GROUNDWATER POTENTIAL AND RECHARGE ZONE MAPPING USING GIS AND REMOTE SENSING TECHNIQUES: A CASE STUDY OF MELKA KUNTURE WATERSHED IN THE UPPER AWASH RIVER BASIN IN ETHIOPIA

By

Solomon Tulu Bulbula

A Thesis Submitted to the Department of Water Resources Engineering School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirements for the Degree of Master of Science in Water Resources Engineering (Irrigation Engineering)

Office of Graduate Studies
Adama Science and Technology University

Adama, Ethiopia
June, 2020

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APPROVAL OF BOARD OF EXAMINERS

We, the undersigned member of the board of examiner of the final open defense by Solomon Tulu Bulbula (A/PR15404/10) have read and evaluate his thesis entitled: Groundwater Potential and Recharge Zone Mapping Using GIS and Remote Sensing Techniques: A Case Study of Melka Kunture Watershed in the Upper Awash River Basin in Ethiopia and examined the candidate. This is, therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the Degree of Master of Science in Water Resources Engineering (Irrigation Engineering) compiles with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Subject: Thesis Submission

This is to certify that the thesis entitled ''Groundwater Potential and Recharge Zone Mapping Using GIS and Remote Sensing Techniques: A Case Study of Melka Kunture Watershed in the Upper Awash River Basin in Ethiopia'' submitted in partial fulfillment of the requirements for the degree of Master of Science in Water Resource Engineering (Irrigation Engineering), the Graduate program of the department of Water Resources Engineering, and has been carried out by Solomon Tulu Bulbula (A/PR15404/10) under our supervision and guidance. Therefore, we recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis to the department.

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DECLARATION

I, SOLOMON TULU BULBULA hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all source of material used for this thesis have been duly acknowledged.

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Solomon Tulu Bulbula

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ABBREVIATIONS AND ACRONYMAS

AHP	Analytic Hierarchy Process
AWBA	Awash Basin Authority
BCM	Billion Cubic Meter
CI	Consistency Index
CR	Consistency Ratio
DEM	Digital Elevation Model
EMA	Ethiopia Mapping Agency
FAO	Food and Agricultural Organization
GIS	Geographical Information System
GW	Groundwater
GWP	Groundwater Potential
GWPI	Groundwater Potential Index
GWPZ	Groundwater Potential Zone
GWR	Groundwater Recharge
GWRZ	Groundwater Recharge Zone
IDW	Inverse Distance Weighted
LULC	Land Use Land Cover
MCDA	Multi-Criteria Decision Analysis
MCDM	Multi-Criteria Decision Making
MCE	Multi-Criteria Evaluation
MCM	Million Cubic Meter
MIF	Multi-Influence Factor
MoWR	Ministry of Water Resources of Ethiopia
MoWIE	Ministry of Water, Irrigation and Energy
NDVI	Normalized Difference Vegetation Index
NGWA	National Groundwater Association
NMAE	National Meteorological Agency Evaluation
OWWDSE	Oromia Water Work Design and Supervision Enterprise
PCMs	Pair-Wise Comparation Matrix’s
R	Recharge
RI	Random Index
RS	Remote Sensing
WIOA	Weighted Index Overlay Analysis
WOA	Weighted Overlay Analysis
WWDSE	Water Work Design and Supervision Enterprise

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ABSTRACT

Groundwater is the most valuable natural resources for mankind for drinking, industrialization and irrigation in present day, but the availability is reduced gradually due to over exploitation and lack of management. However, identifying the groundwater potential zones in certain areas of Ethiopia is still challenging in terms of time and cost for resolving water scarcity problems and the management system of groundwater. The broad aim of this study was to map groundwater potential and recharge zone using integrated approach of Geographical Information System (GIS) and Remote Sensing (RS) Technologies with Analytic Hierarchy Process in the Melka Kunture Watershed of Upper Awash River Basin in Oromia Reginal state, Ethiopia. Eight parameters (lithology, geomorphology, slope, lineament density, land cover, rainfall, drainage density, and soil) that affect groundwater potential and recharge were identified first based three theoretical selection criteria setting which derived using Saaty's Analytic Hierarchy Process (AHP) approach are considered in this study. The thematic layers of lithology, geomorphology, slope, lineament density, land use/cover, rainfall, drainage density, and soil were prepared and used for groundwater potential and recharge zone map development by assigning weights to each thematic layer and features. The weights of each thematic layer were assigned (weighted), normalized and ranked based on their Suitability, characteristic and relationship with the potentiality to groundwater and recharge zone occurrences and movements by AHP method through Pairwise Comparison Matrix (PCM). Accordingly, the result groundwater potential zone of the study highly influenced by lithology (37%) and geomorphology (22%) whereas rainfall (33%) and lineament density (23%) highly influence groundwater recharge potential zone of the study area when compared with other factors. Finally, the reclassified thematic maps were integrated by a weighted sum overlay analysis (WOA) tool to develop groundwater potential and recharge potential zones map. The result showed that the study area can be categorized into four different groundwater potential zones: areas of high groundwater potential are estimated to cover 1105.60 km^2 (25.70% of the study area), moderate potential 2308.00 km^2 (53.73%), low potential 880.0 km^2 (20.49%), and very low potential 47.80 km^2 (1.10%). It was also found that the study area can be categorized into three different groundwater recharge potential zones: areas of high groundwater recharge are estimated to cover 250.20 km^2 (5.80% of the study area), moderate recharge 3647.90 km^2 (84.00%), and low recharge 443.50 km^2 (10.20%). Hence, the study areas has more suitability for groundwater potential and recharge zone as compared to its total areal coverage. The groundwater potential zone map was validated using the existing water source inventory point (pumping wells yield) and so most wells yield are observed in high and moderate GW potential zone in central and north east part of the study area respectively. This indicated a good prediction accuracy of 88%. As indicated on groundwater contour map, the groundwater flow direction of the study area is from highland (recharge areas) to where groundwater potential (discharge areas) found at central part of the study around becho plain and the main Awash River, topographically. Thus, potential zones identified and delineated in the Melka Kunture Watershed of Upper Awash River Basin by the GIS and RS based multi-criteria decision analysis technique are reliable.

***Keywords**: AHP, GIS, Groundwater Flow Direction, Groundwater Potential, Groundwater Recharge, Melka Kunture Watershed, Remote Sensing (RS)*

1. INTRODUCTION

1.1 Background of the Study

Groundwater (GW) is the most preferred and vital natural resources for the reliable and economic provision of potable water supply in both urban and rural environments in the major portion of the world. According to National Groundwater Association (NGWA) Report, GW is the most widely used source of fresh water and extracted as raw materials with withdrawals rate currently in the estimate range of 982km^3/year in the world. About 60% of groundwater withdrawals worldwide is used for agriculture, which is globally about 38% of irrigated land is equipped for irrigation with groundwater and about of 25% to 40% was used for domestic and the rest is used for industry (Siebert *et al.*, 2010). In Ethiopia, the annual water resources potential is estimated to be 122 BCM with 40 BCM of groundwater potential and 28-36 BCM of annual groundwater recharge (Puertas, 2015).

Groundwater potential (GWP) in Ethiopia is shaped by complex geological formation and the diversity of topography, climate, and soil (MoWR, 2012). As cited by Berhanu *et al*. (2014), the difficulty in obtaining productive aquifers is an odd feature in Ethiopia, because it's characterized by the wide heterogeneity of geology, topography, and environmental conditions. Actually, the geology of the country provides usable GW and provides good transmission of rainfall to recharge aquifers, and produce springs and feeds perennial rivers. The geological formations/water bearing rock with sufficient saturated permeable materials are transmitted and yield water in significant quantity towards point of discharge (Bereket, 2017). In many parts of the country, GW is the major source of water supply for meeting domestic need, industrial, irrigation and other developmental initiatives, due to its longer resident time in the ground, low level of contamination, wide distribution, and availability (Sewnet *et al.*, 2016).

The occurrence, distribution and movement of GW resource in any place is not a matter of chance, but the interaction of different factors such as climate (rainfall), geomorphological (land feature, land use/cover), physiographical (topography), hydrological (drainage density, water bodies, etc.), geological factors, lineament density and soil (Murasingh and Jha, 2013). However, the extent to which they affect it may differ from place and time. Considering this factor has significant potential to evaluate the groundwater resource and improve success in selecting the favorable sites for boreholes and wells (Badamasi *et al*., 2016). Years ago, several conventional methods such as geological, hydrogeological, and geophysical techniques were applicable to investigate the presence of GW based on ground survey but, it is laborious, time-consuming and cost ineffective. However, integration of geospatial tools (geographical information system (GIS) and remote sensing (RS)) has established to be more convenient (powerful-tool), time-saving and cost effective techniques means to assess and mange groundwater resource than that of conventional method in producing valuable database and map groundwater potential on the area (Murasingh and Jha, 2013; Arulbalaji *et al*., 2019). It also helps to check the accuracy of result and reduce the bias on any single factor. In addition to GIS and RS techniques, multi-criteria decision analysis (MCDA) approach of Analytic Hierarchy Process (AHP) method is used to evaluate the level of influence (importance) of each factor governing groundwater and prioritize accordingly. Additionally, its suitable to evaluate the consistence of the weight assigned through pairwise comparison in order to reduce the bias on decision making process (Manna *et al*., 2017).

Upper Awash River Basin in Ethiopia is well-known aquifer and the most well developed and intensively used by providing water supply for the capital city (A.A), for special zone of Oromia (Sebata, Gelan), Holeta Debrezeit, Mojo, Awash Kunture, Awash Melka, Tulu Bolo and other small town found in the area (Dereje *et al*., 2015). The groundwater extracted from this aquifer through pumping well by drilling is providing to the communities for domestic use, agricultural, municipality and industrial purpose. Simply pumping and/or over-withdrawal of the GW resource is not necessary because of limitation of GW resource. Therefore, Groundwater recharge has been given to better possible attention or requirement for rapid depletion of groundwater level in the investigation area (Abel, 2017). Consequently, identification of GW resources in advanced way and fairly require systematic approach of geospatial techniques (GIS and RS) to mapping potential GW and recharge site.

Considering all these, this study deals with identifying and mapping potential groundwater and recharge zone using the integrated approach of GIS and RS techniques with AHP method in a case of Melka Kunture Watershed from the upland of Upper Awash River Basin in Ethiopia to ensure sustainable development and utilization of groundwater resource in efficient and effective manure.

1.2 Statement of the Problem

In the world scenario, the availability of groundwater is reduced gradually due to over exploitation, and the lack of groundwater management. Knowing Groundwater occurrences and distribution, and identifying a good site for groundwater exploration is one of the biggest challenges, and key concern for water resource development and management in the most countries today. Proper GWP and recharge investigation, and site selection done by using geophysical and hydrogeological method is still more difficult/laborious, time taking and cost ineffective. Improper groundwater potential site selection often leads an economic and time wastage for exploration, and unsustainable utilization resource is becoming increasingly an evident problem or challenging, and the key concern for many developing countries (Tesfaye, 2015; Abdul-Aziz *et al*., 2017). Thus, using integrated approach geospatial tools (GIS and RS) with MCDA-AHP helps to evaluate the level of importance and consistence of weighted through pair wise comparison in order to reduce the bias on single factor on decision making process and to identify the main factor(s) responsible for groundwater resource development.

In fact, the exponential growth of urban population, insufficient surface water due to irregular rain season and agricultural-led industrial development have resulted in greater attention to groundwater identification (Dessalegn, 2018). Nowadays, as per the previous unpublished studies and report conducted by Awash Basin Development Office (2018) indicates that most irrigation scheme, industries and intensive agricultural practice have been established in Melka Kunture watershed. However, using groundwater resource for such development potential studies always has less attention due to less information about the groundwater potential and distribution on the site in spatial, which leads much difficult to access, plan and manage groundwater resource and recharge potential on the site (Dereje *et al*., 2015). Also, the over-exploitation or excessive abstraction of groundwater exist in particular areas require replenishment capacity (artificial recharge) by identifying recharge potential site.

To solve such identified problems the current study is designed to provide groundwater information (database), distribution and map of potential site of GWP and recharge of the study areas by advanced geospatial techniques of GIS and RS. Therefore, it is better to understand spatial dynamics of groundwater resource and identifying the GWP areas even in large and inaccessible areas and to prepare proper plan and management for the sustainable utilization of water resource with short time and minimum cost.

1.3 Objectives of the Study

1.3.1 General objective

The general objective of the study is to map groundwater potential and recharge zone using integrated approach of GIS and RS techniques with AHP method in a case of Melka Kunture Watershed in the Upper Awash River Basin in Ethiopia.

1.3.2 Specific objectives

The specific objectives of the study are to:

- Assessing suitability level of factors influencing groundwater potential and recharge zone.
- Delineate suitable groundwater potential and recharge zone through integration of different thematic layers.
- Validate groundwater potential zone map and demonstrate groundwater flow direction of the study area.

1.4 Research Questions

The following questions have been formulated to achieve the research objectives.

- What are the main factors affecting the occurrence and movements of groundwater in study area and how to assess their suitability level?
- What is the groundwater recharge potential of the study area under considering integration effect of different thematic layer?
- How to validate the developed groundwater potential zone map of the study area and what is the groundwater flow direction of the study area?

