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Groundwater Potential Zone delineation using GIS and Remote sensing Techniques in Sululta and Surrounding Watershed, Ethiopia

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This is to certify the Thesis Prepared by **Tamiru Tolcha Bekele** Entitled as **"Groundwater Potential Zone Delineation Using GIS and Remote Sensing Techniques in Sululta and Surrounding Watershed, Ethiopia."** Is Submitted in Partial Fulfillment of the Requirements for The Degree of Master of Science in Geodesy and Geomatics (Specialization in Geomatics) Compiles with the Regulations of the University and Meets the Accepted Standards with its Originality and Quality.

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DECLARATION

I hereby declare that the thesis entitled **"Groundwater Potential Zone Delineation Using GIS and Remote Sensing techniques in Sululta and Surrounding Watershed, Ethiopia"** has been, carried out by me under the supervision of Dr. Daniel, A. School of Civil and Environmental Engineering respectively, Addis Ababa University during the year 2018-2019 as a part of Master of Science in Geodesy and Geomatics (Specialization in Geomatics). I further declare that this work has not been, submitted to any other University or Institution for the award of any Degree or Diploma.

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ABSTRACT

Groundwater was recognized as one of the most valuable natural resources, immensely important and dependable source of water supply in all climatic region of all over the world. The general objective of this study was to delineate groundwater potential zones of Sululta and Surrounding watershed using Geographical Information Systems and Remote Sensing techniques. The present study integrated the thematic layers viz., Geomorphology, geology, soil, slope, Land use/Land cover, drainage density, lineament density, rainfall and other related features to delineate the groundwater potential zones using geo-informatics techniques. Integration of various themes was achieved through the development of a models/assigned weightages delineates groundwater potential zone and finally to generate a composite map. About 20 bore wells yield data had been collected to quantify the yield from groundwater potential zone map derived from geo-informatics. The final result map was reclassified into four groundwater potential zones by integrating GIS and Remote Sensing techniques and weighted overlay analysis with Analytical Hierarchy Process (AHP) methods. The classifications are very high, high, moderate, and low groundwater potential zone. Weight age and ranking scores are assigned to each thematic layer with respect of influencing rate of water percolation. Finally, weight age, multiply by ranking and computed all the multiply values for delineation of groundwater potential zones. The produced result was verified by comparing with the existing groundwater borehole databases developed by the Department of Minerals and Geoscience, Malaysia (JMG). The results show that there are good agreement between the predicted groundwater potential map and the existing groundwater borehole database. The study concludes that majority of the area covered by very high potential zones as it is supported by the statistical data of groundwater borehole wells and the new generated predicted groundwater potential map. The study suggested that, generated GWPZM will serve as useful guidelines for planners, engineers and decision makers providing quick decision- making in the management of groundwater resources.

Keywords: *Ground water Potential Zone, Remote Sensing, Geographic Information Systems*

List of Abbreviations

AHP	Analytical Hierarchy Process
AOI	Area of Iterance
ARC	Aeronautical Reconnaissance Coverage
DEM	Digital Elevation Model
EGS	Ethiopian Geological Surveys
ETM+	Enhanced Thematic Mapper plus
ERDAS	Earth Resource Data Analysis System
GIS	Geographic Information system
IDW	Inverse Distance Weight
IWMI	International Water Management Institute
JMG	Department of Minerals and Geoscience, Malaysia
LANDSAT	Land Space Application Technology
LULC	Land Use Land Cover
MCDA	Multi-Criteria Decision Analysis
MOA	Ministry of Agriculture
RS	Remote Sensing
SRTM	Shuttle Radar Topographic Mission
USGS	United State Geological Survey
UTM	Universal Transverse Mercator
WOA	Weighted Overlay Analysis

Table of Contents **Pages**

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 Background

Groundwater is one of the most valuable natural resources supporting human health, industrial and ecological diversity (Waikar & Nilawar, 2014). It is important natural resource in the world and most fundamental for growth and development of one country. It is also defined as subsurface water that fills all the pore space of soils and geologic formations below the water table (Freeze and Cherry 1979). Groundwater flows in the aquifer layers towards the point of discharge, which includes wells, springs, rivers, lakes, and the ocean. Groundwater makes up about 60% of the world’s fleshed water supply, which is about 0.6% of the entire world’s water (EPA 2009). Groundwater is also recognized as one of the most valuable natural resources, immensely important and dependable source of water supply in all climatic region of all over the world (Todds and Mays 2005).

Groundwater was one of the most important natural resource occurring both as surface water and groundwater resources on the surface of the earth’s. Development of our country is dependent on the reliability and use of adequate water found on the area. The precious is sometimes there is a lack, sometimes there is abundant but unevenly distributed, both in space and time. It is the second-most abundantly available freshwater resources and constitutes about 30% of freshwater resources of the globe (Subramanya, 2008). Around more than 1.5 billion people in the world are depend on the groundwater for drinking water or for domestic purpose. Generally it is derived from precipitation and recharge from surface water. Groundwater is water that has infiltrated into the earth directly from precipitation, recharge from streams and other natural water bodies and manmade recharge due to action of person.

Ethiopia has a high surface and groundwater resources potential; the preliminary estimated quantity of yearly groundwater recharge of the country is about 28,000 mm^3 (Kuniansky et al., 2007). Most of the developed groundwater resources are used for domestic and also for industrial use. Today, more than 80% of Ethiopia’s drinking water supply comes from groundwater (Awulachew et al., 2007).

The main sources of groundwater recharge are precipitation and flow and of discharge include effluent seepage into the streams and lakes, springs, evaporation and pumping. Because of its continuous availability and excellent natural quality, it becomes an important source of water supply in both urban and rural areas of any country (Todd and Mays 2005).There are several methodologies to locate and map the occurrence and distribution of groundwater. Satellite data provides quick and useful baseline information on the parameters controlling the occurrence and movement of groundwater even in inaccessible areas (M. Thangarajan, 2007). The information on the input parameters in the above can be acquired and integrated through remote sensing and GIS techniques. The concept of integrated remote sensing and GIS has proved to be an efficient tool in groundwater studies, in facilitate better data analysis and their interpretations (Saraf, A.K. et. Al. 1998, Krishnamurthy et. al. 1996 and murthy, 2000). In addition, greatest advantages of using remote sensing data for hydrogeological investigations and monitoring is its ability to generate information in spatial and temporal domain, which is very crucial for successful analysis, prediction and validation (Saraf, 1999).

The integration of GIS and remote sensing are efficient techniques in groundwater studies; in facilitating better data analysis and their interpretations of groundwater potential controlling parameters. In the present study, an attempt had been made to delineate and classify possible groundwater potential zones in the Sululta and surrounding watershed using integrated Remote s Sensing and GIS techniques. The thematic layers considered in this study are geomorphology, geology, drainage density, lineament density, land use land cover, soil, slope and rainfall were prepared using the Landsat ETM+ imagery and ArcGIS software. All the thematic layers were then assigned weights according to their relative importance in groundwater occurrence were obtained based on the Saaty's Analytical Hierarchy Process. These weights were applied in linear summation equation to obtain a unified weight map containing due weights of all input variables.

The thematic layers were finally integrated using ArcGIS and IDRISI Software to produce a groundwater potential zone map. Thus, four groundwater potential zones were identified, namely very high, high, moderate and low. The very high potential zones corresponding to flood plain, ventric cambisols which coincided with the low slope, low drainage density and very high lineament density areas. The low groundwater potential zones are present in the structural hills, chromic cambisols, very high slope, drainage density and low lineament density areas.

Delineation of ground water potential zones using GIS and Remote Sensing is an effective tool and is very useful in identifying the potential zone also in the arid to semi-arid region (Ganapuram et al. 2009). The occurrence of ground water, especially in fractured bedrock aquifers, in a given area is governed by factors such as topography, rainfall, geology, geomorphology, slope, drainage pattern, lineament density and soil types. As a result, the groundwater potential zones vary from place to place, sometimes within a few meters and even within the same geological formation (*Dar et al, 2010).* In hard rock terrain availability of the ground water is limited and is essentially confined to fractured and weathered zones. There are several techniques employed for delineating groundwater potential zones such as geological, hydrological, geophysical and remote sensing techniques. The Integration of various thematic maps was results, in the generation of groundwater potential zone map. Today Remote Sensing and GIS techniques are proved to be cost effective and time- saving tool.

The availability, accessibility, movement and occurrence of groundwater potential depend on geology, slope aspect, lineaments, drainage density, land- use/land-cover, rainfall, surface runoff and geomorphology of the area (Shaban *et al*., 2005). Evaluation, exploitation, delineation and maps of groundwater potential zone need a serious caution, as it is cost and time effective. Modern technology such as (GIS) and (RS) is the optional methods to provide all parameters which influence delineate groundwater potential occurrence and recharge zone of one area and it can access, manipulate and analysis the spatial and temporal data from satellite image (Kamal, 2017).Today, modern technologies like Geographic Information System is being used for various purpose such as ground water investigations and many authors (Shahid and Nath 2002; Singh and Prakash 2002) have attempted to delineate ground water potential zones. GIS techniques facilitate integration and analysis of large volumes of data, whereas the field studies help to further validate of the results.

The different inputs taken for GIS analysis were from Geological data, soil data, Landsat images and SRTM data. Remote sensing with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within short time has become a very handy tool in assessing, monitoring, delineating and conserving groundwater resources. Satellite data provides quick and useful baseline information on the parameters controlling the occurrence and movement of groundwater like geology, geomorphology, soil, land use/land cover, in this study; remote sensing data of LANDSAT image of year 2018 have been used for the preparation of land use land cover. Thematic layer generated using remote sensing data of land use/land cover, can be integrate with the reclassified, drainage density, lineament density, slope, Geology, data in a Geographic Information system (GIS) framework and analyze by using weight overlay analysis to derive at groundwater potential zones delineation. Data integration and map overlay is performing through GIS technique (1:50,000 scales).

Weighted Overlay Analysis (WOA) is a simple and straightforward technique for a combined analysis of multi-class layers. The Weighted Overlay Analysis can be incorporated in the analysis to consider the relative importance and lead to a better representation of the actual ground situation (Nag, 2005). Some researchers such as Sarma and Saraf (2002), Muthikrishnan and Manjunatha (2008) and also have applied this Geographical Information Systems (GIS) Modeling technique for delineation of groundwater potential zones at Upper Part of Langat Basin, Selangor, Malaysia, Using GIS and Remote Sensing. This study used GIS modeling technique of weighted overlay method to delineate groundwater potential zone map.

The study focuses on development of Remote Sensing and GIS based analysis and methodology in delineation of groundwater potential zones studies in Sululta and Surrounding Watershed. In order to implement delineate groundwater potential zones, it is essential to delineate groundwater potential zones. Conventionally, Remote Sensing and GIS methods are deployed to delineate a suitable area for implementation of groundwater potential zones.

1.2 Statement of the Problems

There was study conducted in the study area and its surroundings by other researcher but, There was a gap on using modern technology such GIS and remote sensing during previously works in the study area on delineation of groundwater potential zones. This study fills the gap by applying GIS and Remote Sensing techniques. These techniques were very easy to access, delineate groundwater potential zone of large and inaccessible areas and also helps to formulate environmental protection policy, management policy, the utilization of delineate groundwater potential zones.

Integrate approach of remote sensing and GIS can provided the appropriate platform for convergent analysis of divergent datasets for decision making is not only mapping and planning of groundwater resources but it is also used for management of groundwater resources for its efficient and cost effective use for a region and country. In general, there is no scarcity of groundwater in the study area rather there were the lack of shown that groundwater for concerned body by delineating the area which having or having not enough groundwater using modern technology which was time saved and cost effective.

At present, there are still few gaps in knowledge, skills and experiences for a proper assessment and delineation of groundwater potential zone using GIS and Remote Sensing technology. This study fills the gap by applying GIS and remote sensing technique and helps to formulate environmental protection on water resource management by shown the delineating groundwater potential zones area.

1.3 Research Questions

- Which factors influence the delineation of groundwater potential zones in the study area?
- Which method integrates all thematic maps in identifying groundwater potential zones of the study area?
- What is the level of reliability of the delineated groundwater potential zones using GIS and Remote Sensing Techniques?

1.4 Research Objectives

1.4.1 General Objectives

The general objective of this study is to delineate groundwater potential zones of Sululta and Surrounding Watershed by using Geographic Information Systems and remote sensing techniques.

1.4.2 Specific Objectives

- To identify the factors that influences the delineation of groundwater potential zone of the study area by using its thematic map.

- To delineate groundwater potential zones by integrating all thematic maps through analyzing in GIS environment.
- To validate the delineated groundwater potential zone map of the study area.

1.5 The Scope

The study is limited to delineate ground water potential zones in Sululta and Surrounding watershed. It focuses on some technical aspects of delineate groundwater potential zones. The issues under consideration in this study are only delineating ground water potential zones. The study not includes explore, engineering, supply and design part of the construction. Delineating criteria is limited to Geomorphology, Geology, Land use Land cover, Drainage Density, Lineament Density, Soils, Slope and Rainfall. The various methods that are commonly used in this study was Analytical Hierarchy Process, Weight Overlay Analysis and reclassification will be adopted for the study.

1.6 Significance

The finding of this study would serve as a worked document for Sululta Water resource and energy management office in the identification and delineation of groundwater potential zones for planning the Town in suitable manner. Not only this industrial company and agricultural participants were also used this document for select the station for their work. The techniques and procedures used in this study may be used as a reference material for any concerned body or individual for further study to conduct in other places.

1.7 Limitations

The present study was limited to Sululta and surrounding watershed. There were also many other limitations in which researcher face challenges during the researching period. From Those the lack of the whole groundwater inventory data and unevenly distribution of data point are the major limitation of this study.

1.8 Thesis Structures

This research contains five chapters on ground water potential delineation by using GIS and Remote Sensing techniques.

CHAPTER ONE: INTRODUCTION. This chapter mentioned briefly about introduction and background, the problems statement of the study, research questions, objectives, and scopes of the study, Significances, limitations and thesis structures.

CHAPTERS TWO: LITERATURE REVIEW. This chapter provides an overview of groundwater status Sululta and surrounding watershed and previous works of using GIS and Remote Sensing techniques for delineated groundwater potential zone mapping. Then, discussion describing Factors Affecting Groundwater Potential Zonation and application of GIS and RS for delineate ground water potential.

CHAPTER THREE: METHODOLOGY. This chapter was describes in details about the characteristics of the study area. Then followed by the materials, methodology and methods used for delineation of groundwater potential zones using GIS and remote sensing techniques, types of data used in these research and description of the study area such us topographic, slope, climate, geology, preparation of different thematic maps and reclassification according to standard. Methods to integrate and analyze the various thematic layers using a GIS and Remote Sensing are given. Moreover, the steps to generate groundwater potential delineation using in GIS presented in detail.

CHAPTER FOUR: RESULTS AND DISSCUSSION. This chapter concentrates on outcomes of the study including results of integration GIS modeling techniques which supporting by figure, tables, equations and charts. This is followed by data analysis, results interpretations and discussion of ground water potential zone delineation of the study area.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATION**.** This chapter provides the overall conclusions from this study, recommendation for concerned body and further research for the study area.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of groundwater status in Sululta and surrounding watershed and previous works of using GIS and Remote Sensing techniques for delineated groundwater potential zone mapping. Then, discussion describing Factors Affecting Groundwater Potential Zonation and application of GIS and RS for delineating ground water potential.

2.2 Definition of groundwater potential zones

Groundwater is the water that is found underneath the Earth's surface at profundities where all the open spaces in the soil, sediments, or rock are completely stacked with water. Groundwater of any structure whether from a shallow well or a significant well, devises and is refilled (energized) by rainfall. Groundwater is a piece of the hydrologic cycle, beginning when a piece of the precipitation that falls on the Earth's surface infiltrates through the soil and enters diving to wind up ground. It is the water that found underground in the cracks and spaces in soil, sand and rock in the study area. It is stored in and moves slowly throughout geological formation of soil, sand and rocks were called aquifers (Toddy, 1995).

There are different definitions given to groundwater potential zone by different authors in different time. As (Rashman., 2016), said groundwater is the most important natural resources found beneath the earth surface stored in void space of geological stratum used in economic development, domestic life, and ecological diversity. And also he concludes that, the occurrence and flows system of groundwater is depending on geological characteristics of its porosity and permeability and the formation of landforms such us high mountains, Rift Valley's and flat areas and the role of landform on surface runoff and infiltration to the ground.

There were a Varity of researches undertaken in delineation of groundwater potential zone mapping based on the application of GIS and remote sensing techniques. Very few of the relevant literatures reviewed are summarized/listed below.

(*Deepesh Machiwal et al.*, 2010) proposed that a standard methodology to delineate groundwater potential zones using integrated RS, GIS and multi-criteria decision making techniques. The methodology is demonstrated by a case study in Udaipur district of Rajasthan, western in India. Initially, ten thematic layers have been considered. Weights of the thematic layers and their features then normalized by using Analytic Hierarchy Process (AHP), Mult-Criteria Decision Making (MCDM) technique and eigenvector method. Finally, the selected thematic maps were integrated by weighted linear combination method in a GIS environment to generate a groundwater potential zone map in the study.

(*Jobin Thomas et al.,* 2011) delineation of groundwater potential zone in Tropical River Basin (Kerala, India) using remote sensing and GIS techniques. The information on geology, geomorphology, lineaments, slope and land use/land cover was gathered from Landsat ETM+ data and Survey of India (SOI) top sheets of scale 1:50,000 in addition, GIS platform was used for the integration of various themes. The composite map generated was further classified according to the spatial variation of the groundwater potentiality. The spatial variation of the potential indicates that groundwater occurrence is controlled by geology, structures, slope and landforms of that study area.

(*Murugesan Bagyaraj et al.*, 2012) have carried out groundwater study in the Dindigul district of kodaikanal hill, which is a mountainous terrain in the Western Ghats of Tamilnadu. Groundwater potential zones have been demarcated with the help of remote sensing and GIS techniques. All thematic maps are generated using the resource Landsat (IRS P6 LISS IV mx) data and Inverse Distance Weight (IDW) model is used in GIS data to identify the groundwater potential of the study area. For the various geomorphic units, weight factors were assigned based on their capability to store groundwater potential.

(*Prabir Mukherjee et al.,* 2012) made an attempt to determine the groundwater potential zones within an arid region of Kutch district, Gujarat. Thematic layers have been generated by using ancillary data and digital satellite image. The potential zones have been obtained by weighted overlay analysis, the ranking given for each individual parameter of each thematic map and weights were assigned according to their influence on groundwater potential.

(*M. Thangarajan et al.,* 2007) showed that, the advantage of remote sensing and GIS science in resources management.

(Vasanthavigar et al., 2011) delineated groundwater potential zones in Thirumanimuttar Basin with an integrated approach using Remote Sensing and Geographical Information System (GIS).

