GIS and Remote Sensing Application for Groundwater Potential Zone Delineation: the Case of Nili River Catchment of Tekeze River Basin Amhara Region Ethiopia.

TADESSE DAGNEW ALEMU

A THESIS SUBMITTED TO

COLLEGE OF DEVELOPMENTAL STUDIES, CENTER FOR ENVIRONMENT AND DEVELOPMENT IN WATER RESOURCE MANAGEMENT PROGRAM

THESIS SUBMITED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN WATER RESOURCE MANAGEMENT PROGRAM

ADDIS ABABA UNIVERSITY

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Adviser Shimeles Damene (PhD)

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OCTOBER, 2020

Statement of the Author

By my signature below, I announce and confirm that this thesis is my own work. I have followed all ethical and technical principles of research in the preparation, data collection, data analysis and compilation of this thesis. Any scholarly article that is included in the thesis has been given acknowledgment through reference.

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This is to certify that the thesis prepared by Tadesse Dagnew, entitled: **AS GIS Application for Groundwater Potential Zone Delineation: the Case of Nili River Catchment of, Tekeze River Basin Amhara Region Ethiopia** and submitted in partial fulfillment of the requirements for the Degree of Master of Science **(Water Resource Management)** complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the Examining Committee:

Examiner Molla Maru_____________ __ Signature ________Date ______________

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ABSTRACT

*Groundwater is treasured and very important natural resource globally. It is also the most essential for the development of a country. However, groundwater potential zone mapping still remained uncertain due to the challenge nature of groundwater and also less studied. Therefore, this research aimed at delineating the groundwater potential zone of Nili river catchment by using the integration of Geographic Information System (GIS) techniques Hence, in this estimation seven controlling factors are used as thematic layer which, were derived from 30m*30m resolution Digital Elevation Model (DEM) data, and exiting map of geology, geomorphology, slope, drainage density and land use/land cover, rainfall, and soil texture. The groundwater potential evaluation of Nili river catchment utilized the above factors as an input data using weighted overlay analysis and Analytical Hierarchy Processes (AHP) methods. In this analysis each thematic layers were weighted, calculated and compared with different literature values of similar researches at different localities. After weighted average calculation of each thematic layer, relative importance was assigned values according to AHP scale.The analysis showed that groundwater potential of the study area ranges from moderate (31.66%) to very poor (16.13%) with intermediate potentials rated as good (27.59%) and poor (24.62%). The analyses revealed that most important influencing factors of the groundwater potential zones of the study area (Nili river catchment) are geology, geomorphology, land use land cover and slope as compared to the other controlling parameters such as rainfall, drainage density and soil texture. The model result also indicated that good groundwater potential is associated with low slope, flood plains, crop lands, low drainage densities and high rainfall areas. In converse, poor groundwater potentials are associated with steep slopes mainly to mountains areas, bare lands, high drainage densities and low rainfall areas. Therefore, this research shows vigorous technique using GIS is economically affordable, technically competent and valuable for delineating groundwater potential zones. It is also recommended that the Nili river catchment needs geophysical investigations and further wells drilled in the catchment to get supplementary subsurface formation.*

Keywords: Groundwater potential, GIS, Remote Sensing ,Blesa, Nili River, AHP

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Acronyms and Abbreviations

AAU	Addis Ababa University
AHP	Analytic Hierarchy Process
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
BMC	Billion Meter Cubic
CI	Consistency Index
CR	Consistency Ratio
DEM	Digital Elevation Model
E	Easting
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GSE	Geological survey of Ethiopia
GW-MATE	Groundwater Management Assistance Team
GWPZ	Groundwater potential Zone
HSG	Hydrological Soil Group
IDW	Inverse Distance Weighed
IWMI	International Water Management Institute
ITCZ	Inter Tropical convergence Zone
KM	Kilometer
LULC	Land Use Land Cover
M	Meter
MCDA	Multi Criteria Decision Analysis
MM	Mili Meter
MoA	Ministry of Agriculture
MoWE	Ministry of Water and Energy
MoWR	Ministry of Water Resource
N	Northing
NMA	National Metrological Agency

NRCS	Natural Resources Conservation Service
Q	Discharge
RS	Remote Sensing
RSCZ	Red Sea convergente zone
SSA	Sub-Saharan Africa
STZ	Subtropical Jet
T	Transmissivity
TDS	Total Dissolved Solids
TEJ	Tropical Easterly Jet
SRTM	Shuttle Radar Topographic Mission
USDA	United States Department of Agriculture
UTM	Universal Transversal Mercator
WWDSE	Water Works Design and Supervision Enterprise
RCMRD	Regional Center for Mapping of Resource for Development

Chapter One

1. Introduction

1.1 Background

Groundwater is a vital resource in steadily increasing demand by human for water .Thus it is one of the most important natural and dynamic resources that stored in subsurface geological formation. In the history of water use, groundwater has been the source for domestic, industrial and agricultural consumption in all over the world. Groundwater is recharged by surface naturally from precipitation, streams and rivers when these recharge riches the water level it may be discharged from surface naturally at springs, leakages and can form swamplands (Sophocleous, 2002).

The arid and semi-arid regions described by short period of rainfall and long dry periods, in such regions constant replacement, storage and supportable consumption of groundwater is in-dispensable to address the water needs for the community. Human activities such changes in land use/cover and natural factors like, soil cover cause fluctuations and reduction in groundwater recharge (Kumar *et al.*, 2016).

The source, an occurrence, distribution, movement and chemical constituent of groundwater depends on various features such as geology, slope, and geomorphology; land use/cover, geological structure, drainage density, soil texture and climatic factors mainly rainfall characteristics (amount, intensity and distribution) and temperature that affect evapotranspiration (Tessema, 2015).

According to Kebede, (2013) the most groundwater resource of Ethiopia depends on tertiary volcanic and sedimentary rocks that covers two thirds of the country area. Off the nine (9) wet river basins in Ethiopia Tekeze river basin is among water strained areas due to the result of air, erosion of fragmented plateau, absence of appropriate drainage and geomorphologic structures-to accumulation of surface-and–groundwater(Kebede, 2013).Therefore, it is important to understand the groundwater potential of such basins so as to do proper management and plan. For doing so different methods exist to map and to investigate groundwater occurrences and distribution in the world both in traditional and advanced technology. Among this, nowadays, the `Geographical information system

(GIS) and Remote Sensing (RS) techniques are most powerful methods in investigating the groundwater occurrences particularly in non-accessibility areas using sophisticated systems and large area coverage (Prasad *et al*.,2008).

Geographic information system can be deliberated a provision system decision making and a best instrument for monitoring certain hydrogeological processes with socio economic impats.Despite the extensive analysis and technological advancement, the study of groundwater has remained more, as there is no direct technique to facilitate observation of water below the surface. Its presence or absence can only be inferred indirectly by learning the geologic and surface parameter (Libasse, 2007).

The Analytical Hierarchy Process (AHP) generates a weight for every analysis criterion allowing to the decision maker's pairwise comparisons of the criteria. The higher weight corresponds to the more significant the consistent criterion. Next, for a fixed criterion, the AHP assigns a score to every choice according to the decision maker's pairwise comparisons of the choices based on that criterion (Wind and Saaty, 1980).

Therefore this study applied Geographic Information Systems and remote sensing techniques to delineate groundwater potential considering Nili river catchment of the Tekeze river basin, which have water stress, which located in Amhara Notional Regional State.

1.2 Statement of the Problem

Nowadays the consumption of water for domestic, industrial and agricultural uses depends on groundwater as the surface water availability becomes declining over time in the study area in particular and generally in the basin. In the previous different studies had been carried out in the Nili River Catchment about groundwater potential assessment by using different groundwater investigation methods such as hydrogeological, geological, and geophysical methods. These methods have technical limitation as they are based on few samples and robustness of the techniques in extrapolating the limited data set. In this regard applications of GIS and remote sensing might be key techniques to plug accuracy of physical data based studies. In this aspect, so far there was no any specific and separate study around this by using the application of GIS and remote sensing methods exclusively in relation to groundwater potential assessment. The groundwater assessment using GIS and remote sensing techniques are more important than the traditional methods such as (-hydrogeological, geological and geophysical-). The GIS and RS groundwater assessment techniques are more effective for large areas, fast, cost effective, time effective than the traditional methods but the traditional methods are time consuming and costy and also needs large human resources than the GIS and remote sensing techniques (Ahmed, 2016). The study area has short period of rainfall and long dry periods that influence continual replenishment of groundwater storage, thus sustainable utilization of the limited resource has been punishing to address the needs for the community. Moreover, the study area is also characterized by semiarid climate where most of the time the surface water usage is reducing and hence, it is not sufficient for the community in terms of water need. The community water supply depends on ground water so the groundwater needs critical attention to develop and extract the groundwater potential zones in the study area.

Therefore, generally this research is aimed to gain knowledge on groundwater potential of the study catchment and also application of GIS and remote sensing techniques.

1.3. Objective of the Research

1.3.1 General Objective

The main objective of this research is to delineate the groundwater potential zones of Nili river catchment in Tekeze river basin using the application of integrated Geographical Information System and Remote Sensing techniques.

1.3.2 The Specific Objectives of the Study Area

1. To identify the groundwater controlling factors using GIS and Remote sensing techniques.
2. To asses groundwater potential zone of the study area using GIS and Remote sensing techniques
3. To cross validate the groundwater potential zone with the existing borehole data.

1.4. Research Question

1. Do lithology, slope, drainage density, lineament density, rainfall, soil and land use/cover determine the groundwater potential of the study area?
2. Do all parameters have equal value to delineate the groundwater potential zone?
3. What is the groundwater potential zone in the study area?

1.5. Significant of the study

The population of the study watershed is used waters for drinking, irrigation and other livestock consumptions from groundwater.The decrease rainfall trend of dry zone and increase of population size and demands of water for irrigation and other livelihood requirement's calls for sustainable exploitation of the groundwater resources in the basin based on adequate knowledge and information.

Understanding the application of geographic information system for groundwater assessment is most popular which is time and cost effective and also important for management, proper utilization and future planning of water resources for sustainable development. Therefore the study will provide knowledge and information about groundwater resource controlling factors. In addition the research is vital for best use of available water and test application of GIS techniques in groundwater potential assessment. Moreover, this study will have added value for further researches in groundwater resources, mainly on

- Planners and development actors use the finding to prevent water shortage problems by managing water resources.
- The result can be used as the tool or guidelines in future related studies in the study area and similar areas.
- To test applicability of GIS and remote sensing in groundwater potential delineation.

1.6. Limitation of the study

There was lack of the whole data groundwater inventory data and there was a lack of full, high resolution meteorological data of the study area.

1.7. Structure of the Thesis

This research contains five chapters on GIS and RS application of groundwater potential zone determination. **Chapter one** contains introduction and background, statement of the problem, the general objective of the research, the specific objective of the research, research question, significance of the study, limitation of the study and the structure of the thesis. **Chapter two** contains the literature review of different papers that done on Groundwater potential zone mapping using GIS and RS application and related with this title. **Chapter three** contains the description of the study area, location, materials and methods, rainfall and temperature, physiography and drainage, soils and vegetation.The methods of generating groundwater potential zone using geographic information systems in detail. The hydrogeology and groundwater flow direction, thematic maps of the study area, the pair wise comparison of the normalized weight of the controlling factors and relative importance of the thematic layers with groundwater potential **Chapter four** contains result and discussion of the research, the result of seven thematic maps are also projected in chapter four **Chapter five** also contains the conclusion and recommendation.

Chapter Two

2. Literature Review

2.1 Groundwater Definition and Use

Groundwater is defined as all water which occurs in the soil and geological formations below the land surface. An aquifer is a geologic formation, group of formations, or portion of a formation capable of yielding usable quantities of groundwater to wells or springs (Marcus *et al*., 2012).

The amount and value of groundwater resources in the worldwide is vulnerable by unmanageable water extractions and intakes. This request for groundwater is the result of fast population and commercial development and growing urbanization and commercial farming and is basically uncontrolled by effective governance structure. Groundwater demonstrates a crucial and increasing role in overall drinking water supply and food security (Tuinhof *et al.,* 2011). Margat and Vander Gun, (2013) stated that groundwater is frequently used in various countries. It is the principal source of drinking water and gives importantly to irrigation, therefore towards food security in arid and semiarid areas. Consequently it donates the significant elements of water economy.

Groundwater is the fundamental source of water for human existence and financial improvement in the widespread drought-prone regions of Sub-Saharan Africa, Usually through this area it has been the availability of groundwater through dug boreholes, at springheads and the seepage parts that organized the degree of social settlement outside the main river valley and riparian areas and, This subsurface water was usually improved through civic and governmental advantages (Tuinhof *et al*., 2011). The convenience of groundwater properties in SSA is reserved by hydrological situations and displays extensive spatial variation, so this resource to different advantages in urban water supply according to the residential situations. The massive of small-medium sized towns depend on for their municipal water supply over enormous range of hydrogeological situation (Tuinhof *et al.*, 2011).

2.2 Water Resource in Ethiopia

2.2.1 Surface Water Resource in Ethiopia

Surface water is any body of water that found on the surface, including streams, rivers, lakes, wetlands, reservoirs and creeks. The 0.7 percent of the country coverage occupied by the bodies of water (MoWE, 2013).This includes 12 river basins. Different researchers give different estimation of surface water and groundwater potential of the country. The largest lakes of Ethiopia are 12 which are encompassed by area of 7300 km^2 and the storage capacity is 84.79 BMC. The lakes found in the different regions of the nation and they have diverse elevation, drainage and surface, depth as well as storage volume (Worku, 2018).

According to Berhanu *et al*., (2014) the surface water capacity in Ethiopia is estimated approximately 124.4 (BCM). More than half of the Ethiopian rivers are transboundary, subsequently 97 % of this predictable yearly river flow of the nation flows outside Ethiopia into bordering countries and only 3 % of this quantity residue inside the nation. Lakes capacity is estimated approximately 70 (BCM). The surface water potential is projected to increase irrigation by 3.8 million hectares and likely to generate 45,000MW hydropower. Climate pollution adversely affects the life of surface water supplies and contributes to decrease groundwater tables to the point of wells and springs drying (GSE, 2013).

2.2.2 Ground water in Ethiopia

The event of groundwater is primarily affected by the geology, geomorphology, tectonics and climate of the nation. The inconsistency of these variables in Ethiopia emphatically impacts the amount and quality of the groundwater available in the different parts of the country. The geology of the country gives usable groundwater and gives great transmission of precipitation to revive aquifers, which create springs and bolster lasting streams (Alemayehu, 2006).

Understanding the phenomenon of groundwater to make proper use of the groundwater resource in spatial and time distribution proper management and effective optimization are required. However, there are very few studies available on the country’s groundwater infrastructure (Awlachew *et al*., 2007).

The country is also endowed naturally with significant amount of groundwater resource which is not computed exactly because of deficiency of appropriate hydro geological data**.** Groundwater potential of Ethiopia is estimated to be 30 (BCM) resources (Berhanu *et al.*, 2014, MoWR and GW-MATE, 2011). Ethiopia has lower groundwater capacity relative to surface water supplies (Awulachew *et al.*, 2007).

The Ethiopia domestic water resource mainly depends on groundwater about (85%). Groundwater resources have no treatment before provided to the user because it has natural protection from pollution (Pavelic *et al.*, 2012).

Annual renewable groundwater resources are expected at around (36 billion cubic meters) with estimates of total groundwater storage varying from 1,000 to 10,000 billion m^3 (Kebede *et al.*, 2016).

The origin of groundwater is primery affected by the geophysical and weather situation of the region.The attempt to enter useful aquifers is a peculiar structures of Ethiopia, which is considered by the extensive hetroginity of geology, geomorphology and enviromental circumstances (Alemayehu, 2006).

Ethiopian's groundwater/aquifer systems are manly different types of aquifer systems which exist in the country's various river basin or regional states. The temporal and spatial variability of the occurrence of groundwater is very high and difference of depths and yields is very also very high among wells located within short distances (GSE, 2013).

2.2.3 Application of Geographic information system and Remote Sensing for Groundwater Studies

Now a day ground water needs more attention for drought problems, for water resource and for diverse irrigation systems in any country. Modern technology is used for mapping of groundwater prospective zones such as GIS and remote sensing. The integration of these modern technologies has been verified to be an efficient tool in groundwater studies (Libasse, 2007).