1.5 Significance of the Study

Mapping groundwater potential and recharge zone is important to understand groundwater occurrence and distribution in space and time of the area, which used for proper plan, management and utilization and/or may give better information for the success in selecting the favorable sites for efficient exploration (boreholes/or hand dug wells/or tube well drilling), and for the construction of artificial recharge structure (check dam, recharge pit, recharge well, etc) in efficient and effective (Sreenivasa *et al*., 2011, Badamasi *et al*., 2016). It is hoped that communities and private organization and/or individual in study area, and the government are the main beneficiary of the study.

Specifically, the main beneficiary of this study includes (1) the communities are benefited from this study when the government or non-government bodies take action to develop and explore groundwater resource for community development without time and cost constraint. This enable them to get enough water for domestic use and agricultural (irrigation) purpose (2) the government, and any non-government organization are also benefited from this study, when they can take an action or decision-making on sustainable development, plan, management and utilization easily, and reduces the time and the cost for selecting potential sites. It is also essential for planning the location of new abstraction well to meet the increasing demand of water and providing a digital data set which serve as groundwater database for exploration, future monitoring programs and inventory GW resource of the selected sites (3) the study is also helpful for an individual who want to do more analysis on groundwater resource identification and evaluation, and modeling and one may get his own research ideas from this study as a reference material as well as for education. It also will helpful as bench mark for those who want to carry out further investigation for identification on groundwater resource identification on the study area and elsewhere.

1.6 Scope and Limitation of the Study

The geographical scope of this study is to map groundwater potential and recharge by using GIS and RS techniques for the case of Melka Kunture Watershed, in south-west and western Shewa zone; Oromia regional state; Ethiopia. Geographically bound between 08˚06'30" N to 09˚18'45" N latitude and 37˚37'34" E to 38˚40' 10" E longitude at 1500-

3600m altitude. The conceptual scope of study would be made to identify and map the possibility of groundwater potential and recharge zone based on eight (8) main governing factors mainly lithology, geomorphology, slope, lineament density, land use/cover, drainage density, soil and rainfall, and classify the areas as very high, high, moderate, low and very low groundwater potential and recharge zone based on suitability level factors and validate the finding with existing water inventory point and to assessing the accuracy of the result.

The limitations of this research were lack of detail groundwater inventory point data (especially well yield (discharge) data) and unevenly distribution of point data. This well yield point data would not actually determine the exact potential well yield of the site in the study area due to carried out improper pump test and/or may use of under capacity pump. Due to this some of wells yield data were taken from different organization and individual.

1.7 Thesis Organization

This thesis was organized into five (5) main bodies. The first body (Introduction) contains the background of the study and provides the brief overview of the study undertaken. It also provide the information on why this research done (study problem) as well as its objectives and highlight the significance and scope/limitation of the study. Second body (Literature Review) was emphasized on brief explanation of GWP and recharge, and its occurrence. It also contains some of theoretical and empirical work/studies in the worldwide and Ethiopia related to the current study (application of GIS and RS as groundwater potential site selection tools, factors influence GWP and recharge were reviewed in detail, and the conceptual framework of GWP and recharge zone mapping was formulated at the end of this section. Third body (Methods and Materials) was explain brief description of the study area, materials used, data required and its source as well as methods of data preparation and analysis used to accomplish the whole objective of the study was described. Fourth body provide the result and discussion of the study corresponding to the research objectives and previous work respectively, and finally (under fifth body) conclusions and recommendations was forwarded at the end of thesis body.

2. LITERATURE REVIEW

This chapter provides a review of some important definition and theoretical bases for groundwater potential and recharge zone mapping, factor influence GW potential and recharge, GIS and RS application in Hydrology and related empirical research were reviewed and finally, conceptual framework of the study was formulated.

2.1. Brief Explanation of Groundwater Potential and Recharge

Groundwater is the one of the hydrological cycle which is formed when rainfall and surface water soak (infiltrate or percolate) into cracks and opening in beds of rock (gravel) and soil (sand) and enter subsurface of the ground to water table. Groundwater potential mapping is the way of identifying and delineating the prospective groundwater zones in an area by qualitative assessment of the controlling and indicative parameters (Preeja *et al.*, 2011; Anbazhagan and Jothibasu, 2016). In other ways, groundwater recharge is the hydrologic processes where water move down ward into the aquifer through the unsaturated zone during a specific period. It can take place due to the rainfall that enter into the sub-surface through direct infiltration of precipitation into the aquifer or though tectonic discontinuities (such as faults, joints, fractures, etc.) or through infiltration of water bodies into the aquifer.

Mapping of groundwater recharge potential zone is important to identify potential site specific to groundwater recharge structure (i.e. construction of artificial recharge structure (and managed aquifer recharge system based on factors influence groundwater recharge occurrences. Artificial recharge helps to augmenting the natural movement of surface water into underground using artificial recharge structure such as check dams, percolation tank, recharge well/pit, etc.) The potentiality of the groundwater and recharge on the area is explained based on lithology, topography and structure of the area. Many author (Nagarajan, and Atal, 2012; Thapa *et al.*, 2017; Das *et al.*, 2018; Arulbalaji *et al.*, 2019) were discussed that GIS-RS based hydrological assessments were used to identify and delineate potential sites for locating groundwater potential and recharge zone considering groundwater control parameter. They were also classified the area into different zone (class) depend on the suitability level of factor affect groundwater occurrences.

2.2 Groundwater Occurrence in Ethiopia

The hydrological conditions exist in the country are highly varied as a result of the complexity of geology, physiography and climate change. Groundwater is highly influenced by different geophysical and climatic factor like geology, topography and environmental condition which affect the productivity of aquifer positively or negatively based site specific properties. Due to that the occurrence of groundwater is not uniform anywhere (Dessalegn, 2018). As stated by Seifu Kebede (2013), in global map of groundwater or groundwater aquifer, the Ethiopia aquifer were classified as volcanic rock, sedimentary, metamorphic and alluvial lacustrine sediment aquifer which is the most complex, compartmentalized and relatively low storage with moderate range of productivity. He, also describe the source of groundwater recharge in Ethiopia is under flood recharge, rainfall recharge, mountain block recharge and runoff. As stated by Berhanu *et al*., (2014) the country can be characterized with generalized classifications, such as 18% of the Precambrian basement, 25% of the Palaeozoic and Mesozoic sedimentary rocks, 40% of the Tertiary sedimentary and volcanic rocks, and 17% of the Quaternary sediments and volcanic rocks, geologically. Tamiru Alemayehu (2006) investigated the occurrence of groundwater in Ethiopia and describe the most important factors governing the groundwater flow and storage in volcanic rock. The variation in geology, textural and structure in volcanic rock cause the variation in water bearing capacity of the area.

2.3 Theoretical Literature Review

2.3.1 GIS and RS application in groundwater resource identification

Three decade ago, the application of GIS and RS technology in groundwater resources evaluation and modeling has been started to be practiced. Now days, a number of work had been done in worldwide by applying GIS and RS in Various field of water resource for map (model), management and analysis because of its inlaborious, reliability, time and cost effective, and environmental sensitive result (for current situation or problem). Some of researcher literature related to GIS and RS application in groundwater potential and recharge zone identification and mapping were reviewed here below.

Rahman (2015) stated that using GIS with AHP is a tool that reduces the time required and the cost of identifying and selecting suitable/optimum sites for managed aquifer groundwater potential and recharge system and providing a digital data bank for future monitoring programs of area of interest (AOI). It is best suited for dealing with a widespread range of parameter data govern groundwater from various sources in order to comprise the most common process in groundwater potential mapping such as data acquisition, d igitizing a map data, data processing and data analysis. In other hand, remote sensing technology was provide satellite data of environment and earth surface such as geomorphology, slope, elevation, land us land cover, drainage pattern and lineament density for GIS. It can provide an objective information without modifying their nature and capable of providing spatial data that can quantitatively describe environmental process with some range of accuracy (Musa *et al.*, 2015). It also GIS proved an excellent framework for effectively handling large and complex spatial data for natural resource management. In other ways, RS is the helpful tool and effective technology in a wide range of application which provides basic data for GIS in large area's coverage, and even where it's not accessible in spectrally, spatially and temporally (Kumari, 2018).

2.3.2 Analytical hierarchy process (AHP) in groundwater identification

The Analytic Hierarchy Process (AHP), introduced by Thomas Saaty (1980), is an effective tool and internationally acceptable for dealing with complex decision making, and may aid the decision maker to set priorities and make the best-fit decision. It can be used in many field of studies which attempted to identify groundwater potential zones that the important factors which affect the occurrence of groundwater are elevation, slope, drainage density, land use land cover, soil type, lithology, geomorphology, lineament density and rainfall (Aneesh and Paresh Deka, 2015; Ramu *et al*., 2014; Sajikumar and Gigo, 2013). So depending upon the suitability and the type of region of study, all the 9 parameters or any few relevant parameters have been chosen and weighed by AHP to generate Groundwater Potential Zones (Rajkamal *et al*., 2014; Guptaa and Srivastava, 2009; Rambabu *et al*., 2015). In the studies done to identify groundwater potential zones in Bengaluru and Mysuru (Aneesh and Deka, 2015; Ramu *et al*., 2014), all the above mentioned criteria have been used and thematic maps have been made and given proper weight based on their importance to groundwater occurrences and movements. AHP technique has been followed to find the weights not only just for the main criteria but also for the subclasses within each criteria. Normalized weights have been calculated for the criteria features as well as for the subclasses.

2.4 Factors Influence Groundwater Potential and Recharge

The occurrence of groundwater potential and recharge zone is affected by many different geophysical and climatic factors like geology, topography and environmental condition. As discussed by Suganthi *et al*., (2013), and Waikar and Nilawar (2014) groundwater identification and zonation by using GIS and RS was mainly based the analysis of terrain feature like geological structures, geomorphology, Land use/cover, Slope, Rainfall, drainage density, lineaments density and soil which they influence the occurrence and movement of groundwater. Some of major factors influence or responsible for groundwater resource identification and locate potential site are discussed below.

2.4.1 Land use/land covers (LULC)

Different land use/land cover has certain influence on groundwater potential and recharge directly through infiltration, runoff and evaporation (Fashae *et al*., 2014). Land cover is the human land use activities which involves built or modifies the natural environment as vegetation or plantation and others. This is influence or minimize evaporation and runoff and increase the rate of water enter to the sub surface soil (infiltration). Hence, the vegetation cover increases the chance of groundwater recharge and can be an indication for groundwater potential. On other hand, the land cover is the physical materials that cover the land surface by settlement, road/asphalt, grass and water. In settlement and built up area infiltration is low because of land covered by pavement and building, therefor in such area low recharge are expected.

2.4.2 Geomorphology

Geomorphological studies is one of the most significant aspects in the assessment of surface and groundwater resources or hydrological behavior. It is characterize various landforms and structure feature including hills, plateaus, pediment/pedi plain, level plain, flood plain, alluvial plain, valley, etc. of the area which is favorable for groundwater occurrences and recharge. Avinash *et al*. (2011) demonstrated that geomorphology is a good agent for groundwater potential analyses. The hydro-geomorphologic units like alluvial/flood plains, valley fills, level plateau, buried channels and lineaments are very good sources (high significance) for groundwater occurrence. On other hand, mountain or structural hills, pediment zone and gullied lands are poor (less significance) groundwater potential zones. Among different factor, geomorphology was assigned the second highest weight, because it plays dominant role in the movement and storage of groundwater at any place (Kumar *et al*., 2016).

2.4.3 Slope

The slope is one of the important factor which highly controlling the infiltration and runoff capacity of precipitation and surface water flow. Where steep slopes are present, groundwater potential is low because there is more surface runoff and decrease the infiltration rate of water into the ground by allowing less residence time for precipitation. In areas characterized by flatlands and/or valleys, groundwater potential and recharge is high because it is easier for the water to enter (infiltrate) to the ground and decrease the runoff on the surface by allowing more concentration time for precipitation to percolate (Venkateswaran *et al*., 2016). This so indicate high slope regions have high runoff and low infiltration rate that are not suitable for groundwater recharge, because of water cannot get enough time to infiltrate to the ground and vice versa. The slope map of the area is extracted from digital elevation model (DEM) using surface-spatial analysis tools in ArcGIS.

2.4.4 Lithology

Lithology/Geology is one of the most important factor which plays significant role in the distribution and occurrence of groundwater as well as the quantity and quality of the groundwater in the given area. It is determine the aquifer characteristics and underlain rock porosity which govern the infiltration/percolation and permeability of water flow. It is affect ground potential and recharge by controlling the percolation of water flow in subsurface aquifer. Porosity of the rock determines the storage capacity of rock formations. Sedimentary rocks were considered as having a high potential for groundwater due to their high porosity and permeability relative to igneous and metamorphic rocks. Sandstone and sandstone with limestone are considered as potential water bearing formation and hence higher ranking was assigned. Relatively among others factor, geology is the most dominant factor influencing groundwater and recharge which assigned the highest weight among all factor (Thapa and Gupta, 2017).

