model (DEM) as percentage rise. For each cell, the Slope tool calculates the maximum rate of change in value from that cell to its neighbors. Basically, the maximum change in elevation over the distance between the cell and its eight neighbors identifies the steepest downhill descent from the cell.

The terrain of busitema sub county is relatively flat with steep slopes in the two hills of busitema college and syaule. The slope ranges from 0 – 14 degree.

Four subclasses of soil thematic layer were assigned through reclassification method as shown in the map below.

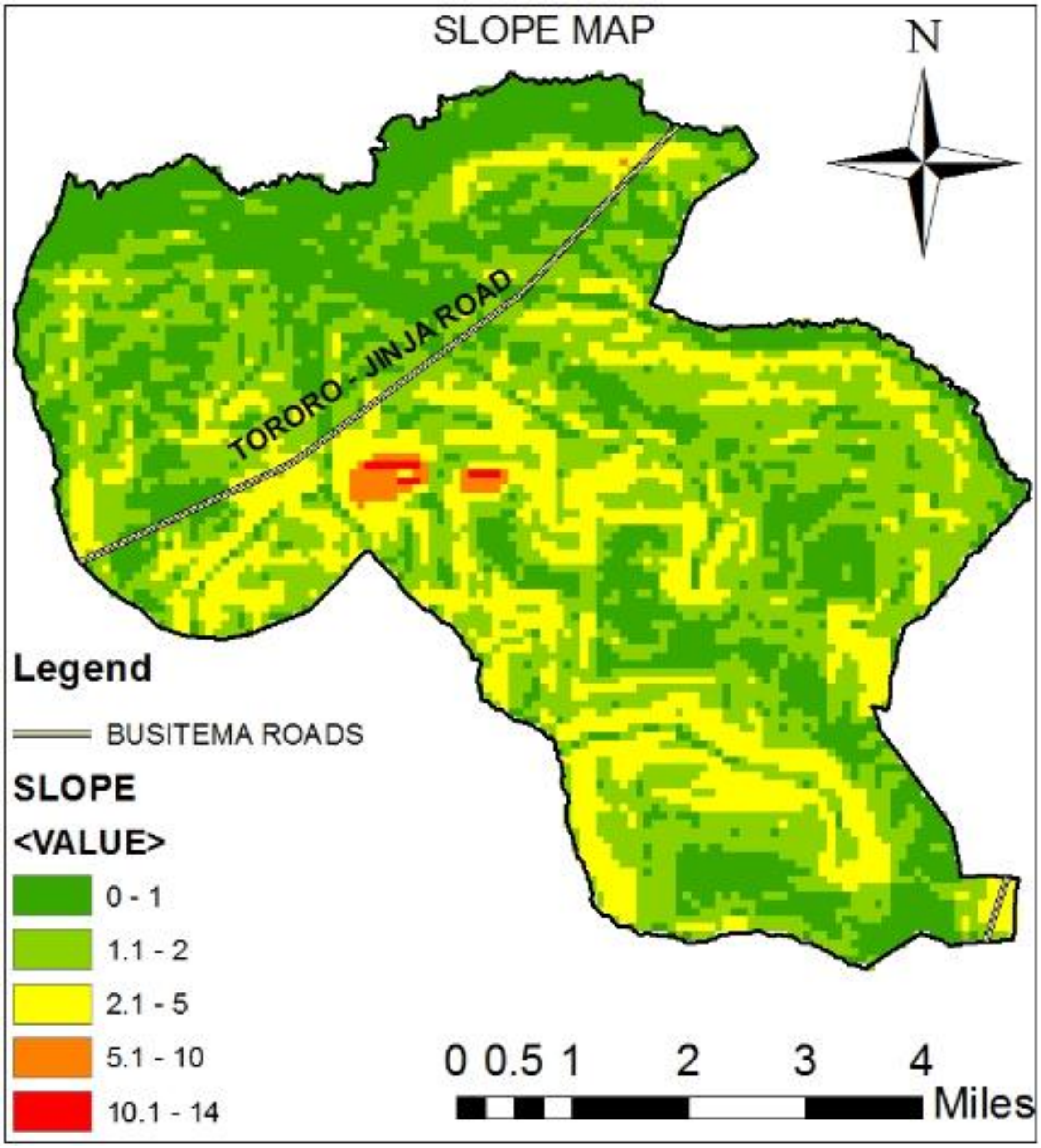

Figure 4.6: A thematic layer showing the slope of Busitema Sub County

4.3.5. Soil map

Soil type and texture directly affect ground water existence in any area as it directly affects infiltration of runoff whenever it rains. The soil layer of Uganda was obtained from NARO and later, the one of Busitema Sub County was clipped out. Busitema Sub County has got three soil texture types; clay, clay loam and loam as shown in the thematic map below.