The Geographic Information System (GIS) are an operative tool for storage, handling and revealing spatial data often faced in water resources management. The application of geographic information system in water resource is constantly on the growth (Tsihrintzis et al., 1996). Remote sensing is an exceptional tool for hydrologists and geologists in understanding the "confusing" issues of groundwater exploration. In current years, Satellite remote sensing data has been extensively used in locating groundwater potential zones. Satellite remote sensing data isn't solely efficient, reliable and timely but also meets the essential requirements of data in (GIS) domain, that are “current, sufficiently accurate, comprehensive and offered to a uniform standard”. Integration of the information on the dominant parameters is best achieved through GIS which is an effective tool for storage, management and retrieval of spatial and non-spatial data as well as for integration and analysis of this information for meaningful solutions. The technique of integration of remote sensing and GIS has evidenced to be very helpful for groundwater studies (Arkoprovo *et al.*, 2012).

The idea of integrated remote sensing associated with GIS has tested to be economical tools in groundwater investigations in facilitating higher knowledge analysis and their interpretation. In addition, the benefits of using remote sensing knowledge for hydrogeological investigation an observance is its ability to come up with information in spatial and temporal domain, that is incredibly crucial for undefeated analysis prediction and validation (Tessema , 2015).

Geographic Information System has emerged as a powerful tool in analyzingand quantify ing such multivariate aspects of groundwater occurrence. It is very helpful in delineation of groundwater prospect and deficit zones (Carver, 1991). Modern technologyies such as remote sensing and geographic information systems have evidenced to be suitable for learning geological,structeral and geomorphological conditions togeather with typical surveys.Integration of the two technologies has verfied to be an economical tool in groundwater studies (Saraf and Choudhury 1998).

Satellite images are progressively used in groundwater exploration because of their value in identifying varied ground features, that could serve as either direct or indirect indicators of presence of groundwater (Jasmin and Mallikarjuna, 2011). A predominantly popular use of RS to groundwater has existed the identification of lineaments that are assumed to be linked to faults and fracturing in hard-rock (Salwa, 2015). The seeking of subsurface water impending by unadventurous technique of field examination for the study area is time intense, costy and desires extra man power. Geographic information system is a fast and economical, tool for finding groundwater prospective zones (Rajaveni *et al*., 2015). Remote sensing technique offers a plus of getting access to giant coverage, even in inaccessible areas. It is fast and efficient tool in manufacturing valuable information on geology, geomorphology, lineaments, slope, etc. that helps in interpreting groundwater potential zone (Banerjee *et al.,* 2008).

Surface geophysical method is one of the groundwater exploration methods. One of the surface geophysical methods is therefore the vertical electrical sounding method. Vertical electrical sounding (VES) is one to deliver valuable information regarding the vertical successions of subsurface geo-materials in terms of their individual thicknesses and corresponding resistivity values. It is rapid and much effective in estimating aquifer thickness of an area and is cost effective technique for groundwater study (Ha *et al.*, 2016)

2.3 Controlling Factor of Groundwater Occurrence

To investigate the origin, occurrence, movement and situation of groundwater using GIS data based indirectly analysis of openly visible landscape features like geological structures, geomorphological, land use/cover, slope, rainfall, drainage density and lineament density (Aneesh and Deka, 2015). The controlling factors that affect the groundwater potential zone determination and their relative importance are taken from previous literatures with the same representative of the controlling factors were selected.

2.3.1 Drainage density

The drainage density (km/km^2) used to measure the length of stream channel per unit area of the drainage watershed (Magesh *et al.*, 2012). Drainage density is that the total length of all streams and rivers found in a catchment divided by the area of the geographic region. Soil porousness (infiltration capacity) and underlying rock sort have an effect on the runoff during a watershed; water-resistant ground or exposed bedrock can cause a rise in surface water runoff and so to a lot of frequent streams (Magesh *et al.*, 2012). Rugged regions or those with embossment have the next drain density than alternative drain basins if the opposite characteristics of the basin are identical. High densities may indicate a larger flood risk. High drainage densities conjointly mean a high division magnitude relation. Drainage density is well calculated with the assistance of Arc Map software.

Very high drainage density/course areas have poor groundwater potential due to low infiltration and high runoff. On the other hand, areas with low drainage density permit more infiltration to recharge the groundwater and, thus, have more potential for ground water occurrence (Murasingh, 2014).

Table 2-1 Reviewed drainage density for groundwater potential

Factors	Km/km2	Rank in numbers	Rank in Words
Drainage density	0-0.24	5	Very high
	0.24-0.61	4	High
	0.61-0.98	3	Moderate
	0.98-1.44	2	Low
	1.44-2.91	1	Very low

Source: Shekhar and Chandra (2014)

Where Km = length of stream channel and Km2 = the area of the drained catchment

2.3.2 Land use land cover

Land use indicates that how the people are using the land where as land cover indicates that the physical land type such as forest, water body crop land grazing land. The land use affects groundwater properties through changes in recharge and by varying demands for water unfortunate land use principally humble land management. Human activities in ecology have controlled to adverse effects in aquifer with main values being the loss of vegetation and water accessibility (Gonzalez et al., 2017).

The land use land cover shows a crucial part in groundwater prospecting. The part of penetration is straightforwardly relative to the thickness of vegetation cover, i.e., on the off chance that the surface is enclosed by thick woodland, the penetration will be more and the runoff will be less. A forest, water bodies and crop land was allocated highest rank for groundwater recharge. Barren rocky wastelands and built up area have no groundwater revive (Raviraj *et al.*, 2017).

According to Tesema, (2015) the land use land cover has very essential appearances for overflow process that affects infiltration, erosion and evapotranspiration. Land use /Land cover of various area depends on geomorphology, agro-ecology, climate and human induced activities and it is affects for groundwater existence and accessibility (Hussein *et al.*, 2017). Singh,(2014) specified that the LULC information is a significant feature in subsurface water storage and recharge the category and nature of LULC on groundwater controlling factors in order to increasing put as :Plantation>Shrubs Land>Cultivation Land> Grazing Land. According to this information shrub land and plantation area are more suitable for groundwater prevalence area due to well infiltration. The degree of agriculture is extremely increased because of the manifestation of good groundwater potential. Land cover governs the extent of water for permeation. Highly porous land cover favors the groundwater potential whereas low porous land cover raises runoff thus restrictive the filtration to subsurface (Choudhary and Pathak, 2016)**.**

2.3.3 Slope

Slope is one important factor to control the groundwater potential of the region. Rapid run- off occurs in the case of steep slope due to the higher velocity of the water (Das, 2018). Slope shows a fundamental character in the groundwater occurrence as infiltration is inversely related to slope. A break in the Slope (i.e. steep slope followed by gentle slope) largely supports substantial groundwater infiltration (Saraf *et al.*, 1998).

Slope is one of the important terrain factors which are defined by horizontal spacing of the contours. Generally, closely spaced contours characterize steeper slopes and sparse contours demonstrate gentle slope. The lower slope values specify the flatter terrain (gentle slope) and higher slope values relate to steeper slope of the terrain. Slope is one of the features governing the infiltration of groundwater into subsurfa ce; hence an indicator for the suitability for groundwater prospect. In the gentle sl- ope the surface runoff is slow allowing more time for precipitation to percolate in to the subsurface, while high slope area facilitate high runoff permitting fewer residence time for precipitation hence relatively less infiltration than gentle slope. Over 85 % of the upper Tekeze basin has a steep slope which is more than 60 degrees and the most elevated portion of the region is dismembered, cliffs through minor inconsequential less than 15% intermountain valleys available for agriculture (Wwdse, 2008).

2.2.4 Geomorphology map

Geomorphology of the area is one of the main important landscapes during assessing groundwater potential and prospect. Geomorphology map is mostly used to classify the numerous geomorphological units and the possibility of the groundwater occurrence in every unit (Pradhan, 2009). A logical study of several landforms and geomorphic units supports to decide the potential zones of groundwater in the study area. Geomorphological units are particularly supportive for selecting groundwater potential zones and artificial recharge sites (Elango *et al.*, 2013). The prominent geomorphic units recognized in the study area through interpretation of satellite imageries are denudation hills, residual hills, inselberg, linear ridges/dykes, pediments, Pedi plain, and valley floor. These landforms act as groundwater storage reservoirs, and some of them act as recharge and runoff zones (Rao *et al.,* 2003; Jha *et al.,* 2007).Geomorphology and its features are essential components for understanding landforms evolutions controlling the movement and occurrence of groundwater.

2.3.5 Geology

Geology offers crucial information around the fundamental geological setup and the topographic feature hence widely used in groundwater-related studies (Machiwal *et al.,* 2011).According to Mohr, (1983) and Mengesha *et al.,* (1996) the Ethiopian geology classifies into two classes which are Eden serious and trap serious (Pre-rift). The trap serious classifies into four from oldest to youngest (*Ashangie, Aiba, Alaji and Tarmaber*).The *Ashangie* formation deeply weathered, flows are laterally discontinues and several springs emerge between these lithology contacts. The *Ashangie* basalts are brecciated and it has low permeability. The A*iba* and A*laji* formation are characterized by low degree weathering, thick layering and cliff topography. The *Tarmaber* formation is characterized by fracture, joint, cliff topography and flat tops. Geologically the country can discern broad classification, such as 18% of the Precambrian basements, 25% the Paleozoic and Mesozoic sedimentary rocks, 40% of the tertiary sedimentary and volcanic rocks, and 17% of the quaternary sedimentary and volcanic rocks (MoWR, 2009).Geology shows an essential role in the distribution and existence of Groundwater (Krishnamurthy and Srinivas, 1995). Geology is considered as the first principal factor since the distribution and magnitude of spring discharge, the degree of fracturing of the rock unit, the thickness of the formation, the grain size, the type and degree of cementation and the extent of the weathering are some of the indirect evidences combined in geological properties and they define as to whether a certain area is likely to be a low, moderate or high groundwater potential.

2.3.6 Soil texture

Soil texture and depth have the main impression on groundwater potentiality of the study area (Mehra and Singh, 2018). Soil is the disjointed portion of the rocks. Information on the soil is imperative for the hydrologic evaluation. The interference and runoff comparative depends on the soil properties and its grain. It has been well-known from the GPM that the soil in deposited plains and the cultivation land (high permeability and porosity) supports completely for the greater groundwater potential zones because of their high rate of infiltration (Champak and Dinesh, 2018). The soil characteristics are very important for groundwater quality as well as quantity. The soil is derived from in different rock types or the breakdown of rocks at the earth's surface, by the action of different geological activates of by rainwater, by extremes of temperature, wind depending on climate.

Table 2-2 Soil classification and rank relative to groundwater potentiality

Factors	Classification	Rank in words	Rank in numbers
Soil texture	Clay	Very poor	1
	Clay loam	Poor	2
	Sandy Clay loam	Moderate	3
	Sandy loam	High	4
	Sandy and wetland	Very high	5

Source Lemmesa (2017)

2.3.7 Rainfall

According to Alemayehu, (2006) rainfall is limited with irregular distribution; groundwater is the focal basis to meet numerous water demands in northern Ethiopia.

Rainfall is one of the controlling features of groundwater potential in the study area. Rainfall distribution along with the slope gradient directly affects the infiltration rate of runoff water hence increases the possibility of groundwater potential zones (Bhuvaneswaran; et *al.*, 2015).

Rainfall is one of the main bases of recharge. And it governs the amount of water that would be accessible to penetrate into the subsurface systems. Generally, high annual rainfall distribution indicates the presence of high GP (Sener *et al.*, 2005; Rose and Krishnan, 2009; Fashae *et al.*, 2014). Precipitation could be that most critical feature and duration and magnitude of the precipitation are the most contributing factor for groundwater recharge (Adiat *et al.*, 2012).

Precipitation in Ethiopia is the result of multi-weather frameworks that incorporate Subtropical Jet (STJ), Intertropical Convergence Zone (ITCZ), Red Sea convergence Zone (RSCZ), Tropical Easterly Jet (TEJ), and Somali Jet. The spatial conveyance of precipitation in Ethiopia is significantly influenced by geographical changeability of the country (NMA, 1996).The concentrated, position, and heading of these climate frameworks lead the changeability of the sum and conveyance of precipitation within the country. Thus, the precipitation within the nation is characterized by regular and inters annual inconstancy (Seleshi and Zanke, 2004).

Chapter Three

3. Materials and Methods

3.1. Description of the Nili River Catchment

3.1.1 Location

The Tekeze river basin is situated in the northwestern part of Ethiopia and covers a total area of approximately 82,350 km^2 within Ethiopia exclusively in Amhara and Tigray regional states. The river basin is divided in to three sub basins namely Tekeze itself, Angereb and Guang. The 70% of the river basin lies on the highland part of Ethiopia. The river water of annual flow was estimated to be about 8.2 billion m^3 and to be 0.2 billon m^3 groundwater resources (MoWR, 1997). Except in a few areas of the basin the ground water supply is not good promising. The quality of surface water is suitable for irrigation (Awlachew *et al.*, 2007). According to WWDSE, (2008) the upper Tekeze river basin groundwater's considered to have low total dissolved solids (TDS) and generally meets the water quality for drinking and irrigation.

The study area is found in Northern Ethiopia in *Amhara* National Regional State in Tekeze River Basin specifically Nili river catchment. The study area touches two administrative *woredas* specifically East *Belesa* and *Ebnat woreda.* The distance to the river catchment is measured about 700km from the country capital Addis Ababa and 135km from the regional capital Bahirdar. In geographical-term and it is located between from 37° 57 ' 26 " to 38^0 23 ' 43 " E and from 12°10' 55" to 12° 38' 34" N in (Figure 3-1). In total, the Nili River Catchment covers 1259 km^2.The catchment is characterized by complex topography with elevation ranging from 1257m to 2805. The Nili river catchment is one of the tributaries of Tekeze River and it is one of the perennial river flows.

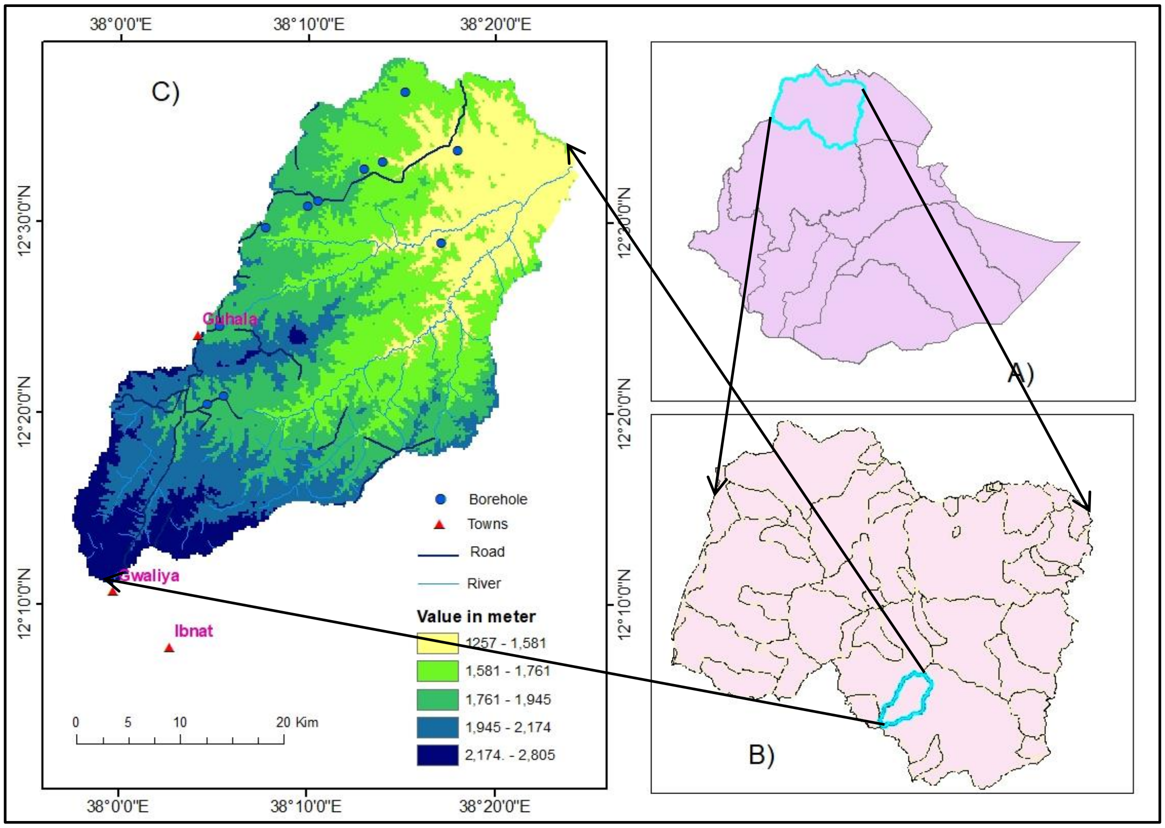

Figure 3-1 Location map: A) River basin of Ethiopia B) Tekeze river basin C) Nili river catchment

3.1.2 Rainfall and Temperature

The study areas lie in sub-tropical climate zone, which is traditionally classified as *Dega* (cool high land); *Woynadega* (milled high land) and *Kola* (hot low land) climate zones (Hurni, 1998). As shown in figure 3.2 the *Dega*, *Woyna-dega* and *Kola* climate zones covers 3.48%, 87.65 % and 8.87% of the study area respectively. The climate within the area is more affected by altitude (Hurni, 1998). The study area has bimodal rainfall where main rainfall received between June and August, which locally called as *kiremt* season while the small rainfall season referred to as *Belg* occur between (mid-February and mid-May) based on Tekeze river basin master plan (MoWR,1997). The mean annual rainfall is 742mm with 604mm and 974mm minimum and maximum rainfall recorded in 1991 and 2006 respectively (figure3.4). The temperature of the study area is varying from month to month. The mean, minimum and maximum of the study area 24.3°C, 12.6°C and 36°C respectively.