2.4.5 Lineament density

Lineament are basically the weakness topography or discontinuity of structural features such as joint, fault, crack, fissures, bending, fractures, rock cleavage etc. that are arranged in a straight line or a slight curve as detected by remote sensing. Hence, lineament play a fundamental role in groundwater potential and recharge as the structural weakness or underlain by zone of localized weathering are increase the infiltration capacity, permeability and secondary porosity. These factors are hydro-geologically very important as they the path ways for groundwater movement and storage. Lineament density of an area can indirectly reveal the probability of groundwater potential occur, since the presence of lineaments usually denotes a permeable zone. Lineament density (Ld), as defined by (Murasingh and Jha, 2013; Das and Pardeshi, 2018) is the total length of all the lineaments demarcated divided by the total study area expressed in (Km/Km^2), as:

$$Ld = \frac{\text{Total length of all Lineament}}{\text{Total area}} = \frac{\sum_{i=1}^{n} Li}{A} \text{ (Km/km}^2\text{)} \quad (1)$$

Where, Li - the total length of lineament (km), and A - the Unit areas (km^2). Areas with high lineament density are good for groundwater potential and recharge zones where as the areas with low lineament density are poor groundwater potential and recharge. Therefore, as lineament density of the area increases, the potentiality of groundwater and recharge of the area are increases.

2.4.6 Soil

Groundwater recharge and runoff that occur due to infiltration is highly dependent on the type of soil and soil texture. The water holding capacity of the area is depend upon soil porosity and their permeability. Gravel and sandy soils have large particle constituents, which makes it have high transmissivity and infiltration values. On the other hand, clay and silt soils have small particle constituents, resulting in low transmissions which is low in permeability however fine sand and loamy soils exhibits to moderate permeability. Soil properties influence the relationship between runoff and infiltration rates which controls the degree of permeability that determines the existence of groundwater potential and groundwater recharge zone (Tesfaye, 2015). So that the more permeable soil is the more chance to have high GWP and recharges and vice versa. In terms of their capacity for GWP and recharge, sandy soils are assigned higher rank, clay soils are assigned lower rank and loamy soils are assigned intermediate rank (Kumar *et al.*, 2016; Zhou and Wang, 2018).

2.4.7 Rainfall

Rainfall is one of the most important source/hydrologic factor for groundwater occurrence and high determinant factor for groundwater recharge occurrence because rainfall is the only unique source of water percolate into the ground to recharge groundwater. High intensity and low duration of rainfall possess less infiltration and high runoff but low intensity and high duration of rainfall possess high infiltration and low runoff. The precipitation pattern may be influenced by irregular topography. Therefore, distribution of rainfall along with slope gradient easily affects the infiltration rate and runoff water hence increases the possibility of groundwater potential zones (Sar *et al.*, 2015). The high rainfall amounts imply the possibility of high groundwater recharge thus high groundwater potential zones while low rainfall indicates low groundwater recharge thus low groundwater potential zones. Rainfall can be interpolated using averaged values ranging from daily, monthly or annual aggregation levels, using different interpolation methods.

2.4.8 Drainage density

Drainage pattern is a reflection of the rate that precipitation infiltrated compared with surface runoff. They are indicates the inverse function of permeability capacity, infiltration capacity and recharge capacity of rocks and soil surface which is an important factor for groundwater evaluation (Mesfin, 2011). The term drainage density of the basin first introduced by Horton (1932) which is defined as the ratio of the total (cumulative) line length of the stream network to the basin area (the area of under consideration) which describe the closeness of the spacing of the stream channel and river. It can be calculated by using the following formula:

$$\text{Drainage Density (Dd)} = \frac{\text{Total Length of the Stream Network}}{\text{Total area of basin}} = \frac{\sum_{i=1}^{n} Si}{A} \ (\text{Km/km}^2)\text{……… (2)}$$

Where Si denotes the total length of stream network (drainage) (km), and A denotes the unit area (km^2). High drainage is the resultant of weak or impermeable surface (fine texture soil type), sparse vegetation and mountain relief which have high runoff and low infiltration result, while low drainage density is the result of high permeable subsoil (course texture soil type) and low relief which have less runoff and high infiltration. High drainage density indicate high runoff and less infiltration which results in less occurrence of groundwater and the reverse are true, low drainage density has less runoff and high infiltration results in high contribution of groundwater potential and recharge. (Waikar and Nilawar, 2014). High drainage density may indicated (1) by the existence of a mature well developed channel system (2) surface runoff move rapidly from hill slopes(overland flow) to channel(lowland) (3) thin(deforested) vegetation cover (4) basin rocks/soils/surface has generally low infiltration rate. The place where density of the drainage network closer there is the probability of finding high groundwater. But, moving away from the drainage, the groundwater potential decreases (Fashae *et al*., 2014).

2.5 Groundwater Potential and Recharge Site Selection Tools

The use of geospatial techniques of GIS and RS with multi criteria decision making (MCDA) - AHP method in GW and recharge potential site studies only began very recently (Chowdhury *et al*., 2010). For the last three decades integrated approach of GIS and RS with MCDM-AHP techniques have been used in solving site selection problems. A brief description of the strength and weakness of each tool with regard to sitting problems is provided below.

2.5.1 Geographical information system (GIS) and remote sensing (RS)

Capability of the Remote Sensing and GIS technologies for ground water study is unique. Establishing the integration relationship between GIS and Remote Sensing data with hydrologic phenomenon maximizes the efficiency of identification of potential zones for water resources development. Geographic information systems (GIS) have emerged as useful computer-based tools for spatial description and manipulation. Satellite data obtain through remote sensing technology are the main input for preparing groundwater prospect map in ArcGIS software. The information thus extracted from the satellite data at different stages, has been converted, simultaneously, into spatial data base (GIS layers). Using the GIS layers, the ground water prospects is generated through different steps (Tessema, 2011).

2.5.2 Multi criteria decision analysis (MCDA)

In GIS framework, multi criteria decision analysis is sub-discipline of operation research and systematic procedure for combine layers of spatial data of criteria to analyzing and selecting the best feasible option from the given alternative. It was designed in the 1960 to help decision-makers to integrate various alternative. They analyze and support decision through formal analysis of alternative options, their attribute, evaluation criteria, goals or objectives, and constraints. Many studies was Suggested that, MCDA techniques is an effective and selective tool to analyze structure decision problem and choose the best option based on designed criteria for delineating groundwater potential and recharge zone. Among different MCDA method, this study mainly depend on Analytical Hierarchy Process (AHP) (Malczewski, 2006).

2.5.2.1 Analytical hierarchy process (AHP)

The Analytic Hierarchy Process (AHP), introduced by Thomas Saaty (1980), is the well-known an effective tool for dealing with complex decision making, and may aid the decision maker to set priorities and make the best decision (judgment). AHP is the knowledge based method which is utilized when dimensions are independent. the AHP incorporates a useful technique for quantifying weightage depending on its significance or interaction to groundwater storage and recharge and checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision making process (Malczewski, 2006). By reducing complex decisions to a series of pair wise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. The AHP generates a weight for each evaluation criterion according to the decision maker's pair wise comparisons of the criteria. Hence, AHP allows for calculation of Consistency index (CI) and Consistency Ratios (CR) such that if the C.R is less than or equal 0.1 (10%) then the inconsistency is acceptable otherwise reevaluated again.

2.5.2.2 Pair-wise comparison matrices (PCMs)

Many number of studies have adopted a pairwise comparison matrix format for assessing the weights for the criteria by comparing criteria against each other. In a study done in Krishnagiri district, Tamilnadu (Rajkamal *et al.*, 2014) pairwise comparison matrix has been made and relative ranks have been given for a total of seven criteria like Geomorphology, geology, slope, land use land cover, NDVI, rainfall and drainage density (in descending order of weightage) by using AHP-Multi Criteria Evaluation (MCE). A similar method was applied previously by Tarun Kumar *et al.*, (2013) in Drugs district of Chattisgarh where pairwise comparison matrix was developed for thematic maps and knowledge based rating has been done for subclasses. Further, for the pairwise comparison matrix, normalized weights have been calculated to arrive at the weightage. AHP is based on the construction of a Pair-wise Comparison Matrices (PCM) series, which is comparing all the criteria to one another based on a scale of importance of nine points (1-9). Saaty's scale, 1-9 numbers indicate how many times one factor more important than other factors (Table 1). The PCMs involves comparing all the possible pairs of criteria in order to determine which of all the criteria is of a higher priority. It has been applied in wide variety of areas including planning, selecting a best alternative, resource allocation and resolving conflict.

Table 1**:** Scales for the Pair-Wise Comparisons (PCM) method

Intensity of relative importance	Definition	Explanation
1	Equal importance	Two criteria contribute equally to the objective
2	Weak or slight	Slightly moderate importance
3	Moderate importance	When judgment moderately favours one criterion over another
4	Moderate plus	Slightly strong importance
5	Strong Importance	When judgment strongly favours one criterion over another
6	Strong plus	Slightly very strong importance
7	Very strong	When judgment very strongly favours one criterion another
8	Very strong-extreme	Slightly extreme importance
9	Extreme Importance	When evidence favoring one criterion over another is extremely/highest
2, 4, 6 & 8	Intermediate values	When compromise is needed between two criteria
Reciprocals	Values for inverse comparison	If criterion i had one of the above numbers assigned to it when compared with criteria j, then j has the reciprocal value compared with i

Source (adapted from Saaty, (1980)

2.6 Empirical Literature Review

The different empirical studies related to groundwater potential and recharge zone mapping was accessed from unpublished and published research literature and some of them have been discussed below by classifying at global scale in worldwide level and local scale in country level.

2.6.1 Global scale

Large number of studies were published in worldwide recently by applying many method to identify potential site for groundwater potential and recharge. Some of techniques could be reviewed from many of the studies which attempted to identify groundwater potential zones based on the important factors which affect the occurrence of groundwater are elevation, slope, drainage density, land use/cover, soil type, lithology, geomorphology, lineament density and rainfall (Aneesh R and Paresh Deka, 2015; Ramu *et al.*, 2014; Sajikumar and Gigo, 2013). For instance, Table 2 shows a summary of a number of those studies that have been used GIS and RS integrated with MCDA-AHP for the selection of potential sites for groundwater and recharge.

Table 2: Number of studies used GIS, RS and MCDA for mapping GWP and recharge zone

S.No	Study(Author)	Method	Criteria	Country
1	(Arkoprovo *et al.*, 2012)	GIS and RS	Geomorphological, geological, slope, drainage density, lineament density.	India
2	(Thapa *et al.*, 2017)	GIS and MIF	Geology, geomorphology, soil type, elevation, lineament and fault density, slope, drainage density, land use/land cover, soil texture, and rainfall.	India
3	(Saraf & Choudhury, 2010)	GS and RS	Geomorphology, Geological, Lineament and NDVI.	India
4	(Gupta & Srivastava, 2010)	GIS, RS and MCE	Lineament density, drainage density, digital elevation model (DEM), slope map and land use/land cover (LULC).	India
5	(Chowdhury *et al.*, 2009)	GIS and RS	Lithology, landform, drainage density, recharge, soil, land slope and surface water body.	India

6	(Venkateswaran *et al*., 2016)	GIS and RS	Topography, Geology, lineament, drainage patterns, land use/land cover, slope and soil.	India
7	(Kumari, 2018)	GIS and RS	Topographic maps Land use and land cover map Lineament map Drainage map Soil, Slope Rainfall.	India
8	(Singh *et al*., 2013)	GIS,RS and MCE	Geomorphology, lithology, drainage density, slope and lineaments.	India
9	(G. K. Das, 2018)	GIS and RS	Geology, geomorphology, drainage density, slope, landuse/land cover, soil.	India
10	(Yeh *et al*., 2016)	GIS and RS	Lithology, land use/cover, lineaments, drainage, and slope.	Taiwan
11	(Oikonomidis *et al*., 2015)	GIS, RS and PCMs	Rainfall, potential recharge, lithology, lineament density, slope, drainage density and depth to groundwater.	Greece
12	(Chaudhary & Kumar, 2018)	GIS and RS	Geology, geomorphology, drainage density, slope, landuse/land cover.	India
13	(Savita *et al*., 2018)	GIS and RS	Geology, geomorphology, soil, slope, Land Use/Land Cover (LULC) and drainage density.	India
14	(Sar *et al*., 2015)	GIS,RS and AHP	Drainage density, geomorphology, lineament density, land use/land cover, soil type, water bodies density, normalized difference vegetation index (NDVI), slope and mean annual rainfall.	India
15	(Bera & Bandyopadhyay, 2012)	GIS and RS	Geology, land use land cover, slope, soil, drainage density and geomorphology	India
16	(Souissi *et al*., 2018)	GIS, RS and MCDA	Land use/land cover, lineament density, drainage density, lithology, slope, rainfall, geomorphology and soil type.	Tunisia
17	(Arulbalaji *et al*., 2019)	GIS and AHP	Geology, Geomorphology, Land Use/Land Cover, Lineament density, Drainage density, Rainfall, soil, slope, Roughness, topographic Wetness Index, topographic position Index and Curvature	India
18	(Fashae *et al*., 2014)	GIS, RS and MCDA	Geology, rainfall geomorphology, soil, drainage density, lineament density, landuse, slope and drainage proximity.	Nigeria
19	(S. Das & Pardeshi, 2018)	GIS, RS, IF and FR	Lithology, geomorphology, slope, soil, lineament density, drainage density, land use and rainfall.	India
20	(Badamasi *et al*., n.d.)	GIS,RS and AHP	Drainage, geology, geomorphology, land cover, lineament, rainfall, slope and soil.	Nigeria

21	(Kumar *et al.*, 2016)	GIS, RS and AHP	Geomorphology, geology, soil type, slope, and land use/land cover.	Switzer land
22	(Gumma & Pavelic, 2012)	GIS, RS and WOA	Geomorphology, geology, slope, drainage density, annual rainfall, land use/land cover, and soil type	Ghana

Therefore, the above studies indicate that GIS and RS through MCDA using AHP were the common and well known method for delineating groundwater and recharge zone. This methods helps to integrating all thematic layers. So depending upon the suitability and the type of area of the study, all the parameters or any few relevant parameters have been chosen and weighed by AHP to delineate suitable groundwater potential and recharge zones. Also, a review of this literature indicated that eight criteria (factors) were mostly considered and subsequently taken into consideration when identifying optimal sites for groundwater potential and recharge. This include; Geology (lithology), Geomorphology, slope, lineament density, drainage density, landuse land cover, soil and rainfall. All the above mentioned criteria (factor) have been used and thematic maps have been made and given proper weight based on their importance to groundwater availability.