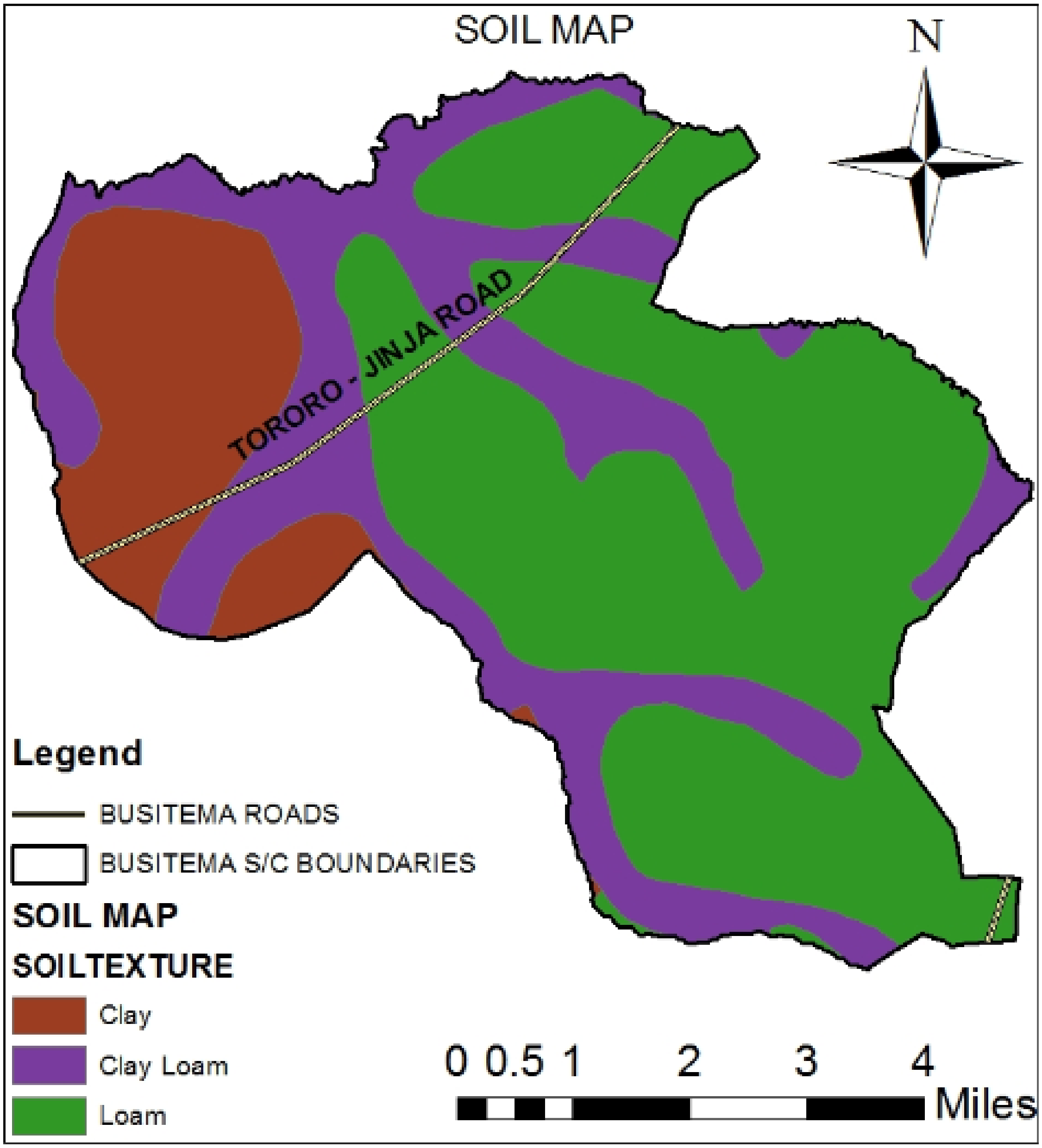

Figure 4.7: A thematic layer showing the soil of Busitema Sub County

4.3.6. Lithology map

Lithology is the branch of geology that studies rocks, their origin and formation and mineral composition and classification. The map of lithology was obtained from DGSM and later the existing borehole lithology were geo referenced for accuracy.

The following lithological formations were found in the study area.

- ✓ Alluvium ; sand, silt, gravel

Alluvium are loose, unconsolidated soil sediments which has been eroded, reshaped by water in some form and deposited in a non-marine setting. They are majorly made up of fine particles of silt and clay and larger particles of sand and gravel. Alluvial deposits are good ground water aquifers because of their high porosity. Most alluvial aquifers are shallower than sedimentary and fractured rock aquifers

- ✓ Cherty quartzite, shale, black shale and BIF

Cherty quartzite a metamorphic rock composed of primarily microcrystalline, cryptocrystalline and micro fibrous quartz. Ground water in quartzite is majorly found in fractures and there are no fractures, water is hardly found. Shale is also another poor ground water aquifer because of its low permeability

- ✓ Mafic and intermediate metavolcanic rock

Mafic rocks are igneous rocks that are dominated by silicates pyroxene, amphibole, olivine and mica. These minerals are high in magnesium and ferric oxides. The major example is basalt, whereas meta volcanic rock is a type of metamorphic rock that was produced by volcano.

- ✓ Mafic metavolcanic rock

These are dominantly tholeiitic basalt and basaltic andesite flows and tuffs, associated with sheet dikes, massive and layered metagabbro and ultramafic rocks,

- ✓ Masaba biotite granite

Biotite granite is a grey to white, medium grained, massive to layer and range in composition from granite to quartz diorite.

- ✓ Quartzite, metagreywacke

This is a hard non – foliated metamorphic rock which was originally pure quartz sandstone. Sandstone is converted into quartzite through heating and pressure usually related to tectonic compression within orogenic belts.