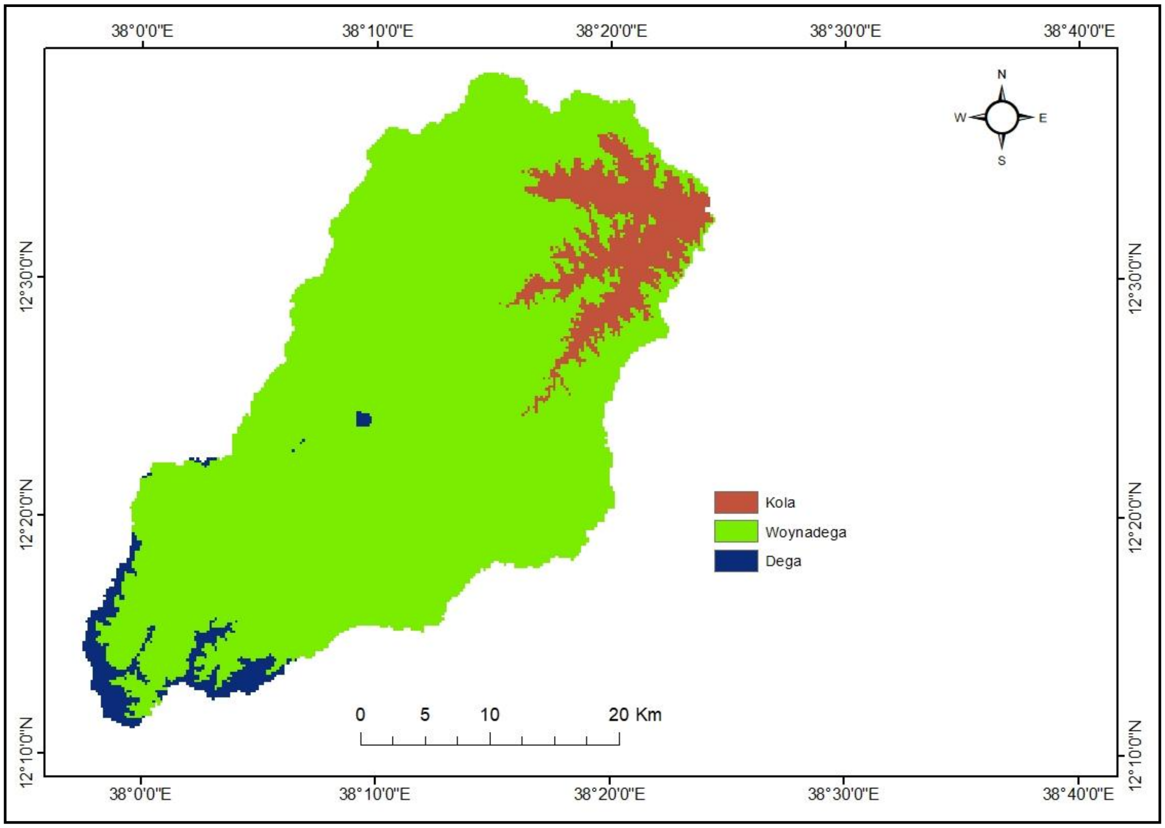

Figure 3-2 Agroclimate map of Nili catchment

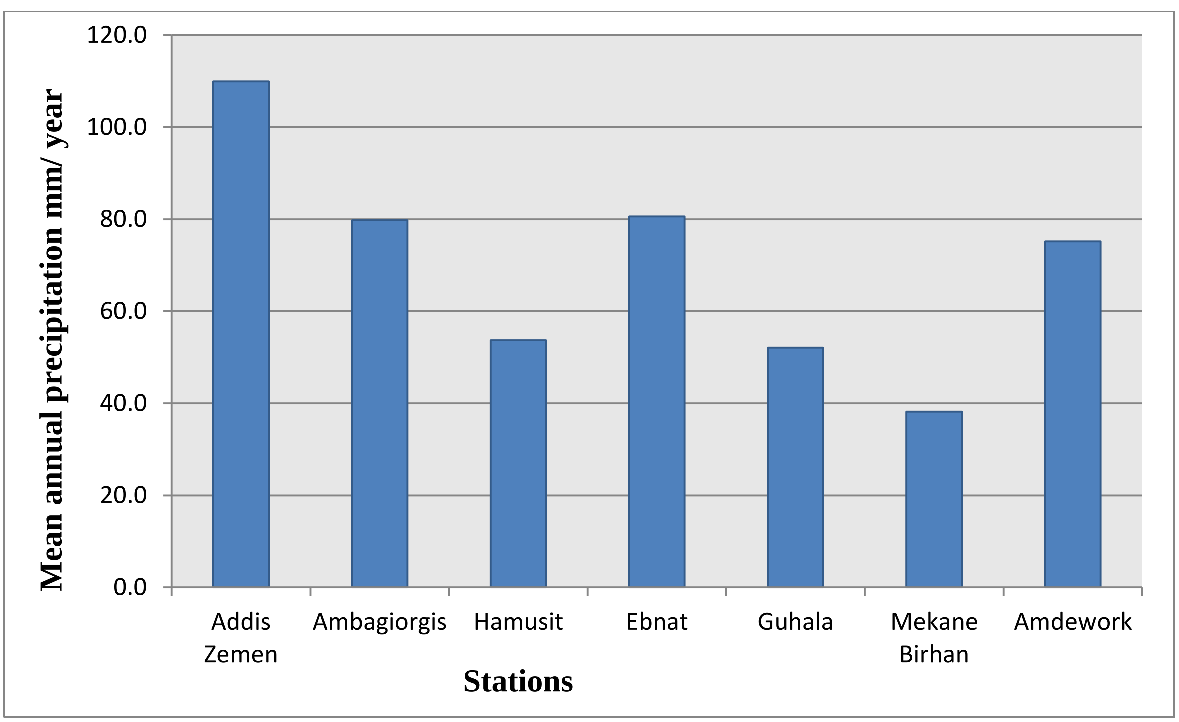

Figure 3.3 Mean annual rainfall distribution of the station

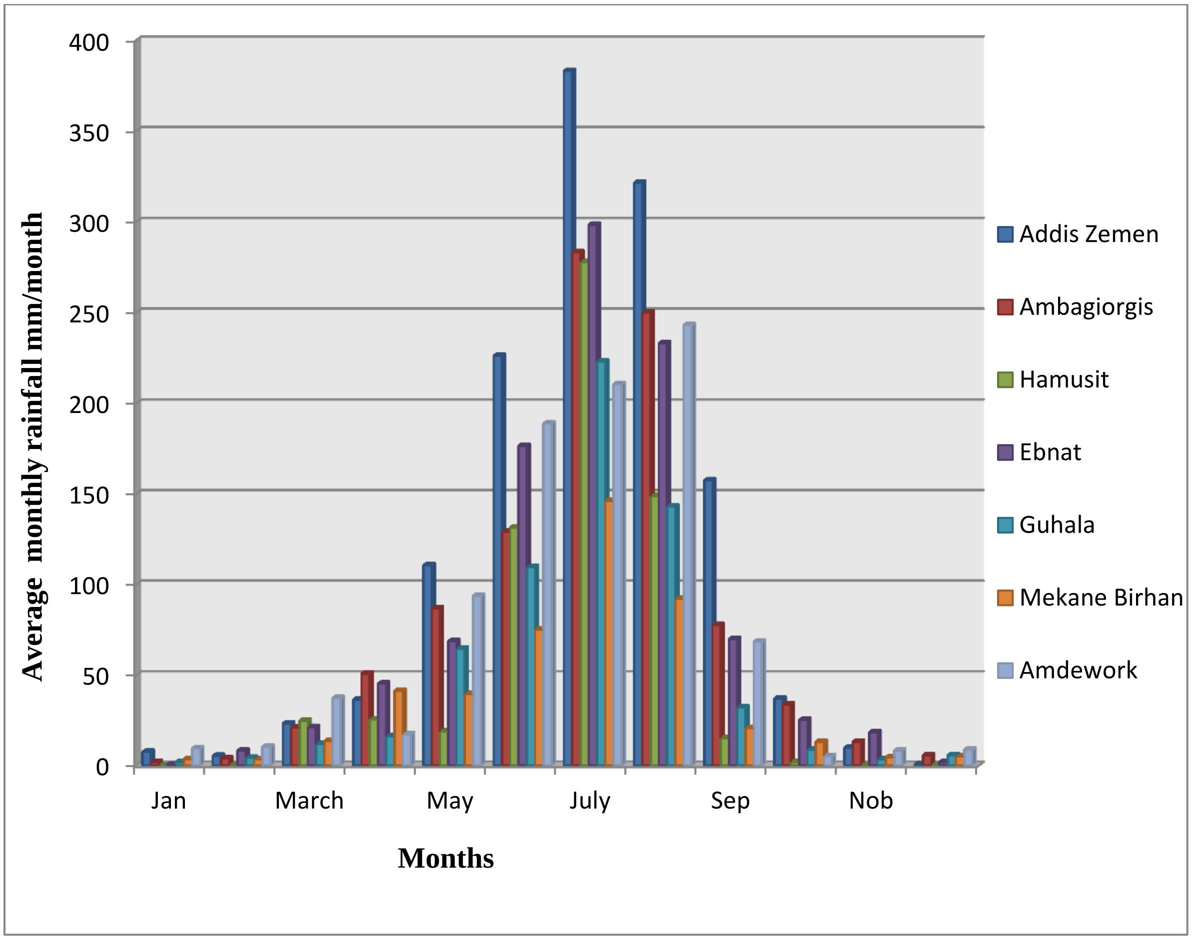

Figure3-4 Average monthly rainfall of the Nili river catchment

3.1.3 Physiography and drainage

The study area is found in part of the Northwestern Ethiopian plateau, which has relatively high relief elevation varying on the basis of morphology and drainage type. This indicates that the topography of the area ranges from lowland plain areas to highly rugged and mountainous elevated terrain areas. The physiographic configuration of the area has two distinctive river basins of Abbey and Tekeze river basin. The Abbay basin is located in southern part of the study area and drains southward from the northern highlands. The Tekeze river basin drains into westward from the highlands of northwestern plateau. The area is divided into the following physiography divisions with dissected gorges, mountains and ridges. The dissected physiography displays commonly the steeper and vertical morphology. The mountain and ridges is formed a very steep morphology. Tekeze drainage basin is the stream includes many intermittent and perennial (Mena, Meri, Tela, Nili and Tirare) rivers. Mena and Meri are one of the largest tributaries of the Tekeze River (GSE, 2011).

The Upper Tekeze region is marked by prominent uplifting, massif volcanoes, strong dissection and erosion fragmentation, several changes in base level and stream geometry. The boundary of the basin is defined by prominent regional structures (the rift margin from east, the Lake Tana Graben from south and west, and the basement foliation from north). The most outstanding consequence of the uplifting and erosion fragmentation in the upper Tekeze is their part in separating the entering rainfall water and in distressing the mean residence time of presented water in the catchments. Runoff response to rainfall is fast and mean contribution of base flow is minimal because of these (Wwdse, 2008).

This study focuses on Nili River catchment. The Nili catchment is one of the tributaries of the Tekeze River and it is found in the upper part of the Tekeze basin and drained from south to north direction (Figure 3-5).

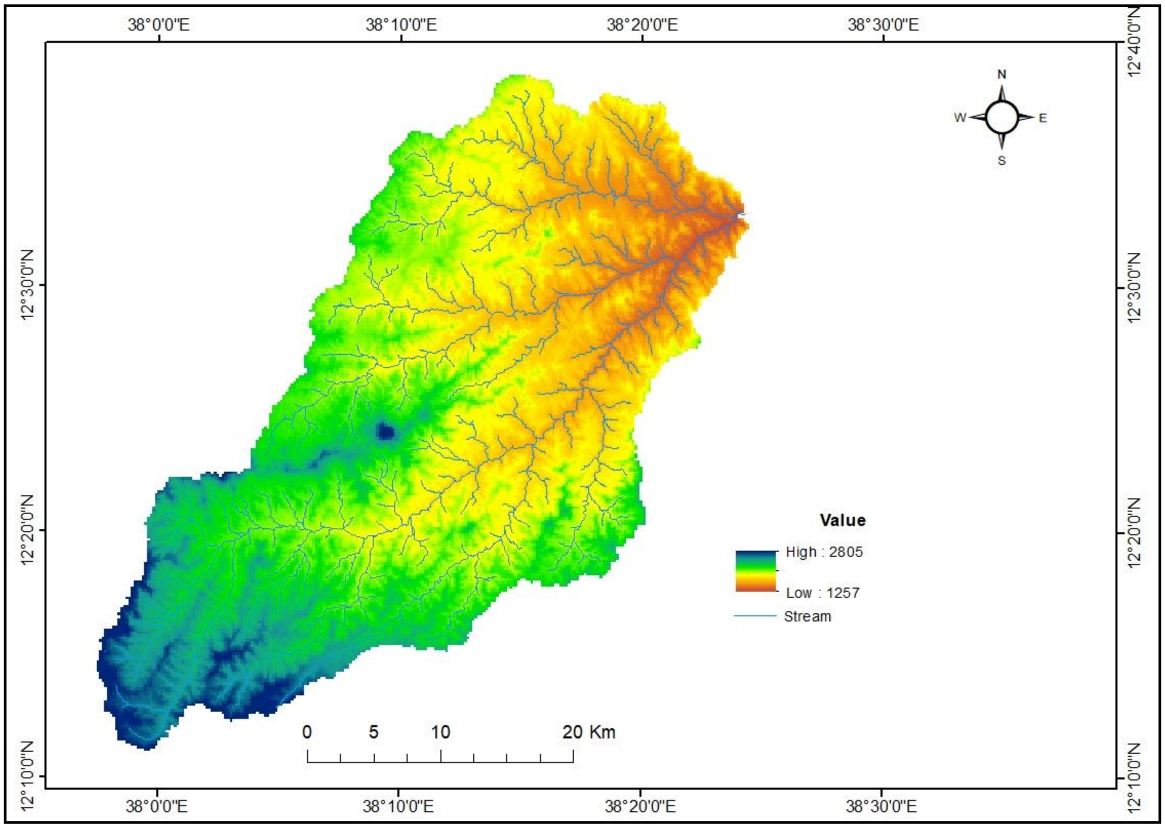

Figure 3-5 Drainage pattern of the Nili catchment

3.1.4 Soil and Vegetation Type

There are three major soil groups in the catchment under study, the soil types (textures) are (clay), (loam) and (sandy loam) are under study among these (loam) are the most dominant in the study area according to (MoA, 2016). The soil composition and the soil texture are very important for hydrological process. Moreover, the soil types in its soil texture and the soil index properties have great roles on infiltration rate of water into the groundwater and runoff. The amount of the permeability and porosity are very crucial for hydrogeology that indicates the groundwater potential. The vegetation that are originate in the Nili catchment are used to provide to reduced water loss or deprivation of surface runoff or overflowing by capturing and precipitation and penetration of water to soil to groundwater table. The vegetation delivery in the Nili catchment is different from place to place depending on difference in altitude, climate condition and population density. The vegetation that is found in the Nili river catchment is Vernonia *Amygdalina (Bisana), Wood Land, Acacia (Girar) and Podacarpus Grcilior (Zigiba).*

3.2 .Hydrogeology and Groundwater flow direction

3.2.1. Hydrogeology

The volcanic rocks in the upper Tekeze region are primarily the upper basalt categorization of critical aquifers. Such rocks forming the western and eastern highlands allow for considerable secondary permeability resulting from the effects of large weathering, jointing, faulting and cracking. The occurrence of important discharge springs from this basalt sequence indicates the efficiency of aquifer systems (Kebede, (2013). The hydrogeology of the Nili catchment has affected by erosional destruction of the plateau. The disintegration of the plateau reduces the size of the aquifers and there by the groundwater potential storage becomes low. The study area has formed by A*laji* and A*iba* basaltic formation. The A*iba* and A*laji* development manifest by their relation that decides to cliff topography, freshness and thick layers, thus the formation is not promising for groundwater storage potential (Kebede, 2013). Different aquifer groups are well-known based on the geology of the Nili catchment. The lower basalt forms the minimum creative aquifer compared to the youngest basalts in the floodplains (Kebede 2013). The hydrogeology of the area is also affected by geology and geomorphology as the groundwater level was originated by sharing from the static water level of the surface ground elevation (Lammesa, 2017). As shown in the figure 3.6 extensive and highly productive fissured aquifers and aquifer units are tertiary upper basalts and trachyte (TV3).Extensive and moderately to low productive fissured aquifer and aquifer unit consists tertiary lower basalt (TV1) and middle basalt flows (TV2), respectively. According to GSE (2013), widespread and highly useful fissured aquifer (T =100-500 m^2/d, Q =5-25 l/s) are aquifer unit of tertiary upper basalt and trachyte (TV3).Extensive and moderate to low fissured aquifer (T =1-100 m^2/d, Q=1-5 l/s) are aquifer units that consists tertiary lower basalt (TV1) and middle basalt flows (TV2).