2.6.2 Related previous (empirical) studies in Ethiopia

Concerning this area, numerous studies and research have been done previously based on different factors in different method like the hydrogeological studies, Geophysics survey methods, evaluation of water balancing method; base flow separation and groundwater potential evaluation using GIS and RS were conducted in the Upper Awash River Basin and its surrounding. But the application of GIS and remote sensing in groundwater study was still not (well) known in Ethiopia, but now there are the promising beginnings.

Tesfaye (2015) had made an attempt to delineate and classify possible groundwater potential zones in the Bilate River catchment of the south Ethiopian rift escarpment, found in SNNPR using integrated remote sensing and GIS techniques. Groundwater potential evaluation based this technique in the case of this study area, he described around 58.04 km^2 was high, around 3175.35 km^2 was moderate, around 2218.82 km^2 was low and around 54.31 km^2 was poor groundwater potential zone. Finally, the generated ground water potential Zone map was compared with the point discharge or the well yield data. In this work, it has been concluded that Integrated GIS and RS are efficient techniques in groundwater studies to facilitating better data analysis.

Abdul-Aziz *et al.* (2017) had also conducted a study in Northern Ethiopia, Wollo Zone, in Gerardo River catchment to spatially delineate the ground water potential areas using geospatial and multi criteria Decision Analysis (MCDA) tools. Eight major geophysical and environmental factors like geomorphology, lithology, slope, rainfall, land use land cover (LULC), soil, lineament density and drainage densities were considered in the research to develop the groundwater potential map. The sources of these data were satellite images, digital elevation model (DEM), existing thematic maps and metrological station data. Landsat image was used in ERDAS Imagine to drive the LULC of the area, while the geomorphology, soil, and lithology of the area were identified and classified through field survey and digitized from existing maps using the ArcGIS software. The slope, lineament and drainage density of the area were derived from DEM using spatial analysis tools. The rainfall surface map was generated using the Thiessen polygon interpolation.

Tegegn (2015) had attempted identify groundwater potential zone and recharge and its distribution in southwest of Ethiopia in Baro Akobo Basin by integrating seven thematic maps (drainage density, slope, lineament density, soil, rainfall distribution, land-use/cover and geology) through ArcGIS weight overlay tool. Slope, geologic formation and rainfall thematic maps were the most influenced factors, respectively. Soil map and land use/ cover map had the average and lineament and drainage density map were the least for the preparation of groundwater potential zone based on the estimated weight value result. The rest thematic maps, lineament and drainage density maps were the least estimated weight value. The weighted value were calculated by priority estimation tool (PriEst) using Eigenvector method and the prepared groundwater potential map was validated with available well yield data.

Bane (2017) studied groundwater potential and recharge zone mapping by using GIS and remote sensing techniques in middle Awash River Basin by using the RS and GIS by integrated with Analytical Hierarchy Process (AHP) techniques and reported that as the area having about 34% very high groundwater potential, 8.83% high groundwater potential, 32.47% very moderate groundwater potential, 22.73% moderate groundwater potential, and about 1.27% as a very low groundwater potential zone. Finally, he summarized that very high potential zone indicates the most suitable area present in structural landforms of alluvial plains, lacustrine sediments, the fracture valleys, and valley fills, which coincide with the low slope, high rainfall and high lineament density, of the study area. Very low groundwater potential falls in the area volcanic landform, bare lands, high slope and high drainage density.

2.6.3 Hydrogeological Studies of Upper Awash River Basin

Several hydrogeological studies has been conducted on Upper Awash River Basin and its surrounding areas. Some of the hydrologeological studies conducted in the Upper Awash River Basin and inside catchment were discussed as below.

Ketema Wogari (2006) evaluated the water resource potential of Holeta River Catchment and identified that the basaltic lava flows (Alaji and Tarmaber formation), Trachytic and Rhyolitic volcanic rock, pyroclastic deposits and Quaternary alluvial sediments deposit are the major geological unit in the area. Hussen Endre (2006) had also conducted water resource evaluation of Berga River Catchment and discussed that the main aquifer in the catchment was weathered and fractured basalt. The other hydrogeological investigation conducted in Becho area is groundwater resource potential evaluation of Teji River Catchment (Andualem, 2008). It investigation shows that the annual recharge of the catchment is 325.39 mm.

WWDSE (2007-2008) has been conducted comprehensive study which supported by geophysical investigation and deep well drilling on the tittle of groundwater resource evaluation of the Ada'a and Becho plain for irrigation. They classified the main aquifer of the area into upper and lower basalt aquifer and alluvial and lacustrine deposit aquifer. The upper basalt aquifer includes Weliso Ambo basalt, Akaki basalt and Addis Ababa basalt whereas the lower aquifer includes Tarmaber basalt and Aiba basalt. The Rhyolite and Trachytes of Wechecha, Furi, Yerer and Ziqual was mapped as regional groundwater barrier. Finally, the study revealed that the annual groundwater recharge of the plain was about 965 million cubic meter/year (MCM/year) and also the annual exploitable groundwater are estimated to be about 642 MCM/year and 1046 MCM/year in Becho and Ada'a Plain respectively.

Yitbarek *et al.,* (2012) investigated the hydrogeological and hydrochemical framework of the Upper Awash River Basin and describe the aquifer properties of the basin is categories as primary porosity aquifer (aquifer related to Quaternary alluvial and Lacustrine deposit) and double porosity aquifer (aquifer related to basaltic aquifer and which is again subdivide into upper and lower basaltic aquifer separated by less permeable along fractured and weathered zone). The alluvial and lacustrine aquifer (primary porosity) aquifer are found dominantly in the southeast around Debrezeit and Modjo, and locally in the northwest part of the Becho plain and along the main perennial Awash river.

2.7 Weighted Overlay Analysis and Groundwater Potential Zone Map

To evaluate different groundwater potential and recharge zones, essential factor influence groundwater movement and storage were considered, and groundwater potential zone map is prepared based on the analysis of various thematic layers such as geology, geomorphology, land use/ land cover, lineaments, drainage pattern and soil. These maps were converted to raster data set and different weightage were assigned as per factor affect groundwater potential and recharge capacity of the area and reclassification of each individual thematic map was done based on the weighted values produced by pairwise comparison matrix technique (Rahul V. Chaudhar et al., 2018). These weight were applied in groundwater potential and recharge index equation to obtain the final map of groundwater potential and recharge map.

$$GWPZ = \sum_{n=1}^{N} w_n . r_n \quad (3)$$

Where, GWPZ = groundwater potential Zone, w_n = map weightage (% influence) and r_n = rank of individual (subclass) theme.

Groundwater potential and recharge index equation is the linear summation of criteria weighted of the thematic map and the individual weightage obtain after reclassification of each thematic map. All the thematic map factor influence groundwater potential and recharge integrated through weighted overlay analysis in ArcGIS software to identify groundwater potential and recharge zone prospect. By integration of all the thematic map, groundwater potential and recharge zone were delineated and classified as: very high potential, high potential, moderate potential, low potential and very low potential.

2.8 Validation of Groundwater Potential Map

Many researcher (Gumma and Pavelic, 2012; Fashae *et al*., 2014; Abdul-Aziz *et al.*, 2017; Shamuyarira, 2017; Bane, 2017; Das *et al*., 2018) was validated GIS and remote sensing based groundwater potential map with existing parameter by existing point source inventory data such as existing surface water source(swamp area), spring data, dug well, bore well, tube well, etc. According to Tesfaye (2015), groundwater potential map produced using existing water sources data and actual well yield data which reflects the actual groundwater potential and water flow dynamics verified the groundwater potential map generated by GIS analysis to ascertain the validity of the map developed. The point source inventory data coordinate were overlaid on the groundwater potential zone in GIS software and the groundwater potential zone was so validated when point source was exactly match and coincide with the classified zone.

2.9. Groundwater Flow

Groundwater does not usually remain stationary, but moves or flow underground according to natural slope (topography), geological formation and external pressure due to pumping well/well drilling. Measuring the elevation of groundwater at different location and map the contour line (connect the point of equal elevation) as equipotential line on the area is the most direct method of determining the direction of groundwater movement. Groundwater moves along a flow path perpendicular to equipotential line, and direction of movement is from higher elevation line to lower elevation and drain into stream, lake, sea, ponds and boreholes (Oborie and Nwankwoala, 2017).

Mulugeta (2007) had conducted groundwater circulation and hydrochemistry of the corridor at upper Gidabo River and Lake Hawassa, Sidama zone, Ethiopia. Groundwater flow system evaluated by identifying source of contamination (chemical difference between high and low elevation) by examining hydrochemical parameter data like the distribution of total dissolved state (TDS). According to this method (chemical tracing method) higher elevation area have low TDS values whereas low elevation have high TDS values. The orientation of faults are also one of the possible method to determine groundwater flow direction, because groundwater always flow along fault oriented or aligned.

2.10 Conceptual Framework of GW Potential and Recharge Zone Mapping

Conceptual framework is summarized how all reviewed literatures under this chapter is contextualized to the current study in order to formulate simplified view (framework) for identifying and mapping potential groundwater and recharge zone. In order to prepare groundwater potential and recharge zone map some necessarily important data needed to be identified that are relevant to a particular study area. To map groundwater potential and recharge zone satellite data, conventionally existing data, hydrological data and meteorological data are obtained from different sources to develop potential groundwater and recharge zone map of the current study. Hence, it is necessary to understand the methods and way to approach towards groundwater potential zones identification and mapping.

From the analysis of related literature above, this study summarizes groundwater potential and recharge zone mapping using GIS and RS techniques by identifying factor influence the occurrence of groundwater and recharge. It can be established from many of the studies which attempted to identify groundwater potential zones that affect the occurrence and movement of groundwater are slope, drainage density, land use/cover, soil type, lithology, geomorphology, lineament density and rainfall. So depending upon the suitability and the type of region of study, the main parameters or any relevant parameters have been chosen and weighed by AHP to generate Groundwater Potential and Recharge Zones.

Establishing relationship between GIS processing, RS data and hydrologic phenomenon maximizes the efficiency of identification of potential zones for water resources development. For the same, all those are used to develop a composite map showing different classes of ground water potentialities, the layers have to be integrated in the GIS environment by giving different weightages to the respective layers in terms of their influence on ground water, this method is called Weighted Index Overlay Analysis method. However, the weights of different parameters/ themes/ layers can be given arbitrarily by the user on the basis of his personal judgment. Here, the role of decision maker is critical. Hence, by using AHP, multiple criteria can be evaluated, compared with each other, priorities can be set and their weights can be accorded on a rational quantitative basis, thus aiding the decision maker in making rational decisions. The map generated from weighted overlay in GIS environment with AHP method helps very well in predicting the groundwater potential surface and also predicts suitable zones for setting up ground water recharge facilities.

Overall summarized conceptual framework of all reviewed literatures under this chapter is contextualized to the current study (to formulate simplified view (framework) for identifying and mapping groundwater and recharge zone) was shown on Figure 1 below.