Landsat TM 30m resolution data and topographic maps has been used to generate thematic maps like geology, geomorphology, lineament and lineament density, drainage network, drainage density, slope map of the study area. A number of geomorphic units such as Denudation hills, Structural hills, Bajadas, colluvial plain, Pedi plain, and Alluvial plains have been observed. A composite groundwater potential map has been generated as very high, high, medium, low and very low based on the groundwater availability area. The upper, middle and downstream of the basins have been identified as potential zones. The data generated was validated with field inventory data checks and observed to be in conformity with the same.

(Ganapuram et al., 2009) explore the groundwater availability for agriculture in the Musi basin. Remote sensing data and Geographic Information System were used to locate potential zones for groundwater in the Musi Basin. Different types of maps base, hydro-geomorphological, geological, structural, drainage, slope, land use/land cover and groundwater prospect zones were prepared using the Remote Sensing data along with the existing maps. The groundwater availability of the basin is qualitatively classified into different classes (i.e., very good, good, moderate, poor and nil) based on its hydro geomorphological conditions. The alluvial plain in filled valley, flood plain and deeply buried Pedi plain were successfully delineated and shown as the prospective zones of groundwater.

(*Musa et al.,* 2000) used an integrated Remote Sensing and GIS system to produce various thematic maps for classifying groundwater potential zones Langat Basin, Malaysia. They used Landsat TM data, topographic maps, soil map and relevant field data for preparing various thematic layers such as annual rainfall, lithology, lineament density, drainage density, land use land cover, slope and soil type, and combined all the layers using a GIS and Remote Sensing techniques and weighted overlay analysis methods. The polygons in each of the thematic layers were categorized depending on their suitability/relevance to the groundwater potential and suitable weights were assigned to them. Finally, all the thematic layers were integrated using a groundwater potential model to derive the final layer. It was concluded that the integrated assessment of thematic maps using a GIS-based model proved to be the most suitable method for groundwater potential zoning in hard-rock terrains.

(*Sikdar et al.,* 2004) used Remote Sensing and GIS techniques to delineate groundwater potential zone in and around Raniganj coal mining area of Bardhaman District, West Bengal, India.

Various thematic layers namely geomorphology, lithology, drainage density, slope, lineament density and current land use and land cover pattern were considered to delineate groundwater potential zones. These thematic layers were prepared using GIS package, and ranked in a scale of 0 to 5 depending upon their suitability for groundwater potential. The rank of each map was then converted to a probability weight using Bayesian statistics and finally a multi-criteria overlay analysis was used to find groundwater potential zones. The groundwater abstraction structures (i.e., dug wells, mini-deep tube wells or deep tube wells) feasible in each of the delineated potential zones were also suggested.

(*Sujatha Biswar et al.*, 1999) Used of satellite data to identify various geomorphic features of the upper Baitarani river Basin of Orissa. Further, the authors have classified the land features into denudation and fluvial origin and evaluated the groundwater potential of various landforms of the study area by delineated its occurrence.

(*Shanta Kumar et al.*, 1996) was used Remote Sensing and GIS technique for delineating groundwater potential zones in the entire state of Tamil Nadu of the study. Thematic maps such as geomorphology, geology, soil, slope, land use/land cover, drainage density, lineament density, runoff and depth of water table zones were taken into consideration in the study.

It is estimated that approximately one third of the World's population use groundwater for drinking (*Jose et al.*, 2012). Ground water is also the source for irrigation and domestic purpose. 80% of the rural areas are use ground water for domestic purpose and in other way 50% of the urban areas use the ground water for domestic purpose. Due to more dependent on usage of ground water for domestic purpose and irrigation and for other sectors may results in exploitation of ground water resources (Shakak, 2015). Ground water is dynamic and replenish able resource. The exploitation, occurrence and exploration of ground resources needs to understanding geology, geomorphology that are found in the study area. The thematic maps of factors such as satellite images, soil data, geology data, drainage data and rainfall data, are helpful for mapping ground water potential zones (Giri &Bharadwaji, 2012).

There is the increasing trend of using RS and GIS for the delineation of ground water potential and other ground water related issues mainly in India and other south Asian countries. The National Remote Sensing Agency in India was the first to integrate information from remote sensing and GIS for delineating the ground water recharge potential zone in India at 1987.

Krishnamurthy et al (1996) used Geographical Information System to demarcate ground water potential zones of Marudaiyar Basin using different thematic maps such as lithology, landforms, lineaments, surface water bodies, drainage density, slope classes and soil map.

2.3 Groundwater in Ethiopia

Tamiru (2006) studied groundwater occurrence in Ethiopia and described the most important factors governing the groundwater flow and storage in volcanic rocks. In addition, he summarizes that the variation in mineralogy, texture, and structure of volcanic rocks cause the variation of water bearing capacity of the area.

Seifu (2010) conducted on the groundwater occurrence in Ethiopia, partly divide the source of groundwater recharge in Ethiopia under flood recharge, Wadi flood recharge, rainfall recharge and mountain block recharge, runoff and summaries the water isotope is the evidence.

(Yitbarek *et al*., 2012) describe type and distribution of lithology in Ethiopia and they categorize sedimentary and Mesozoic sandstone to the southern, karstic rocks to eastern and southeastern, quaternary volcanic rocks and unconsolidated sediments in rift valley and low land depression area, fractured intrusive rocks, old Precambrian rocks and metamorphic rocks to western part of Ethiopia and their aquifer characteristics.

(Adetunji *et al*., 2011) conducted water balance of upper Awash River basins based on the satellite data on his MSc thesis, understanding the spatial variations of water balance components upper Awash River basins was provide full information for the management surface and groundwater. The results show that the geology of main Ethiopia rifty valley is very complex, which are difficult to describe the hydrology of the area because of variability and lateral discontinuity of volcanic rocks (Ernesto *et al*., 2015).

2.4 Groundwater Potential in the Study Area

The present study focused on the delineation of groundwater potential zone in Sululta and Surrounding watershed Ethiopia based on integrated GIS and Remote Sensing techniques. Groundwater in the study area is abundant when it considered with other part of Ethiopia such as rift valley and other low land parts. This abundant groundwater potential was used in domestic purpose and in some industrial company. In general, there is no lack of groundwater in the study area but there are the lacks of shown that groundwater for concerned body by delineating area which have and have not groundwater showing its groundwater potential zone mapping by using GIS and remote sensing techniques.

2.5 Factors Affecting Groundwater Potential Zonation

Groundwater potential zonation means identifying and mapping the prospective ground water potential zones in an area by qualitative assessment of the controlling and indicative parameters analysis. In this study the main factors responsible for groundwater potential zone developments are geology, geomorphology, lineament, slope, soil, drainage pattern, land use and rainfall etc.

Groundwater potential zone was affected by different factors that control/facilitate this process according to different previous works. As discussed by (Prasad, 2008) on deciphering of the ground potential zone in hard rock water through the application of GIS. Partly he discussed on the geology, geomorphology, lineament, slope, soil, drainage pattern, land use and rainfall. Finally, he summarizes, as those above parameters are very important factors in ground water potential zone mapping.

(Annesh and Paresh, 2015) Study origin of occurrence and movement location of groundwater by using remote sensing data based on indirect analysis of directly observable terrain features like geological structures, geomorphology, Land-use/land-cover, Slope, Rainfall, drainage density, and lineaments.

The integrated GIS and Remote Sensing are efficient techniques in groundwater delineation; in facilitate better data analysis and their interpretations of groundwater potential controlling parameters. In the present study, an attempt had been made to delineate and classify possible groundwater potential zones in the Sululta and Surrounding watershed using integrated Remote Sensing and GIS techniques. The thematic map for factors area prepared and all the thematic layers were then assigned weights according to their relative importance in groundwater potential zones were obtained based on the Saaty’s Analytical Hierarchy Process.

2.6 Application of GIS and RS for Delineate Ground Water Potential zone

Jose and Antony (2015) Remote Sensing and Geographic Information System has become one of the important tools in the field of hydro geological science, which helps in assessing, monitoring, delineating and conserving groundwater resources. It allows manipulation and analysis of individual thematic layer of spatial data. It is used to analyzing and modeling the interrelationship between the layers. The present study mainly deals with the integrated approach of Remote Sensing and Geographical Information System (GIS) to delineate groundwater potential zones in Sululta and Surrounding Watershed. The application of GIS tools helps to increase the accuracy of results in the delineation of ground water potential zones (Rao and Jugran, 2003). It has been summarized that delineation of ground water potential zones by using GIS is convenient and times saving as large number of data can be handled in the GIS (Pathak, 2017).

The remotely sensed data at the scale of 1:50,000 and topographical information from available maps, have been used for the preparation of groundwater prospective map by integrating geology, geomorphology, soil slope, soil, land use of the study area. Further, the data on yield of aquifer, as observed from existing bore wells in the area, has been used to validate the groundwater potential map.

Suganthi et al. (2013) delineate the groundwater potential zones of the Coastal part of the Arani and Koratalai River Basin, Southern India area using Remote Sensing (RS) and Geographic Information System (GIS) techniques. Weighted overlay analysis was used to demarcate the groundwater potential zones. Various thematic layers such as geology, geomorphology, soil, lineament density, drainage density, rain fall and land use maps were prepared for the delineate groundwater potential zones. The geological map was prepared using a Geological Survey of India (GSI) district resource map. Satellite imagery was used to prepare the geomorphology, soil, lineament density, drainage density, and land use maps. The final groundwater potential map was prepared by assigning appropriate weight age to different thematic maps and adding them to the final groundwater potential zone map. The derived groundwater potential map was overlaid with the groundwater level and location of well fields for validation of the results.

Remote Sensing and Geographic Information Systems are the modern technology which have proved to be useful for studying geological, structural and geo-morphological conditions together with conventional surveys. Satellite images are increasingly used in groundwater delineation because of their utility in identifying various ground features, which may serve as either direct or indirect indicators of presence of groundwater potential zone. The Geographic Information System has emerged as a powerful tool in analyzing and quantifying such multivariate aspects of groundwater occurrence.

It is very helpful in delineation of groundwater potential zones. Remote Sensing data provide accurate spatial information and are cost-effective compared with conventional methods of hydro-geological surveys. Digital enhancement of satellite data improves maximum extraction of information useful for groundwater studies. GIS techniques facilitate integration and analysis of large volumes of data through weighted overlay, whereas field studies help to further validate results. Integrating all these approaches offers a better understanding of features controlling groundwater occurrence. Remote Sensing and Geographic Information System has become one of the important tools in the field of hydro-geological science, which helps in assessing, monitoring, delineating and conserving ground water resources. It allows manipulation and analysis of individual layer of spatial data. It is used for analyzing and modeling the interrelationship between the layers. Remote Sensing technique provides an advantage of having access to large coverage, even in inaccessible areas. It is a rapid and cost- effective tool in producing valuable data on geology, geomorphology, lineaments, slopes, etc., that helps in delineate groundwater potential zone. A systematic integration of these data with follow up of hydro-geological investigation provides rapid and cost-effective delineation of ground water potential zones. Remote Sensing and GIS are playing a rapidly increasing role in the field of hydrology and water resources development.

CHAPTER THREE

METHODOLOGY

3.1. Introduction

This chapter describes in detail about the characteristics of the study area. Then followed by the materials, methodology and method used for delineation of groundwater potential zones using GIS and remote sensing techniques, types of data used in these research and description of the study area such us topographic, slope, geology, preparation of different thematic maps and reclassification according to standard. Methods to integrate and analyze the various thematic layers using a GIS and Remote Sensing are given. Moreover, the steps to generate groundwater potential zone delineation using in GIS presented in detail.

3.2 Description of the Study Area

3.2.1 Location and Area

The study area is found in the central part of Ethiopia, Oromia Special Zone Surrounding Finfinnee and reached via the main high way of Addis Ababa-Bahir Dar. Astronomically, the study area extends from 9^o 5'40''N to 9^o 15'15''N latitude and 38^o 32'30''E to 38^o50'45''E longitude with the total Area coverage of 328.5 km^2 as shown in Figure 3.1. In relative terms, the study area is located at a distance of 23km along Addis Ababa- Bahir Dar road and in south direction by Addis Ababa and in the left three directions by Sululta rural woreda. The Universal Transverse Mercator 37 North (37N UTM) is its Projected Coordinates systems.

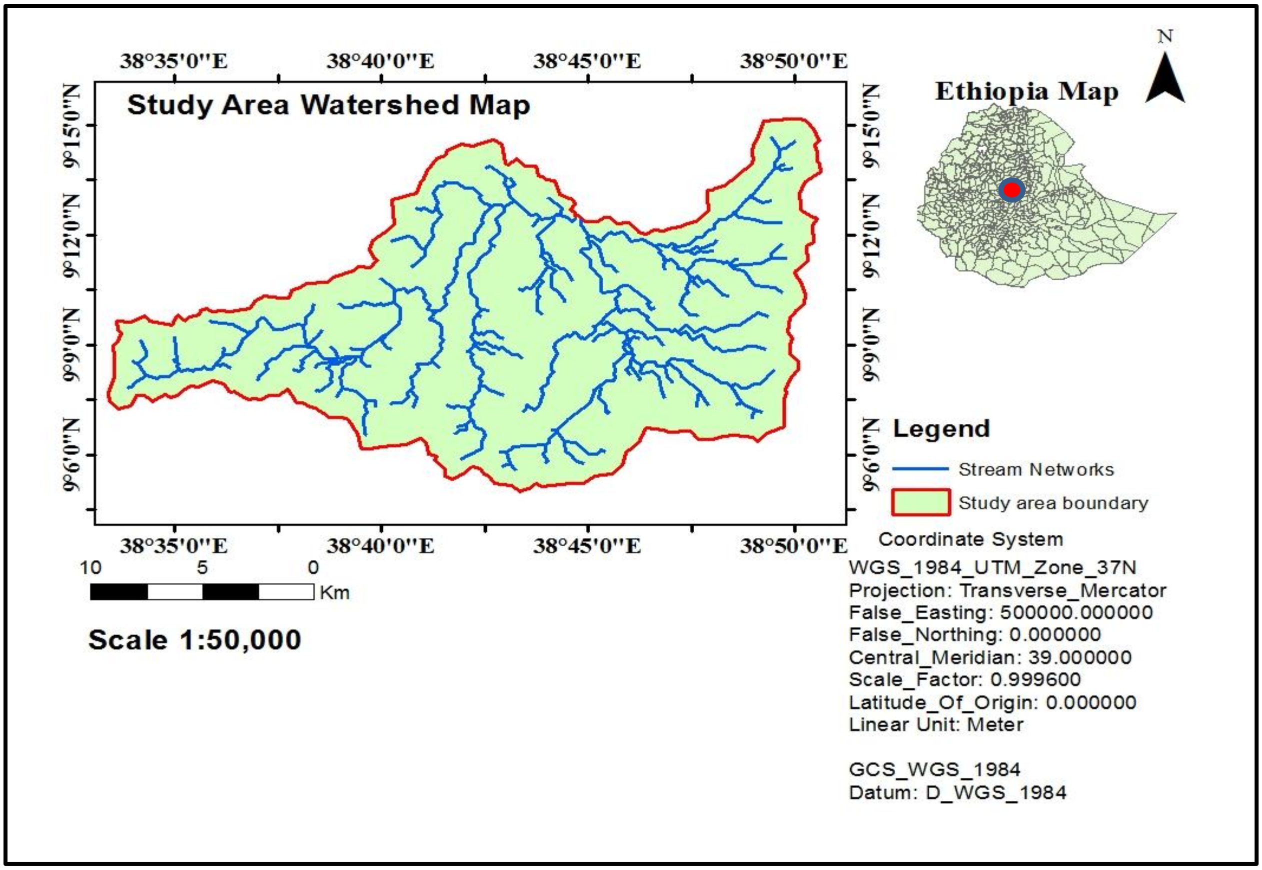

Figure 3.1: Map of the study area

3.2.2 Topography

The topography of the area varies from chains of mountains around entoto ridge in the South to plain lands in the East, North-West, and North. The average elevation in the Town is 2600m above mean sea level. The altitude of the study area generally dropdown south-north direction from 2800m to 2500m above mean sea level. The peak altitude of the area is 2800m at Entoto ridges and the lowest is 2500m to the north fringe of the study area. The elevation map of the area will be generating from SRTM of 30m*30m data. The minute elevation difference with in the whole area contributes a lot for water logging as most of the area is possibly classified as black cotton soil area.

3.2.3 Slope

In the study area the slope is also another topographical aspect that influences the delineate ground water potential. HsinFuYeh (2016). Slope is one of the majors factors that controlling infiltration of water to the ground and the indicator of groundwater potential suitability. Very high sloping region causes more runoff and less infiltration and have poor groundwater prospects when compared to the low slope region. Low slopping regions causes less runoff and high infiltration rate and has good groundwater potential. The steepest slope in the study area is situated in the elevation range of 2640m to 2800m almost around the southern ridge of Entoto and North-Eastern fringes. By implication high run off and lateral erosion is high in these areas compared to the gentle slope locations. The gentle slope lies mostly in the central part of the study area within 2580m to 2700m altitude where the existing built up area lies**.** The flat area of the Town is found in the altitude of less than 2580m in the East and North-West of the study area**.** This area is one of the likely water logging area during the rainy season and potential grazing land in dry season.

3.2.4 Soil Data

Soils are highly affects the movement and infiltration of ground water (Hornsby, 1986, Maurice and Courteny, 1990). Soils are the world's natural resource and a soil map is a spatial representation of these resources. Therefore, soil map is fundamental and should be the starting point when ground water potential zone delineation processed. There were three types of soils found in the study area, viz. chronic luvisols, vertic cambisols and chromic cambisols as shown in figure 4.7.

3.2.5 Generating Land Use/Cover Data

Land cover plays a significant role in the development of groundwater resources. It controls many hydro geological processes in the water cycle viz., infiltration, evapotranspiration, surface runoff etc. Surface cover provides roughness to the surface, reduce discharge there by increases the infiltration. In the forest areas, infiltration will be more and runoff will be less whereas in urban areas rate of infiltration may decrease. It is preferable that wetlands/waterlogged areas, forest covered areas are potential areas for groundwater occurrence.

3.2.6 Drainage Network System

Stream network can be generated from an elevation model (DEM) and satellite image data. A drainage network density describes the way of streams that feed other larger streams and rivers branch off in different directions. Thus, major drainage pattern in the study area can be described as streams and rivers, in which the Streams tend to from about 3 major rivers in the area. These are Lega Dima, Orgogo and Billo rivers, as most areas of the town is flat and the rivers transient through it are narrow in width and shallow in depth, they get over flood. Drainage network or drainage density is an indicator for the natural infiltration of a terrain. A higher drainage network density reflects a higher runoff, hence less infiltration; or as stated in the denser the drainage network, the lower the recharge rate.