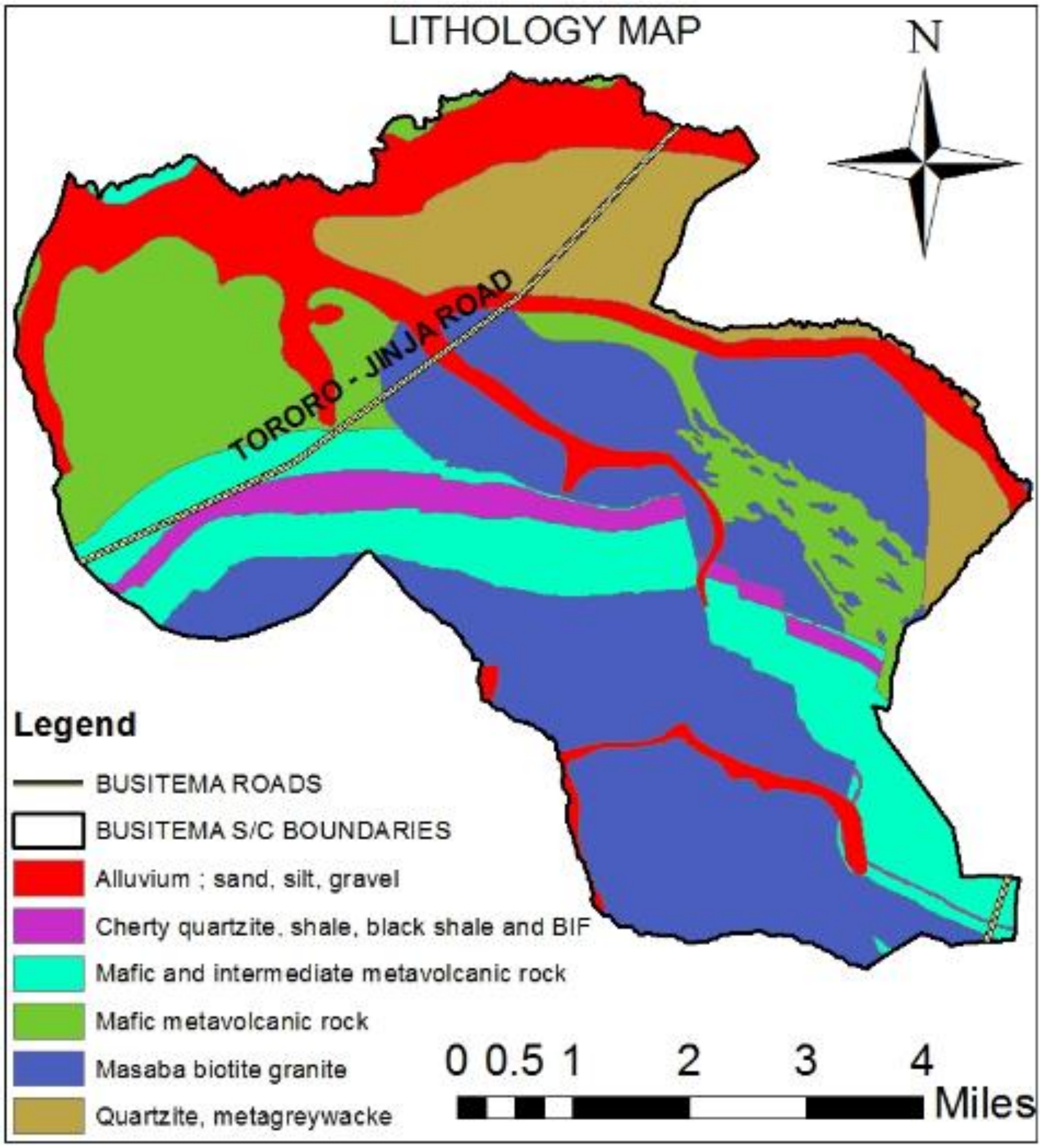

Figure 4.8: A thematic layer showing the lithology of Busitema Sub County

4.3.7. Ground water flow direction

A map of groundwater contour lines with groundwater flow lines is called a flow nets were formulated using the data of the first water strikes (water levels) of the existing boreholes. Most boreholes in the study area are located in the areas where ground water flow to.

The resulting layer indicated that ground water flow from the south to the north of the study area as shown in the figure below.