Where T= transmissibity and Q=discharge

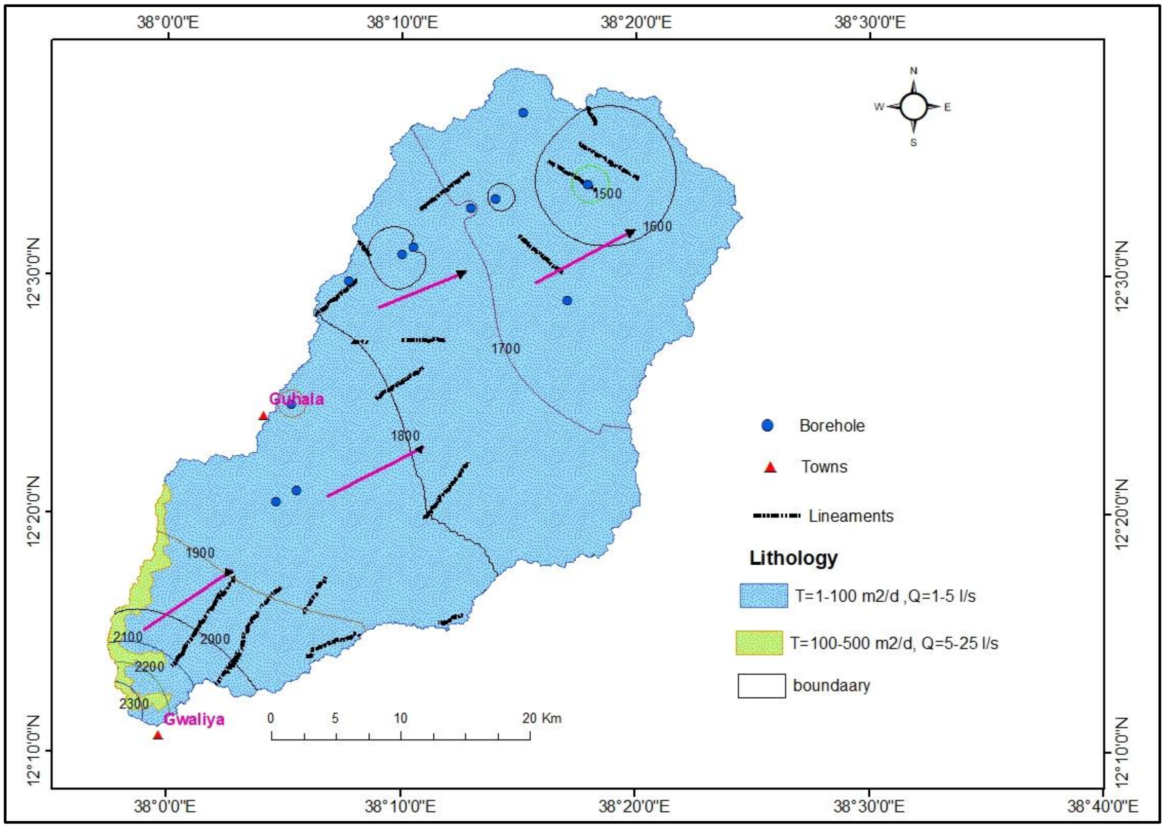

Figure 3-6 Hydrogeology map of the Nili catchment

3.2.2. Groundwater flow direction

Geological flow of Nili river catchment; groundwater is subjected to gravity and is nearly has continuous movement, that flow from high to low elevation areas as shown in figure 3.7 below.Stractures manly faults and some permeable fractures partiality or exclusively controls the groundwater movement (GSE, 2013).

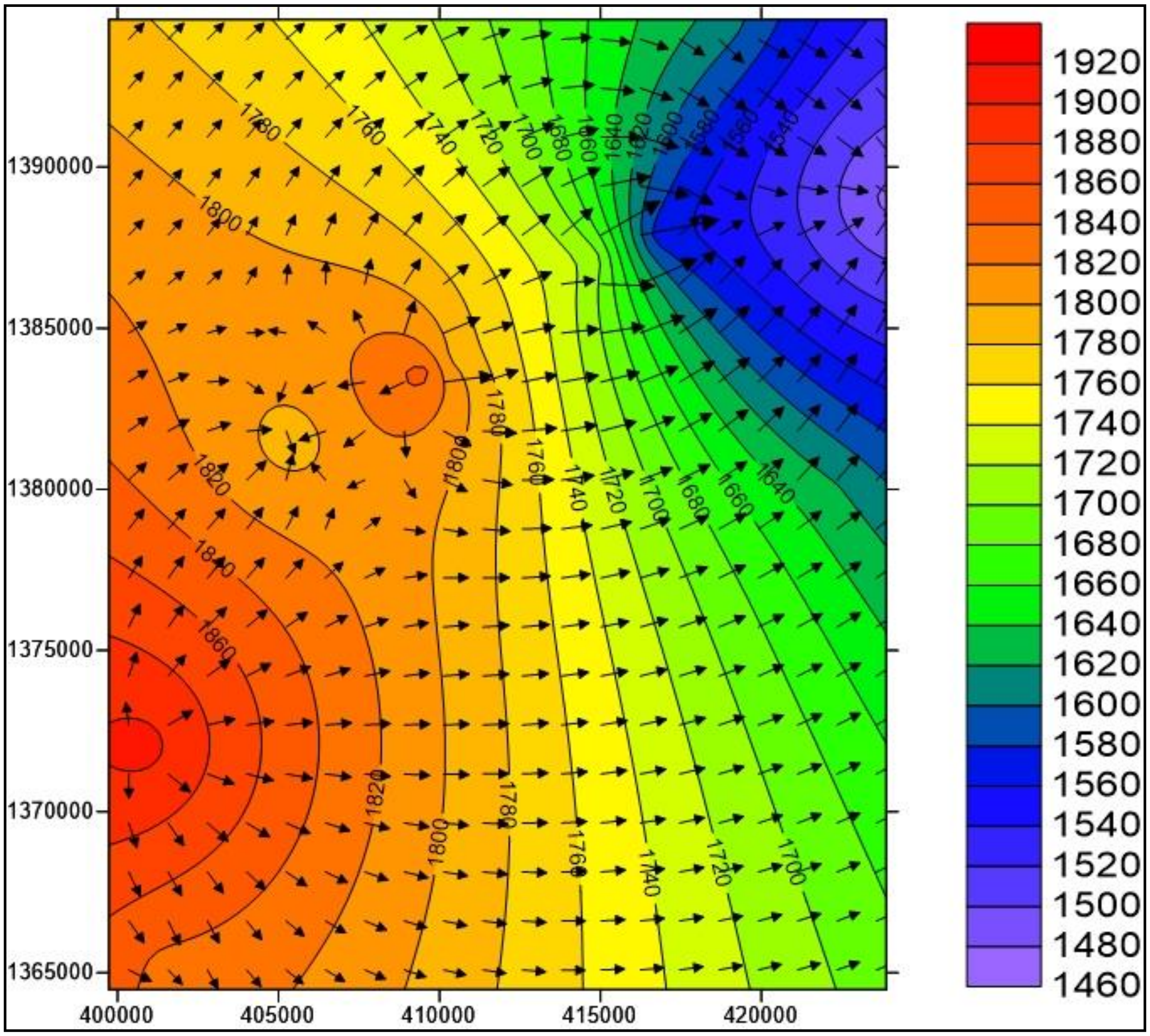

Figure 3-7 Groundwater flow direction of Nili river catchment that derived by using Surfer software

3.3. Data Sources and Analysis

In this study the following data and methods were applied. Problem identification and data identification of the groundwater controlling factors such as, geomorphology, drainage density, slope was derived from digital elevation model (DEM), geology, land use/cover, and soil texture derived from existing maps and rainfall map was derived from seven metrological stations by using IDW interpolation method and changed into digital formats using Arc Map 10.3 software. The details of data sets and applied procedures and techniques are given in subsequent sub sections.

3.3.1. Input data acquisitions and preparation

The derived or collected data were organized into suitable ways for analysis for the groundwater potential zone mapping purpose. Hence, different thematic maps such as drainage density slope and geomorphological maps were derived from Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) of 30m by 30m resolution Arc-Map 10.3. The land use land cover map was derived from the exiting map of land use land cover in Ethiopia RCMRD-SERVIR Africa - 2015 and reclassified using Arc Map 10.3.The geology map was extracted from 1:250,000 scale Ethiopia geological survey Yifag map sheet ND37-14 (GSE, 2011). The rainfall data of seven stations (Ibnat, Addis zemen, Hamusit, Guhala, Amdework, Mekane birhan and Amba giorgis) were obtained from Notional Metrological Agency and interpolated using Inverse Distance Weighted (IDW) method to generate the spatial distribution of rainfall map in Arc Map 10.3.The soil map was derived from the map of ministry of agriculture of Ethiopia (2016).

3.3.2 Data Analysis

After preparing all necessary thematic maps using Arc Map 10.3, groundwater potential analysis used the above seven thematic maps as an input by integrating Arc Map and the pair-wise comparison matrix. In this analysis, Multi criteria decision making (MCDM) and Analytic Hierarchy Process (AHP) tools were integrated using GIS techniques. The (AHP) is the most usual and well known GIS based method to determine groundwater potential zones (Satty, 1980). The method is used to integrate the 7 thematic maps, while the thematic maps were developed to govern the groundwater distribution and storage in given catchment area. The relationships of these factors were weighted based on the relationship with groundwater amount. That means a high weighted parameter is expected high impact, while low weighted parameter has a slight effect on groundwater capacity (Arulbalaji *et al.,* 2019). Therefore, weight values of each thematic map were classified based on these assumption and relationships with groundwater occurrence.

3.3.3. Model of data analysis and interpretation

In the figure 3-8 each thematic map such as geology, geomorphology, land use/cover, slope, rainfall, drainage density, and soil texture deliver is shown. Further evidence about groundwater distribution and interpretation was conducted by using weighted overlay analysis with the different thematic map layers changed into raster data to produce the groundwater potential zone map. Finally cross validation was conducted using the existing borehole pumping test data in the Nili river catchment.

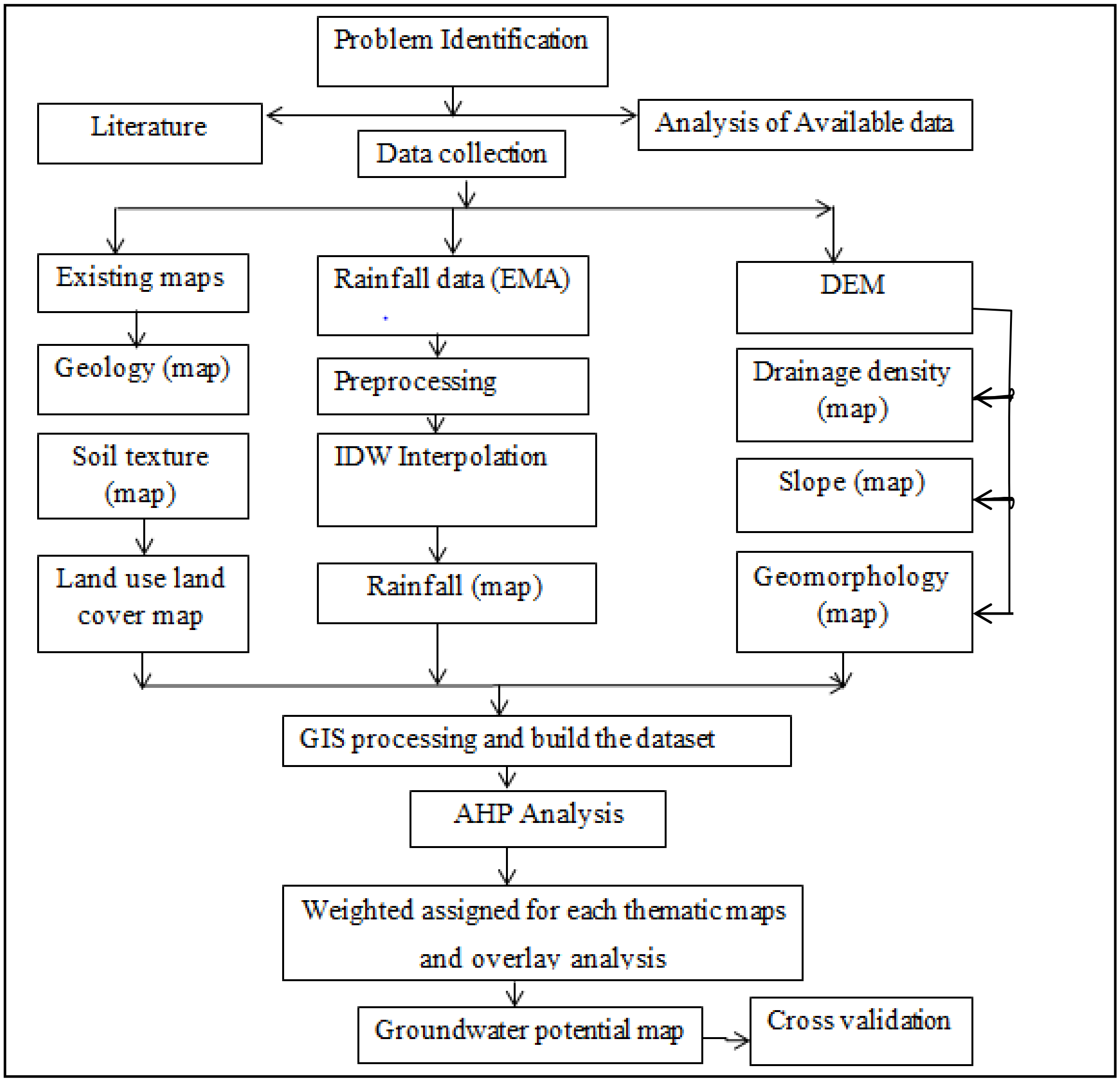

Figure 3-8 Flow chart of groundwater potential zone mapping using GIS techniques

3.4. Description of the data set

Hydrological data used for groundwater potential zone of the study area of data description include (table3-1).

- The reviewed data were collected from published and un-published reports and journals.

- Meteorological data of the study area was collected from National Metrological Agency.
- Geological map was extract from Ethiopian geological survey with the scale of 1:250,000 for geological mapping of Yifag map sheet ND37-14 (GSE, 2011).
- Soil map was obtained from map of ministry of agriculture of Ethiopia (2016).
- Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) data was collected from in USGS website with 30m*30m resolution.
- Land use land cover map was extracted from the exiting map of land use land cover in Ethiopia RCMRD-SERVIR Africa – 2015.

Table 3-1:- Data usage, software and their source.

Data Type	Source	Output Layer	Resolution/scale
Rainfall	NMA (National Meteorological Agency of Ethiopia)	Rainfall Map	
Soil Map	From Ministry of Agriculture map(2016)	Soil Texture	
Geological Map	Geological Survey of Ethiopia	Geological Map	1:250,000
DEM	USGS website	Drainage density ,Geomorphology and Slope map	30m*30m
Surfer	Download from websites	Groundwater flow direction	Version 10

3.5. Processing and preparation of thematic map of the study area

The factors that affect the groundwater potential zone were generated and their relative importance was discussed based on information obtained from previous literature. As indicated in earlier sections with mapping and determination of the major controlling features of groundwater potential zone such as geology, geomorphology, land use land cover, slope, rainfall, drainage density and soil texture. In determining the values of each controlling features, ranges were used to assign values for each mapping units of feature under analysis most applicable under existing national standards. Procedures and methods applied to determine controlling features of groundwater potential zone for area under consideration are detailed in the following subsections.