3.2.7 Lineament Density

Lineaments are the most obvious structural feature that is important from the groundwater point of view (Ramasamy et al., 2001). The Lineament map of the study was generated from the georeferenced Geological map by digitizing and identifying the fault lines in the imagery using the ArcGIS 10.5.1. The study area is found to have a number of crisscrossed lineaments. The intersection of lineaments is considered as good occurrence of groundwater potential zones. Lineaments like joints, fractures and faults are hydro geologically very important and may provide the pathways for groundwater movement. The density of the lineament is generated using the lineament map by using line density methods using spatial analyst tool.

3.3 Data Sources, Materials and Methods

3.3.1 Data Sources

To achieve the aim/objectives of this study, both primary and secondary data are used**.** Some data used in this research generated from different sources. The major data used in this study includes Soil data from Ministry of agriculture of Ethiopia, Geological Map of study area from Geological Survey Ethiopia (GSE), Rainfall data taken from Ethiopia National Meteorology Agency, Land use land cover, slope, geomorphology and drainage data were generated from downloaded all land sat 2018 from USGS earth resource observation system data center. (https://earthexplorer.usgs.gov). All images were downloaded at level 1 geotiff format and all the images are from Landsat ETM+ and all have a 30m spatial resolution.

Rainfall Map prepared from Ethiopia National Meteorological Agency, Lineament density map, geological map were prepared from Geological Survey of Ethiopia by digitizing after georeferencing and rectifying is process, drainage density map, Geomorphology map and slope map prepared from DEM. Soil map of the study area prepared from soil data from ministry of agriculture, field observation, reports, and journals. All the above data are collected, manipulated, and analyzed in GIS and RS Environment to use for further analysis on determining groundwater potential zone delineation.

3.3.2 Primary Data

The primary data are use Landsat 7 current land use/land cover of the study area and it is downloaded from U.S. Geological Survey Global Visualization Viewer Website without the presence of cloud cover. SRTM images derive from USGS with spatial resolution of (30 m * 30m) are used to extract Digital Elevation Model (DEM) of Sululta and surroundings and it is use to extract slope map, drainage density map, geomorphology map, borehole wells collected from field and used to validate the predicted groundwater potential zone map with the existing groundwater potential zone map, rainfall data taken from National Meteorological Agency to create rainfall map of the study area. Field observation with experts of environmental protection officers and residents who are near to the study are to get more information.

3.3.3 Secondary Data

The secondary data used in this study includes soil map of the study area from ministry of agriculture for mapping soil types in the study area and Geological map of study area obtained from Geological Survey of Ethiopia (GSE). Additionally, secondary data for the study was gathered from reports, journals and governmental institutions manuals used in the management of water resource. In general types of data and its sources are listed in table 3.1 below.

Table 3.1 Types of data and data source

Data Types	Data	Scale/Resolution /Format	Source	Functions
Primary Data	DEM Data	SRTM (30m*30m) Resolution	United States Geological Survey (2018)	Used to generate Slope, Drainage and Geomorphology map of the study area
	Landsat 7 of (2018) data	ETM+ (30m*30m) (2018 year: path 168 and Row 54)	United States Geological Survey (2018)	Used to generate Land use Land cover map of the study area
	Rainfall data	Excel Format	National Metrological Agency(2005-2015)	Used to generate Rainfall map of the study area
	Borehole Data	Excel Format (1998-2003)	Collected by Handled GPS	Used to validate the groundwater potential map
Secondary Data	Geology Map	1:250,000	Ethiopia Geological Survey (2011)	Used to generate Geological and Lineament Map of the study area
	Digital soil Map	Shape File	Ministry of Agriculture	Used to generate the soil map of the study area

3.3.4 Building the Research Geodatabase

In the study area the generated, collected and digitized data was organized into logical groups of entities concerning geological factors and lineament density, drainage density, physiographic factors (geomorphology, slope, Land use/ Land cover). Then, individual entities assigned and converted to characteristic spatial representation format in order to make them suitable for analysis in GIS environments. After making decision on the research geodatabase, the data sets prepared so that it help to develop the following maps in the study area.

In order to delineated the groundwater potential zones of the study area different thematic maps on 1:50,000 scales and 30m*30m cell size prepared from remote sensing and existing maps.

Drainage density map prepared from SRTM data 3DEM hydro processing, Slope map prepared using Digital Elevation Model (DEM) from SRTM spatial analyst, and Land use/Land cover map prepared using supervised classification in ERDAS 2014 Software for Landsat ETM+ Image 2018. Groundwater potential zone map prepared by weight overlay analysis using IDRIS 7.02 and Arc GIS 10.5.1 software's.

3.3.5 Data Analysis

In this stage, digital image processing of the satellite data carried out for extraction of important information. The groundwater delineation in the study area involved thematic map generation and their integration through GIS environments. Prior to integration of different information, individual class weights and map scores was assessed based on satty's Analytic Hierarchy Process where a pair-wise comparison matrix prepared for each map using a nine point important scale and weighted depending on relative importance .

The result unified weight map containing due weights of all input variables. The weight values this final map further logically was classified to arrive at delineation of groundwater potential zone map. This provides a broad idea about the groundwater prospect off the study area. To achieve the final target of the study, delineation of groundwater potential zones, different thematic layers; geology, geomorphology, lineament density, drainage density, slope, soil, land use/land cover and rainfall integrated using GIS and Remote Sensing techniques.

3.4 Materials

This study used different instruments and technology to determining ground water potential zone site for Sululta and surrounding watershed. With regard to this study for data preparation and organization, data analysis and output generation computer hardware and software are used for study. The hardware includes Personal Computer, Printer, and digital camera. The software also for preparing and analyzing of data in materials are used to collect and store. The software uses for data pre-processing and preparation, data analysis, editing and output generation are Arc GIS 10.5.1 and IDRISI Selva 17.02. The details information of the application software used in this study was shown in (Table 3.2) below.

Table 3.2 List of application software

No	Software	Purpose	Remark
1	ARC GIS Software	Integration of spatial and non-spatial data, thematic map generation and also for map layout preparation	Version 10.5.1
2	ERDAS IMAGE 2014 Software	Digital image processing like image enhancement, image preprocessing, layer stacking, Classification…	Version 2014
3	IDRISI Selva Software	calculate weights for each factors using relative importance value and combine	Version 17.02
4	Arc-Swat Software	Used for watershed delineation	data
5	Google Earth	Ancillary data downloaded	data
6	MS word and MS excel	Writing, chart preparing and statistical analysis	Version 2016

3.5 Methods

3.5.1 Data Collection Methods

The methods for data collection are dependent on the required data for each specific research question. Collecting accurate and reliable data is the most determinant factor for any research as it determines the quality of the research. Data use in this study collects through field observation, by downloading, by purchasing from different organization, by capturing digital photograph. Accordingly, the necessary data were collected from the respective sources.

Borehole data like groundwater depth, borehole wells points and borehole discharged/yields (m^3/h) was obtained from Sululta Town Water management office. Geology Map of Sululta Town was obtained from Geologic Survey of Ethiopia for mapping geologies and Geological data of the study area are used to extract geology and lineament density of the study area. Landsat ETM+ of 2018 image of the study area used to map the current land use /cover of the study area. SRTM (30m*30m Resolution) were used to extract Digital Elevation Model (DEM). The DEM was used to extract slope, geomorphology and drainage pattern of the study area. GPS were used for collecting borehole data like Ground water depth and location of the study area. All the above data were collected, manipulated and analyzed in GIS environment to be used for further analysis.

3.5.2 Data Analysis Methods

As it is described in the above section this research benefit from combination of data from different sources. Likewise, different data analysis methods and tools will be employed in this study such as methods of GIS operation for suitability analysis. Methods like rectifying, digitizing, reclassify, Analytical Hierarchy Process and weighted overlay analysis are the major ones uses in this study to delineate groundwater potential zone maps. In general this chapter presents methods that are used during the research study.

3.5.3. Digitizing

Digitization is a process to capture an analog signal to a digital form and also it is the process of drawing or tracing map features to create a new geographic file. The aim of the digitization is to enhance access and improve presentation. This function of GIS is used to develop features such as like soil types, Geology and lineament density are produced from the soil map and geologic map by this digitizing method.

3.5.4. Thematic Map Preparation

Thematic maps are an important source of GIS information. These tools were tools which used to communicate geographical concepts in the form of map. The thematic maps such as rainfall, land use land cover, geomorphology, geology, slope, lineament, soil and drainage density map are prepare by using digitization, overlay analysis with the appropriate criteria.

3.5.5 Analytical Hierarchical Process

Analytical Hierarchical Process (AHP) is a multi-criteria decision making method developed by Thomas L Satty in (1980) and this method is used in the study. It is a strategy to get proportion scales from paired difference. The information has been taken from actual measurements such as weights, price and from subjective as shown in (Table 3.3) below.

Table 3.3 Satty's Analytic Hierarchy Process a nine point important scale

Rating	1/9	1/7	1/5	1/3	1	3	5	7	9
Qualitative Description	Extremely	Strongly	Strongly	Moderately	Equally	Moderately	Strongly	Strongly	Extremely
	Less importance					More importance			

3.6 Data Preparation Methods

In present study different polygons in the thematic layers labeled separately and then they were converted into raster and registered. In the final thematic layer initially each one of the raster qualitatively the final potential groundwater map.

The methodology of the present study, a delineation of groundwater potential zone for further hydrogeological investigation selected using GIS and Remote Sensing techniques. The study is carried out in 4 major steps, in which inputting data sets , deriving data sets, reclassifying data sets and weighting and combining datasets of the thematic maps are integrating and analysis of all data will be processing.

The, steps required are discussed as follows:-

3.6.1 Inputting dataset

In this study data sets such as SRTM data, Landsat image and geological data of the area are identified and used as inputting data sets for further processing. Inputting data sets used for this study is SRTM (Shuttle Radar Topographic Mission) 30*30m resolution to generate digital elevation model of the area, geological data of Sululta town to extract geological data of the area and Landsat image of year 2018 have been used for the preparation of land use land cover as inputting data sets, soil data digitized from soil map of ministry of agriculture.

3.6.2 Deriving Data set

In these step data analysis is Applied to extract new information from existing data or input data to get thematic map. drainage network data generation, computing drainage density, extracting elevation, lineament data generation, computing lineament density, digitizing geology data, and generating land cover data are analysis to show the ground water potential zone delineation.

3.6.3 Reclassifying Datasets

The extract data are reclassified to a common scale giving higher values to more Suitable attributes and low value to less suitable attribute. Reclassifying slope, soil, land use/land cover, geology/rock type, drainage density and lineament density, geomorphology and rainfall will be analysis in general.

3.6.4 Weighting Overlay and Combine Datasets

The present study analysis the reclassified layers by Giving weight value to each reclassified data sets according to their influence in the suitability mode and combines them to delineated ground water potential zone of the area. The weight of the parameters can be deriving using weight over lay analysis. By assigning percentage influence (%) of parameters, and comparing the relative importance of criteria. Finally, to arrive the groundwater potential map and all the thematic layers was overlaid using weightage overlay module in Arc GIS 10.5.1 and validated with ground truth.

In general Remote sensing and GIS techniques were applied to delineate groundwater potential zone of the Sululta and surrounding watershed through Analytical Hierarchy Process. The methods used for the study includes following steps/stages: i) identification of criteria, Data collection, iii) Preprocessing, iv) input dataset, vi) reclassified input layers, vii) pair wise comparison of criteria and give weight with (AHP), x) weighted overlay analysis ArcGIStools, Ranking the final value. The general work flow of the study are illustrated as shown in (fig 3.2)

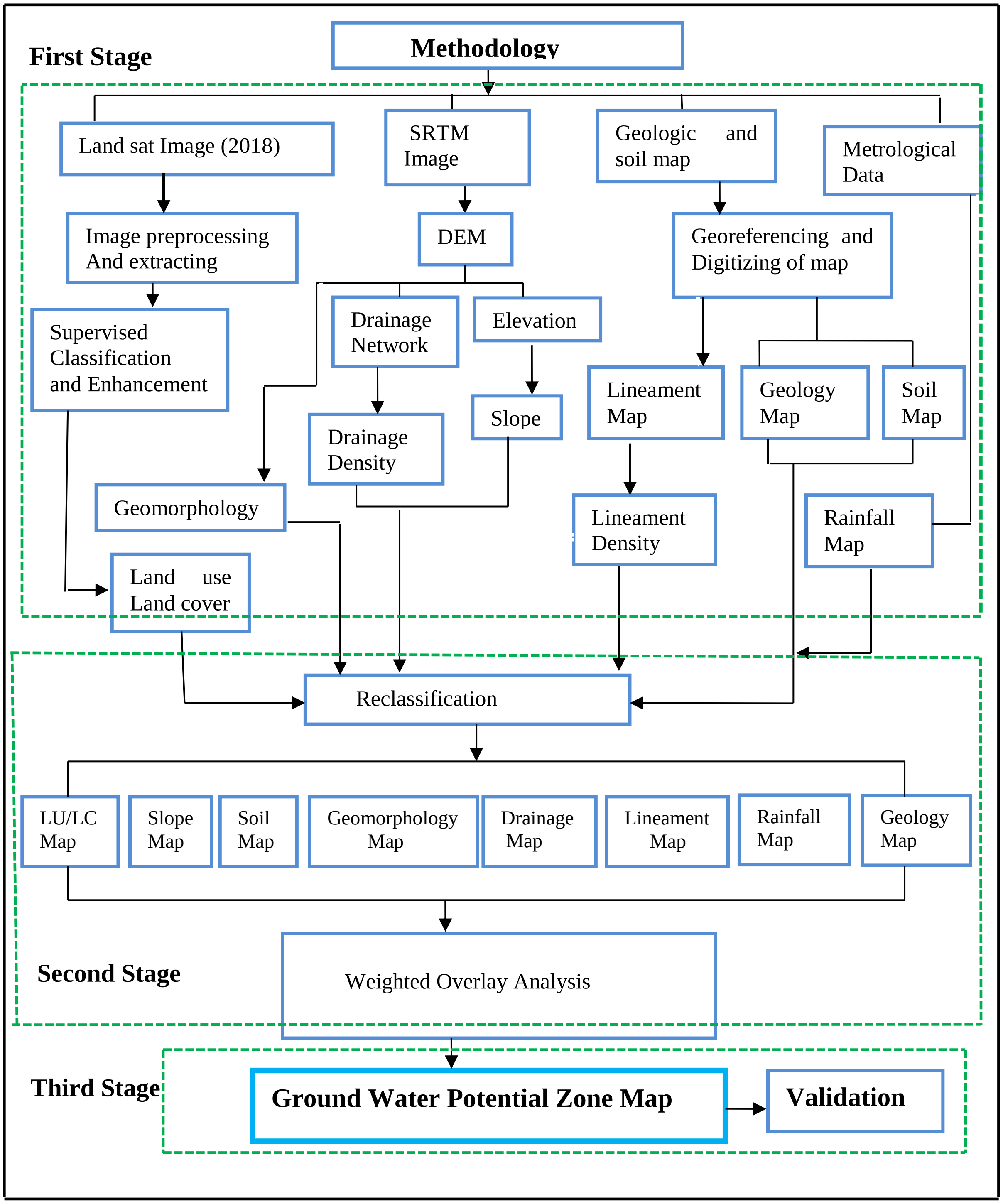

Figure 3.2: General work flow of the study

CHAPTER FOUR

DATA ANALYSIS, RESULTS INTERPRETATION AND DISCUSSIONS

4.1 Introduction

This study conducted in Sululta and surrounding watershed to delineate ground water potential zones of the area. The chapter concentrates on outcomes of the study including results of integration GIS modeling techniques which supporting by figure, tables, equations and charts. This is followed by data analysis, results interpretations and discussion of ground water potential zone delineation and validation of the results.

To delineate the different ground water potential zones, essential parameters were considered, and the thematic maps were prepared for each layer. These maps were converted into raster data sets having the same pixel size (30m*30m) and different weightage were assigned as per their groundwater potential controlling capacity within the study area and reclassification of each map was done based on the weight values produced. Accordingly the value 1 was given for very high controlling units, 2 for high controlling units, 3 for moderate controlling units and 4 for low controlling reclassified units. Finally, the maps integrated using GIS software and weighted overlay analysis with the purpose of intended to delineate the groundwater potential areas for the study region.

Essential parameters considered during delineate ground water potential zones were slope, Geomorphology and Drainage are extracting by mask from DEM of the area. Geology types area digitizing from Geological survey map of Ethiopia. Soil types digitizing from soil map of ministry of agricultural. Land use land cover map prepared from Landsat image (2018). Rainfall map prepared by calculate Mean Annual Precipitation data (2005-2015) 11 consecutive years and interpolate using Inverse Weight Distance method. These maps were converted into raster data sets having the same pixel size(30m*30m) and different weightage were assigned as per their groundwater potential controlling capacity within the study area and reclassification of each of map was done based on the weight values produced. Finally, the maps integrated using GIS software to delineate groundwater potential zones for Sululta and Surrounding watershed by using the GIS capability and weighting product of AHP method. For geomorphic units, flood plains were assigned by highest value, Pedi plains were assigned by high value, denudation hills were assigned by moderate value and structural hills with low lineament density and higher drainage density were assigned low values.

For Geology units Cheleka Basalts were assigned by highest value, Middle Basalts/Quaternary superficial sediments were assigned by high value, Quaternary Basalts were assigned by moderate value, Trachyte/Entoto Volcanics were assigned low values.

For Land Use Land Cover Water body were assigned by highest value, Forest Area were assigned by high value, Agricultural Land and Bare land were assigned by moderate value, built up Area were assigned low values. For Drainage density weightage was assigned in increasing manner for the (0-7.728)km/km^2 very high, (7.729-24.04)km/km^2 high, (24.05-49.37)km/km^2 moderate, and (49.38-109.5)km/km^2 low respectively. For lineament density weightage was assigned in increasing manner for the (1.73-2.29)km/km^2 very high, (1.16-1.72)km/km^2 high, (0.574-1.15)km/km^2 moderate, (0-0.573)km/km^2 low respectively. The slope percentage between (0-4.617)% very high, (4.618-10.48)% High, (10.49-18.82)% moderate and (18.83-45.28)% low was assigned on account of increasing run off and decreasing infiltration respectively. In the soils types for chromic cambisols low value was assigned whereas chronic luvisols was assigned by moderate value and ventric cambisols was assigned by very high value for their low water holding capacity and permeability allow fast percolation (Ayenew, 1998). Similarly owing to influence the groundwater infiltration and alters the rate of percolation of precipitation in areas.

Finally, high rainfall and recharge values favor groundwater potential and thus, the weightage was assigned in increasing order of rainfall amount mention in the rainfall map (Figure 4.9). All the weighted thematic maps were integrated and defined criteria weight using the IDRIS software and overlay analysis done using ArcGIS software and groundwater potential zones were delineated.