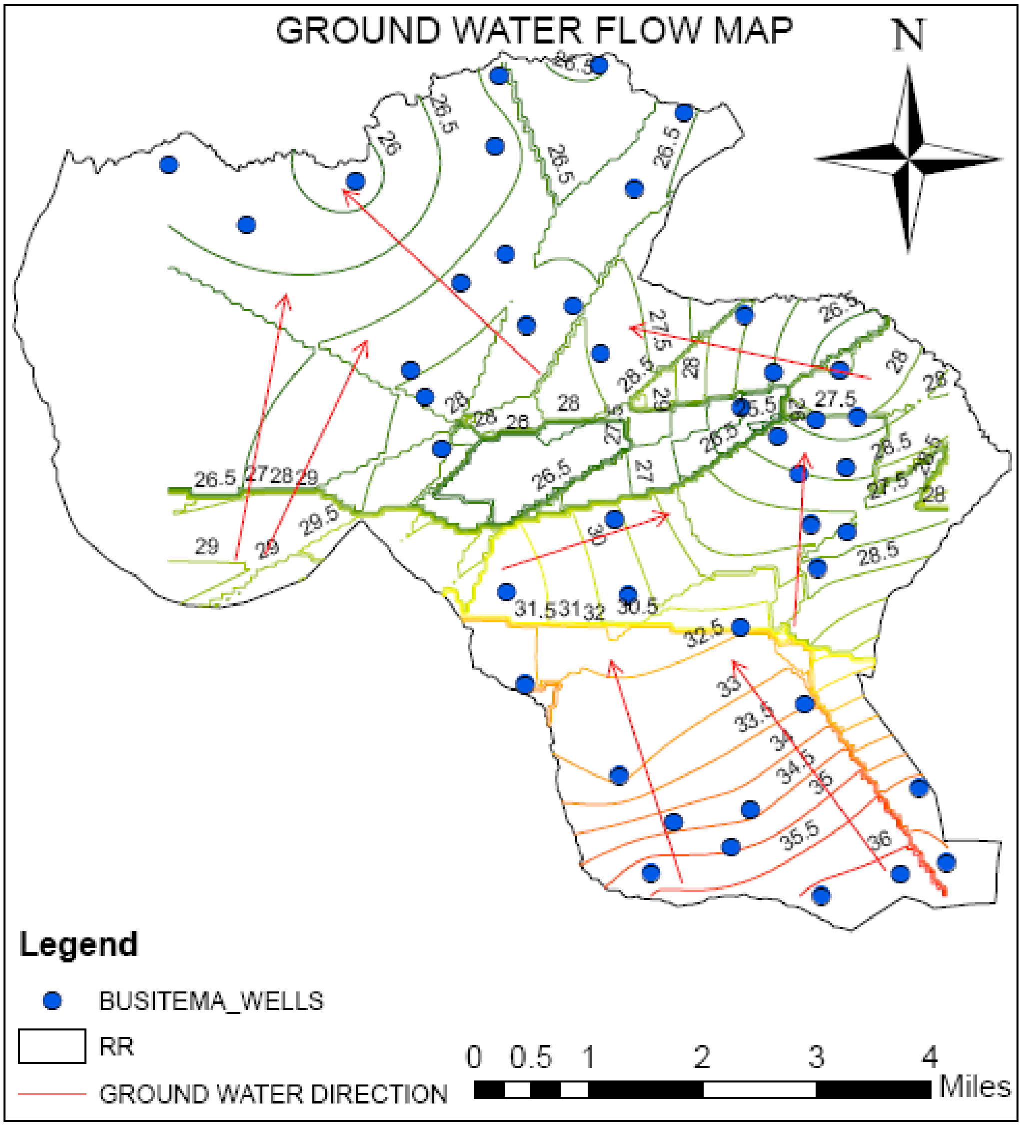

Figure 4.9: A thematic layer of Busitema Sub County showing the ground water flow nets (water table contours) and direction.

4.4. Weighted overlay analysis

4.4.1. Analysis of Drainage density layer

Drainage density is an inverse function of permeability, and therefore it is an important parameter in evaluating the groundwater zone. Area of high drainage density indicates high infiltration which restricts runoff and hence acts as a good groundwater potential zone. This is because major part of the rainwater over the area is lost as surface runoff with little infiltration for recharging the groundwater reservoir in areas with low drainage area. On the other hand low drainage density areas permit low infiltration and recharge to the groundwater reservoir, hence can be described as a poor zone for groundwater prospecting.

Table 4.1: Attributes and Weights for drainage density layer

S/N	**Classes**	**Raster Value (km/km^2)**	**Weight (Fraction)**	**Weight (Decimal)**	**% influence**	**Relative Weights for WIOA**
1	Very low	0 – 0.5	1/5	0.2	0.06	1
2	Low	0.6 – 1.5	1/4	0.25	0.10	1
3	Moderate	1.6 – 2.5	1/2	0.5	0.18	2
4	High	2.6 – 4.0	1	1	0.31	3
5	Very high	4.1 – 7.5	1	1	0.34	3

4.4.2. Analysis of Slope layer

The slope varies between zero and 14 degree (Figure 4.6). Area of high slope value will cause more runoff due to low retention time and less infiltration thus, have poor groundwater prospective zones as compared to low slope regions where the retention time is high and the infiltration is also high leading to low runoff. Therefore, regions with low slopes, allow high runoff infiltration and hence more water to replenish the ground water aquifers.

Table 4.2: Attributes and Weights for slope layer

Serial No.	**Classes**	**Raster Value**	**Weight (Fraction)**	**Weight (Decimal)**	**% influenc**	**Relative Weights for WIOA**
1	Very low	0 – 1.0	1/9	0.111111	0.04	0
2	Low	1.1 – 2.0	1/7	0.142857	0.06	0
3	Moderate	2.1 – 5.0	1/5	0.2	0.15	2
4	High	5.1 – 10.0	1/3	0.333333	0.25	3
5	Very high	10.1 – 14.0	1	1	0.51	5

4.4.3. Analysis of Lithology layer

Lithology is another important aspect for the ground water delineation mapping. Busitema sub county is underlaid by the following geology formations; Alluvium (sand, silt, gravel), Masaba biotite granite, Mafic and intermediate metavolcanic rock, Mafic metavolcanic rock, Quartzite, metagreywacke and Cherty quartzite, shale, black shale and BIF.

The attribute table of lithology is defined below and the weighted map of lithology is shown in the table. The weights have been assigned to these geological formations and ranking according to their reliability to form ground water aquifers and their potential for ground water prospecting.

Table 4.3: Attributes and Weights for Lithology layer

SN	Classes	Raster	Weight (Fraction)	Weight (Decimal)	% influence	Relative Weights for WIOA
1	Alluvium ; sand, silt, gravel	1	1/9	0.111111	0.43	4
2	Masaba biotite granite	2	1/7	0.142857	0.2	2
3	Mafic and intermediate	3	1/5	0.2	0.1	1
4	Mafic metavolcanic rock	4	1/3	0.333333	0.08	1
5	Quartzite, metagreywacke	5	1	1	0.05	1
6	Cherty quartzite, shale, black shale and BIF	6	1	1	0.m5	1

4.4.4. Analysis of Lineament density layer

Low lineament zones indicate low sub surface water percolation into the rocks. Higher lineament density favors percolation of water into the geological formations underlying the area of interest.