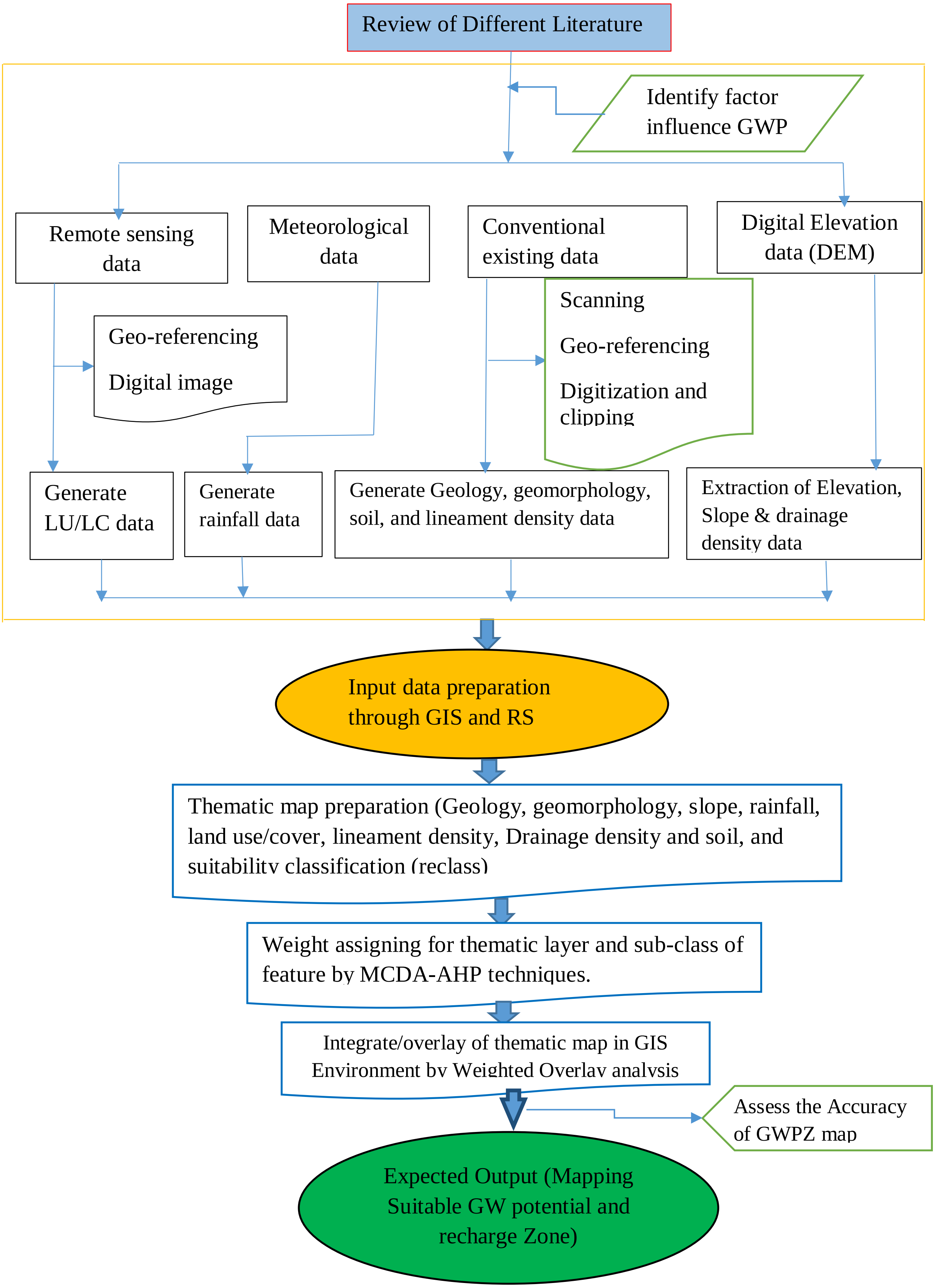


Figure 1: Conceptual framework of potential groundwater and recharge mapping

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location and accessibility

The Melka Kunture Watershed is located in the Ethiopian highland plateau, which is a part of both South West and Western Shewa Zone in Oromia Regional State (Figure 2). The watershed is located in Upper Awash River Basin, which is 50km far from the South of Addis Ababa. The Wereda and their major town in the area are including Welemera Wereda (Holeta), Dendi Wereda (Ginchi), Ejere Wereda (Addis Alem), Alem Gena Wereda (Sebata, Tefki, Boneya), Becho Wereda (Debre Genet, Tulu bolo) and Tolle Wereda (Bantu liben). The watershed is cover a total surface area of 4456 km^2, which is bounded by 08˚06'30" N to 09˚28'45" N latitude and 37˚37'34" E to 38˚40' 10" E longitude geographically and located in elevation ranging from 1950 to 3600m above sea level (m.a.s.l) (Figure 2 and Figure 3). Hint: The watershed boundary of the study area is the domain surface water hydrology not the domain of groundwater hydrology.

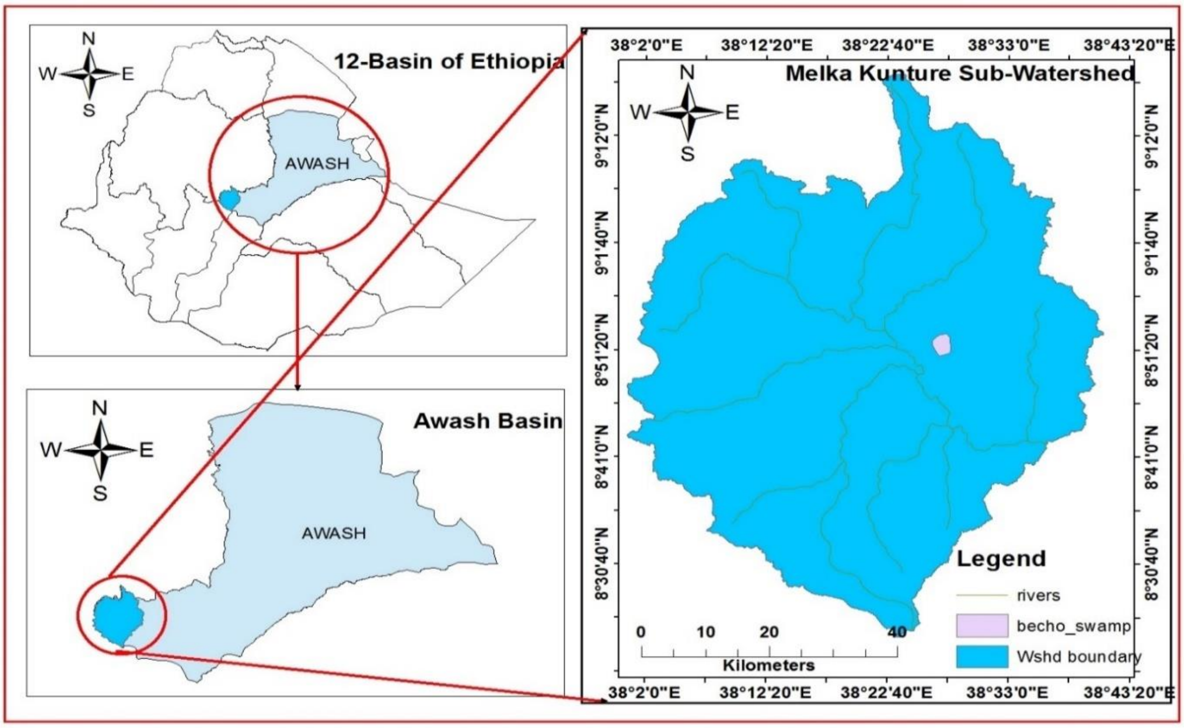


Figure 2: The study map of Melka Kunture Watershed

3.1.2 Geology setting

Ethiopia can be divided into four major physiographic region, widely known as the western, plateau, southeastern plateau, main rift and afar depression. The Upper Awash River Basin is enclosed within the north-central plateau and adjoining escarpment and rift valley. The regional geology of Upper Awash River Basin is underlain by a wide range of high grade metamorphic rock and situated to different rock categories that have different age of formation. From this Mesozoic Sedimentary successions, Tertiary and Quaternary age group of acidic, basic volcanic rock, Quaternary Lacustrine and Alluvial deposits composes the regional geologic formation of the study area.

Melka Kunture Watershed is included the uppermost part of Awash Basin, which is composed from same geological formation of Upper Awash Basin. According to geological Survey of Ethiopia studied by (OWWDSE, 2017) the major geology formation found in this study area are includes Addis Ababa Ignimbrite(Nadl), Central volcanic of Wechecha, Fur, and Yerer(NcvTy), Tarmaber Basalt(PNtbB), Weliso Ambo basalt(QwaB), Entoto becho-rhyolite(NebRy), Akaki basalt(NakB) and alluvial deposits(Qal). The main Ethiopia Rift (MER) is desired typically by a fault arrangement (sequence) trending in the direction of a NE-SW fault system and N-S to N-E trending system. The structural setting of Upper Awash Basin is located at the intersection of two important structure NNE-SSW trending MER and the E-W trending Ababa-Nekemte volcanic lineament which is in the direction of NE-SW, E-W and NW-SE are subjected to large area faulting system.

3.1.3 Physiography and climate

Based on physical and socioeconomic factor the Awash Basin has been traditionally divided into Upland (all lands above 1500m), Upper valley and Middle (area b/n 1500m and 1000m), lower valley (area b/n1000m and 500m) and eastern catchment (closed sub-basin b/n 2500m and 1000m). Melka Kunture Watershed lies in Upland watershed because Upper Awash River Basin is a part of both Upland and Upper watershed.

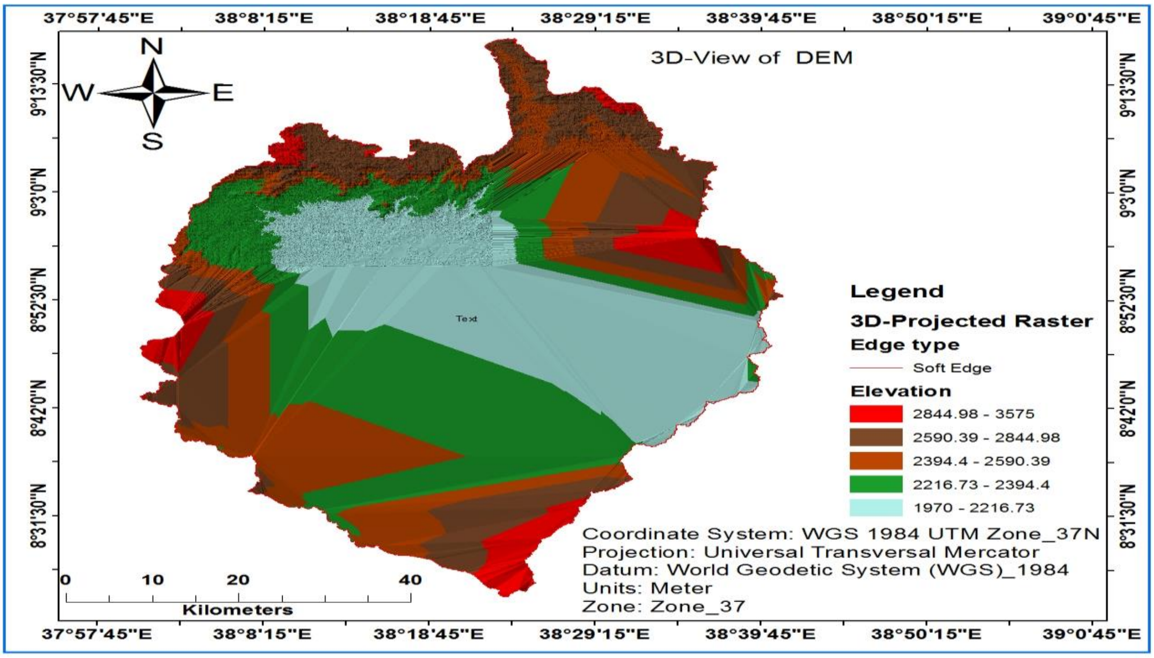


Figure 3: Physiographic map of the study Area produced from DEM in 3D-View

The Climate of the study area is characterized by long-term statistics of the weather (meteorological) elements (e.i rainfall, temperature (Tmax/Tmin), relative humidity, wind speed and sunshine).

3.1.3.1 Rainfall characteristic of the study area

Rainfall is the greatest extent widely measured meteorological element in Upper Awash River Basin as well in Melka Kunture Watershed. There are around 156 rainfall gauging stations in the whole Awash Basin. Among these total gauging stations, around 50 metrological stations were available in the Upper Awash River Basin to represent the areal rainfall distribution (Kiesel, 2006; Abel, 2017). From these 50 meteorological stations of Upper Awash Sub Basin, 10 meteorological stations were available in/around the Melka Kunture Watershed (Table 3) and the detail were described in Table in Appendix 1.

The mean annual precipitation of the area calculated using arithmetic mean method from monthly long-term rainfall record of ten stations (2002-2018), namely Tulu Bolo, Asgori, Tefki, Boneya, Ginchi, Sebeta, Teji, Welenkomi, Bantu Liben and Holeta obtained from National Meteorology Agency of Ethiopia (NMAE) amounts to 961.27mm (Figure in Appendix 1).

Table 3: Selected meteorological station in study area from 2002-2018 years

10-Wise meteorological Gauging Station					
S.No	Gauge Station Name	Elevation a.s.l (m)	Longitude E (Decimal-Degree)	Latitude N (Decimal-Degree)	Mean Annual RF(mm)
1	Tulu Bolo	2190	38.21	8.65	1087.44
2	Asgori	2072	38.33	8.79	971.45
3	Tefki	2063	38.49	8.84	945.87
4	Boneya	2251	38.64	8.78	834.22
5	Ginchi	2132	38.13	9.02	1115.82
6	Sebeta	2240	38.63	8.93	959.91
7	Teji	2091	38.37	8.83	941.84
8	Welenkomi	2165	38.25	9.00	946.27
9	Bantu Liben	1991	38.12	8.97	707.43
10	Holeta	2380	442854	100254	1102.4
	Mean annual precipitation				961.27

Source: NMAE, 2019

As displayed in rainfall bar graph in Appendix 2 the maximum and minimum mean annual precipitation is recorded (for 17 years) in the station of Ginchi and Bantu Liben respectively. Therefore, on an average, the peak rainfall occurring across the watershed from June to September which contribute heavy runoff (surface flow) during this month (Figure 4).