4.2 Data Analysis

All the weighted thematic maps were integrated and defined criteria weight using the IDRIS software and overlay analysis done using ArcGIS software and groundwater potential zones were delineated. GIS analysis such as geologic structures, drainage density, interpolation of rainfall point data, extraction of slope from DEM and overlay analysis for producing the groundwater potential area were done; moreover Analytical Hierarchy Process and weighted overlay were done for analysis of the different parameters that control groundwater potential zone delineation. All data layers derived were converted to raster data sets having the same pixel size. Each data sets in a single map were given weight by pair-wise comparison in addition the factor maps were compared each other in pair- wise comparison. Reclassification of each map was done based on the weights produced.

The eight thematic layers taken for the determination of potential groundwater were drainage density, slope, land use/land cover, lineaments, geology, soil, geomorphology, and rainfall. GIS-based mult-criteria evaluation was used to determine rates for the classes in a layer and weights for each thematic layer based on Saaty's Analytical Hierarchy Process (AHP). Combination of the thematic layers was done by Weighted Overlay Analysis (WOA) methods.

4.2.1 Data Interpretation

Giving weight value to each reclassified data sets according to their influence in the suitability mode and combines them to delineated groundwater potential zone of the study area. The weight of the parameters can be calculating using AHP weight derivation and followed by weight overlay analysis. By assigning weight percentage influence of parameters, and comparing the relative importance of criteria.

The main task in this stage was to carry out analysis and interpretation of satellite data, in order to produce thematic maps, such as geology, geomorphology, land use and land cover soil, slope, drainage density, lineament density and rainfall maps. It was followed by processing the digital images using the various processing techniques such as enhancement, accuracy assessment, classification and other GIS processes. It was validated through ground truth. All the available spatial data was assembled in the digital format and properly registered to make sure the spatial component overlays perfectly. Digitizing of all the maps followed by transformation and conversion from raster to vector, interpolation and other GIS processes were undertaken. Finally to arrive the groundwater potential map and all the thematic layers was overlaid using weightage overlay module in Arc GIS 10.5.1 and validated with ground truth.

4.2.2 Image Acquiring

The images which used for LULC analysis was downloaded from Google Earth because of to get reliable data that has high resolution. The raw images were obtained from Earth Explorer (http://earthexplorer.usgs.gov) for free. Prior to the usage of the images, geo-referencing, layers staked, subset (AOI), accuracy assessment and classification techniques had been applied to get an image overlay to the study area.

4.2.3 Image Classification Process

First high resolution image downloaded from Google Earth and geo referenced the image. Next clip the image with the study area boundary and conducted manual digitization techniques for classifying the image. This method is reliable because the features are clearly identifiable. The image is classified and to make some correction before accuracy assessment, a post classification editing method applied to resolve some minor geometric errors. The vector classified image converted to raster format and in ERDAS Imagine 2014 software were generated and these points converted to Google Earth format(.kml), which displayed on Google Earth and their representation taken and performed the accuracy assessment.

The image classification shows to grouping image pixels into categories or classes to produce a thematic representation. There are two main methods which are called supervised and unsupervised classification in image classification process. One is supervised classification which was “A procedure for identifying spectrally similar areas on an image by identifying ‘training’ sites of known targets and then extrapolating those spectral signatures to other areas of unknown targets”. It can be used to cluster pixels in a data set into classes corresponding to user-defined training classes. This classification kind requires that researcher select training areas for use as the basis for classification. Various comparison methods are used to determine if a specific pixel qualifies as a class member. In order to identify the class features of the images, due to the visibility of the image and the study area is small, manual digitization techniques has been applied in this techniques.

It requires the manual identification of Point of Interest areas as reference (ground truth) within the images, to determine the spectral signature off identified features. This is the most common types of classification techniques in which all pixels with similar spectral value are automatically categorized into land cover classes or themes. So in general land use land cover of project area classified in 5.

1. Agricultural Land: This may be defined broadly as land used primarily for production of food and Fiber.
2. Urban or Built-up Land: It is comprised of areas of intensive use with much of the land covered by structures such as: cities, towns, villages, strip developments along highways, transportation, power, and communications facilities, and areas such as those occupied by mills, shopping centers, industrial and commercial complexes, and institutions that may, in some instances, be isolated from urban areas.
3. Forest Lands: It has a tree-crown areal density (crown closure percentage) of 10 percent or more are stocked with trees capable of producing timber or other wood products, and exert an influence on the climate or water regime.
4. Barren Land: This is land of limited ability to support life and in which less than one-third of the area has vegetation or other cover. In general, it is an area of thin soil, sand, or rocks. Vegetation, if present, is more widely spaced and scrubby than that in the Shrub and Brush category of Rangeland.
5. Water body**:** water bodies are lakes, ponds, streams, rivers can act as recharging zones.

4.2.4 Accuracy Assessment

In thematic mapping from remotely sensed data, the term accuracy is used typically to express the degree of correctness ‘of a map or classification. A thematic map which derived with a classification may be considered accurate if it provides an unbiased representation of the land cover of the region it portray (Foody, 2002: pp 186). Therefore, it is used to measure how many ground truth geo-spatial classes were classified correctly.

Land use Land cover map was derived from classification of images usually contains some sort of errors due to several factors that range from classification techniques to methods of satellite data capture. Accuracy assessment determines the quality of the map created from remotely sensed data and prepared for any data analysis. It can be qualitative or quantitative, expensive or inexpensive, quick or time consuming and well designed. The goal of quantitative accuracy assessment is the measurement of map errors during delineation of groundwater potential zone in this study.

Two types of accuracy assessment map which are positional and thematic accuracy assessment. Positional accuracy deals with the accuracy of the location of map features, and also measures how far a spatial feature on a map is from its ground truth (Bolstad, 2005). Thematic accuracy deals with the labels or attributes of the features of a map. It is used to measures whether the mapped feature labels are different from the true feature label. The accuracy of any map or spatial data set is a function of both positional accuracy and thematic accuracy.

An error matrix is a square assortment of numbers defined in rows and columns that represent the number of sample units assigned to a particular category relative to the actual category as confirmed on the ground truth/real. The rows in the matrix represent the remote sensing derived land use/land cover map, while the columns represent the reference data that were collected from field work. Tables produce many statistical measures of thematic accuracy including overall classification accuracy, percentage of omission and commission error and kappa coefficient-an index that estimates in the influence of chance (Congalton and Green, 1999).

Omission error is the percentage of pixels that should have been put into a given class but were not. Commission error was indicated pixels that were placed in a given class when they actually belong to another. These values are based on a sample of error checking pixels of known land cover that are compared to classification on the map. Error of commission and omission can be expressed in terms of user's accuracy and producer's accuracy.

Reference data labels**:** The class label of the accuracy assessment site, which is derived from data collected that is assumed to be correct.

classified data labels: The class label of the accuracy assessment site derived from the map.

Based on data collected by GPS from field and Google Earth Map, which were not used for classification purpose, confusion matrix table was produced (Table 4.1). This matrix compares the relation between known reference data (ground truth) and the corresponding results of the classification.

Table 4.1 Confusion Matrix Table for 2018 land use and land cover

	Reference Data					
Classified Data	Bare Land	Water Body	Agricultural Land	Built up Area	Forest area	Total User
Bare Land	51	1	0	0	1	53
Water Body	0	53	1	1	0	55
Agricultural Land	1	0	57	0	1	59
Built up Area	0	1	1	50	1	53
Forest area	0	0	1	1	55	57
Total Producer	52	55	60	52	58	277
Number of LULC correctly classified=266 Overall Classification Accuracy% = ((51+53+57+50+55)/(277))*100 = 96.03%						

As shown in (Table 4.1) the confusion matrix indicates that the overall accuracy assessment is very strong i.e. 96.03% which is greater than requirement for strongly acceptable classification, i.e. 84% (Anderson, 1997). The users and producer's accuracy assessment also calculated for each land classes and indicated acceptable agreement. The kappa hat value of 0.9586 indicates a better accuracy that the classification that was resulted from random sample classes classification. Since the kappa hat value fell above 80%, it represents strong agreement.

User accuracy: User accuracy is a measure indicating the probability that a pixel is Class of sample given that the classifier has labeled the pixel into sample class as shown in (Table 4.2)

Table 4.2 Users Accuracy Table

Class Name	Users Accuracy
Bare Land	51/53*100 =96.237%
Water Body	53/55*100 =96.36%
Agricultural Land	57/59*100 =96.61%
Built up Area	50/53*100 =94.34%
Forest area	55/57*100 =96.49%

Producer accuracy: The producer accuracy is a measure indicating the probability that the classifier has labeled an image pixel into sample area given that the ground truth of sample area.

Overall Accuracy: The overall accuracy is calculated by summing the number of pixels classified correctly and dividing by the total number of pixels sample. The ground truth image or ground truth training area defines the true class of the pixels. The pixels classified correctly are found along the diagonal of the confusion matrix table which lists the number of pixels that were classified into the correct ground truth class. The total number of pixels is the sum of all the pixels in all the ground truth classes as shown in (Table 4.3).

Table 4.3 Producers and Overall Accuracy Assessment

Class Name	Producers Accuracy
Bare Land	51/52*100 =98.08%
Water Body	53/55*100 =96.36%
Agricultural Land	57/60*100 =95.00%
Built up Area	50/52*100 =96.15%
Forest area	55/58*100 =94.83%
Overall Classification Accuracy% = ((51+53+57+50+55)/(277))*100 = 96.03%	

The kappa coefficient is calculated by multiplying the total number of pixels in all the ground truth classes by the sum of the confusion matrix diagonals, subtracting the sum of the ground truth pixels in a class times the sum of the classified pixels in that class summed over all classes, and dividing by the total number of pixels squared minus the sum of the ground truth pixels in that class times the sum of the classified pixels in that class summed over all classes as shown in (Table 4.4). In addition, it is a way to measure the actual agreement and a chance agreement between the reference data and the classified data.

The Kappa coefficient represents the proportion of agreement obtained after removing the proportion of agreement that could be expected to occur by chance (Foody, 2002). This would be expressed in terms of the percentage of strong, moderate and poor agreement i.e. a value >0.80 (80%) strong agreement; a value b/n 0.40 and 0.80 (40 to 80%) represents moderate agreement; and a value < 0.40 (40%) represents poor agreement.

Table 4.4 overall Kappa Statistics Table

Land use land cover types	Conditional kappa for each LULC class	In Percent (%)
Bare Land	$\frac{(277*266)-(52*53)}{(277*277)-(52*53)}$ = 0.9588	95.88%
Water Body	$\frac{(277*266)-(55*55)}{(277*277)-(55*55)}$= 0.9587	95.87%
Agricultural Land	$\frac{(277*266)-(60*59)}{(277*277)-(60*59)}$ = 0.9584	95.84%
Built up Area	$\frac{(277*266)-(52*53)}{(277*277)-(52*53)}$= 0.9588	95.88%
Forest Area	$\frac{(277*266)-(58*57)}{(277*277)-(58*57)}$ = 0.9585	95.85%
Overall kappa statistics =0.9586		95.86%

4.2.5 Analytical Hierarchy Process

To determine the relative importance or weights of each thematic map with another paired-comparison matrix was prepared by pair wise comparison on Satty's importance scale. These matrices have the property of consistency known as consistency rations (CR). Satty indicates that the matrices with CR ratings greater than 0.1 should be re-evaluated. This way it helps to analyses the matrix to determine the inconsistency in defining the interrelationships. In this case the consistency value was 0.05 which is accepted (Table 4.6).

The weights were normalized by multiplying with 100 to avoid complexities of computation as shown in (Table 4.7). These weights were applied in linear summation equation to obtain a unified weight map containing due weights of all input variables, which was further reclassified to arrive at groundwater potential map.

The rates for the classes in a layer and weights for the thematic layers were computed based on saaty's AHP (Saaty 1980). Saaty's AHP is the most widely accepted method for scaling the rates/weights of factors whose entries indicate the strength with which one factor dominates over the other in relation to the relative criteria (Tesfaye 2010). In this method the relative importance of individual class within the same map and thematic maps were compared each other by pair-wise comparison matrices. As such, matrices were constructed, where each criteria was compared with the other criteria, relative to its importance, on saaty's scale from 1 to 9. A score of 1 represents equal importance between the two factors, and a score of 9 indicates the extreme important of one factor compared to the other one as shown in (Table 4.5) below.

Table 4.5 Saaty's (2008) Relative Weight Parameters and their explanation

Intensity of the importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one parameter over another
5	Strong importance	Experience and judgment strongly favor one parameter over another
7	Very strong importance	One parameter is favored very strongly and is considered superior to another its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one parameter as superior to another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	Compromising criteria is needed

Table 4.6 Paired comparison matrix

	Drain Den	Lin Den	Geom	Geo	LULC	Soil	slope	Rain fall	Weight	Weight (%)
Drain Den	1								0.35	35
Lin Den	1/3	1							0.22	22
Geom	1/3	1/3	1						0.16	16
Geo	1/3	1/3	1/3	1					0.10	10
LULC	1/5	1/5	1/3	1/3	1				0.07	7
Soil	1/5	1/5	1/5	1/3	1/3	1			0.05	5
Slope	1/3	1/3	1/7	1/5	1/3	1/3	1		0.03	3
Rain fall	1/7	1/7	1/9	1/5	1/7	1/5	1/3	1	0.02	2

Table 4.7 Calculated of eigenvector and weights influence in percent

The eigenvector of weights is	Weight	Weight (%)
Drainage density	0.35	35
Lineament Density	0.22	22
Geomorphology	0.16	16
Geology	0.10	10
Land use and Land cover	0.07	7
Soil	0.05	5
Slope	0.03	3
Rain fall	0.02	2
Total	1	100
Consistency Ratio=0.07 which is acceptable		

Key

Geo = Geology Slope = Slope Geom. = Geomorphology/Land form Soil = Soil Lin = Lineament density Drain Den = Drainage density LULC = Land use/ Land cover Rain Fa = Rainfall

Consistency Ratio= 0.07

Consistency is acceptable.

From the table above Geomorphology and Geology hold highest relative to the other parameters for the complex spatial and temporal distribution and rainfall and slope hold low values.

In this study, a total of eight parameters were used to delineate the ground water potential zones such as slope, drainage density, lineament density, geology, geomorphology, and land use and land cover, soil and rainfall pattern. DEM data has been used to create drainage density map, slope map and Geomorphology map. The LANDSAT ETM images were used to classify the land use image. Drainage density map is created GIS software and weights are calculated. These parameters are prepared in GIS environment and weights are assigned for each classes are assigned using analytical process (Ramu & vinay, 2014). For mapping of ground water potential zones totally eight parameters are used such as geology, geomorphology, drainage density, slope, soil, land use and land cover, Lineament density and rainfall map. Digitizing is done in GIS into vector format and converts into the raster format. The analytical hierarchical process is used to create thematic layers and weights are calculated and assigned. The ground water potential zones are classified into four categories are very high, high, Moderate and low (Waikar & Nilawar, 2014).

Analytical Hierarchical Process (AHP) matrix has been developed using set criterions and then the weight value of each parameter is estimated using IDRISI 17.02 software According to (Saaty, 1980), the allowable CR value should be less than 0.1. The Comparison result indicates that the consistency ratio (CR) of 0.07 is by far less than 0.1 and it is acceptable look at table 4.7 above.

4.2.6 Weighted Overlay Method

In this method firstly the spatial data base has been developed from Landsat 7 ETM+ image. Various thematic maps such as drainage density, slope, geomorphology, geology, rainfall and soil are prepared by using GIS and remote sensing. Then the DEM data is used to obtain geomorphology, drainage density and slope map. The image processing of satellite data is used for creating land use and land cover. The geological data used to create geology map and lineament map. Soil data used to create soil map of the study area. Rainfall data used to create rainfall map of the study area.

Therefore all the thematic maps are used to analyze in overlay and weights are assigned for each thematic layer and ranks are assigned to evaluate the groundwater potential zone (Waikar & Nilawar, 2014).

The identification of groundwater potential zones for the study area was made by grouping of the interpreted layers through Weighted Overlay Analysis and finally assigned different potential zones. Depending upon the groundwater potentiality, each class of the main eight thematic layers (geomorphology, slope, geology, drainage density, lineament density, soil, land use/land cover and rainfall) are roughly placed into one of the following groups viz., 1.very high, 2. High, 3. Moderate, 4. Low. Suitable weighted on a scale of ‘1 - 9’ has been given to each class of a particular thematic layer based on their contribution towards ground water potentiality. The weighted and % of influence assigned for various classes on all thematic layers are shown in the Table 4.8 All the thematic maps have been integrated. A final groundwater potential map is prepared with application of above technique. Most of the region in study area concerns good level of ground water potential zone and hill side areas has low ground water potential zones.

All the reclassified thematic layers were integrated with one another through GIS using the weighting overlay analysis.

The following equation was used for the generation of the groundwater potential zone map (GPZM):

GPZM = 16 * Geomorphology map+10*geology map + 7* Land use/ Land cover map+ 5* soil map+35* drainage density map+22* lineament density map + 3* slope map + 2*rainfall map

From the composite layer, the delineation of groundwater prospect zones was made by grouping the polygons into different prospect zones: Very high, High, Moderate and low.

4.3 Results Interpretation

The interpretation of this study was depending on the results and finding of the delineation of groundwater potential zones was involved thematic map generation and their integration through GIS and Remote Sensing techniques. Thematic maps were prepared in the scale 1:50,000 with a spatial resolution of 30m*30m pixel size from satellite imagery, geological mapping, soli mapping and other hydrogeological field data. The maps were developed in a GIS environment using eight input parameters that indicate the delineation of groundwater potential zones as shown in the next section.

Groundwater potential zonation means identifying and mapping the prospective groundwater zones in an area by qualitative assessment of the controlling and indicative parameters. The main factors responsible for groundwater resource development are rainfall, geology, geomorphology, land use/land cover, drainage density, slope, soil, and lineament density.

Thematic maps for each parameter prepared as follows:

4.3.1 Geomorphology

Geomorphology was the study of the form of the earth (landforms), its description and genesis (Gupta, 2003). It is the study of earth structures and also helps in process relating to the delineate groundwater potential zones and also structural features. The geometric features of different landforms are created by the dynamic action of several geological processes such as temperature changes, freezing, chemical reactions and moving of wind and water. Many of these features are favorable for the delineation of groundwater and are classified in terms of groundwater potentiality. So this study analysis the cause and effects of this geomorphology on delineate ground water potential zone. It is mainly depend on geological formation (Waikar & Nilawar, 2014). In general, geomorphology reflects various landforms and structural features (Prasad et al. 2008). The geomorphological features of the area has been identified from DEM and used as the inputs of geomorphological map. The geomorphological features of the area is classified into four geomorphological features in order to know about the water resources areas which are denudation hills, Structural hills, Pedi plains and flood plains. Its details are shown in figure 4.1.