3.5.1 Generating geologic feature data

Topographically secondary structures upgrade the secondary porosity and penetrability that directly impact the penetration (percolation) and thereby, controlling the groundwater potential. For example foliation (bedding) plane act as the entry for water into the surface. In same way, geological structures like joints, faults, thrusts, fold axis, and others known to impact the groundwater as they control vertical and horizontal water movement within the geological formations (Champak and Dinesh, 2018). Geological time is an essential aspect in the hydrogeological possessions of the volcanic rocks. Permeability and porosity have a tendency to decreases with geological time. The permeability of fresh lava flows may be reasonably high; on the other hand permeability is mainly a mixture of the primary and secondary arrangements in the rock. Dykes are the main upright obstacles in undeveloped volcanic rocks. Pyroclastic are commonly leaky but not very pervious because of humble sorting and large quantity of fine material (GSE, 2013). The geological map was extracted from Geological Survey of Ethiopian with the scale of 1:250,000 in yifag map sheet by clipping of within my study boundary.

Lower Basalt (TV1):-Dominantly weathered and fractured with variable composition color and grain size towards the top parts of the succession the basalts interlayered with pyroclastic and lenses of sandstone. It also covers large areas of the study area and lower lava flows with stratified flood basalts intercalated with scoria and trachytic obsidian. (GSE, 2011).

Middle Basalt (TV2):-The middle basalt was formed by continuous basalt layers stratification and show joining, fine grained basalts otherwise interposed with pyroclastic flow and which demonstrations mostly vertical and sharp topography and forming cliff area (GSE,2011).

Upper Basalt and Trachyte (TV3):-The upper basalt mainly aphanite in grain size, dark gray, and fine grained and it is characterized by jointing by fracturing and spheroidal weathering and rarely columnar and are manly massive, dense and compact flows. Its area coverage is small in the Nili river catchment (GSE, 2011).

3.5.2. Generating Geomorphology data

According to Shifaji and Nitin, (2014), the identification and categorization of numerous landforms and structural features is very important from geomorphological study perspective. For example denudation hills created by erosion and weathering processes have low infiltration of surface water (Ramaiah *et al.,* 2012). Machiwal *et al.,* (2010) pointed out that geomorphological highlights give signs of groundwater assets and roundabout evidence of groundwater event, development and advancement. Different landforms such as structural hill, pediments, buried pediments, and valley fills are formed by geological formations and developing the assortment of diverse capacity of water holding there by showing varied aquifer potentials. The geomorphology map was extracted from digital elevation model (DEM) with 20m by 20m resolution using Arc map 10.3 software – arc toolbox-surface – hill shed then –spatial analysis-match-times.

3.5.3 Land use land cover

Land use Land cover is one of the controlling factors in groundwater potential zone determination in the study area. It contributes the critical information about infiltration rate, soil moisture, groundwater and surface water in addition to this providing groundwater indicator (Arulbalaji *et al.,* 2019). Land use/land cover (LULC) data is an imperative figure in groundwater capacity and energize. In cooperation surface water and groundwater are subjective by land use land cover of region concentration. For example the occurrence of plants and heavily cultivated land considerably reduces the surface runoff complete interference and enlarged permeation of the overall precipitation that could besides flow to watercourses and ponds (GSE, 2013).Land use land cover map was extracted from the existing map of land use land cover in Ethiopia RCMRD-SERVIR AFRICA -2015 by using Arc map 10.3 software and reclassify by unsupervised classification methods based on their groundwater recharge potential.

3.5.4. Slope feature data generation

Slope is one of the important factors in groundwater potential zone determination and it has important properties on the infiltration of surface water in to subsurface. According to Libassie, (2007) steep slope areas water moves as runoff quickly. Thus, such areas are characterized by low infiltration rate compared to flat areas. In contrast, flat areas are capable of holding the precipitated water and thus allow groundwater recharge. The slopes with flat and gentle areas are suitable for groundwater occurrence compared to the steep slope as flat and gentle slope areas have long time to permit the water into subsurface result higher infiltration rate and less runoff, thus all these facilitate very good groundwater potential (Tesfaye, 2012). The slope map was generated from Digital elevation model (DEM) using Arc-Map 10.3 software and changed into raster file to overlay with other controlling factor to produce the groundwater potential map.

3.5.5. Rainfall feature data generation

Precipitation is very imperative portion of the water cycle, where its movements, flow direction water from highlands to lowlands (Adiat *et al.,* 2012). Rainfall is the major sources of groundwater recharge that determines the amount, available water to percolate into the groundwater systems. Although, the rainfall system in Ethiopia is characterized by spatial and temporal variability, rainfall is the major factors for the development of groundwater potential. Therefore the rainfall map of the study area was interpolated using Arc-Map10.3 by Inverse Distance Weighted (IDW) methods. The rainfall data obtained from Ethiopian metrological agency was composed and used for the current analysis.

3.5.6. Drainage density feature data

Drainage density is the flow of water through well-defined channel. There are different types of drainage patterns, where the common drainage patterns are Dendritic, Radial drainage pattern and Rectangular drainage. A drainage system is made up of the principal river and its tributaries. The drainage pattern is outcome of the geological processes, nature and structure of rocks, topography, slope, amount and the periodicity of the flow. The drainage density has reverse function with permeability as high drainage density indicates high runoff and low groundwater potential (Raviraj *et al.,* 2017). Lower drainage density value has better groundwater prospects than the higher drainage density. Therefore stream networks were used to generate the drainage density of the study area. The density (closeness) of streams and the pattern of surface drainage usually suggest where infiltration is occurring and also may reveal certain structural features such as faults, folds, or joint system. Dense drainage pattern indicates the layer is impermeable. The drainage density map was extracted from the existing digital elevation model by using GIS environment in Arc map 10.3 software and reclassify into five groups.

3.5.7. Soil texture based soil feature data generation

The soil texture of Nili river catchment are Eutric Vertisols (clay), Haplic luvisols (loam) and lithic leptosols (sandy loam) are under study among these haplic luvisols (loam) are the most dominant in the study area. The spatial inconsistency of soil surface to a great extent depends on the nature of the basic rocks, physiography, climate, land use/land cover and weathering forms (Tessema *et al.,* 2014). Soil texture could be a soil property utilized to portray the relative extent of distinctive grain sizes of particles and show the general nature of soil physical properties. The key inherent factor influencing percolate is the soil composition, or the proportion of sand, silt, clay in the soil. Water moves more rapidly through the expansive pores in sandy soil than it does through the little pores in clayey soil, particularly on the off chance that the clay is compacted and has small or no stricter or accumulation (Brady and Weil, 2002). Soils have an essential role within the worldwide hydrologic cycle by administering precipitation, penetration and groundwater recharge which eventually influences the horizontal transport of water and ensuring runoff potential (Ross *et al.,* 2018).The soil texture map was extracted from the existing map from ministry of agriculture of Ethiopia 2016 using arc map 10.3 software and reclassify into three classes.

3.6. Analytical Hierarchy Process

Analytic hierarchy process (AHP) is one of the most active multi-criteria decision making (MCDM) methods which supports a decision maker facing difficult problems and conflict and internal multiple criteria. Analytical Hierarchy Process (AHP) is model of extent by pairwise comparison and depends on the judgment of expert to derive significance scales. The comparison was made on a scale of numbers 1-9 which demonstrate how many times the layer is prominence than the other Satty. (1980) Analytical hierarchy process (AHP) considers criteria to compare the different factors (geomorphology, geology, lulc, slope, drainage density, rainfall and soil) to prepare a square matrix, i.e., a= (aij). The matrix A is a reciprocal and it must be consistent, for each element (aij) of matrix.

Table 3-2.Satty, s Scale of intensity Relative importance

Intensity of Relative Importance	Definition
1	Equal Importance
2	Weak or Slight
3	Moderate Importance
4	Moderate Plus
5	Strong Importance
6	Strong Plus
7	Very Strong
8	Very Very Strong
9	Extremely Importance

Source: Satty (1980)

3.7. Weight Assessment and Normalization

The pairwise comparison matrix was conducted by using Analytical Hierarchy Process (AHP) methods. To calculate the cumulative weight of the main criteria, the relative weight of their consistent was measured. Map categorization and weight assignment for groundwater potential zone of seven controlling factors was selected. Pairwise comparison matrix of assigned weights for various thematic layers and their individual classes were constructed using Satty (1980) AHP method and weights were normalized by eigenvector approach. The consistency ratio (CR) calculated to examine the normalized weights of thematic layers and their individual classes according to Satty. (1980) procedure.

To compute the consistency ratio of the various thematic layers and their individual important classes, the following steps were carried out.

$$\text{aij} = \frac{1}{aji} \qquad \text{(Eq 1)}$$

For a reciprocal matrix, all the contrast aij follow the equality a=bi/bj where bi is the priority of the alternative i (Eq2).

$$A = \begin{bmatrix} b11 & b12 & \dots & b1n \\ \vdots & \vdots & \vdots & \vdots \\ b21 & b22 & \dots & b2n \\ bn1 & bn2 & \dots & bnn \end{bmatrix}, bij = \frac{bij}{\sum ij} \; Where \; ij = 1\ 2\dots n \qquad (Eq\ 2)$$

In this study, seven by seven matrixes are formed for each thematic layer to evaluate rates for the courses in layer and one matrix is designed to calculate the weight of each layer.

$$X = \begin{pmatrix} x1 \\ x2 \\ \vdots \\ xn \end{pmatrix} Xi = \sum_1^n \frac{xij}{n} \quad \text{for all n} = 1, 2 \ldots \text{n and X'} = \begin{pmatrix} X1' \\ X2' \\ \vdots \\ Xn' \end{pmatrix} \qquad \text{(Eq 3)}$$

$$\lambda\text{max} = \frac{1}{n} \left(\frac{x'}{x1} + \frac{x'}{x2} \ldots \frac{x'}{xn} \right) \qquad \text{(Eq 4)}$$

Where X: eigenvector,

Xi: eigenvalue criteria i and

λmax: Average eigenvalue for the pair of comparison matrix.

Consistency ratio (CR) is the measurement of the consistency of pair wise comparison matrix. It is the indication of acceptability reciprocal matrix and it is calculated using the following equation

$$\text{CR} = \frac{CI}{RI} \qquad \text{(Eq 5)}$$

Where CI is consistency index and RI is Random Consistency Index

$$\text{CI} = \frac{\lambda max - n}{n-1} \qquad \text{(Eq 6)}$$

Where n is the number of factors

The matrix has a property of consistency known as consistency ratio (CR). If the consistency ratio of matrix is greater than 0.1 the matrix must be revised.

Table 3-3 Satty. (1980) Random Consistency Index for the different N <10 values

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

3.8 Weight (subjective) Assessment

The relative weights of the thematic layers such as (geomorphology, geology, LULC, slope, drainage density, rainfall, soil texture in table 3.4 were assigned based on their relative importance for each thematic layer to analyze based on judgment of works carried out by the experts, analysts or information specialists picked up through comparative works on groundwater potential (Tesfaye 2012, Lammesa, 2017). To relate the prominence of two layer maps show that one of them has more effect to groundwater occurrence than the other.

Table 3-4 Relative weight for selected thematic layer

Parameter	Geol	GM	LULC	Sl	RF	Dd	ST
Geol	1.00	1.13	1.13	1.29	1.50	1.80	2.25
GM	0.89	1.00	1.00	1.14	1.33	1.60	2.00
LULC	0.89	1.00	1.00	1.14	1.33	1.60	2.00
Sl	0.78	1.14	0.88	1.00	1.17	1.40	1.75
RF	0.67	1.33	0.75	0.86	1.00	1.20	1.50
Dd	0.56	1.60	0.63	0.71	0.83	1.00	1.25
ST	0.44	2.00	0.50	0.57	0.67	0.80	1.00
Total	5.22	9.20	5.88	6.71	7.83	9.40	11.75

Where **Geol**=Geology, **GM**=geomorphology**, LULC**=Land use/Cover, **SL**= Slope **RF**=Rainfalls, **Dd**=Drainage density, **St**=Soil texture

3.9 Weight Normalization

The Weights normalization was computed by using equation 2 and calculated by averaging the values in every row to get the corresponding rank which gives the outcome of the normalized weights for each parameter. From the result, as observed geology, geomorphology, land use land cover and slope have the highest value from the other parameters respectively in table 3-5.So; this indicates high value indicates high influencing in groundwater potential zone and low values which are (Rainfall, Drainage density and Soil texture) indicate the low influencing in groundwater potential zone determination in the study area (Nili river catchment).

Table 3-5 Pairwise comparison matrix & normalized weight affect for groundwater potential

Parameter	Geol	GM	LULC	Sl	RF	Dd	ST	N.weight	Weight %
Geol	0.191	0.122	0.191	0.191	0.191	0.191	0.191	0.182	18.16
GM	0.170	0.109	0.170	0.170	0.170	0.170	0.170	0.161	16.14
LULC	0.170	0.109	0.170	0.170	0.170	0.170	0.170	0.161	16.14
Sl	0.149	0.124	0.149	0.149	0.149	0.149	0.149	0.145	14.54
RF	0.128	0.145	0.128	0.128	0.128	0.128	0.128	0.130	13.01
Dd	0.106	0.174	0.106	0.106	0.106	0.106	0.106	0.116	11.60
ST	0.085	0.217	0.085	0.085	0.085	0.085	0.085	0.104	10.40
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	100.000

Where **Geol**=Geology, **GM**=geomorphology, **LULC**=Land use/Cover, **SL**= Slope, **RF**=Rainfalls, **Dd**=Drainage density, **St**=Soil texture

3.10 Principal Eigen vector

To check the allocated factor for every parameter in the normalized eigenvector value (λmax) was computed according to the above equation 3 and 4 to develop the consistency ratio. This was prepared by multiplying the weight of the first criteria which is Geology =0.182 as presented in table 3-5 and with the total value of the pair wise comparison matrix as displayed in table 3.4 which is =5.22 and the other six factors also worked as the same way. Lastly the summation of these parameter value provides the consistency vector λmax=7.68 as shown table 3-6 which is computed the consistency index.

Table 3-6 Normalized Principal Eigen Vectors

Parameter	Principal Normalized Eigen Vector
Geol	0.95
GM	1.48
LULC	0.95
Sl	0.97
RF	1.02
Dd	1.09
ST	1.22
λmax	7.68

The consistency index was calculated to overcome based on the formula of consistency ratio which was done by using equation 6.

$$CI = \frac{\lambda max - n}{n-1}$$

Where λmax =7.68
n =7
n-1
7-1= 6

$$CI = \frac{(7.68 - 7)}{6} = 0.11$$

Then consistency ratio was calculated based on equation 5 which is

Where Cl =0.11

RI =1.32 where n= 7

$$CR = \frac{CI}{RI}$$

$$CR = \frac{0.11}{1.32} = 0.08$$

The result 0.08 is less than 0.1 therefore the given weights were valid for additional analysis. Satty (1980) has pronounced that CR of 0.10 or less is satisfactory to precede the examination. In the event that the consistency value is more than 0.10 at that point there's an acquired to change the judgment to find cases of irregularity and correct it. If the CR value is 0, it implies that there is an idealized level of consistency within the pair-wise comparison. The threshold value is not exceeding above 0.10, which suggests the judgment matrix is reasonably consistent. The relative weights acquired from AHP were apportioned to each relevant maps and the weight assessment of each with the most prominent or least weight was allotted in agreement with the genuine circumstance on the field. The outline of allotted and normalized weights of the feathers of the diverse topical layers and the consistency proportion of its topical outline were moreover computed and allotted for individual topical outline. At that point, the seven diverse topical maps were coordinate utilizing GIS Arc map 10.3 software as a summation of by and large groundwater influencing factor calculate to create the groundwater potential zone determination map (GWPZ) for the Nili river catchment all the seven thematic outline layers was combined with weighted overlay investigation strategy with GIS environments after checking all the criteria as takes after.

$$\text{GWPZ} = \sum_{n=1}^{7} W_i X_i \qquad \text{(Eq7)}$$

Where GWPZ is groundwater potential zone,Wi is the weight assigned each thematic layer and Xi is the raster file of each thematic layer and n is number of factors.