Table 4.4: Attributes and Weights for lineament density layer

Serial No.	Classes	Raster Value	Weight (Fraction)	Weight (Decimal)	% influenc	Relative Weights for WIOA
1	Very low	0 – 0.2	1/9	0.111111	0.11	1
2	Low	0.2 – 0.6	1/7	0.142857	0.16	2
3	Moderate	0.6 – 1.0	1/5	0.2	0.18	2
4	High	1.0 – 1.6	1/3	0.333333	0.27	3
5	Very high	1.6 – 2.3	1	1	0.34	3

4.4.5. Analysis of Land use layer

The forest and wetlands are ranked excellent because the runoff water is slow and high percolation due to the presence of trees and water. The vegetation and agriculture have the good percolation capacity of water so it has been ranked in very good category. These are present in sufficient amount covering the study area.

Table 4.5: Attributes and Weights for land use layer

Serial No.	Classes	Weight (Fraction)	Weight (Decimal)	% influenc	Relative Weights for WIOA
1	Wet land	1/3	0.333	0.06	4
2	Forest	1/3	0.333	0.10	4
3	Agriculture	1/5	0.2	0.18	3
4	Farm land	1/6	0.167	0.31	3

4.4.6. Analysis of soil layer

According to the ground water prospect the soil plays an important role in the ground water percolation and holding capacity.

Table 4.6: Attributes and Weights for soil layer

Serial No.	Classes	Weight (Fraction)	Weight (Decimal)	% influenc	Relative Weights for WIOA
1	Loam	1	1	0.62	6
2	Clay loam	1/3	0.333	0.28	3
3	Clay	1/5	0.2	0.09	1

4.5. Model development

The model building tool was used to interpolate and overlay all the multi influencing factors using Weighted Index Overlay Analysis.

The formulated thematic layers of the basic factors were overlaid by attaching scale factors to each factor basing on their influence to the existence of ground water and the ground water prospective zones map was obtained.

The layers that were in vector form were first converted to raster form where grids were formed depending on the scale factors attached to them.

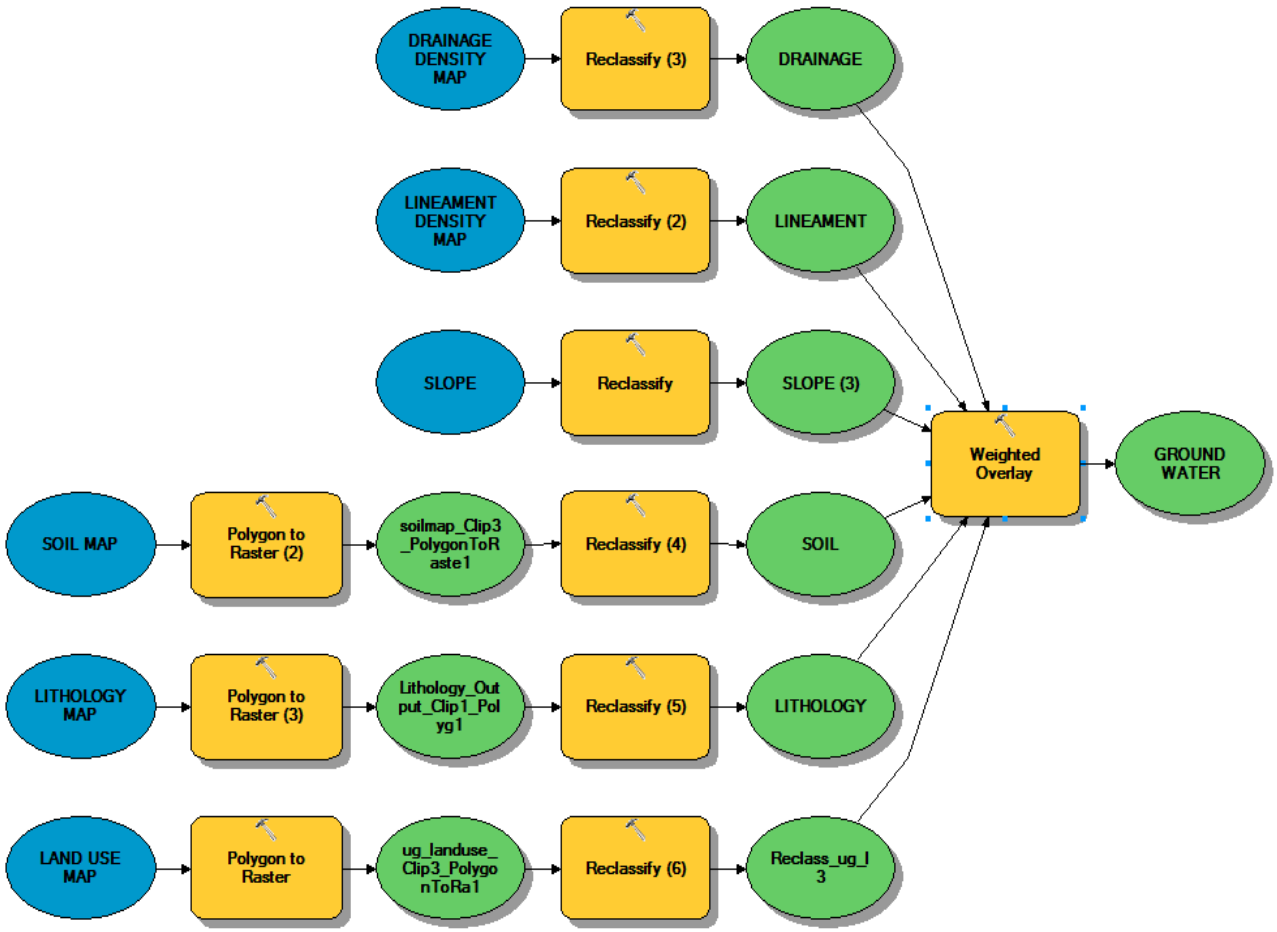

Figure 4.10: The model used to overlay all the multi-influencing factors of ground water.