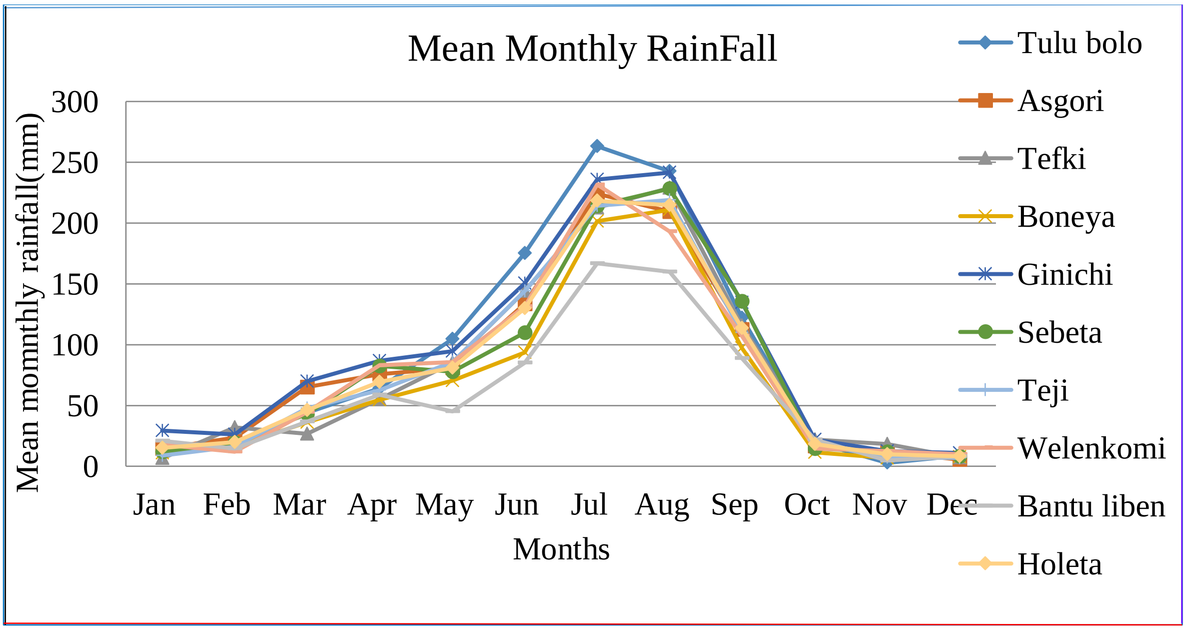


Figure 4: Seasonal and spatial mean rainfall (mm/month/year) distribution in study area (2002-2018) (Source: NMAE, 2019)

3.1.3.2 Temperature Characteristic of the study area

As described in Table in Appendix 2, the meteorological data of the study area shows that the monthly maximum temperature is between 21˚C and 27˚C, and the monthly minimum temperature is between 8˚C and 12˚C (Figure 5). The hottest temperature appear in Feb-May, which corresponds to the end of the dry season while coldest temperature appear in June-Sept, which corresponds to summer season. There are three main agro-climate zone found in Melka Kunture Watershed which is Wurch, Dega and Weyena Dega as described in detail Appendix Figure 2. Dega and Wurch climate zone are found in highland areas with 2500-3000m and greater than 3000m m.a.s.l attitude, respectively. Among these Agro-climate zone, the study area is mostly dominated by Weyena Dega which is found in the range of 1900-2500m m.a.s.l altitude with optimum temperature.

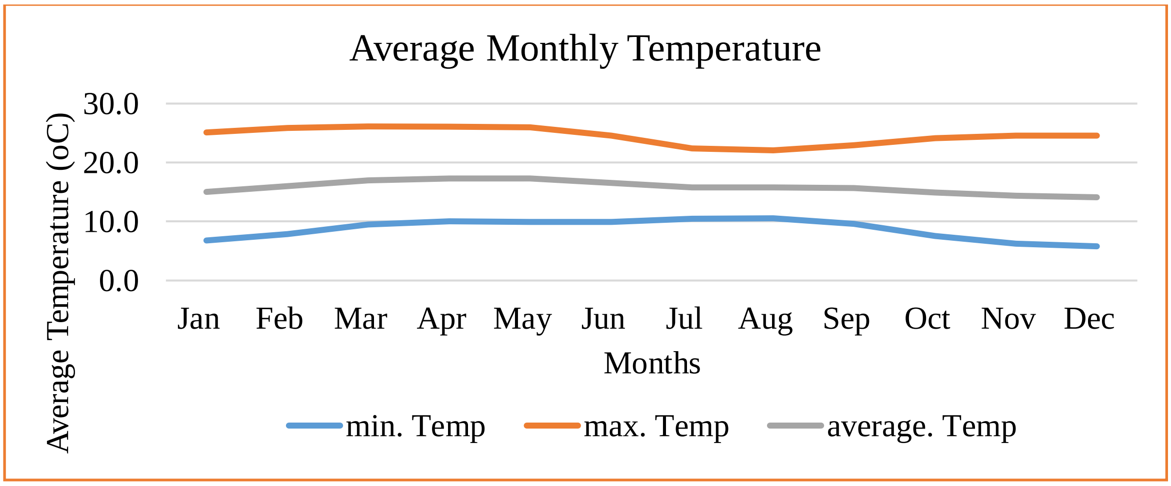


Figure 5: Mean monthly Temperature (°C) of the study area (Source: NMAE, 2019)

3.1.4 Surface hydrology in watershed

Awash River begins from the high altitude of 3000m in the western most region of the basin near Ginchi and flows west-east direction. Afterwards it destroyed into the Becho Plain which makes an alluvial plain with regular amount of altitude of 2,060m. Awash River and its streams flowing in to the larger river i.e. Awash River and its tributaries form dendritic drainage pattern and Awash River move steadily in a NW – SE general direction.

In the Awash basin there are about 76 river gauging stations, out of 21 stations are found in the Upper Awash sub-basin particularly in the upstream of Koka Dam (Mengistu, 2008).

From, 21 rivers gauging in the Upper Awash River Basin, 7 stations are found in Melka Kunture Watershed (Table 4). Among this river gauging station Bello, Melka Kunture, Melka Hombole, Mojo and Akaki stations have automatic water level recorder. Gauging station at the site of Awash Melka Kunture and Modjo are located in a very stable cross-section and hence have unique rating curve for the entire record (Sileshi Gobena, 2010).

Table 4: River Gauge Station and Sub-Catchment in the Melka Kunture Watershed

S.No	Station Name and Site	River length (km)	Catchment Slope (%)	Catchment Area (km2)	Latitude N (UTM)	Longitude E (UTM)
1	Awash @ Ginchi	58.36	24	76	997173	404697
2	Berga Nr. Addis Alem	13.488	17	249	996668	428556
3	Holeta Nr. Holeta	14.97	76	119	1004010	446886
4	Teji @ Asgori	24.14	61	663	970876	426678
5	Awash @ Belo	32.38	35	2568	978231	435855
6	Jemjem Nr.Wolenkomi	26.43	25	781	970264	428720
7	Awash @ Melka Kunture	57.35	30	4456	961622	455998

Source: MoWIE, 2018

The mean annual flow Characteristic and their distribution from 2000-2012 years in the main river gauging station are shown flow bar (Figure 6).

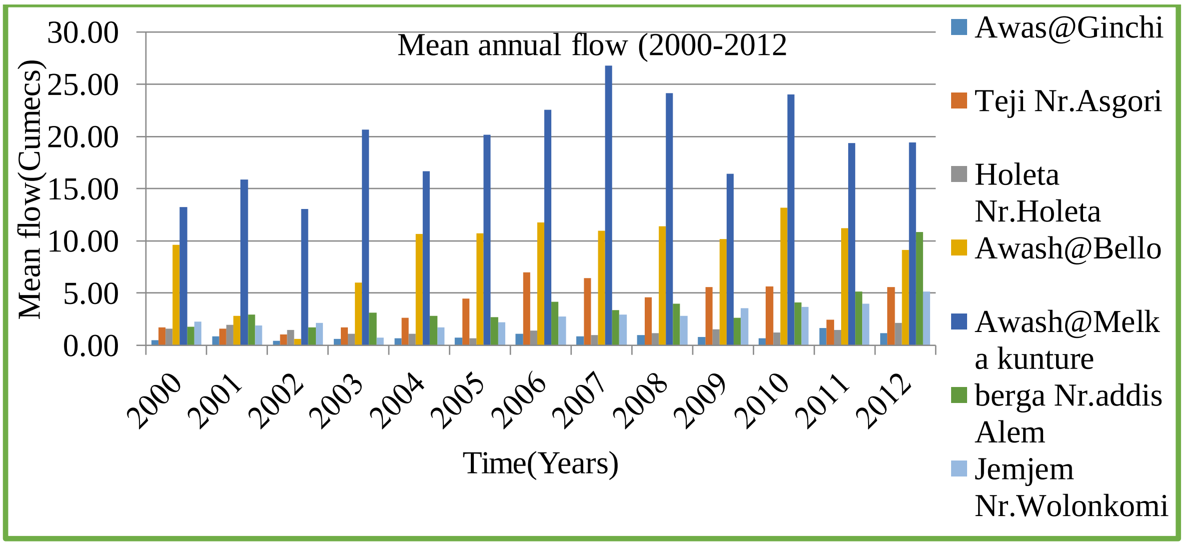


Figure 6: The Mean annual flow Characteristic in River Gauging Station in study area

(Data Source: MoWIE, 2018)

Melka Kunture Watershed at Awash River outlet is fed by many numbers of tributaries. The stream like Ginchi, Berga, Holeta, Teji, lemen, Bantu and Jemjem are the most significant tributaries of Awash River at the outlet of Melka Kunture Watershed. Most of these tributaries are Perennial River. The watershed covers a total land mass of 4456 km^2 of which contribute almost entire surface flow of the watershed. There is a good network of hydrological station for flow measurement in the area (Figure 7).

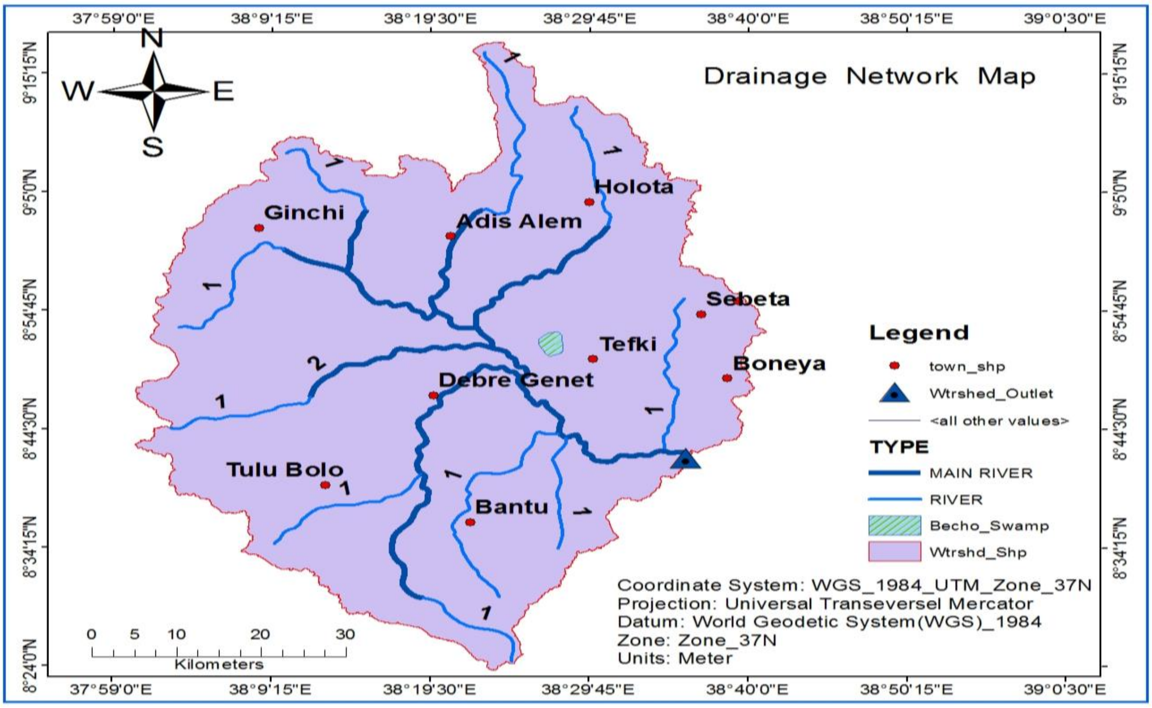


Figure 7: Drainage network in Melka Kunture Watershed

3.1.5 Land use/cover and soil type

The land use condition in the Upper Awash River Basin is mainly covered by cultivated agricultural land, grassland, and forestland, rural and urban settlement. Sileshi Gobena (2010) estimated that 67% is intensively cultivated, 25.5% is moderately cultivated, 4.5% is bush land/shrub land/wood grassland and 3% is urban areas and vegetation. Even though Melka Kunture watershed is one of sub-watershed in Upper Awash River Basin, land use is mainly dominated by cultivated agriculture and other diverse land use. The most common soil type in the area are clay, sand, loam, clay loam, sand clay loam and silt loam (OWWDSE, 2018).