GWPZ = (0.182*Geo) + (0.161*Gm) + (0.161*LULC) + (0.145*SL) + (0.130*RF) + (0.116*Dd) + (0.104*ST)

Where **Geol**=Geology, **GM**=geomorphology, **LULC**=Land use/Cover, **SL**= Slope, **RF**=Rainfalls, **Dd**=Drainage density, **ST**=Soil texture

Chapter Four

4. Result and Discussion

4.1 Groundwater controlling factors analysis outputs

The result of the current study of groundwater potential zone was done by the analysis of different thematic layers such as geology, geomorphology, LULC, slope, rainfall, drainage density and soil texture weights and their rank of the parameter values are given based on expert judgment and Satty (1980) scale ratio as shown in subsequent tables and figures. The pairwise comparison matrix, the relative weight matrix and the principal Eigenvector value were calculated based on judgment of works carried out by the analysts or information specialists picked up through proportional works on groundwater potential (Tesfaye 2012; Lammesa, 2017).

Geology

The geologic feature data (figure 4-1and table 4-1) was generated using geological map and assigning values so as to use the map as an input data for groundwater potential zone. In this analysis, 1:250,000 scale geological map of the Ethiopian Geological Survey (GSE, 2011) was used. During assigning of geologic feature data the arranged index data gives a particular attention for occurrence, movement and quality of groundwater. According to this map, the study area is covered by Cenozoic era tertiary geological period dominated by lower, middle and upper basaltic formation as detailed hereunder.

Table 4-1 lithology and its groundwater potentiality of the study area

Lithology	Groundwater potentiality	Area (Km^2)	Percentage (%)
Middle basalt (TV2)	Low aquifer	283.4	23
Upper basalt (TV3) and Trachyte	Moderate aquifer	27.76	2
Lower basalt (TV1)	Good aquifer	947.96	75

Source:-GSE, 2011

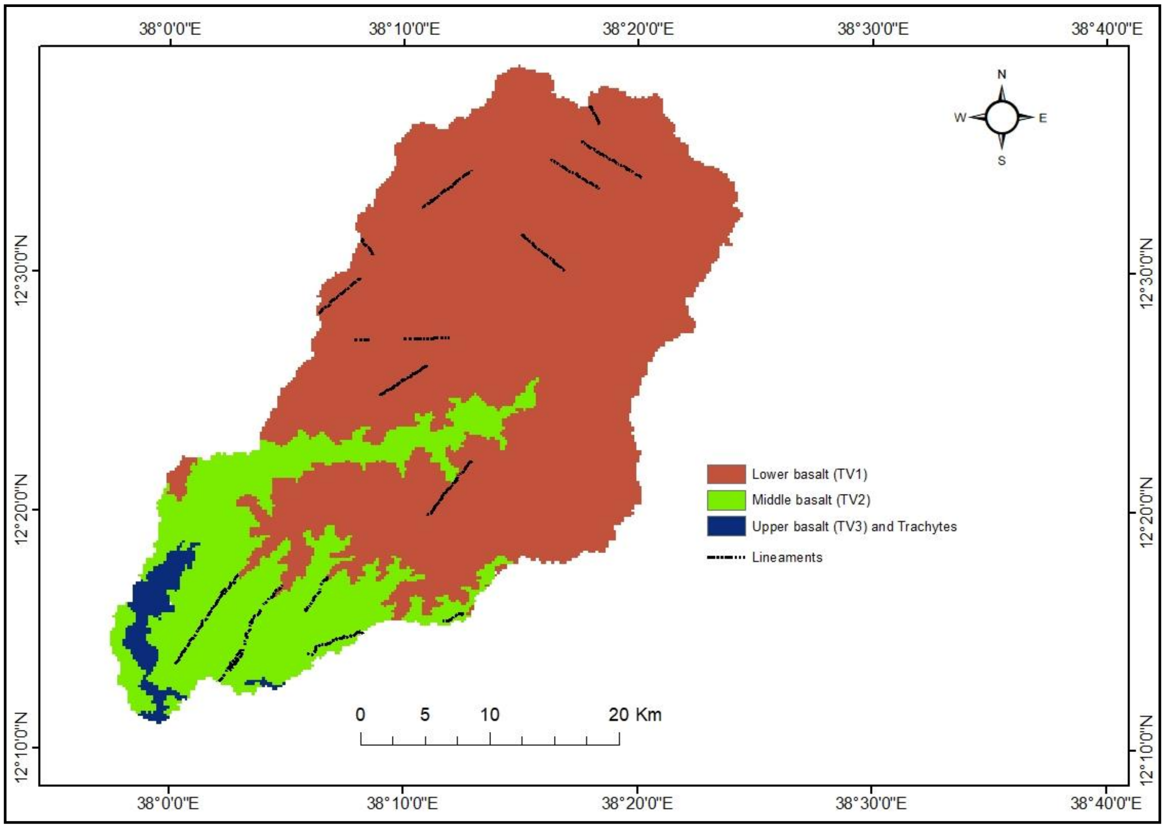

Figure 4-1 Geology map of Nili catchment

Geomorphology

The analysis revealed that the geomorphology of study area is dominated by mountainous and residual hills. It is well known that different geomorphologic setting has different groundwater potential. For example, Pediments are the gentle sloping surface shaped between hill and plain surfaces, which have moderate to good groundwater discharge potential. On the other hand, residual hills, structural hills and linear ridge landforms are characterized by very low groundwater potential as they are not fractured rock and have low infiltration rate. Pedi plain, valley fills and water body has high infiltration rate and have good groundwater potentials (Ra- maiah *et al.*, 2012). The study area has considerable proportion of mountainous part, which has low infiltration rate, high runoff and thus, has low groundwater potential. The dissected landmasses of the study area are also characterized by steeper slopes and vertical morphology which mostly covered by tertiary basalt. The flood plain areas have high groundwater potential than the other geomorphic areas because the precipitation has the success time to percolate into the subsurface. The plateau areas have less promising groundwater potential than flood plain areas and have moderate GWP relative to the hill and mountainous areas as shown in figure 4.2. The hills and the mountainous areas have very poor groundwater potential because the rainfalls do not have time to percolate into the ground rather converted high runoff.

Table 4-2 Geomorphology and its rank as per suitable for groundwater potential

Factor	Geomorphic unit	Ranking in words	Ranking in numbers
Geomorphology	Mountain	Very poor	1
	Structural Hill	Poor	2
	Plateau	poor to medium	3
	Flood plain	Very good	5

Source Lammesa, 2017

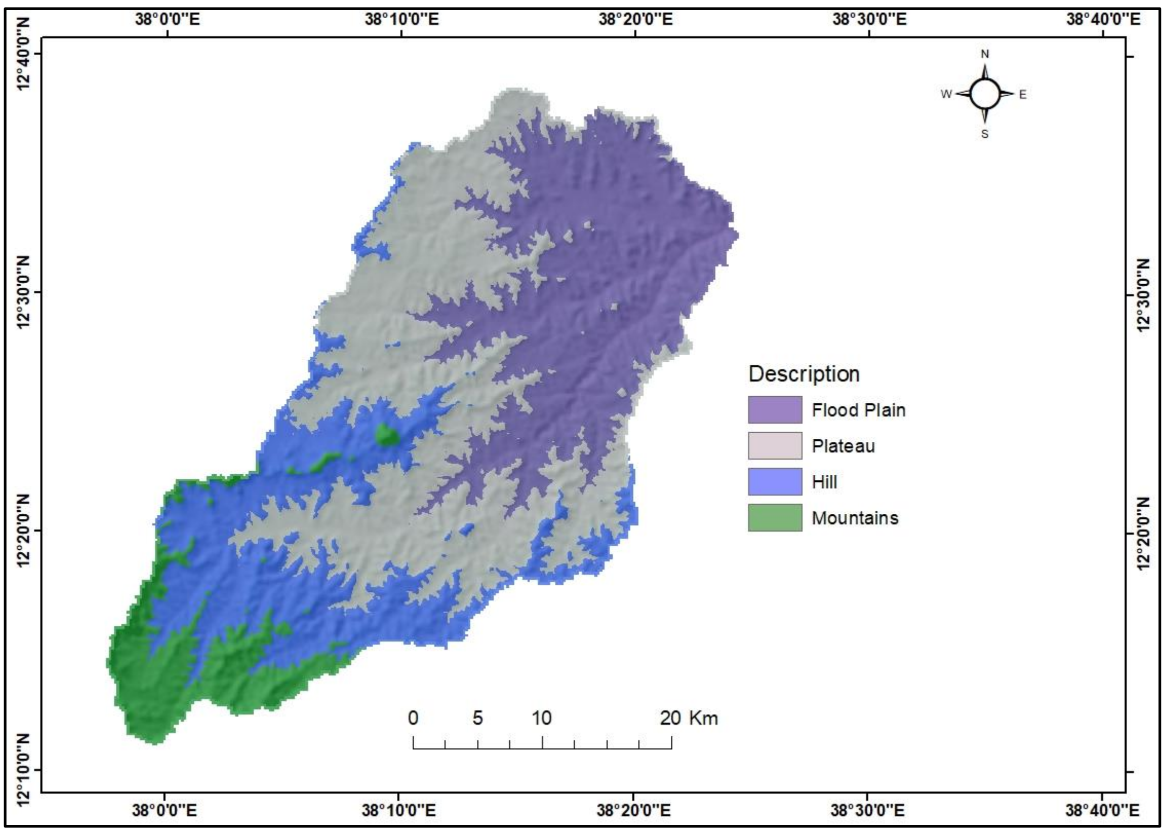

Figure 4-2 Geomorphology map of Nili catchment

Land use land cover

The land use land cover types of the study area used in this analysis was derived from map of land use land cover in Ethiopia RCMRD-SERVIR Africa – 2015 and reclassified by unsupervised classification method using Arc Map 10.3 software. Accordingly the major land use land cover that are found in the study area include: annual croplands, bare soils, closed shrub land, open grassland, open shrub land that account 39.47%, 5.75%, 9.16%, 11.80%, 32.35% and 1.48% respectively (table 4-3).

As shown in figure 4-3 the annual cropland areas have more promising for groundwater potential zone than the other classification because of high infiltration rate, high permeability, high moisture content and less runoff and the slope of these croplands also lower than the other features (Singh , 2014). The shrub lands also have good groundwater potential area than the built up areas and bare land areas due to moderate infiltration rate and low runoff. The built up and bare land areas have less groundwater potential zone due to the presence of low infiltration, poor permeability and high runoff. Recharges on the built up and bare land areas directly changed to the runoff because there is no any type of the shrubs or other forests in the built up and bare land covered area (Arulbalaji *et al.*, 2019).

Table 4-3 land use land covers classification and groundwater potentiality importance.

Land use/Land cover	Area(Km^2)	Percentage (%)	Rank in word	Rank in no
Annual Cropland	496.96	39.47	Very good	5
Bare land	72.4	5.75	Very poor	1
Closed shrub land	115.28	9.16	High	4
Open Grassland	148.64	11.80	poor	2
Open shrub land	407.28	32.35	Moderate	4
Sparse Forest	18.6	1.48	Moderate	3

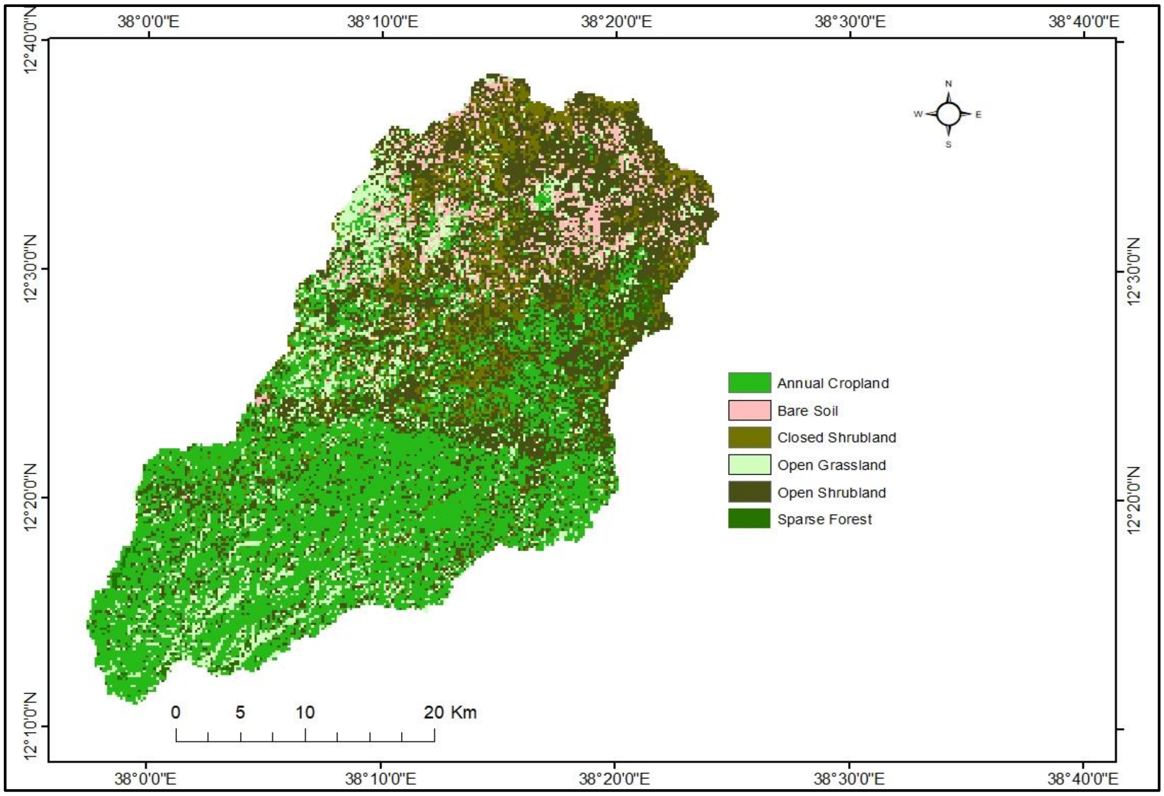

Figure 4-3 Land use land cover map of the Nili catchment

Slope

As shown in figure4-4, slope of the area ranges from 0.2% to 82.9%.As discussed above, low slope areas precipitation will have more time to stay on the surface resulting high infiltration rate and penetration into the subsurface and low runoff and enhance the groundwater potential at low slope areas. On the other hand, high (steep) slope values indicate greater water velocity, and higher runoff and low infiltration as precipitation don't have sufficient time to percolate into the subsurface and don't enhance groundwater potential. Based on the slope map category, the study catchment has been divided into five groundwater infiltration potential as shown in table 4-4.

Table 4-4 Slope value and its rank for suitable groundwater potentiality

Factors	Value (Percent)	Classification	GW(infiltrate potentiality)	Rank
Slope	0.2-8.6 %	Flat Slope	Very High	5
	8.6-15.7%	Sloping	High	4
	15.7-23.9%	Moderate slope	Moderate	3
	23.9-35.9%	Steep Slope	Low	2
	35.9-82.9%	Very Steep	Very low	1

Source: - FAO 2006

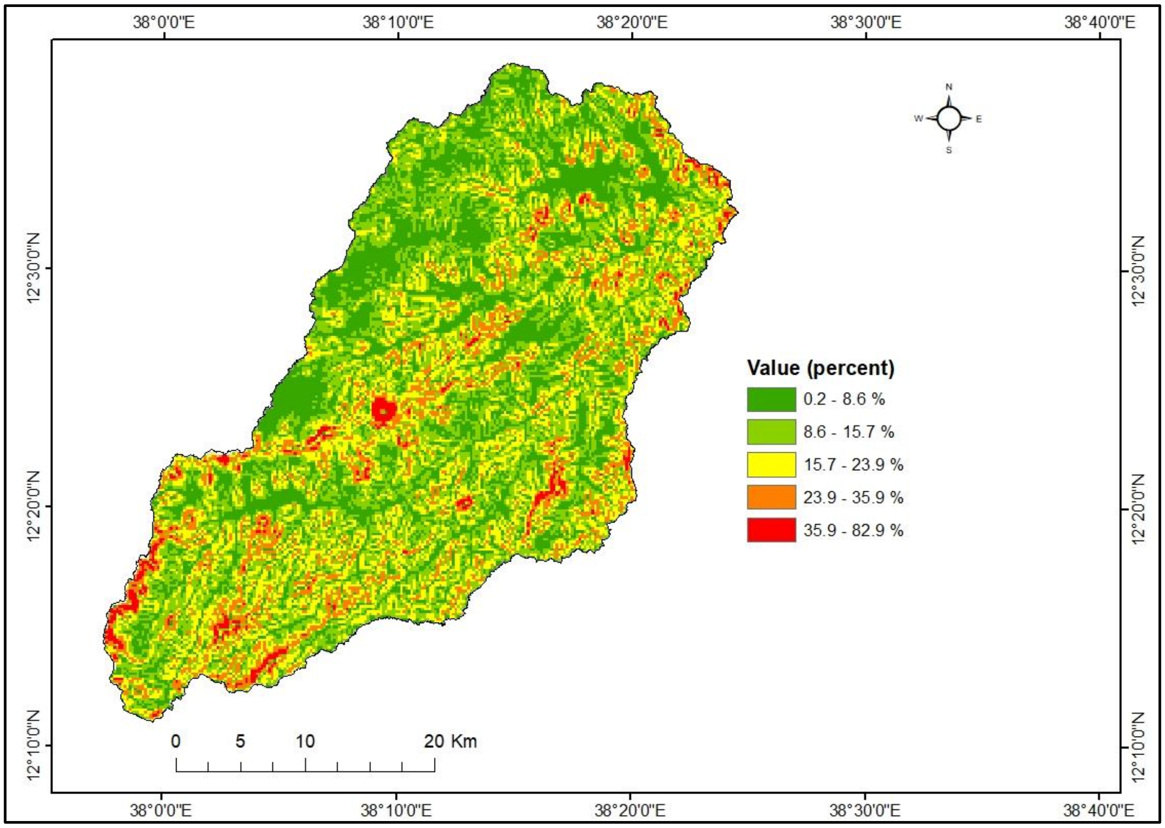

Figure4-4 Slope map of Nili catchment

Rainfall

As shown in figure 4-5, the southern part of the study area receives very high rainfall that range from 853 to 974mm/year relative to other parts. On other hand, the south the small portion of south eastern and north eastern parts of the study area receives high rainfall ranging from 777 to 853 mm/year. The south, southeastern and northeastern parts receives moderate rainfall which varies between 732 and 777 mm/year. The south, central and northwest part receives low 677 -732 mm/year. The southwest and northwest part of receives 604- 677mm/year. Penetration depends on the intensity and period of the rainfall. High intensity and short duration of rainfall effects less infiltration and more surface runoff. Low intensity and long period rainfall effects high infiltration than run-off. Therefore, the analysis revealed that high rainfall areas are characterized by high groundwater potential.