4.6. Ground water potential map

Weighted overlay operation of six thematic layers with their weights as tabulated above tables was done and the overall percentage of influence of all the influencing factors was also derived using AHP as shown in the table below.

Table 4.7: Weights for WIOA of all multi-influencing factors.

Serial No.	Theme	Weight (Fraction)	Weight (Decimal)	% influence	Relative Weights for WIOA
1	Lithology	1	1	0.435	**43**
2	Slope	1/3	0.333	0.235	**23**
3	Lineament density	1/4	0.25	0.138	**14**
4	Drainage density	1/5	0.2	0.093	**9**
5	Soil	1/6	0.167	0.060	**6**
6	Land use	1/7	0.143	0.040	**4**

These weights shown in the table were used to generate a Ground Water Potential Zone Map of Busitema sub county. The delineation of ground water potential zones was carried out by reclassifying into six different groundwater potential zones: Very Poor Zone, Poor Zone, Moderate Potential Zone, Good, very good and excellent Potential Zone.

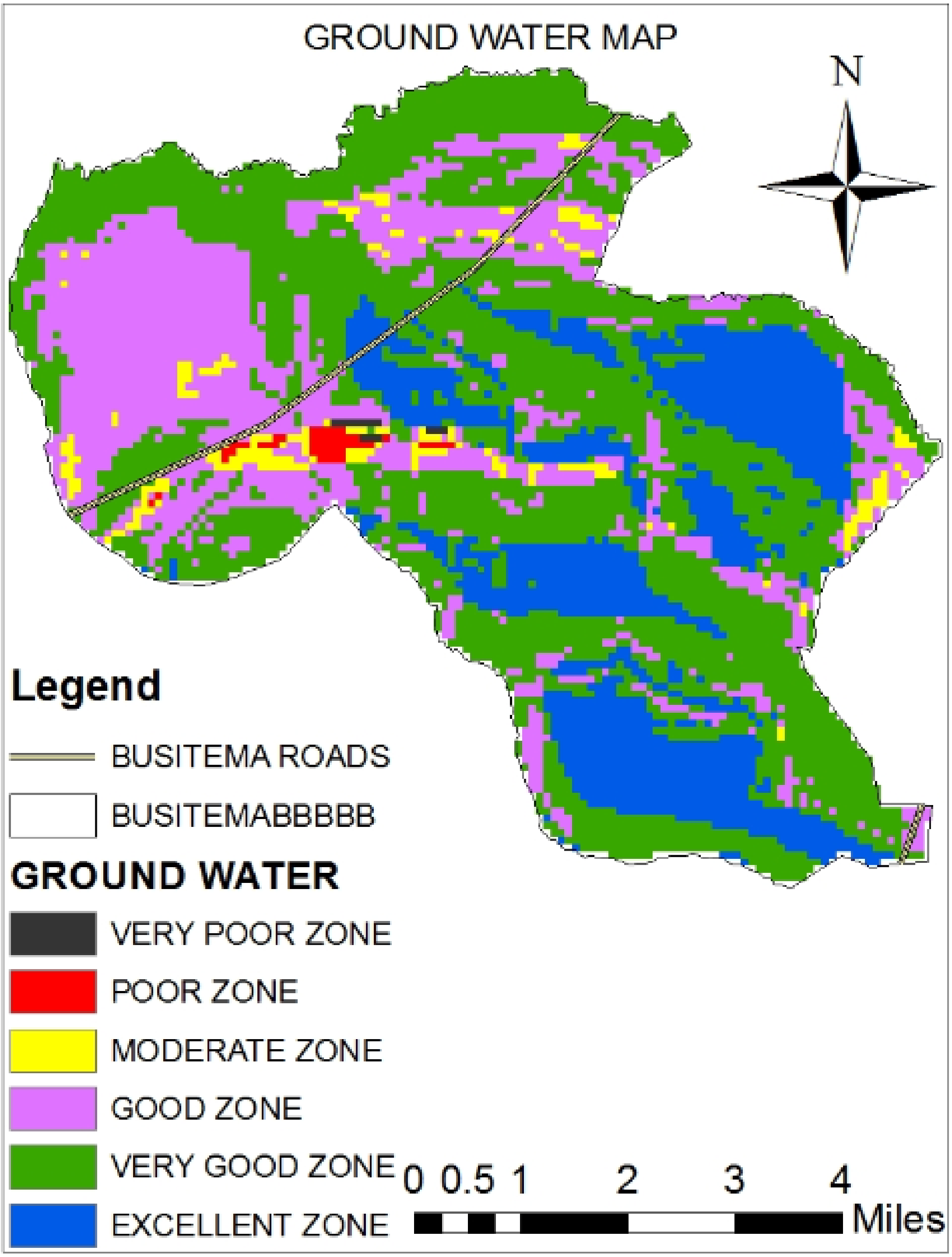

Figure 4.11: Ground water map showing different potential zone

4.6.1. Ground water prospective zones

Total extent falling under each zone was computed as shown in the table below

Table 4.8: Potential zones and depth of water table

Serial No.	**Zones**	**Area (Km^2)**	**Number of wells**
1	Excellent zone	22.62	24
2	Very good zone	34.11	17
3	Good zone	28.87	4
4	Moderate zone	9.27	2
5	Poor zone	3.15	0
6	Very poor zone	0.23	0

4.7. Validation of the model

To verify the generated potential zones, field validation through survey of depths in wells were adopted. For verification of resulted map, secondary field data collected as depth of water in 47 observation wells distributed across the is shown in Figure 4.12. Depths against zones (Table 4.8) clearly indicate that the qualitative classification of groundwater potential zones through WIOA gave fairly accurate potential zone map. Wells were absent in poor and very poor zones identified.