3.1.6 Aquifer characteristic

Occurrence and distribution of groundwater is a function of the degree of porosity, hydraulic conductivity (permeability) and transmissivity of the geological formation and the amount of recharge to the geological formation. It is mainly controlled by the type of geology, degree of geological weathering or geological structures, and geomorphology of the area. The groundwater recharge and flows in the aquifer in Upper Awash River Basin most likely controlled by the geometry of the fault aquifer dipping direction of the underlying lithology, porosity and permeability of the fault lithology. The hydrogeological (aquifer class) in this study area are Alluvial aquifer (primary porosity aquifer), lower basalt aquifer, regional Aquiclude, localized Aquiclude and upper Awash aquifer (Yitbarek *et al*., 2012).

3.2 Materials Used

In order to achieve the objective of this study and to complete this research work the following materials were used:

Computer (Laptop) and Desktop: To Run all software and process the data inside because all work is started and completed in computer after appropriate data was collected by hardware and software.
Handheld GPS receiver (Garmin 78): In order to taking geographical coordinate (latitude, longitude, and altitude) and to check (verify) the accuracy of sample point such as water source inventory point and land use/cover in the study area.
Hardware and Software: Hardware like external hard disk (1 TB storage disk) and software like GIS (ArcGIS 10.4.1), ERDAS 13, SURFER 17 and PC Geomatica.
Published and Unpublished literature and Maps: Such Topographic map, geological map, etc. as a reference.

3.3 Data Description and Source

Different types of Primary and Secondary data on hydrological, geological and conventional exist were identified as parameter factor were collected and used for this study in the process of mapping and analysis. In order to map and process the analysis various software were also used. The types of data and software used in this study are mentioned and described in the Table 5 and 6.

Table 5: Types of data used and their source

Data used	Source	Purpose
Meteorological Data	National Meteorological Agency of Ethiopia	To create rainfall map
Conventional Soil map	Ministry of Water, Irrigation and Energy (MoWIE)	To create soil type and texture map
Satellite data	htt://earthexplorer.usgs.gov /or from EMA	To create land use/cove and extract lineament density map
Conventional Geological data	Ethiopia Geological Survey	To create lithological map
Digital-Elevation-Model (20×20m) resolution DEM)	Geospatial information Institute (former name: Ethiopia Mapping Agency)	To create drainage density, slope and geomorphological map
Ground truth (water source inventory) data	Upper Awash Basin Authority/Awash Basin Development Office	To validate the groundwater potential zone of the study area
Geomorphological data	Oromia Water Work Design and Supervision Enterprise (OWWDSE)	To create geomorphology mapping of the study area

Table 6: Types of software used and their purpose

No	Software Used	Purpose
1	ArcGIS 10.4.1	To create the thematic map of parameter affect groundwater occurrence and delineate the groundwater potential and recharge zone map of the study area
2	ERDAS 13	By layer stacking, mosaic and classifying land use land cover
3	PC Geomatica 17	For lineament features digitization/generation and mapping.
4	Surfer 17	For generation groundwater contour map and flow direction and also used for 3-D visualization of groundwater flow or the land surface.

3.4 Method of Data and Thematic Layers Preparation

Geospatial and multicriteria decision rule (knowledge-based factor analysis) techniques were applied to prepare overall data for identifying suitable areas and mapping groundwater potential and recharge zone of the study areas using integrated approach of GIS and RS techniques. The overall activities carried out for this research work include; data collection, data extraction and analysis, Prepare input thematic maps, resample and reclassify input thematic maps, pair wise comparison by AHP, weighted linear overlay analysis in ArcGIS tools, develop groundwater potential zone and recharge zone maps.

Therefore, all these activities were take place under the following steps (major steps in generating the map): (1) selection factors (2) assessment of the suitability levels of factors for GWP and recharge (3) assignment of weight to these criteria (4) collection and organize spatial data for factors through various source (5) development of GIS-based suitability map by integration of thematic layers (6) generation of suitable GW potential and recharge map.

Thematic map preparation

Thematic maps represent the layers/maps that indicate characteristics of different topographical feature, hydrological and geological of a given geographical location of the study area. The thematic maps were the input information (layer) for delineation of groundwater potential and recharge zones. Appropriate layers of factor influencing groundwater potential and recharge zone used for this study area were; slope, drainage density, geomorphology, lithology, lineament, land use/cover, soil and rainfall. It is considered as the main factor responsible for groundwater resource development. It were prepared from remote sensing data, DEM, meteorological data and conventionally exist map using ArcGIS 10.4.1 software in ArcMap. The specific procedures of thematic layers preparation of factor influence groundwater and recharge of was described as below.

Drainage density map was generated from drainage map by using line density in ArcGIS. Drainage map was first prepared from the DEM (digital elevation Model) of watershed boundary of study area by using spatial analysis tools (Hydrology tool) in ArcGIS. Stream to feature was generated from stream order and flow direction after generation of fill, flow direction, flow accumulation, flow accumulation adjusted by raster calculator in map algebra, stream link, stream order. This stream feature of study area is shows the drainage of study area (Figure 8). Then, drainage density of the study area is calculated by drainage line density tools in ArcMap by dividing total length of the stream channel in basins to total area of the given basin of the study.

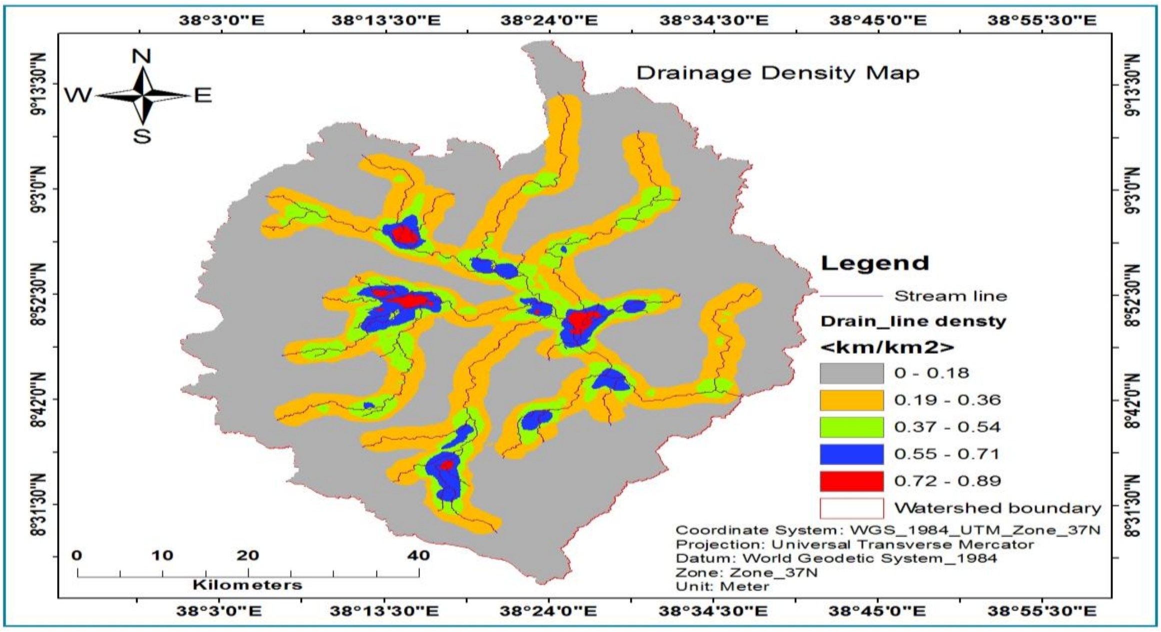


Figure 8: Drainage density map of Melka kunture sub-watershed

Geomorphology map was prepared from of land feature (geomorphology) of Upper Awash Basin taken from OWWDSE and clipped to the study area by shapefile of watershed by using clip option found in geoprocessing in ArcGIS (Figure 9). The clipped geomorphology map was in polygon format (vector format) which need to convert to raster. The clipped feature geomorphology map was converted to raster by using polygon to raster window by selecting from conversion tools. The raster geomorphology map was reclassified by using reclass command in spatial analysis tools.

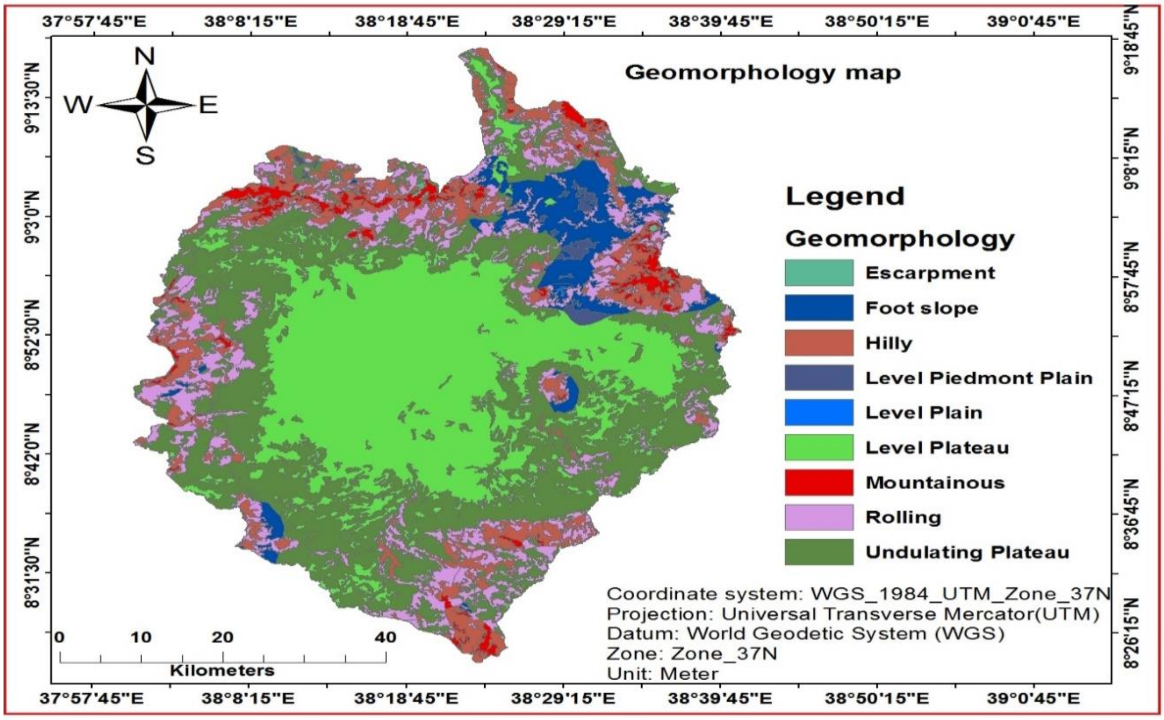


Figure 9: Geomorphology map of Melka kunture Watershed

Land use/cover of Melka Kunture watershed was generated from mosaic Landsat image (SPOT 5) obtained from Geospatial Information Institute (Former name Ethiopia Mapping agency (EMA)) acquired in 2016 through for supervised classifications. Land use land cover map (Figure 10) was prepared using satellite land image (SPOT 5) (Appendix Figure 2) converted from Raster data type landsat image (Table 7).