Flood Plains consist of recent alluvium deposited by the river and generally light blue in the image. During field investigations, floodplains units are found to have occurred along the Laga Dema River in the study area. It is considered as good potential areas for groundwater potential and development because of more recharge in these areas.

Denudation hills are characterized by high topography and high surface runoff zones where the rate of infiltration is low or negligible with poor groundwater prospects (Rai et al. 2008). A denudation hill has low groundwater prospects because of runoff zones and low rate of infiltration.

Generally, for geomorphic units, flood plains were assigned by highest value, Pedi plains were assigned by high value, denudation hills were assigned by moderate value and structural hills with low lineament density and higher drainage density were assigned low values.

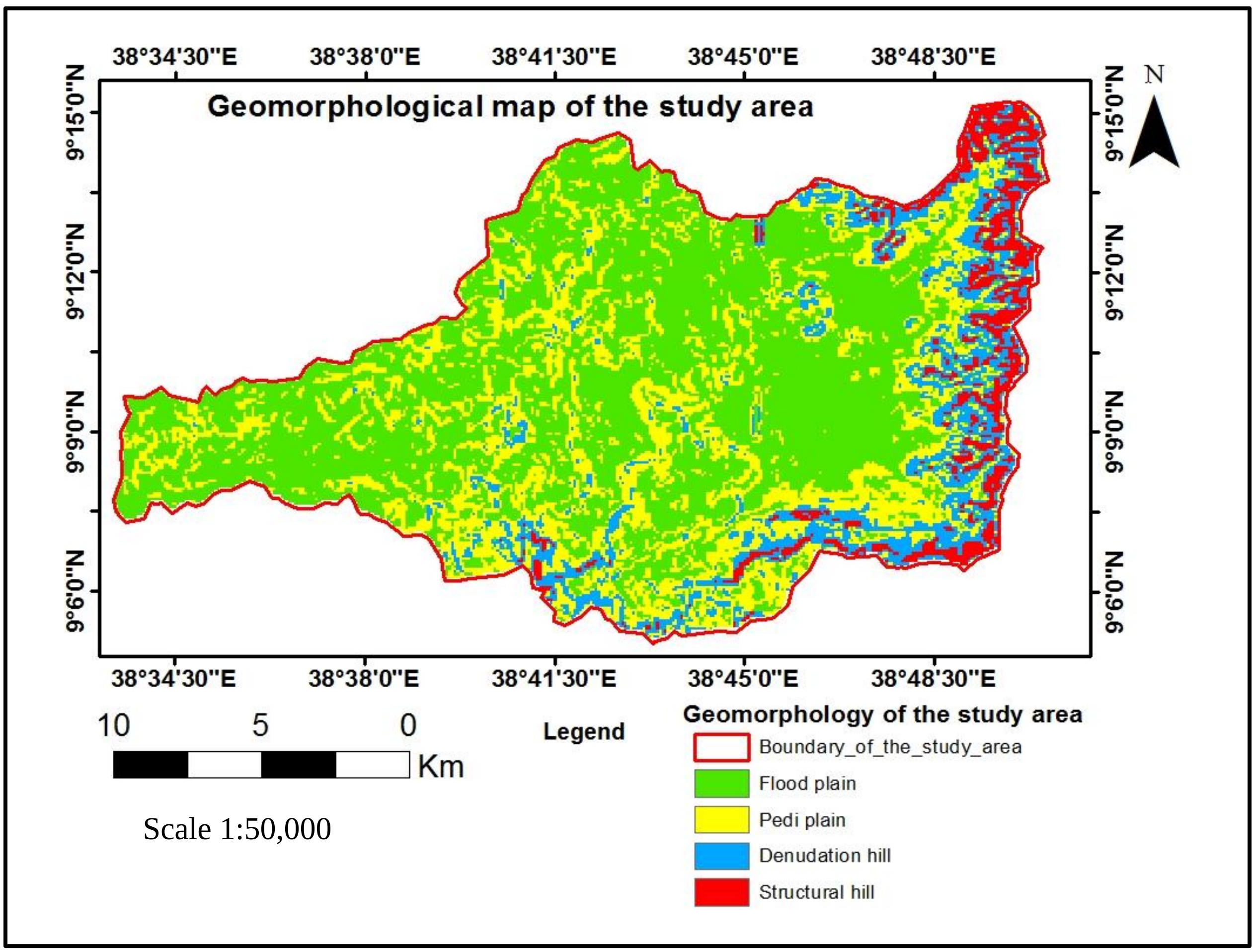

Figure 4.1 Geomorphological map of the study area

4.3.2 Geology

Geology plays an important role in the distribution and occurrence of ground water occurrence (Krishnamurthy and Srinivas, 1995). The types of geology that exposed to the surface are highly affect groundwater recharge by controlling the infiltration and flow of water to the ground Shaban *et al*. (2005) and geology plays a great role in the occurrence and delineation of groundwater potentials zone. The geological setting of the study area is generally classified in to two major groups; namely, Tertiary Volcanic (Plateau Basalts) and Quaternary units (Rift Volcanic and Sediments). These two groups of geological setting study are influence on ground water occurrence potential zones. The classification is based on age of eruptions, special distribution, and mode of occurrence. Tertiary plateau basalts are part of the Trap-series volcanic products consisting huge accumulation of basaltic rocks with minor silica intercalations, whereas the Quaternary Rift volcanic and sediments comprise variety of rock units (both acidic and basic) associated to the formation of the main Rift system during the Quaternary period. However, each of them has subdivisions; where by Tertiary Volcanic (plateau Basalts) consists of Aiba Basalts, Alaji Basalt and Chancho Basalt on the other hand a Quaternary unit (Rift Volcanic and sediments) comprises Adama Group and Entoto silicic (Merga, 2012).

The geological setting of the study area is generally classified in to four subdivisions namely, Cheleka Basalts, Middle Basalts/Quaternary superficial sediments, Quaternary Basalts and Trachyte/EntotoVolcanics as shown in (Figure 4.2) below. This four group of geological setting study are influence on delineate ground water potential zones map. For Geology units Cheleka Basalts were assigned by highest value, Middle Basalts/Quaternary superficial sediments were assigned by high value, Quaternary Basalts were assigned by moderate value, and Trachyte/Entoto Volcanics were assigned low values.

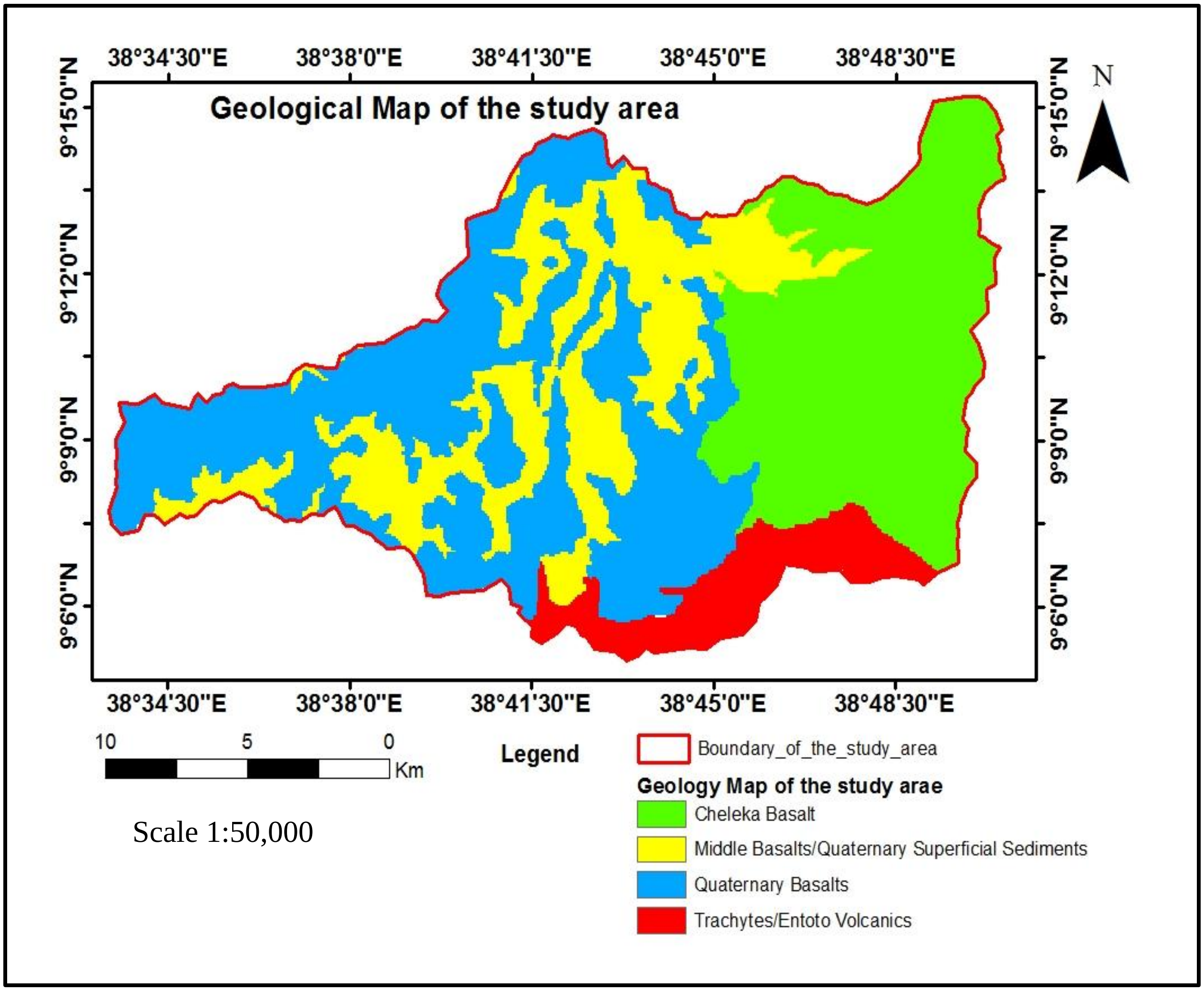

Figure 4.2 Geological Map of the study area

4.3.3 Land Use/cover

Land use/cover is an important characteristic of the runoff process that affects infiltration, erosion and flow of water. The land use/cover map of the area was readily interpreted from Landsat image of the year 2018 by using visual interpretation, supervised classification using ERDAS IMAGINE 2014 software. Land use/Land cover Mapping is one of the significant applications of remote sensing is plays a considerable role in the development of groundwater resources (Waikar & Nilawar, 2014). Land use/land cover plays a significant role in the development of groundwater resources (Shaban et al. 2006). The nature of surface materials and the land use pattern control the infiltration and runoff (Dinesh Kumar et al. 2007).

Classification of land use/cover for analysis was done based on their character to infiltrate water in to the ground and to hold water on the ground. There is a various land use/ land cover classes in the study area which used to delineated groundwater potential zone. The various classes in the study area are: bare land, Water body, Agricultural Land, Built up Area and Forest Area as shown in (Figure 4.3) below in the study area.

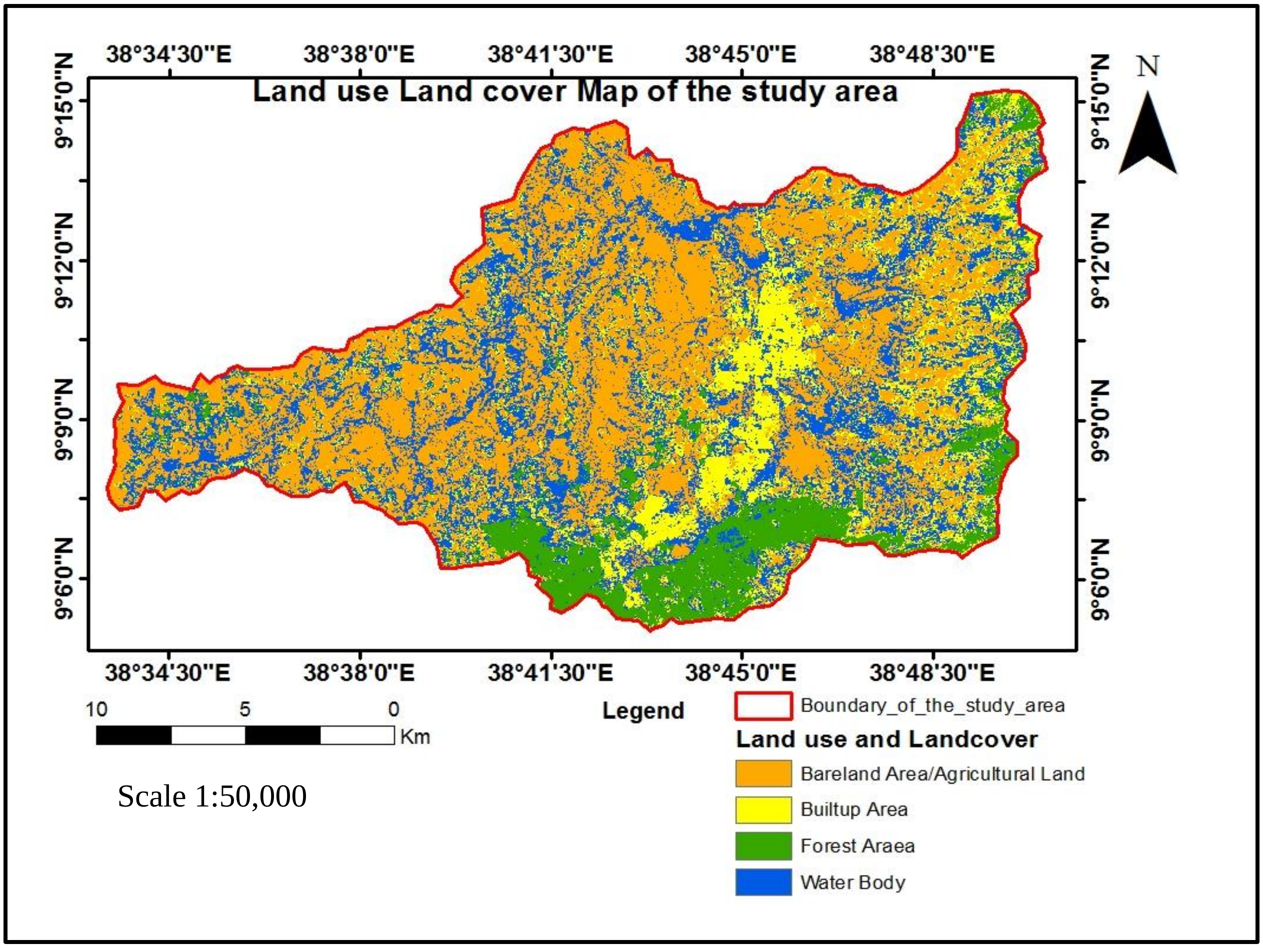

Figure 4.3 Land Use and Land cover Map of the study area

4.3.4 Drainage Network and Density

The drainage is one of the factors which play the important role in groundwater potential zone delineation. They are reflection of the rate that precipitation infiltrated compared to surface runoff. Where rocks of the study area are highly permeable, infiltration to groundwater is high, and less water is transported in rivers as surface water; but where rocks of the study area have low permeability there is little infiltration and more surface water runoff. Low drainage density is therefore related to higher recharge and results higher groundwater potential (M. Thangarajan, 2007). The drainage density is high in the plateau and escarpment and very low in the rift floor (Ayenew T., 1998).

Drainage patterns means formation of surface and subsurface characteristic. Drainage density delineated using 3DEM hydro processing module of SRTM data of the study area after consecutive processes such as filled sinks for undefined values, created Flow Direction, Created Flow Accumulation, Created Stream network, generated stream order and finally converted stream order to drainage density. The stream order values were regrouped to produce a drainage density map that was reclassified into four categories which are 0 - 7.728 km/km^2 (very high), 7.729 - 24.04 km/km^2 (high), 24.05 - 49.37 km/km^2 (moderate) and 49.38- 109.5 km/km^2 (low). That means the area under 0 -7.728 km/km^2 is very high groundwater potential, the area 7.729 - 24.04 km/km^2 the groundwater potential is high, the area 24.05 - 49.37 km/km^2 the groundwater potential is moderate and the area 49.38- 109.5 km/km^2 the groundwater potential is low. The high ranks are given to low drainage density due to more infiltrate (Waikar & Nilawar, 2014).

The details shown in (Figure 4.4)

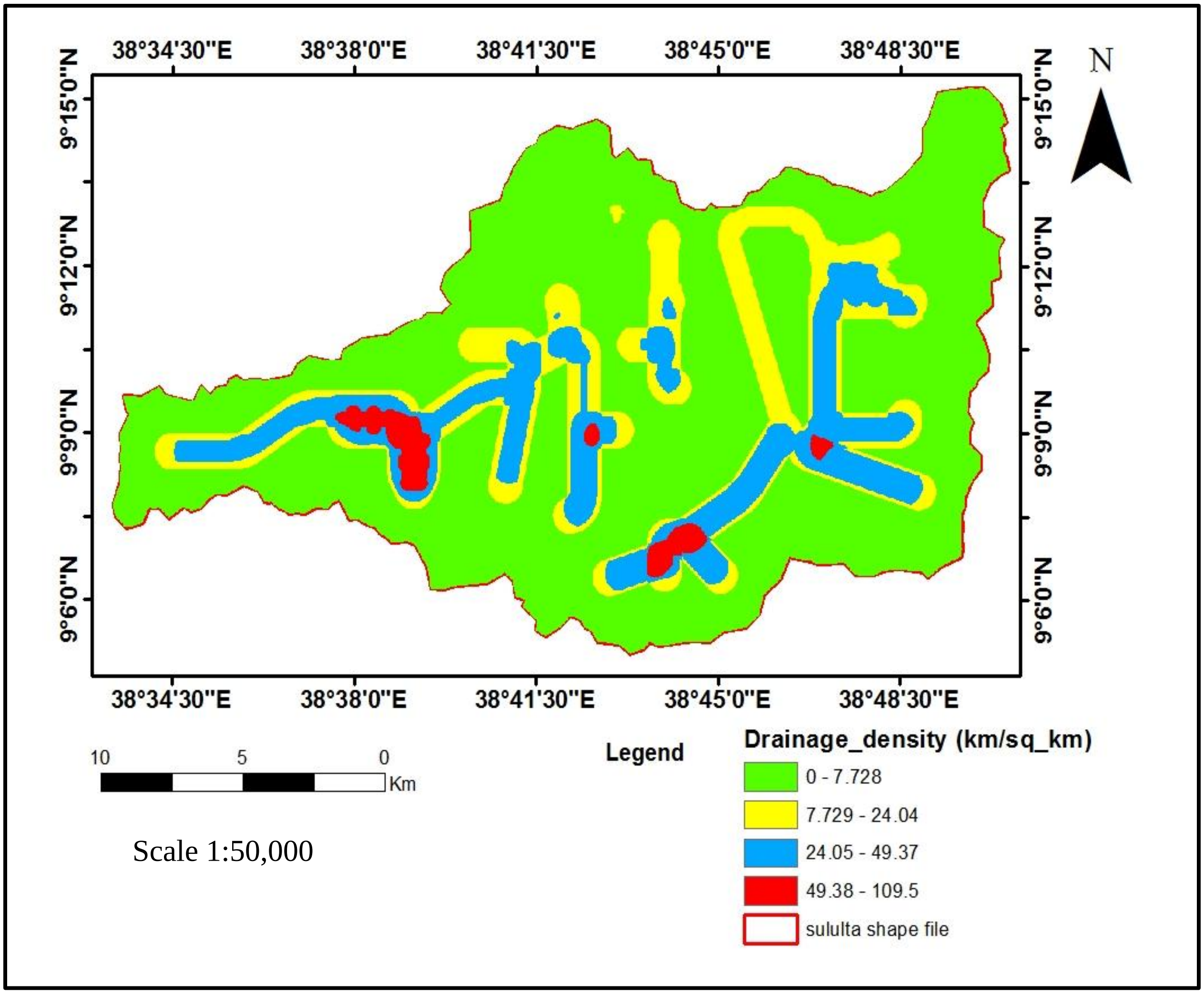

Figure 4.4 Drainage Density Map of the study area

4.3.5 Lineaments Network and Density

The Lineament map is generated from the georeferenced Geological map by digitizing and identifying the fault lines in the imagery using the ArcGIS 10.5.1. The study area is found to have a number of crisscrossed lineaments. The intersection of lineaments is considered as good occurrence of ground water potential zones. Lineaments like joints, fractures crisscross and faults are hydro geologically very important and may provide the pathways for groundwater movement. The density of the lineament is generated using the lineament map by using line density methods. The weights have been given by setting more threat levels to higher lineament density which is groundwater prone. As seen on (Figure 4.5) a very high lineament density of the study area was found in the center parts of the study area.