Since a relationship has been established between potential zones generated through WIOA and depth at which water is available, future research scope lies in modelling the relationship for prediction purpose. Common man is mainly concerned about the depth at which water is available rather than the yield of the aquifer. Hence the identified relationship between potential zones and depth of occurrence of water will enable the common man to predict the depth of occurrence of water before construction of an open well in specific areas.

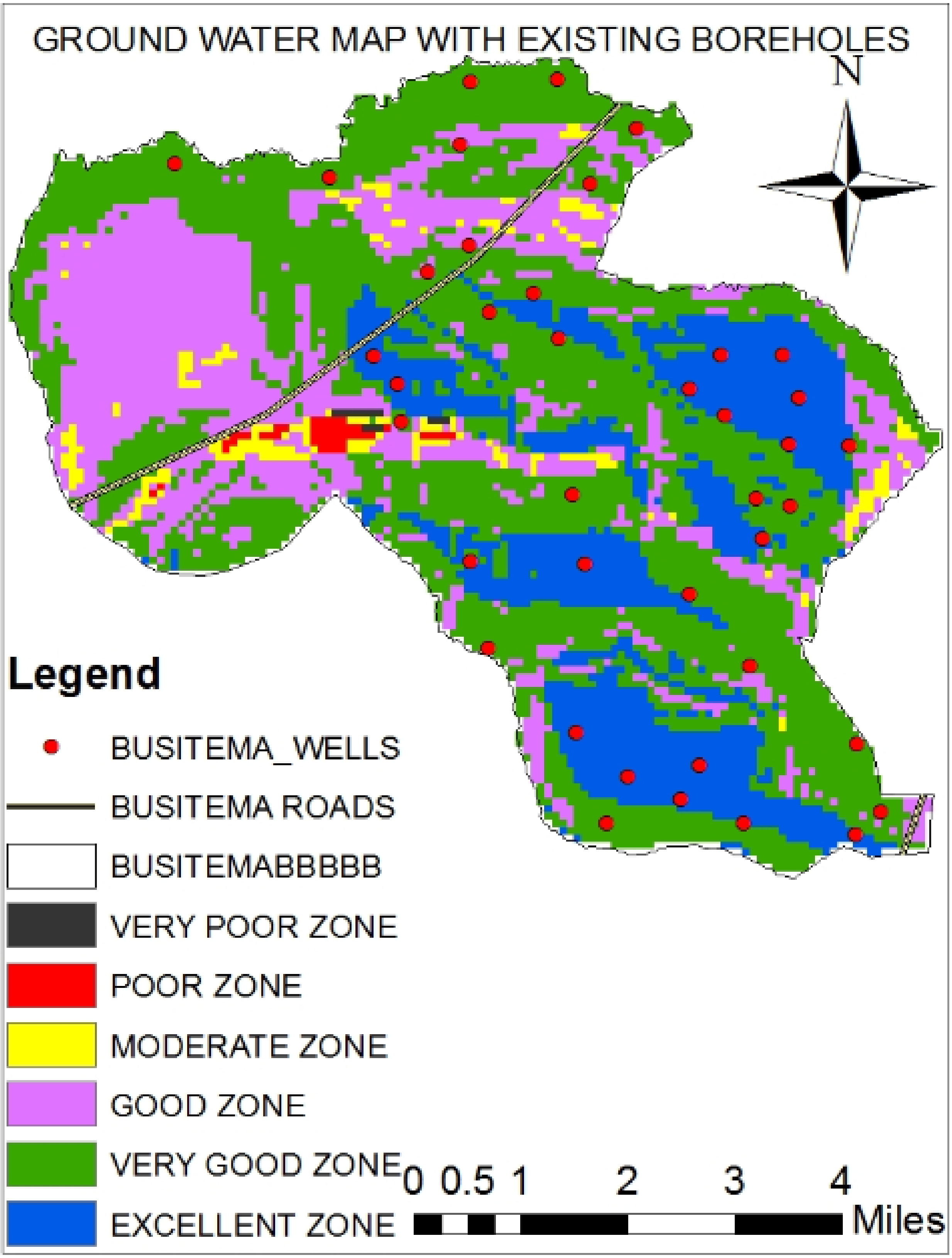

Figure 4.12: The ground water map generated with the existing boreholes.

CHAPTER FIVE:

5. CHALLENGES FACED, CONCLUSION AND RECOMMENDATIONS

5.1 Preamble

This chapter elaborates some of the challenges faced during the study as well as the conclusions of the entire study and clearly shows some recommendations that should be adopted by the several stakeholders to ensure sustainability of this project.

5.2 Challenges Faced

- ✓ The researcher faced a big challenge in obtaining the remotely sensed data from the relevant authorities such as DWD, NARO and DGSM as there was a lot of bureaucracy.
- ✓ Accessing the remotely sensed data such satellite images from the internet was a great challenge due to poor internet network in the university
- ✓ Obtaining the computer soft wares was a challenge to the researcher as some of them were paid for with the limited financial resources.
- ✓ Inadequate funds to carry out the necessary surveys in the study area.
- ✓ Language barrier during oral interviews with the local in the project area.

5.3 Conclusion

With the availability of the data about most ground water multi influencing factors, the findings of this research show ground water assessment, investigation, management, exploration and siting can easily be done there by saving time, money and other resources hence contributing to the country’s social and economic development.