Table 4-5 Rainfall distribution of the study area

Factor	Value (mm/year)	Rank in words	Rank in Numbers
Rainfall	604-677	Very Low	1
	677-732	Low	2
	732-777	Moderate	3
	777-853	High	4
	853-974	Very high	5

Source lammesa, 2017

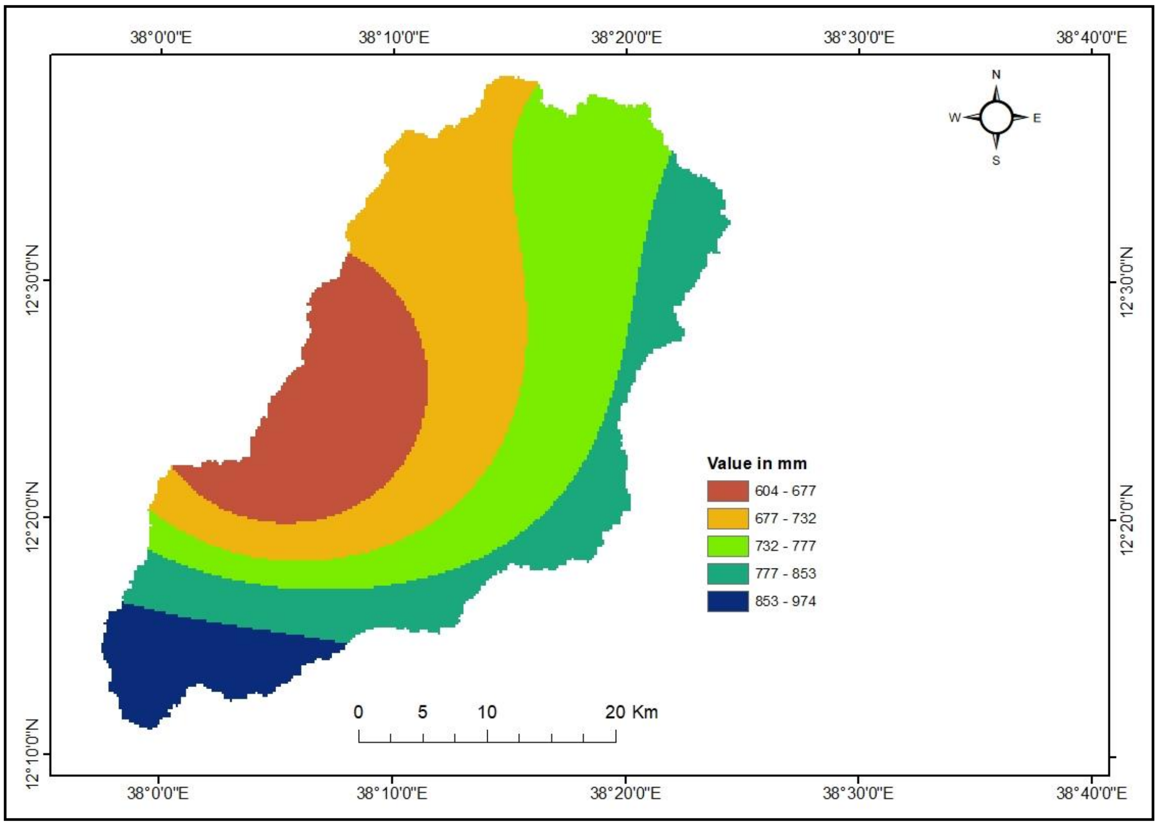

Figure 4-5 Rainfall distribution map of Nili catchment

Drainage Density

For the current analysis, the drainage density was extracted using Digital Elevation Model (DEM) to produce drainage density map using line density tool in Arc- Map 10.3. As shown in figure 4-6 and table4-5, drainage density feature data was mapped and classified in to 5 categories and ranges from 0.0-1.60km/km^2 based on groundwater potential suitability and infiltration capacity.

Table 4-6 Drainage density and their groundwater potentiality Rank

Factors	Km/km2	Description	Rank in Numbers	Rank in words
Drainage Density	0.0-0.32	Very low density	5	Very high
	0.32-0.64	Low density	4	High
	0.64-0.96	Moderate	3	Moderate
	0.96-1.28	High	2	Low
	1.28-1.60	Very high	1	Very low

Source: Shekhar and Chandra (2014)

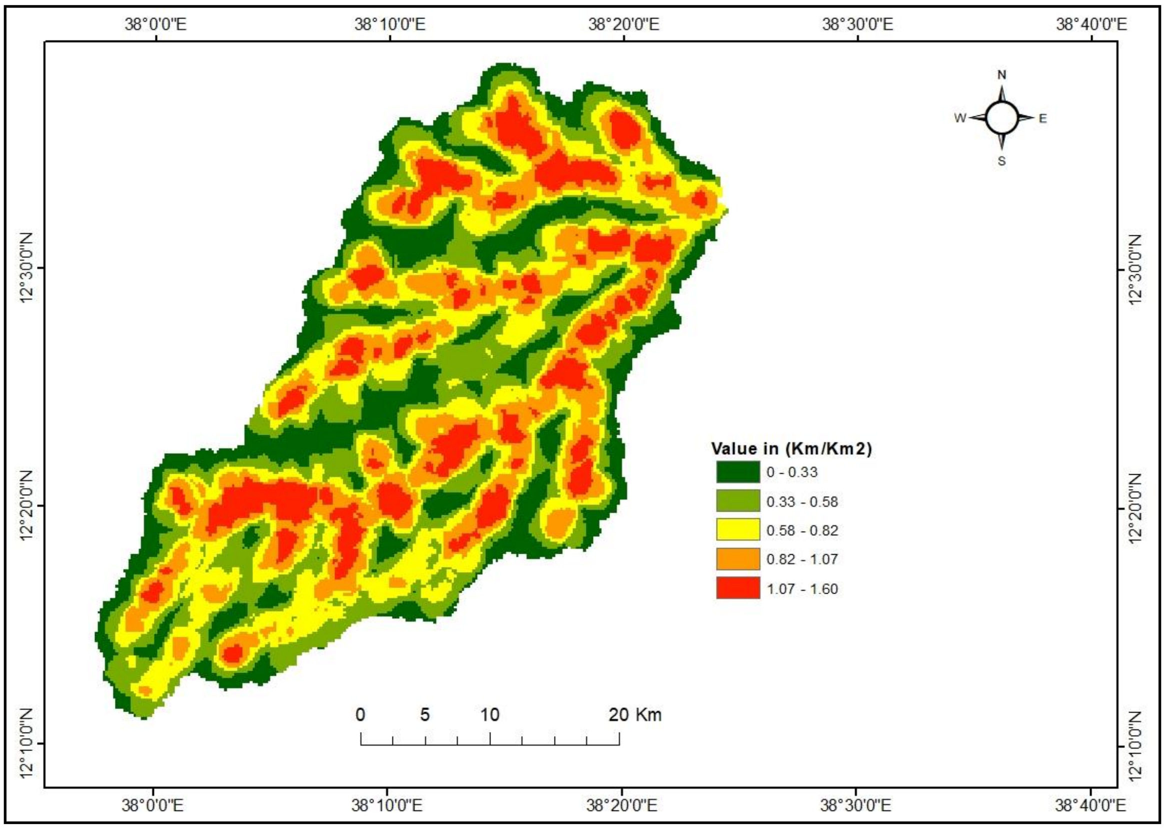

Figure 4-6 Drainage density map of Nili catchment

Soil texture

The type of soil formed in the study area also plays an important role on groundwater recharge through infiltration and loss through run-off. The type of soil and permeability affects the water holding and infiltrating capacity of a given soil (Godebo, 2005). As shown in figure 4-7 for the current analysis the soil texture was extracted from existing map of MoA map (2016). The result of the soil texture in present study is clay, clay loam and sandy loam respectively and covers an area of 1.22%, 84.39% and 14.39%, respectively. According to Ross *et., al* (2018) the soil texture classes such as clay, clay loam and sandy loam has high, moderate and low runoff and very low infiltration , low infiltration and high infiltration rate respectively. HSG-B has reasonably low runoff potential generally contains among 10 to 20% clay and 50 to 90% sand. HSG-C has reasonably excessive runoff potential generally contains among 20 to 40% clay and much less than 50% sand, and HSG-D has the most runoff possible generally contains greater than 40% clay and much less than 50% sand. Where sandy loam is grouped into HSG-B and clay loam is grouped into HSG-C, and Clay is grouped into HSG-D.

Table 4-6 Soil texture and its suitability as per groundwater potential

Factor	Soil texture	Ranking in words	Ranking in numbers
Soil texture	Clay	Very poor	1
	Clay loam	Poor	2
	Sandy loam	High	5

Source: - Ross et., al 2018

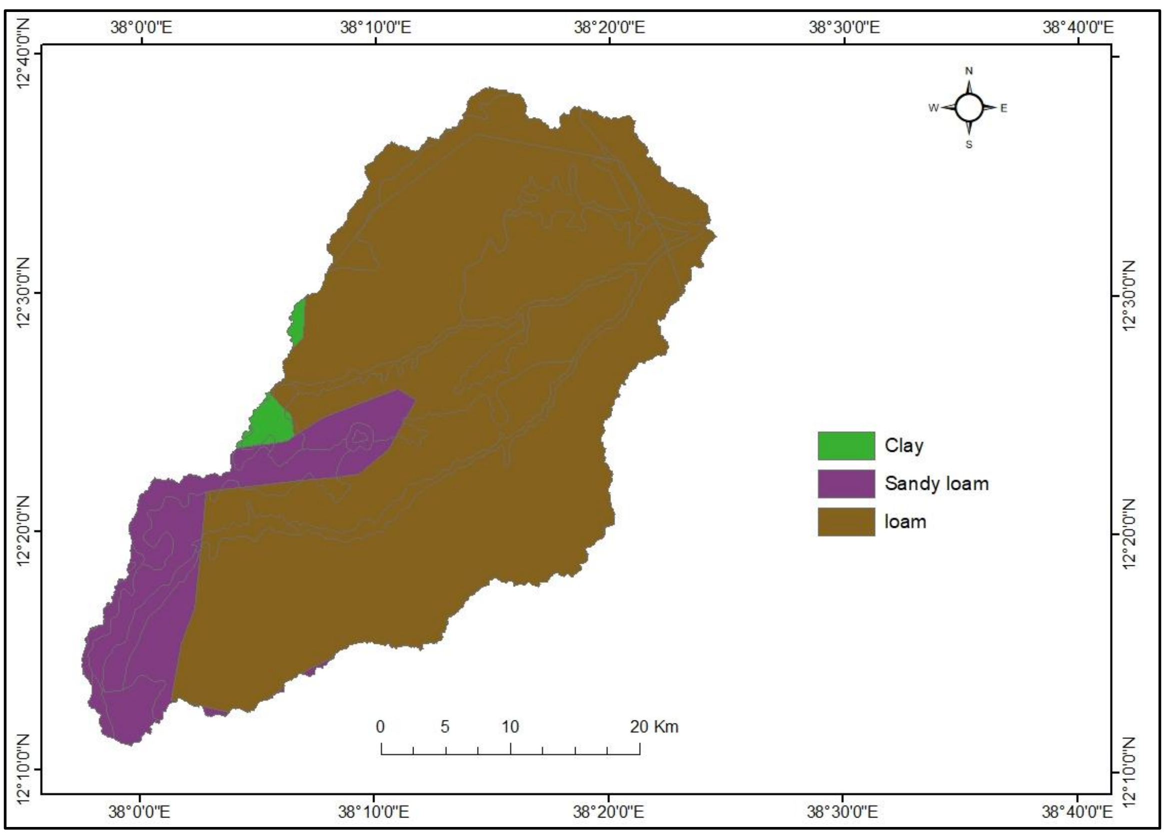

Figure 4-7 Soil map of the Nili catchment

Table 4-7 Categorizations of factors influencing in groundwater potential zone

Factor	Assigned weights	Domain of Effect	Rank
Geology	9	Lower Basalt	3
		Middle Basalt	1
		Upper Basalt	2
Geomorphology	8	Flood Plain area	5
		Plateau area	3
		Hill area	2
		Mountainious area	1
LULC	8	Annual Cropland	5
		Bare Soil	1
		Closed Shrubland	4
		Open Grassland	2
		Open Shrubland	4
		Sparse Forest	3
Slope	7	Flat (0.05°-4.75°)	5
		Gentle(4.75°-8.52°)	4
		Moderate(8.52°-12.75°)	3
		Steep(12.75°-18.55°)	2
		very steep(18.55°-40.03°)	1
Rainfall	6	very low(604-677)	1
		low (677 -732)	2
		Moderate (732-777)	3
		high (777-853)	4
		very high (853-974)	5
Drainage Density	5	Very low(0-0.32)	5
		low (0.32-0.64)	4
		Moderate(0.64-0.96)	3
		high (0.96-1.28)	2
		very high(1.28-1.60)	1
Soil	4	Clay	1
		Clay loam	2
		Sandy loam	5

4.2 Groundwater potential

To demarcate the groundwater potential zone the basic parameters were considered and the maps were arranged for each layer. These maps were changed to raster formats having the same pixel size and weights assigned as per their groundwater potential. In corresponding manner, the value 1 was given for very poor, 2 for poor, 3 for moderate and 4 for good and 5 for very good rank in terms of their GWP (table 4-8). Finally the maps integrated using GIS environment with Arc -Map 10.3 with the purpose intended to delineate the groundwater potential areas for the study area.