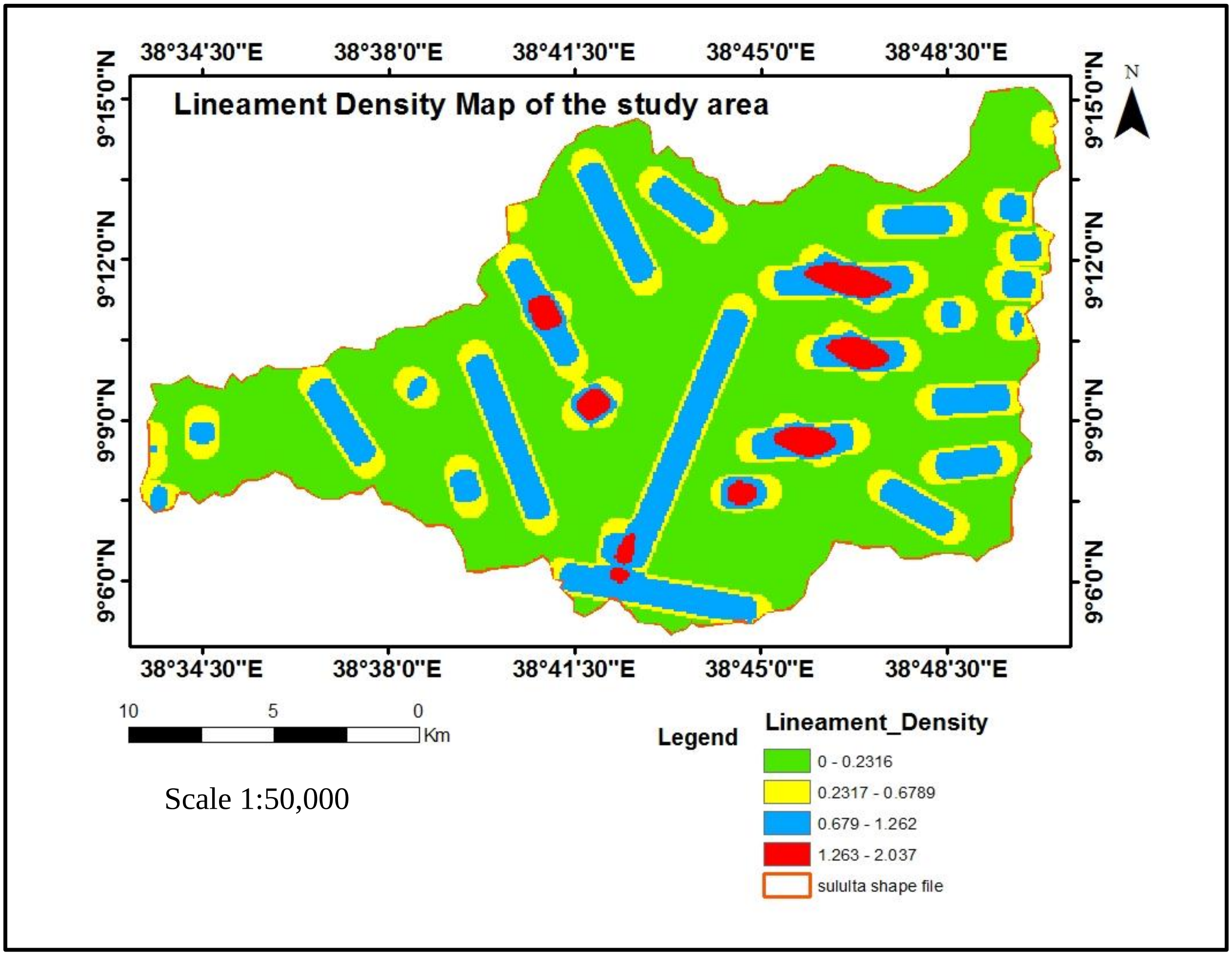

Figure 4.5 Lineament Density Map of the study area

4.3.6 Soil Map

Soils are highly affected the movement and infiltration of ground water (Hornsby, 1986, Maurice and Courteny, 1990). It is the world's natural resource and a soil map is a spatial representation of these resources. Soil map is fundamental starting point when ground water potential zone delineation processed. In the study area there are two major types of soil which are stated below. Cambisols are soils with initial stage of soil formation or weakly developed soils relating to their parent material. The Cambisol in the study area is found distributive in limited places. The soil texture is loamy to clay and identified on undulating to rolling plateaus in the study area with stony phase and limited in depth. Luvisols are soils whose dominant characteristic is a marked textural differentiation within the soil profile, with the surface horizon being depleted of clay and with accumulation of clay in a subsurface. Normally, it is not present as individual particles but is clustered to aggregates that consist wholly of clay or of a mixture of clay and other mineral and /or organic soil material. Luvisols are typically a brown to dark brown surface horizon over a reddish brown to strong brown. As you can observe from the map (Figure 4.6) the large proportion of the study area is occupied by this type of soil particularly the central part of the Town where the existing built up area is lied. The water carrying capacity of an area depends upon the soil types and their permeability. The first infiltration and transmission of surface water into an aquifer system is a function of soil type and its texture. Three types of soils are found in the study area, viz. chronic luvisols, vertic cambisols and chromic cambisols (Figure 4.6) which one type of soil is more dominated by another. The delineation was based on differential manifestations on the imagery in the form of colour, tone, texture and association.

In the soils types for chromic cambisols low value was assigned whereas chronic luvisols was assigned by moderate value and ventric cambisols was assigned by very high value for their low water holding capacity and permeability allow fast percolation (Ayenew, 1998). Similarly owing to influence the ground water infiltration and alters the rate of percolation of precipitation.

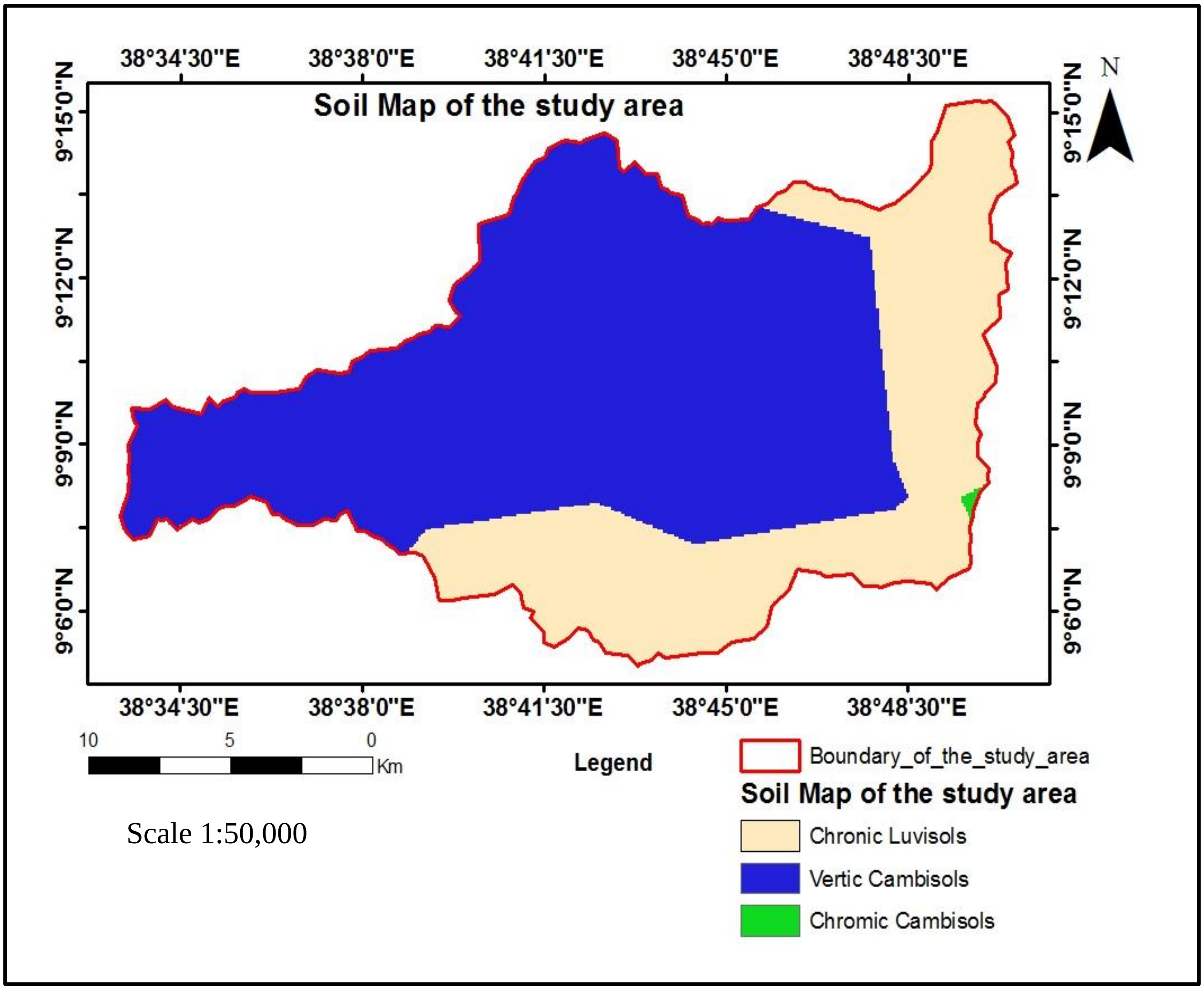

Figure 4.6 Soil Map of the study area

4.3.7 Slope Factor

Topography shows the patterns of land features of the area. In the study slope is one factors of influence the delineate ground water potential zones. It is an important factor in delineate, because slope determines the amount of runoff in the site. In this study, slope of the study area generate from DEM and analysis using Arc-GIS technology. The identified slope category varies from (0-45.28%) in the study area and area classified into four classes like (0-4.617%) gentle, (4.618-10.48%) moderate, (10.49-18.82%) high, (18.83-45.28 %) steep. Gentle slope (0-4.617%) indicates the presence of very high groundwater potential zones where as steep slope(>18.82%)

shows the presence of low groundwater potential zones as water runs rapidly off the surface and does not have sufficient time to infiltrate the surface, keeping other parameters constant.

The Northern part as well as along the main river of the study area falls under the low degree of slope (0-4.617%). These flat to gentle slope area is categorized by very high category for groundwater storage due to the nearly flat terrain, slow of surface runoff allowing more time for rainwater to percolate (Prasad et al. 2008). The area with slope (4.618-10.48) is considered as moderate which categorized as high groundwater potential. The area with a steep slope towards the southern and Northeastern part of the study area is considered as low groundwater potential due high slope, higher runoff, low infiltration and low rainfall recharge zones. The details are shown in figure 4.7 below.

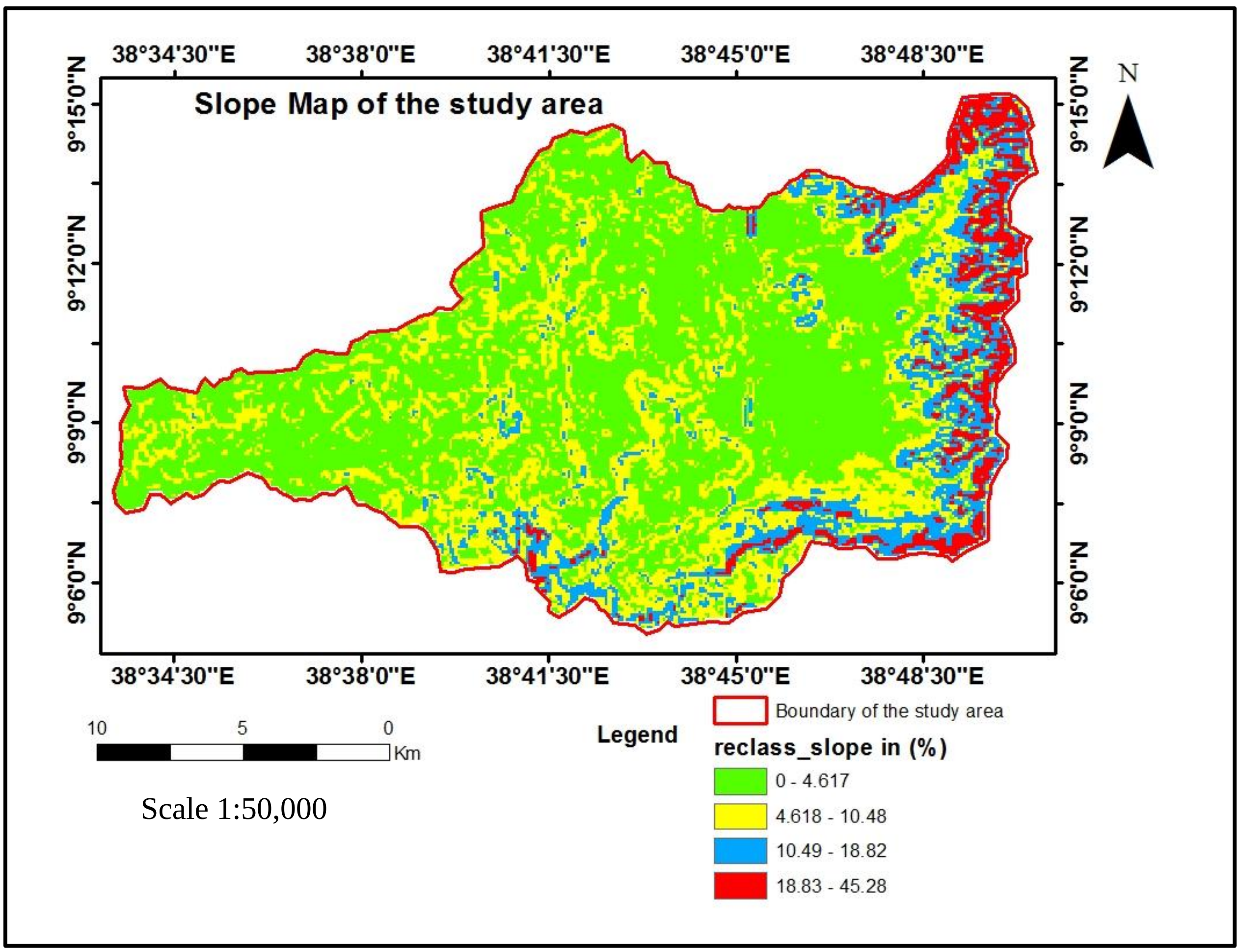

Figure 4.7 Slope Map of the study area

4.3.8 Rainfall Map

Rainfall is main source for recharging the groundwater and for all hydrological process. The annual average rainfall of the study area calculated from Ethiopia National Meteorological Agency on two rain gauge station one is inside of the study area and one is outside of the study area. The monthly data is collected from different rain gauge stations for period of 11 years from Ethiopia National Meteorological Agency. From the rainfall map the results were concluded that the annual rainfall in elevation regions is more when compared to low elevation (Rahmati et al., 2015). The Mean Annual rainfall data is calculated from the rain gauge station for past 11 years and interpolation method has been used to find amount of rainfall has been appeared in the study area. Monthly data for 11 consecutive years and it is mean annual precipitation is around 1146.46 mm. Rainfall of study area classified in to four classes which ranges from 1146.46 mm - 684.204 mm. Low rainfall value gives low weightage and high value has high weightage. Rainfall distribution along with the slope gradient directly affects the infiltration rate of runoff water hence increases the possibility of groundwater potential zones. The zone which gives low rain fall may results in not useful for groundwater zones (Manap et al., 2013). Rainfall is the source of recharging groundwater (Musa et al. 2000).

Two rain gauge stations which one is inside of the study area and one is outside of the study area are shown in the Table 4.8 below.

Table 4. 8 Two Rain Gauge Station Mean Annual Precipitation

No	Station	Mean Annual Precipitation	years
1	Sululta Station	1164.64	2005-2015
2	Addis Ababa Station	1113.3	2005-2015

In the IDW interpolation method, the sample points are weighted during interpolation such that the influence of one point relative to another decline with distance from the unknown point to be created weighting is assigned to sample points through the use of a weighting coefficient that controls how the weighting influence will drop off as the distance from new point increases. The greater the weighting coefficient, the less the effect points will have if they are far from the unknown point during the interpolation process. As the coefficient increases, the value of the unknown point approaches the value of the nearest observational point..

From the rainfall map the results were concluded that the annual rainfall in elevation region is more when compared to low elevation (Rahmati et al., 2015).

Monthly rainfall data of study area is taken from National Metrological Agency of Ethiopia as shown in Appendix (A) for sululta rain gauge station and Appendix (B) for Addis Ababa Rain gauge station and Calculate its Mean Annual Precipitation using sum all monthly data average of them. The sum and average of Sululta and Addis Ababa rain guage station are shown in (Table 4.9 and Table 4.10).