The adopted thematic layers gave fairly accurate clues about groundwater occurrence from because the generated ground water map from WIOA by employing AHP method for weight calculation qualitatively categorized the study area as different zones based on groundwater potential. The field data collected from the already existing boreholes were well matching with the prospected zones. Hence this methodology of integrated remote sensing and GIS approach using Analytic Hierarchy Process (AHP) technique is a promising method for groundwater exploration. Policy and decision making regarding whether to invest in ground water as a source of water supply in certain geographical locations are easily made basing on the findings of the study since its exploitation can easily be done as well as cheap and time saving.

More so, the available data has been put to more use and this will lead to increased strictness in data collection as well as the efficiency and the effectiveness in water resources management and climate change intervention programmes since the responsible authorities can recognize the economic use of such data.

The final findings will also enable the responsible authorities to manage ground water effectively and efficiently as the cost and time of ground water management, assessment and exploration will be less.

5.4 Recommendations

- ✓ I recommend that, whenever data is obtained from the relevant authorities, it should first be verified and tested for consistency in order to reduce the bias and errors in the ground water model generated.
- ✓ Attaching the scale factors to the multi influencing factors of ground water should be obtained using a standard approach.
- ✓ Remotely sensed data should always be updated whenever a ground water prospecting map for any area is to be generated.
- ✓ Adaptation of the research in identification of prospective ground water areas I Uganda as one of the solutions to alleviating drought, promotion of agriculture and sanitation

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APPENDICES

Table 6.1: Rain fall data

UGANDA NATIONAL METROLOGICAL AUTHORITY (UNMA)

MONTHLY RAINFALL TOTALS IN (MM)

YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SPT	OCT	NOV	DEC	TOT	AVERAGE	CUMULATIVE
1990	64.9	208.2	242.3	265.7	263.3	21.1	16.5	114.7	51.6	130.8	83	79.5	1541.6	128.5	1541.6
1991	66	64.8	133.6	192.4	238.3	132.5	50	107.3	105.5	218	158.2	19	1485.6	123.8	3027.2
1992	32.4	83.4	63.4	226.6	171.1	118.4	52.9	147.5	118.3	102.5	178.4	107	1401.9	116.8	4429.1
1993	38.7	24.7	127.5	136.2	268.3	79.4	30.9	30.5	137.3	59.1	62.4	53.4	1048.4	87.4	5477.5
1994	73.8	29.7	175.9	175.9	208.9	164.8	156.2	63.2	114.8	109.6	283	41.3	1597.1	133.1	7074.6
1995	71.7	82	171.5	262.3	177.3	108.7	96.2	93.2	87.8	233.6	160.3	43.8	1588.4	132.4	8663
1996	97.6	118.8	162.9	306.6	199.5	59.4	52.9	185	167.3	231.8	174	20.1	1775.9	148.0	10438.9
1997	54.8	0.7	95.1	166.2	139.6	102.5	77.7	96.1	29.4	239.2	333.4	215.8	1550.5	129.2	11989.4
1998	302	118.9	130.5	266.3	348.3	94.6	69.9	111.9	84.6	188.5	99.4	24.8	1839.7	153.3	13829.1
1999	110.5	0	272.5	136.5	106.7	75.4	66.2	169.7	141.8	154.2	140.8	101.2	1475.5	123.0	15304.6
2000	61.9	16.7	79.5	177.5	181.4	86.1	99.1	100.4	103.5	237.5	170.3	106.2	1420.1	118.3	16724.7
2001	102.9	39.1	186.4	162.8	135.2	128	62	87.7	150.2	184.3	126	69	1433.6	119.5	18158.3
2002	96.7	54	107	279.2	145.5	63.8	49.3	81.6	73.9	103.8	206.5	231.2	1492.5	124.4	19650.8
2003	141	159.6	77.9	169.8	182.3	123.4	66.8	93.4	92.6	99	206.5	89.4	1501.7	125.1	21152.5
2004	33.3	48.7	76.8	162.5	136.5	69.6	64.7	188.9	203.9	126.9	89.5	62.2	1263.5	105.3	22416
2005	32.2	17.4	217.8	223.5	306.5	139.6	177.3	54.8	73	140.1	97.1	0	1479.3	123.3	23895.3
2006	46.6	98.7	238.1	232	222.8	239.5	90.2	173.7	130.3	279.9	255.8	60.4	2068	172.3	25963.3
2007	100.5	114.5	77.3	167.7	203.3	95.3	174.8	142.9	122.8	140.9	103.7	49	1492.7	124.4	27456
2008	67.7	89.2	161.8	171	237	109.5	185.4	131.3	131.9	298.7	234.8	19.9	1838.2	153.2	29294.2
2009	109.2	96.1	99	31.9	195.5	40.9	72.3	112	109.7	256.6	111.9	154.9	1390	115.8	30684.2
2010	86	117.2	85.5	94.4	272.5	163.9	160.9	85.1	254	239.4	103.8	101.6	1764.3	147.0	32448.5
2011	44.7	15.2	148.5	193.6	338	98.9	62.2	193.5	105.2	312	98.3	44.6	1654.7	137.9	34103.2
2012	56.7	43	111	90	201	153	112	134	123	237	121	78	1459.7	121.6	35562.9
2013	88	23	87	76	123	134	143	165	145	187	98	113	1382	115.2	36944.9
2014	93	56	75	112	182	76	114	97	162	158	93	101	1319	109.9	38263.9
AVERAGE	**82.9**	**68.8**	**136.2**	**179.1**	**207.4**	**107.1**	**92.1**	**118.4**	**120.8**	**186.7**	**151.6**	**79.5**			
MAX/MONTH	**302**	**208.2**	**272.5**	**306.6**	**348.3**	**239.5**	**185.4**	**193.5**	**254**	**312**	**333.4**	**231.2**			