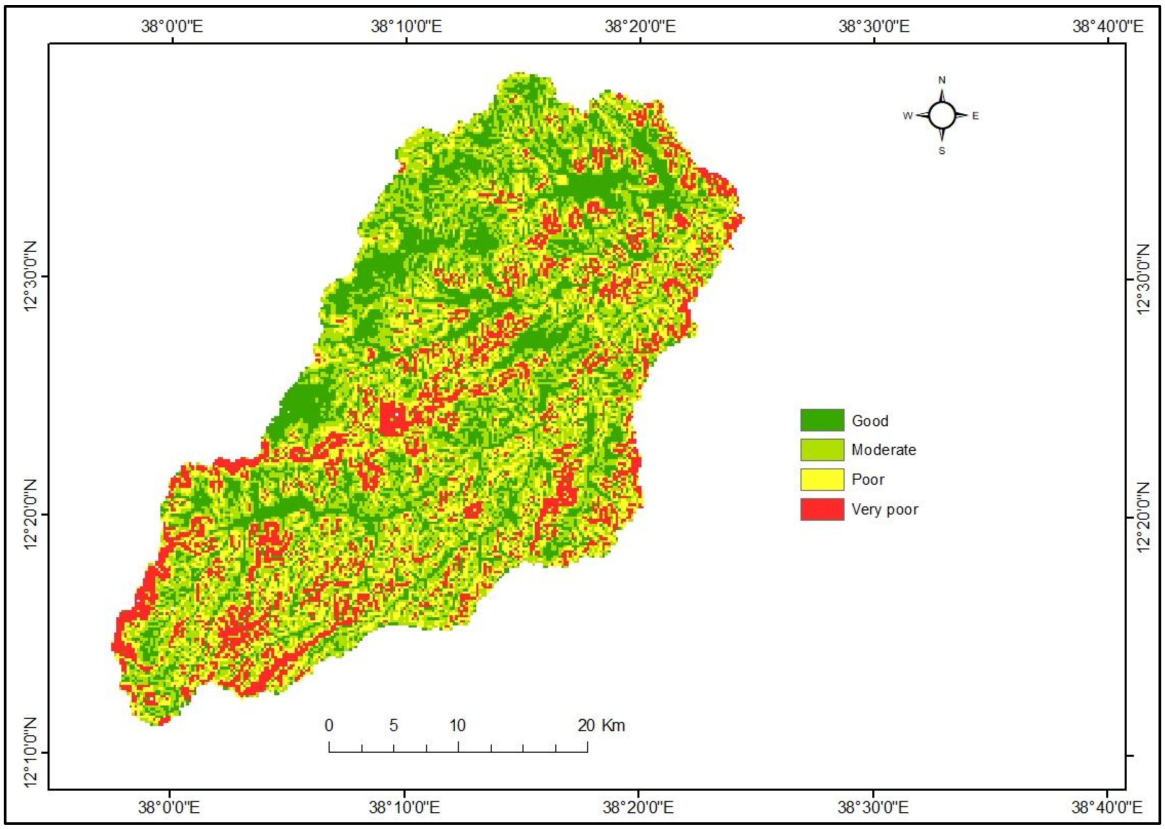

Figure 4-8 Groundwater potential Map of the Study Area

The determination of the groundwater potential zone of the Nili catchment was created by integration of the seven thematic layers. The created groundwater potential zone results were classified into four group specifically Very poor, poor, moderate and good groundwater potential zones. Very poor groundwater potential zone rank covers an area of 203.12 km^2 in percentage (16.13%). The poor groundwater potential zone covers an area of 310.04 km^2 and in percentage (24.62%) the moderate groundwater potential zone covers an area of 398.64 km^2 in percentage (31.66%) and the good groundwater potentiality rank occupies an area of 347.44 km^2 and in percentage (27.59%) the mapped area.

Table 4-8 Groundwater potential zone description

Groundwater potential Zone classes	Area (Km2)	Percentage (%)
Good	347.44	27.59
Moderate	398.64	31.66
Poor	310.04	24.62
Very poor	203.12	16.13

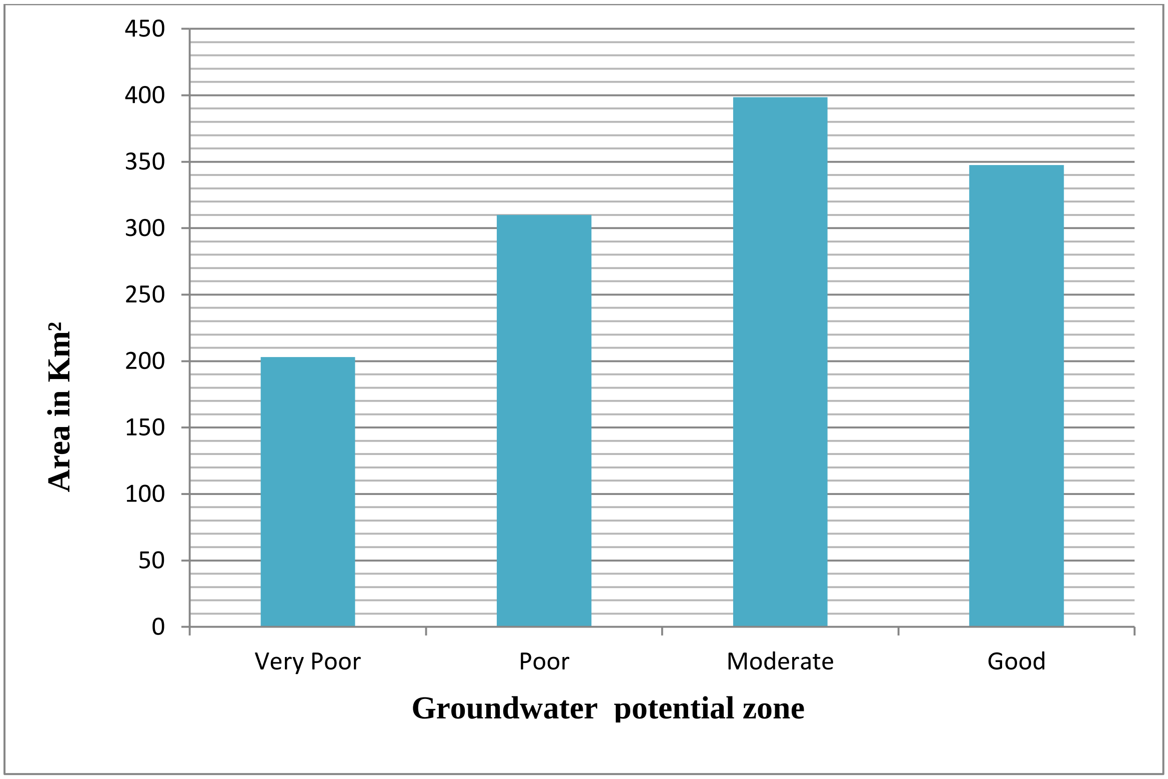

Figure 4-9 Groundwater Potential Zone coverage areas

4.3. Validation of Groundwater Potential zone

Validations of any data are one of very significant works after designing any model in order to check the expertise of the result. To validate the result that has been done on the Geographic Information System technique the available pumping well data of the entire study area were used. Existing well data were collected from the study area and the borehole depth ranges from 45m to 400m and the yield of the borehole ranges from 0.7

l/s to 6.7 l/s .According to the observation of the borehole in the site most of the borehole (9 wells) are found in the good groundwater potential zone and 1 borehole found in moderate groundwater potential zone and 1 borehole found in poor groundwater potential zone area based on hydrogeological characterization of aquifers in the Upper Tekeze area (Kebede, 2012). The validation was performed by coefficient of determination (R^2) it is the statistical measurement that inspects how differences in one variable can be clarified by the difference in second variable, when forecasting the results of a given event. The correlation of Analytical Hierarchy Processes(AHP) raster value and the corresponding of borehole discharges show positive coefficient determination (R^2) of **0.68** (figure 4-10).It show the groundwater potential zone map which was generated by using geographic information system (GIS) methods in the research area have promising result.

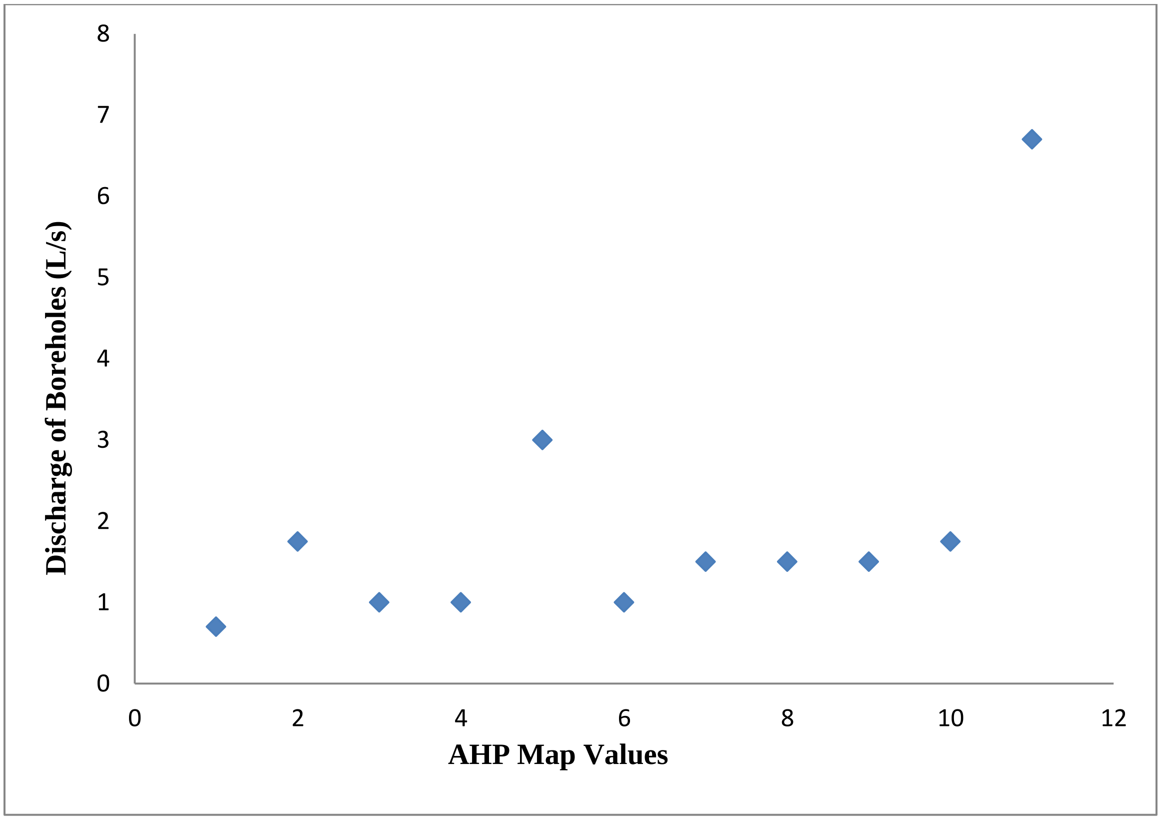

Figure 4-10 The AHP raster value and corresponding discharge of boreholes

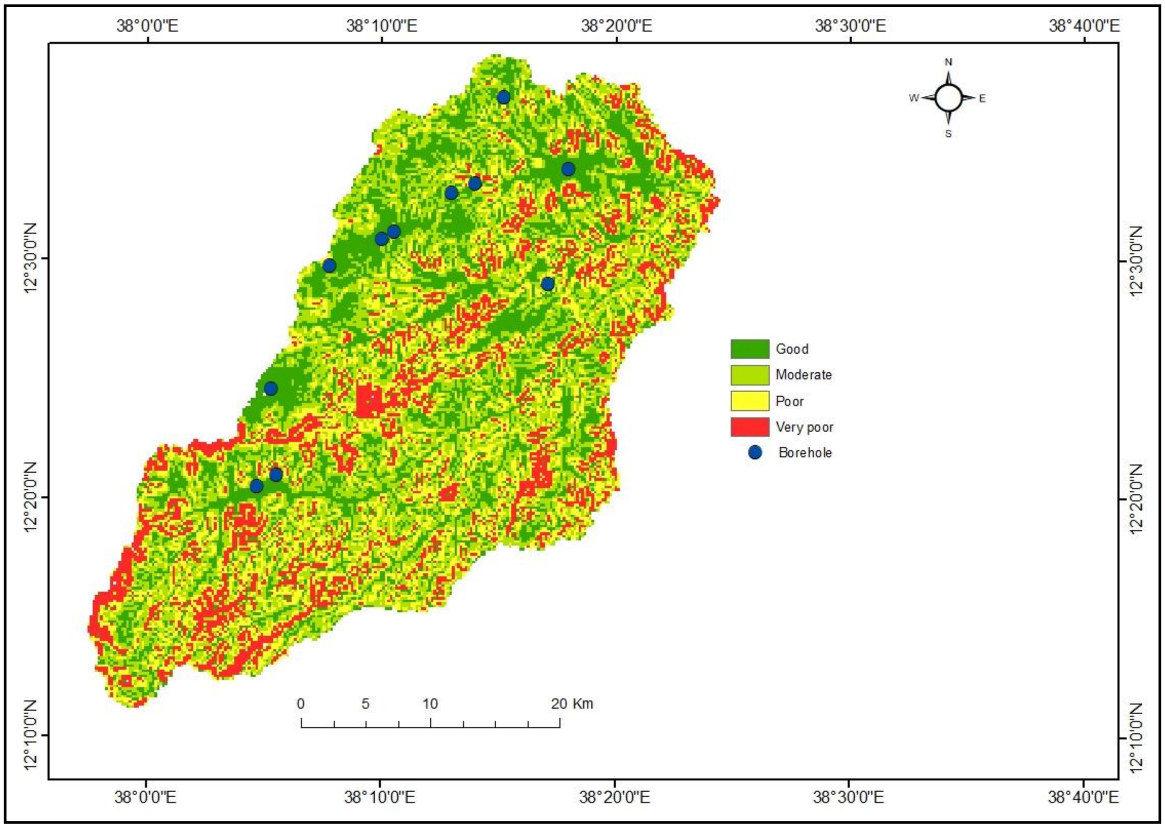

Figure 4-11Groundwater Potential Zone Validation Map of the Study Area

Chapter Five

5. Conclusion and Recommendation

5.1 Conclusion

The integration of Geographic Information System and Remote sensing technique is very essential and very useful, time and cost effective tool to delineate the groundwater potential zone in the study area. The factors deliberated in this study to delineate groundwater potential zone are geology, geomorphology, land use land cover, slope, rainfall distribution, drainage density and soil texture. All these thematic layers integrated using GIS environment and, final groundwater potential zone map is generated. Based on groundwater potential zone map, the study area (Nili river catchment) is categorized into four different zones namely good, moderate, poor and very poor groundwater potential zone. The area with good groundwater potential zone in the Nili catchment is in the flood plain geomorphologic area and areas with agricultural land areas have provided wide possibility of groundwater development and shrub land cover areas of LULC parameters, low slope value or in flat and gentle slope area, lower basalt (TV1) coverage areas, and sandy loam coverage areas. In the highest rainfall distribution occurrence also indicates high groundwater potential and low drainage density area also shows good groundwater potential. The moderate groundwater potential has in tree cover areas, moderate slope coverage areas, upper basalt (TV3)) coverage areas. Poor ground water potential zone has found in the grass land, clay loam soil texture and, low rainfall areas, in converse very poor groundwater potential are characterized by bare lands , steep slopes, clay soil texture, hills, middle basalts, very low rainfall, very high drainage density and mountainous area.

The pair wise comparison indicated that all the thematic map layers are very essential for groundwater potential zone delineation but, the geology, geomorphology, land use land cover and slope has high influencing factors for groundwater potential zone than the other parameters such as rainfall, drainage density and soil texture has low influencing factors. The consistency ratio of the selected thematic layers also 0.08 and satisfies the AHP criterian.Most of the study area 398.64 km^2 of the mapped area covers moderate groundwater potential zone and the next high coverage area under good groundwater potential zone map which covers 347.44km^2, and 310.04 km^2 and 203.12 km^2 coverage areas are poor and very poor groundwater potential zone respectively. In other words they cover 31.66, 27.59, 24.62 and 16.13% of the area respectively. The validation of the demonstrated map also carried out by using available drilling well data. The groundwater potential zone mapping of the present study provides insights for decision maker for proper planning and management of groundwater for urban and agricultural purposes.

5.2 Recommendation

Based on the present study the following recommendations are obtained

- The integration of Geographic Information System Remote sensing techniques are recommended for in accessible and complex topography.
- For further groundwater wells drillings recommended to validate the GIS based analysis and mapping.
- The similar proper methods are recommended for complicated areas to demarcate groundwater potential zone in the study area.
- The groundwater obtainability is not constant in space and time and, therefore detailed and accurate assessment of the groundwater resource is required.

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7. Annex 1 Raw data of the borehole data that found in study area

S/n	Name	Depth(m)	SWL(m)	P Position(M)	Q L/s	X	Y	Z
1	Wenbid	50	5	40	0.7	418894	1394578	1612
2	Agicha	65	5	35	1.75	416718	1387880	1571
3	Adusa	55			1	414853	1387195	1709
4	Worqedia	45	12	36	1	423877	1389005	1475
5	Lebete	62	6	32	3	422294	1380067	1622
6	Hamusit	50	3	35	1	410398	1384129	1795
7	Quna kayina	55	2.5	30	1.5	409493	1383620	1784
8	Qasena	75	19	55	1.5	405406	1381501	1789
9	AsaGot	55	32	55	1.5	401317	1365322	1836
10	Tibliha	74	12	36	1.75	399735	1364481	1847
11	UTPMW1(guhala)	400			6.7	400922	1372023	1907