Table 4.9 Sululta Mean Annual Precipitation

Name	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	sum
Sululta Station	2005	9.6	3.5	33.3	73.9	17.9	41.7	258	250.2	155	24.3	13.7	0	881
	2006	2.5	20.3	82.2	74.5	70.8	179	386	272.8	185	26.4	0	14.1	1313
	2007	38.6	5.8	41.3	37	112	244	284	372.2	121	5.7	4.7	0	1266
	2008	0	19.3	11.9	40.1	66.5	89.3	399	287.4	133	32.9	102	0	1181
	2009	24.3	0	5.2	13.2	0	127	362	0	0	0	0	0	531
	2010	11.3	118	56.8	59.7	117	268	441	374.3	243	11	22.4	10.1	1732
	2011	2.6	5.3	73.8	79.6	0	228	322	375.5	181	0.8	13.6	0	1282
	2012	0	0	37.1	176.3	92.6	124	482	423.6	301	14.9	0	25.2	1677
	2013	6.2	0.3	29.1	59.5	51.3	154	253	340.4	146	33.4	13.7	0.5	1086
	2014	0	25.2	46	65.8	81	60.4	261	309	121	45	0	0.5	1015
	2015	0	28.1	18.7	0.8	83.8	135	219	238.8	98.1	5.4	14.6	2.6	845
Mean Annual Precipitation														1164.64

Source: Ethiopia National Meteorological Agency (ENMA)

Table 4.10 Addis Ababa Mean Annual Precipitation

Name	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
Addis Ababa Obs	1995	0	69	41.5	174.4	68.2	102.9	190	314.9	136.1	0	0		1097.2
	2005	45.9	51.6	83.2	160.9	133.7	179.8	246	315.2	162.5		4.4	0	1383.2
	2006	0.7	11.2		78.9	74.6	150.1	356	243.6	239.1	54	0.3	8	1216.8
	2007	51.3	19.1	59.8	73.8	120.1		262	381.2	147.6	24.8	0	0	1139.5
	2008	0	13	0	49.4	94.3	88.9	277	360.9	256.7	88.2	79.4	22.9	1330.7
	2009	21.3	2.7	28.4	80.6	58.9	82.6	350	388.3	112.7	45.8	4.4	65	1240.6
	2010	2.6	79.8	55.5	97.8	74.4	271.1	314	205.8	237.8	1.8	25.7	15	1381.2
	2011	14.1	13.1	44.3	22.8	66.1	182	181	340.8	146	0	42.3	0	1052.4
	2012	0	0	15.8		50.2	69.4	324	298	215.5	2.3	0	9.8	985.2
	2013	4.4	0		92.3	85	153.2		353.2		58.4	22.3	0	768.8
	2014	1.7	47.4	61.5	26.2	93.6	66.7	220	262.4	264.7	35	1.7	0	1080.8
	2015	0	0					217	309.9	148.9	0	7.7	0.1	683.6
Mean Annual Precipitation														1113.3

Source: Ethiopia National Meteorological Agency (ENMA)

The rainfall factor was calculated according to the equation given by Hurni (1985) which is derived from a spatial regression analysis (Hellden, 1987) for Ethiopian conditions. It was based on the available mean annual rainfall data.

R = (0.55*MAP) -24.7……………………………………………………………….equation 4.1

Where MAP is the mean annual Precipitation in mm

In this study, rainfall data of 11 years (2005-2015) was taken from National Meteorological Agency on two rain gauge stations in and nearby. A rainfall map was generated from the Mean Annual Precipitation of the two stations by using IDW interpolation technique in Arc GIS 10.5.1 the R-value was calculated from the rainfall map with a cell size of 30m*30m using raster calculator function of ArcGIS by using the above formula which suggested by Hurni (1985). The prepared rainfall map is classified into four categories depending on their relation with groundwater potential zone prospects as shown in (Figure 4.8). These are (1,031.64 - 1,146.45mm) very high groundwater potential zone, (916.803 - 1,031.63mm) high groundwater potential zone, (801.977 - 916.802mm) moderate groundwater potential zone and (687.149 - 801.976mm) low groundwater potential zone.

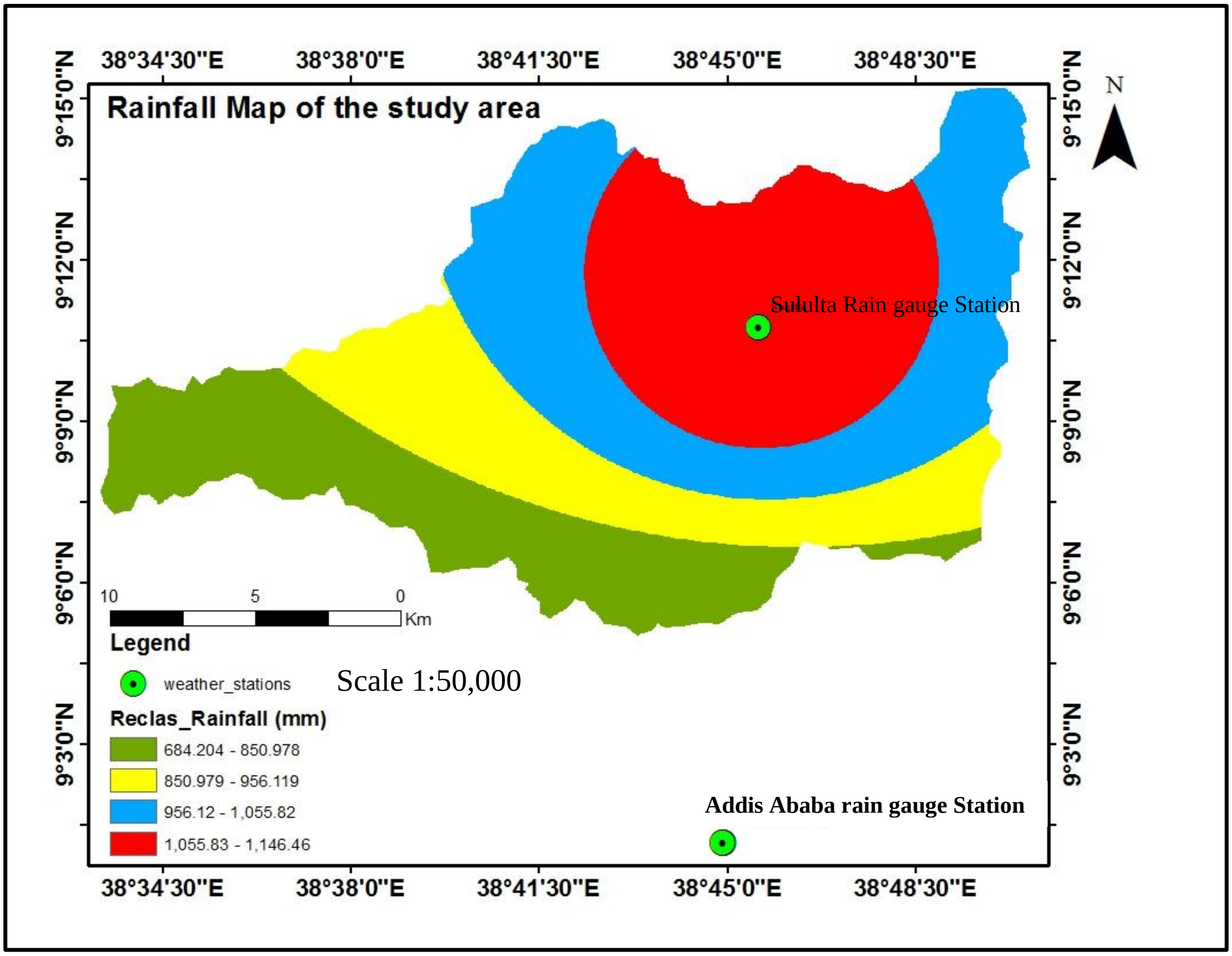

Figure 4.8 Rain fall Map of the study area

4.2.9 Data Integration Analysis in GIS Environment

The present study delineates different groundwater potential zones by considered essential parameters and the maps were prepared for each layer. Theses maps were converted to raster data sets having the same pixels size and different weightage were assigned as per their groundwater potential controlling capacity within the study area and reclassification of each map was done based on the weight values produced.

All the weighted thematic maps were integrated and defined criteria weight using the IDRIS software and overlay analysis done using Arc GIS software and potential groundwater prospect zones were identified (Figure 4.1) and its final ranking and final weighting for each themes are shown in (Table 4.11).

Overlay analysis is a multi-criterion analysis where in analysis can be carried out with complex things for finding out the certain theme with the help of assignment of rank to the individual class of feature and then assigning weightage to the individual feature considering its influence over theme (Shivaji Govind Patil, 2014) and is presented in (Table 4.9) All the thematic maps were converted into raster format and superimposed by weighted overlay method, which consists of rank and weightage wise thematic maps and integration of them through GIS. Integration of thematic maps for carrying out Analytical Hierarchy Process or overlay analysis in GIS environmental was done using Arc GIS software. Finally, the maps integrated using GIS software with the purpose intended to delineate the groundwater potential areas for the study region.

Table 4.11 Final ranking or scale value and Final weightage value for each class

Factors	Class	Ground water prospects	Rank in number	Influence weight (%)
Geomorphic units	Flood Plain	Very high	1	16
	Pedi Plain	Moderate	2	
	Denudation Hill	Low	3	
	Structural Hill	Very low	4	
Geology	Cheleka Basalts	Very high	1	10
	Middle Basalts	Moderate	2	
	Quaternary superficial sediments	Moderate	2	
	Quaternary Basalts	Low	3	
	Trachyte/Entoto Volcanics	Very low	4	
Land use Land over	Water body	Very high	1	7
	Forest Area	Moderate	2	
	Agricultural Land	Low	3	
	Bare land	Low	3	
	Built up Area	Very low	4	

Drainage Density	0 – 7.728	Very high	1	35
	7.729 – 24.04	High	2	
	24.05 - 49.37	Moderate	3	
	49.38- 109.5	Low	4	
Lineament Density	1.73 - 2.29	Very high	1	22
	1.16 - 1.72	High	2	
	0.574 - 1.15	Moderate	3	
	0 - 0.573	low	4	
Slope	(0-4.617%) Gentle	Very high	1	3
	(4.618-10.48%) Moderate	High	2	
	(10.49-18.82%) High	Moderate	3	
	(18.83-45.28%) Steep	Low	4	
Soils	Ventric cambisols	Very high	1	5
	Chronic luvisols	Moderate	2	
	Chromic cambisols	Low	3	
Rainfall	1,031.64 - 1,146.45	Very high	1	2
	916.803 - 1,031.63	Moderate	2	
	801.977 - 916.802	Low	3	
	687.149 - 801.976	Very low	4	

4.2.10 Criteria Weights and Map Scores

The study determine the relative importance or weights of each thematic map with another paired-wise comparison matrix was prepared by pair-wise comparison on satty's importance scale. These matrices have the property off consistency known as consistency rations (CR). Satty indicates that the matrices with CR ratings greater than 0.1 should be re-evaluated. This way it helps to analyses the matrix to determine the inconsistency in defining the interrelationships. In this case the consistency value was 0.07 which is accepted (Table 4.7). The weights were normalized by multiplying with 100 to avoid complexities of computation. These weights were applied in linear summation equation to obtain a unified weight map containing due weights of all input variables, which was further reclassified to arrive at groundwater potential map. The importance matrices and their weights are mentioned as shown in (Figure 4.1).

After categorization, all the reclassified thematic layers were integrated with one another through GIS using the weight overlay analysis, shown in equation 4.2.

The following equation was used for the generation of the groundwater potential zone map (GPZM): GPZM = 16 * Geomorphology map+10*geology map + 7* Land use/ Land cover map+ 5* soil map+35* drainage density map+22* lineament density map + 3* slope map + 2*rainfall map…………………………………………………………………… Equation 4.2

From the composite layer, the delineation of groundwater prospect zones was made by grouping the polygons into different prospect potential zones: Very high, High, Moderate and low.

4.3.11 Groundwater Potential Zone

The delineation/identification of groundwater potential zones for the study area was made by grouping of the interpreted layers through Weighted Overlay Analysis and finally assigned different potential zones. Depending upon the groundwater potentiality, each class of the main eight thematic layers (geomorphology, Geology, Land use Land cover, drainage density, lineament density, soil, Slope and Rainfall) are Prepared. The prospect map describing the ground water potential zone in the study area were identified and presented in (Figure 4.9). From this study Groundwater potential zones were categorized into four types viz., Low (8.80%), Moderate (27.63%), High (52.65%) and very High (10.92%). The best suitable areas were identified in the west direction of the study area because of the presence of flood plain and Pedi plain with minimum slope. The map indicated that maximum plain areas were identified as moderate prospective zones, while steep sloping and high drainage density are classified as low prospective areas like structural hill areas and some places of north-east parts of the study area. The study suggested that the GWPZM generated will serve as useful guidelines for planners, engineers and decision makers providing quick decision- making in the management of groundwater resources, site selection for GW exploration and exploitation. In the study generally the reason for very high groundwater potential is area which has low drainage density, low slope, and very high lineament density and flood plain Geomorphological units. The reason for Low ground water potential zone is area which has very high drainage density, very high slope, low lineament density and structural hill geomorphological units shown in (Figure 4.10).

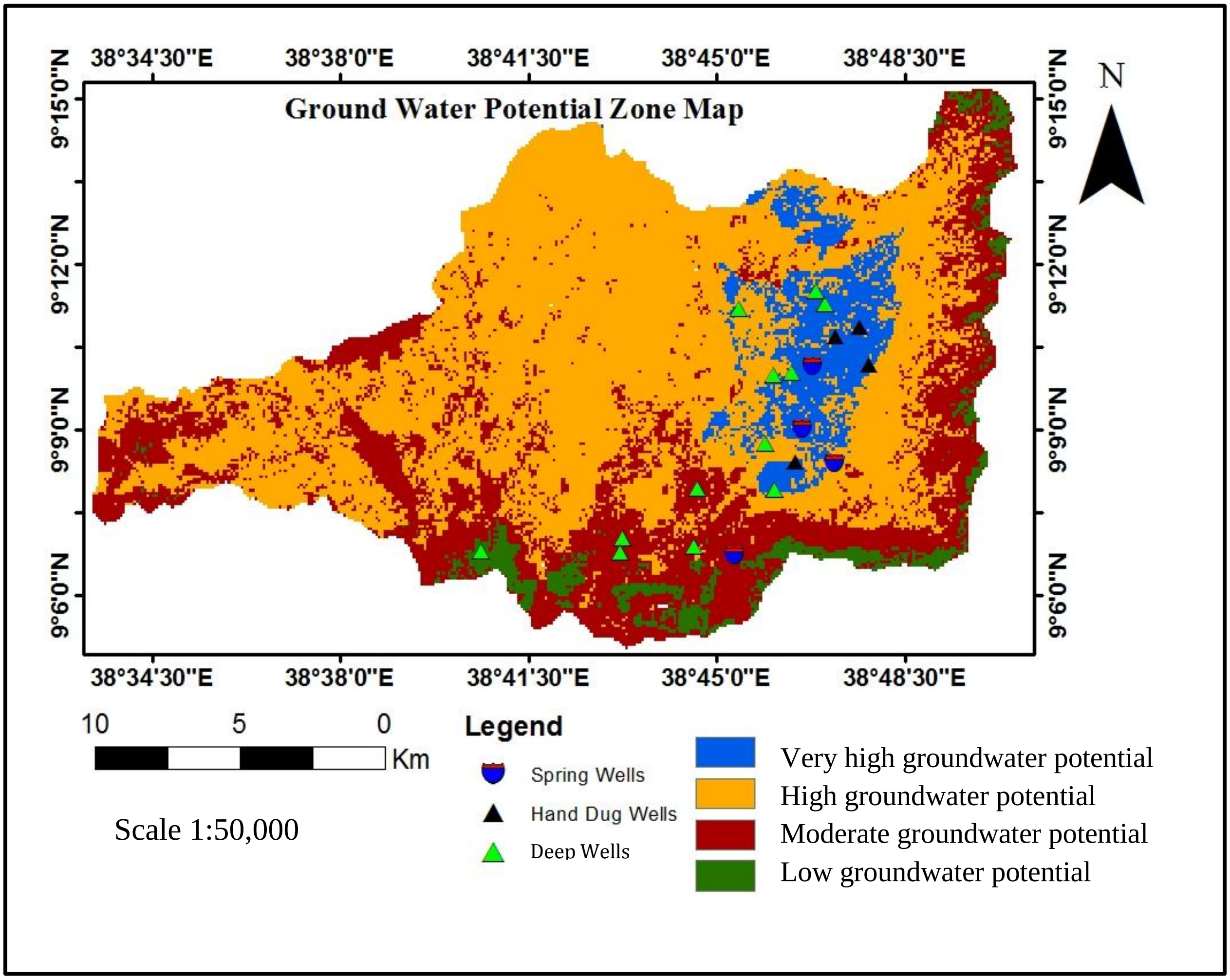

Figure 4.9 Groundwater potential zones Map

Table 4.12 Area in % and in km^2 of groundwater potential zones map

Sr. No	Groundwater Potential zones	Area in (KM^2)	Area in (%)
1	Very High	35.87	10.92
2	High	172.97	52.65
3	Moderate	90.77	27.63
4	Low	28.89	8.80
Total		**328.50**	**100%**

4.3.12 Results Validation

There is comparison of the study between the water level depth data and ground water potential zones map were done by (Kavitha et al, 2011). It was found that the delineation of ground water potential zone by integrated GIS and remote sensing techniques was in close agreement with the available point source inventory data.

For identification of groundwater potential zones, first the individual thematic layers and also their classes were assigned to various weightage scores. The weightage score of rainfall is very low when comparing with another factors and Geomorphology has very high weightage than all factors in this study. ArcGIS weighted linear combination was performed to generate groundwater potential zones of the study area. Groundwater potential zone map produced in this study is shown in (Figure 4.9). Classification of each potential zone is based on JMG generalized groundwater potential classes, i.e., low, medium, high, and very high (JMG 2007).

Analysis of the groundwater potential zones shows that the very high groundwater potential zones constitute 10.92% of the central part of Sululta and surrounding watershed. High groundwater potential zones area seen at upper part, central and north part which has 52.65% area. A moderate groundwater potential zone occupies the 27.63% area of the total watershed area. Meanwhile the eastern part fall under low groundwater potential zones, constituting about 8.80%. Percentage of each groundwater potential zones is shown in (Figure 4.10).

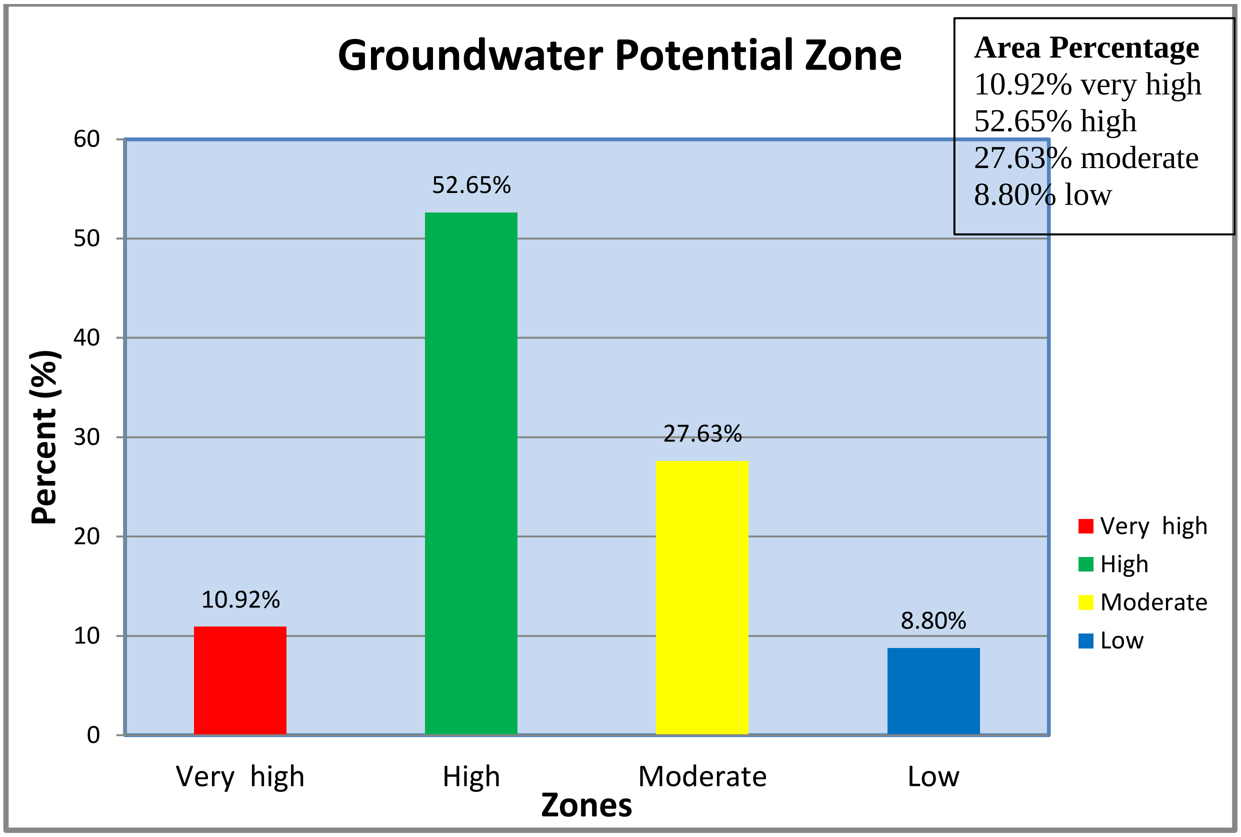

Figure 4.10 the percentage of different groundwater potential zones

Map overlay between predicted groundwater potential map and Groundwater storing controlling parameters found that the area having very high groundwater potential included flat area of slope percentage ranging from (0 to 4.617)%, low drainage density, and high lineament density. Flat areas of slope (0 to 4.617)% and low drainage density are favorable to groundwater potential due to high infiltration rate. Zone of high groundwater potential zones are found also in slope (0-4.617)%, high lineament density, low drainage density, and geomorphology type of floodplain. Musa et al. (2000) only found two factors related to high potential of groundwater which is low drainage density and high lineament density. Zone of moderate groundwater potential zones are characterized by slope degree ranging from 4.618-10.48, land use type of crop, moderate drainage density, and moderate lineament density. Lastly, low groundwater potential zones include geomorphology type of denudation hill, high drainage density, slope degree more than 18.83, low annual rainfall intensity, soil type of clay, and land use type of clear land and urban areas.

The accuracy of the GIS model of predicted groundwater potential map was determined with the existing groundwater borehole wells compiled by the JMG (Table 4.10). Furthermore, field checking was conducted to locate the position of groundwater borehole wells with the help of rapid geological mapping system (RGMS). RGMS is an integrated system which includes a portable data assistant, handheld global positioning system (GPS), digital camera, GIS software, and manual input for geological parameter through a customized user interface. The objective of the RGMS is to mark field observation and enter information in digital format during the course of field work.

The borehole wells data used to validate the predicted groundwater potential with the existing groundwater potential is collected from field and its details information is in Appendix (C). From the data presented for groundwater borehole wells, there are 20 borehole wells with the yield ranging from 2.14-71.43m^3/h. The minimum deep of borehole wells is 15 m and maximum is 380 m. Average deep of borehole wells is 93.05m. Mean yield of borehole wells in the study area is 20.27m^3/h. It falls under JMG groundwater potential classification as “high potential yield” (19 m^3/h). There are 11 borehole wells with very high potential yield (>20 m^3/h).

Model validation of predicted groundwater potential zones with the groundwater borehole wells data shows 80% of accuracy whereas about 16 borehole wells correctly agreed with predicted groundwater potential zones. Only four borehole wells were fall incorrect. It means that generated groundwater potential map has a good agreement with the groundwater borehole wells. In this study, the statistical method of correlation coefficient was also calculated using Microsoft Excel. It is used to determine the degree of association between area percentages of predicted groundwater potential zones vs. mean yield of groundwater borehole wells in the particular zones. The correlation coefficient has value between −1 and +1. A value of +1 indicated perfect positive relationship, while −1 is a perfect linear relationship. A value of zero indicates no correlation. The higher the number, the higher the correlation is. The results showed that the correlation coefficient is 0.80. It means that the strength of correlation is high (Asuero et al. 2006). The details are shown in (Table 4.13) below.

Table 4.13 Model validation using groundwater borehole wells

Wel l no.	T/sourc e	Dep th	Disc harge (Lit/s ec)	Yield (m^3/h)	JMG Classification	Predicted GWPZ	Validation
1	HDW	42	2.9	10.36	High(10-20m^3/h)	High	correct
2	DW	152	5	17.86	High(10-20m^3/h)	High	correct
3	DW	304	12	42.86	Very high(>20m^3/h)	Very high	correct
4	DW	102	2.4	8.57	Moderate(5-10m^3/h)	Moderate	correct
5	DW	161	20	71.43	Very high(>20m^3/h)	Very high	correct
`6	HDW	NA	6.2	22.14	Very high(>20m^3/h)	Very high	correct
7	HDW	15	1.7	6.07	Moderate(5-10m^3/h)	Moderate	correct
8	HDW	35	1.2	4.29	Very high(>20m^3/h)	Very high	Incorrect
9	HDW	85	6.5	23.21	Very high(>20m^3/h)	Very high	correct
10	DW	205	8	28.57	Very high(>20m^3/h)	Very high	correct
11	SPRING	NA	0.8	2.86	Very high(>20m^3/h)	Very high	Incorrect
12	DW	108	10	35.71	Very high(>20m^3/h)	Very high	correct
13	SPRING	28	3.4	12.14	High(10-20m^3/h)	high	correct
14	DW	176	8.7	31.07	Very high(>20m^3/h)	Very high	correct
15	HDW	NA	1.7	6.07	Moderate(5-10m^3/h)	Moderate	correct
16	HDW	30	1.2	4.23	Low(0-5m^3/h)	Low	correct
17	DW	NA	1.36	4.86	Very high(>20m^3/h)	Very high	Incorrect
18	HDW	15	0.6	2.14	Moderate(5-10m^3/h)	Moderate	Incorrect
19	SPRING	20	1.9	6.79	Moderate(5-10m^3/h)	Moderate	correct
20	HDW	380	18	64.23	Very high(>20m^3/h)	Very high	correct

4.4 Discussions

Integration of the Remote Sensing and GIS techniques has proven to be an efficient tool in groundwater studies (Arivalagan, 2014). This study analyzed hydrologic and geographic attributes of the study area and identified eight major factors influencing groundwater recharge potential, viz. geomorphology, geology, land use/land cover, drainage density, lineament density, soil, slope and Rainfall. Each factor was examined and assigned appropriate rank and weight. Based on the groundwater potentiality, all thematic layers were quantitatively placed together and categorized into very high, high, moderate and Low.

The data and thematic maps such as satellite images, soil data, geology data, drainage data and rainfall data, are helpful for mapping ground water potential zones (Giri &Bharadwaji, 2012).

Jose and Antony (2015) remote Sensing and Geographic Information System has become one of the leading tools in the field of hydro geological science, which helps in assessing, monitoring and delineating groundwater resources. It allows manipulation and analysis of individual layer of spatial data. It is used for analyzing and modeling the interrelationship between the layers.

Suganthi *et al.* (2013) delineate the groundwater potential zones of the area using Remote Sensing (RS) and Geographic Information System (GIS) techniques. Weighted overlay analysis was used to demarcate the ground- water potential zones. Various thematic layers such as geology, geomorphology, soil, lineament density, drainage density, rain fall and land use maps were prepared.

This study mainly deals with the integrated approach of Remote Sensing and Geographical Information System (GIS) to delineate groundwater potential zones by analyzed hydrologic and geographic attributes of the study area and identified the major factors influencing groundwater potential zones delineation. Each factor was examined and assigned appropriate rank and weight. A final ground water potential map is prepared with application of above technique.

This study has the methodological agreement with the above researchers regarding with use GIS and Remote Sensing techniques and applies the weighted overlay analysis method to delineate a groundwater potential zone and get more all less the same finding.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

The following conclusions and recommendation provides the overall conclusions from this study, recommendation for concerned body and further research for the study area.

5.1 Conclusions

- Groundwater potential zone was delineated by using GIS and Remote Sensing techniques through Analytical Hierarchy Process methods were delineated and identified based on the influential factors for groundwater potential zone. In this research, eight parameters were selected which have more affects the occurrence of groundwater potential zone prior to overlay analysis. By assigning quantitative weights, it is possible to make important criteria that have a greater influence on the result than other criteria. The AHP, methods were adapted and give the value for each factor. This approach allows decision makers to give the judgments in order to reduce complexity in decision making processes.
- It can be concluded that integration of GIS and Remote Sensing techniques are very useful, time and cost effective tool for the identification/ delineation of groundwater potential zones. This study was focused on the integration of Remote Sensing and GIS technologies in the identification and delineation of groundwater potential zones in the Sululta and Surrounding watershed. The remote sensing and GIS is a potentially effective tool and Very useful in delineation of groundwater potential zones.
- The study concludes that most of the very high potential areas represented by flood plains, chronic luvisols, low drainage density, very high lineament density, coincide with the low slope and very high rainfall areas. The study has resulted the groundwater potential zone map for the Sululta and Surrounding watershed which identified and delineated in four categories namely very high, high, moderate and low.
- The study concludes that the majority of the area is covered by very high potential zones (>20 m^3/h yields) as it is supported by the statistical data of groundwater borehole wells and the new generated predicted groundwater potential map of the study area. Model validation of predicted groundwater potential zones with the groundwater borehole wells data shows

80% of accuracy whereas about 16 borehole wells correctly agreed with predicted groundwater potential zones. Only four borehole wells were fall incorrect. It means that generated groundwater potential map has a good agreement with the groundwater borehole wells.

❖ The study confirms that paired comparison matrix analysis indicates that all parameters are significant but the most effective parameters in the area are: drainage density, lineament density, Geomorphology and geology. Most of the area, around 52.65% zoned under high potential and the next high coverage of the area 27.63% is moderate potential zone where as 8.80% is low potential zone.

5.2 Recommendations

Depending on this finding the following recommendations were forwarded.

- The study suggested that depending on the finding, the delineated groundwater potential map along with other thematic maps forms serve as resource information data base which can be updated from time to time by adding new information.
- The delineated groundwater potential zone information will be useful for effective identification of suitable locations for extraction of water which used to for different purpose. Further, it can be said that the present methodology can be used as a guideline for further research.
- In the present study, integrated GIS and remote sensing techniques were very helpful, time and cost effective tools for the identification and delineation of groundwater potential and analysis. For fast, cost effective and accurate result in delineation of groundwater potential zones investigations integrated remote sensing and GIS approach is highly recommended.
- The study suggested that the GWPZM generated will serve as useful guidelines for planners, engineers and decision makers providing quick decision- making in the management of groundwater resources, on delineate/identify Groundwater potential occurrence zone.
- Finally, further research is also needed to locate a groundwater potential zone using the model incorporating and more additional boreholes/wells using a combination of visual is recommended.

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Appendix A

Name	Elevation	Geogr1	Geogr2	Element	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sululta	2610	38.73333	9.183333	PRECIP	2005	9.6	3.5	33.3	73.9	17.9	41.7	257.7	250.2	155.3	24.3	13.7	0
Sululta	2610	38.73333	9.183333	PRECIP	2006	2.5	20.3	82.2	74.5	70.8	178.6	385.5	272.8	185.2	26.4	0	14.1
Sululta	2610	38.73333	9.183333	PRECIP	2007	38.6	5.8	41.3	37	111.6	244.2	284.2	372.2	120.5	5.7	4.7	0
Sululta	2610	38.73333	9.183333	PRECIP	2008	0	19.3	11.9	40.1	66.5	89.3	398.9	287.4	132.8	32.9	102.2	0
Sululta	2610	38.73333	9.183333	PRECIP	2009	24.3		5.2	13.2		126.5	361.5					
Sululta	2610	38.73333	9.183333	PRECIP	2010	11.3	117.9	56.8	59.7	117.1	267.8	440.9	374.3	243	11	22.4	10.1
Sululta	2610	38.73333	9.183333	PRECIP	2011	2.6	5.3	73.8	79.6		228.4	321.9	375.5	180.8	0.8	13.6	0
Sululta	2610	38.73333	9.183333	PRECIP	2012	0	0	37.1	176.3	92.6	124.1	481.8	423.6	301.1	14.9	0	25.2
Sululta	2610	38.73333	9.183333	PRECIP	2013	6.2	0.3	29.1	59.5	51.3	153.9	252.5	340.4	145.5	33.4	13.7	0.5
Sululta	2610	38.73333	9.183333	PRECIP	2014	0	25.2	46	65.8	81	60.4	261.1	309	121	45		0.5
Sululta	2610	38.73333	9.183333	PRECIP	2015	0	28.1	18.7	0.8	83.8	134.8	219	238.8	98.1	5.4	14.6	2.6

Appendix B

Name	Elevation	Geogr1	Geogr2	Element	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Addis Ababa Obs	2386	38.7475	9.01891	PRECIP	1995	0	69	41.5	174.4	68.2	102.9	190.2	314.9	136.1	0	0	
	2386	38.7475	9.01891	PRECIP	2005	45.9	51.6	83.2	160.9	133.7	179.8	246	315.2	162.5		4.4	0
	2386	38.7475	9.01891	PRECIP	2006	0.7	11.2		78.9	74.6	150.1	356.3	243.6	239.1	54	0.3	8
	2386	38.7475	9.01891	PRECIP	2007	51.3	19.1	59.8	73.8	120.1		261.8	381.2	147.6	24.8	0	0
	2386	38.7475	9.01891	PRECIP	2008	0	13	0	49.4	94.3	88.9	277	360.9	256.7	88.2	79.4	22.9
	2386	38.7475	9.01891	PRECIP	2009	21.3	2.7	28.4	80.6	58.9	82.6	349.9	388.3	112.7	45.8	4.4	65
	2386	38.7475	9.01891	PRECIP	2010	2.6	79.8	55.5	97.8	74.4	271.1	313.9	205.8	237.8	1.8	25.7	15
	2386	38.7475	9.01891	PRECIP	2011	14.1	13.1	44.3	22.8	66.1	182	180.9	340.8	146	0	42.3	0
	2386	38.7475	9.01891	PRECIP	2012	0	0	15.8		50.2	69.4	324.2	298	215.5	2.3	0	9.8
	2386	38.7475	9.01891	PRECIP	2013	4.4	0		92.3	85	153.2		353.2		58.4	22.3	0
	2386	38.7475	9.01891	PRECIP	2014	1.7	47.4	61.5	26.2	93.6	66.7	219.9	262.4	264.7	35	1.7	0
	2386	38.7475	9.01891	PRECIP	2015	0	0	0	0	0	0	217	309.9	148.9	0	7.7	0.1

Appendix C

Well no.	Easting	Northing	Elevation	T/source	Depth	Discharge (Lit/sec)	Yield (m^3/h)	JMG Classification	Predicted GWPZ	Validation
1	473304	1015471	2584	HDW	42	2.9	10.36	High(10-20m^3/h)	High	correct
2	474222	1010969	2602	DW	152	5	17.86	High(10-20m^3/h)	High	correct
3	474515	1013279	2603	DW	304	12	42.86	Very high(>20m^3/h)	Very high	correct
4	469352	1007813	2751	DW	102	2.4	8.57	Moderate(5-10m^3/h)	Moderate	correct
5	475139	1013343	2591	DW	161	20	71.43	Very high(>20m^3/h)	Very high	correct
6	476596	1014584	2636	HDW	NA	6.2	22.14	Very high(>20m^3/h)	Very high	correct
7	469277	1007361	2724	HDW	15	1.7	6.07	Moderate(5-10m^3/h)	Moderate	correct
8	477423	1014882	2583	HDW	35	1.2	4.29	Low(0-5m^3/h)	Very high	Incorrect
9	477753	1013625	2603	HDW	85	6.5	23.21	Very high(>20m^3/h)	Very high	correct
10	476265	1015642	2748	DW	205	8	28.57	Very high(>20m^3/h)	Very high	correct
11	475835	1013592	2654	SPRING	NA	0.8	2.86	Low(0-5m^3/h)	Very high	Incorrect
12	475967	1016072	2676	DW	108	10	35.71	Very high(>20m^3/h)	Very high	correct
13	475471	1011475	2561	SPRING	28	3.4	12.14	High(10-20m^3/h)	high	correct
14	475247	1010379	2752	DW	176	8.7	31.07	Very high(>20m^3/h)	Very high	correct
15	471800	1007540	2570	HDW	NA	1.7	6.07	Moderate(5-10m^3/h)	Moderate	correct
16	464524	1007407	2640	HDW	30	1.2	4.23	Low(0-5m^3/h)	Low	correct
17	474514	1009432	2606	DW	NA	1.36	4.86	Low(0-5m^3/h)	Very high	Incorrect
18	471900	1009497	2634	HDW	15	0.6	2.14	Low(0-5m^3/h)	Moderate	Incorrect
19	473174	1007265	2735	SPRING	20	1.9	6.79	Moderate(5-10m^3/h)	Moderate	correct
20	476585	1010336	2597	HDW	380	18	64.23	Very high(>20m^3/h)	Very high	correct