Table 7: Raster data type of Landsat image for LU/LC map preparation

No	Data type	Sensor type	Year of acquisition	Spatial resolution (m)	Spatial extent
1	Landsat Image	SPOT 5	2016	1.5 (high)	4456km^2

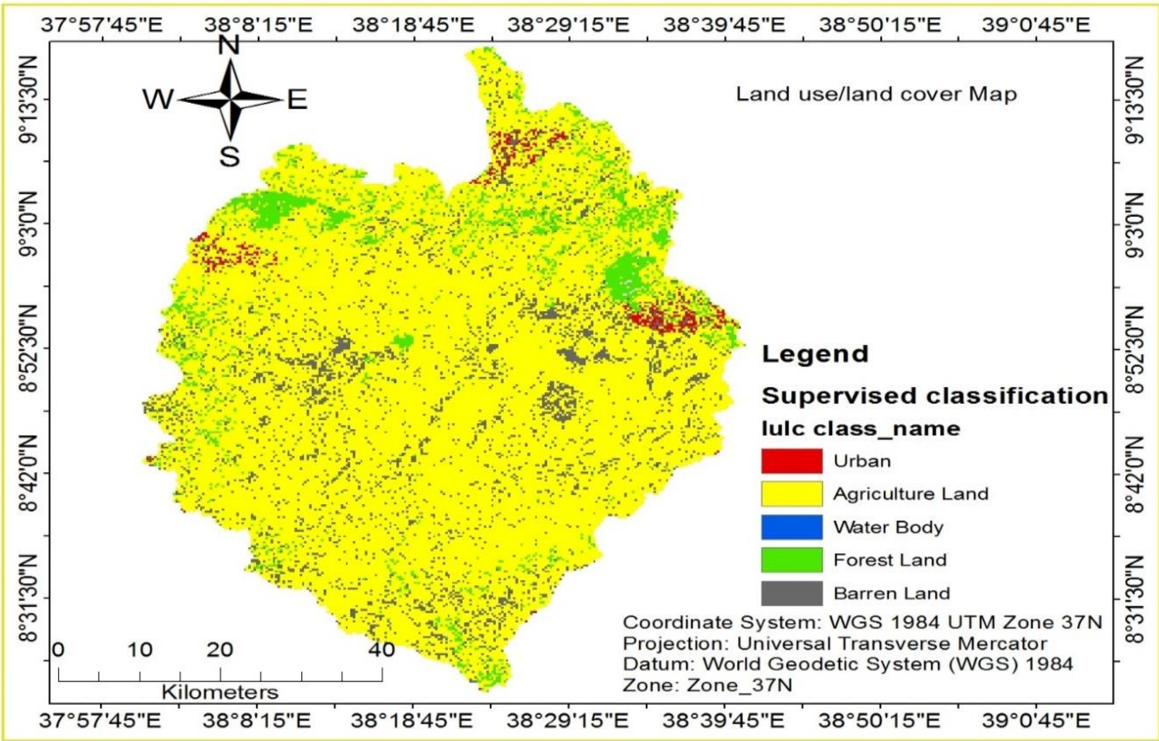


Figure 10: Land-use/land-cover map of the study area

Lineament map was generated from layer staked landsat image of study area. This was done by using PCI geomatica 2017 software. Since the generated lineament were compounds of lines, it was split to single line by using split command in ArcGIS. Then obtained lineament raster were known as lineament map (Figure 11). This splited lineament map were used for generation of lineament density. This lineament density was done by ArcGIS using line density in spatial analysis tools and then reclassified as suitable for delineation of groundwater potential and recharge zone using reclass command in ArcGIS.

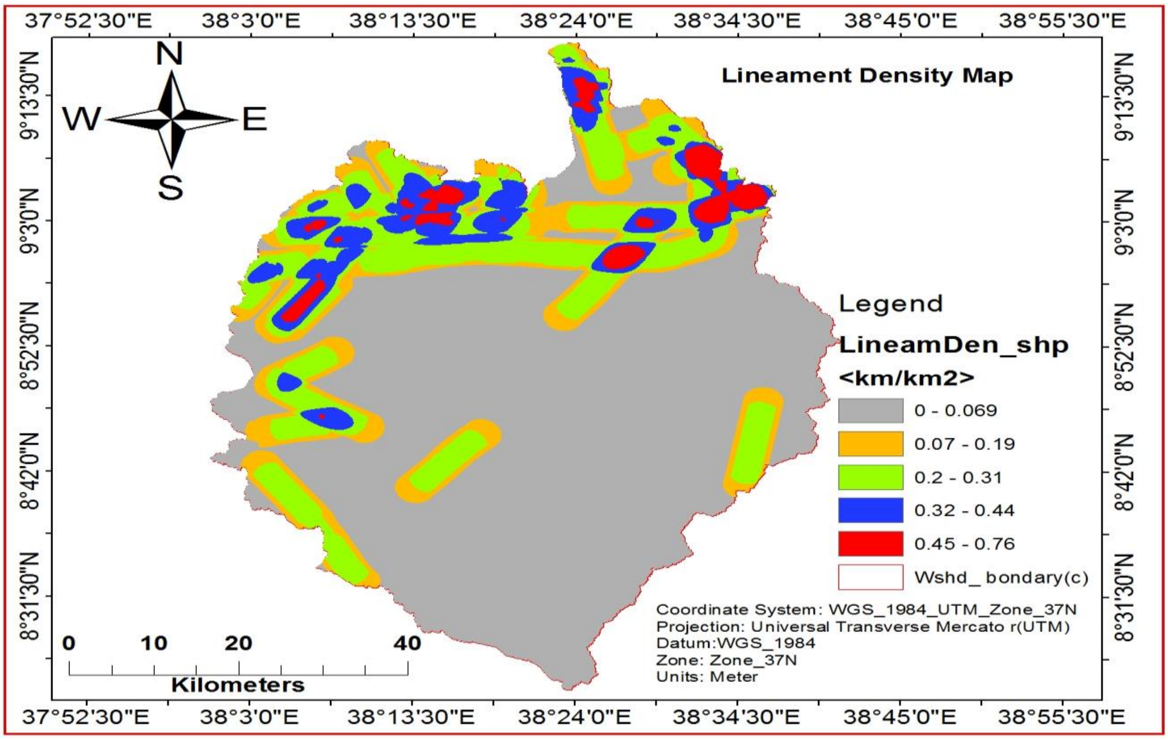


Figure 11: Lineament map of Melka Kunture watershed

Lithology map of the study was prepared by digitizing and clipped from the geological map of Awash Basin done by Oromia water Work design and supervision Enterprise taken from Geological Survey of Ethiopia by using clip option found in geoprocessing in polygon form and then converted to raster and reclassified as suitability to groundwater potential and recharge.

Since, the clipped lithology map was in polygon format, the clipped feature was converted to raster by using polygon to raster window by selecting from conversion tools. The raster lithology map was reclassified by using reclass command in spatial analysis tools in ArcGIS. The detail characteristics of each lithological unit found the study area and its effect on potential groundwater and recharge occurrences was discussed under Appendix Table 3. Among this lithological unit found in the study area, Addis Ababa Ignimbrite cover large portion of the study (49.4%) (Table 8), particularly dominate central part of the study area which overlaid by black cotton soil.

Table 8: Lithological/ Geological unit found in the study area

No	Lithology description	Litho_code	Area_km2	Area (%)
1	Tarmaber basalt: Leaticular basalts with a large amount of scoraceous lava flows.	PNtbB	759.78	17.50
2	Weliso Ambo basalt: Porphyritic basalt, breccia and tuff.	QwaB	343.62	7.92
3	Central volcanic of Wechecha, Furi, Yerer: Porphyritic trachytic lavas.	NcvTy	825.28	19.01
4	Addis Ababa Ignimbrite: welded Tuff deposits and poorly welded pyroclastic.	NadI	2143.24	49.37
5	Entoto becho rhyolite: Obsidian reach rhyolites.	NebRy	193.77	4.46
6	Akaki basalt: Scoria and spatter cones with associated basaltic lava flows.	NakB	49.55	1.14
7	Alluvial deposits: Alluvial bars and swap areas surrounded by volcanic.	Qal	25.78	0.59

Lithological map of the study (Figure 12) was prepared from seven major rocks unit identified in the study area as seen on Table 8 and the detail were described under Appendix Table 3.

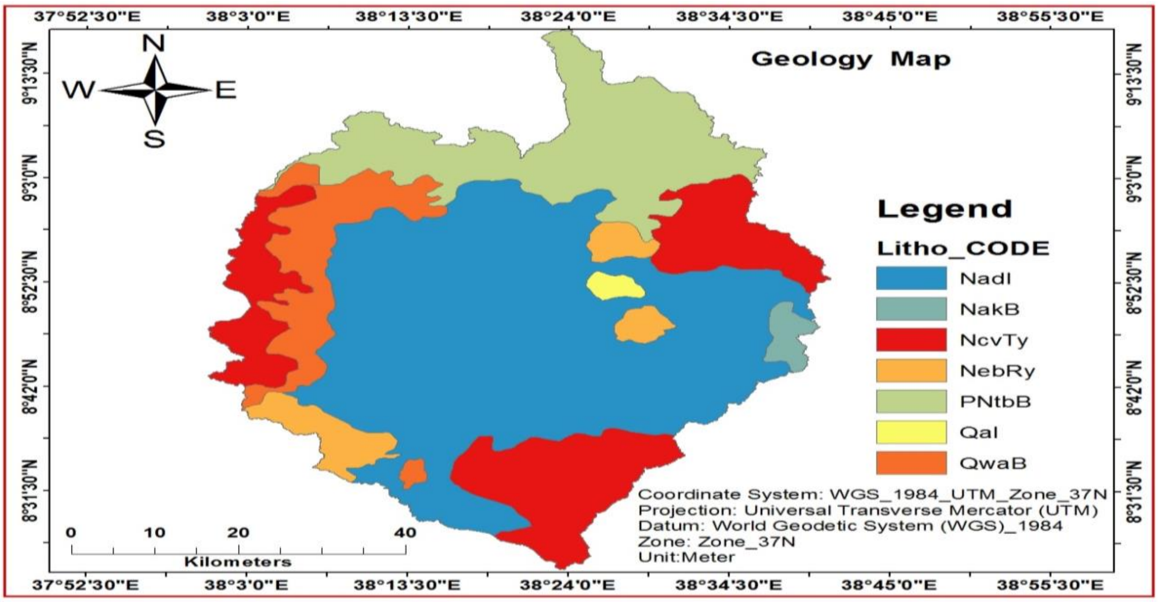


Figure 12: Lithological map of the study area (modified from OWWDSE, 2018)

Rainfall maps were generated from precipitation data taken from NMAE. The average rainfall distribution of the study area was prepared by an 'Inverse Distance Weighting

(IDW)' method using mean annual rainfall (Table 9) and finally appropriated value was selected for analysis (Figure 13). Before analysis, missed rainfall data were filled by using simple arithmetic method. Since the precipitation data were consistent, areal rainfall distribution overall study area were analysed using mean arithmetic method because the rain gauge stations used for this research were approximately near to each other and similar topography.

Table 9: Mean annual rainfall (mm) of the gauge station found in the study area

S.No	Gauge station Name	Elevation a.s.l (m)	Longitude E (DD)	Latitude N (DD)	Mean Annual RF (mm)
1	Tulu Bolo	2190	38.21	8.65	1087.44
2	Asgori	2072	38.33	8.79	971.45
3	Tefki	2063	38.49	8.84	945.87
4	Boneya	2251	38.64	8.78	834.22
5	Ginchi	2132	38.13	9.02	1115.82
6	Sebeta	2240	38.63	8.93	959.91
7	Teji	2091	38.37	8.83	941.84
8	Welenkomi	2165	38.25	9.00	946.27
9	Bantu Liben	1991	38.12	8.97	707.43
10	Holeta	2380	39.89	9.03	943.26

The rainfall map of the study area was mapped as shown on Figure 13 using this mean annual rainfall (mm) found in the area.

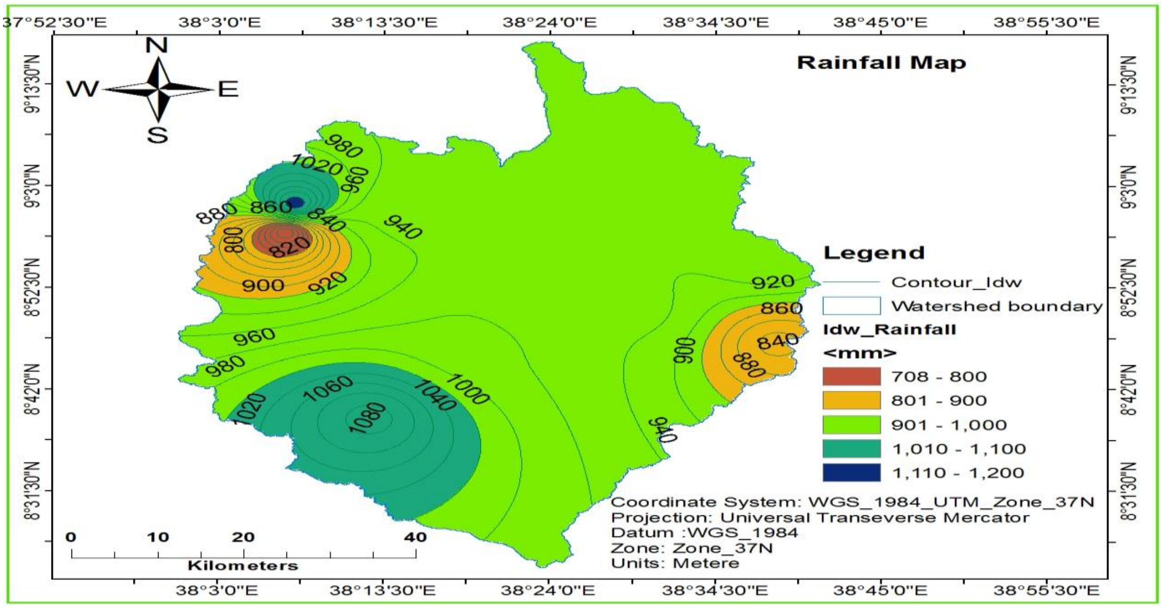


Figure 13: IDW (Isohyetal) Rainfall map of Melka Kunture Watershed

Slope map of study area was generated from DEM which was taken from Geospatial Information Institute (Former name of Ethiopia Mapping Agency). This was done by using spatial analysis tools in ArcGIS. Then the generated slope map was then reclassified using reclass command in ArcGIS (Figure 14).

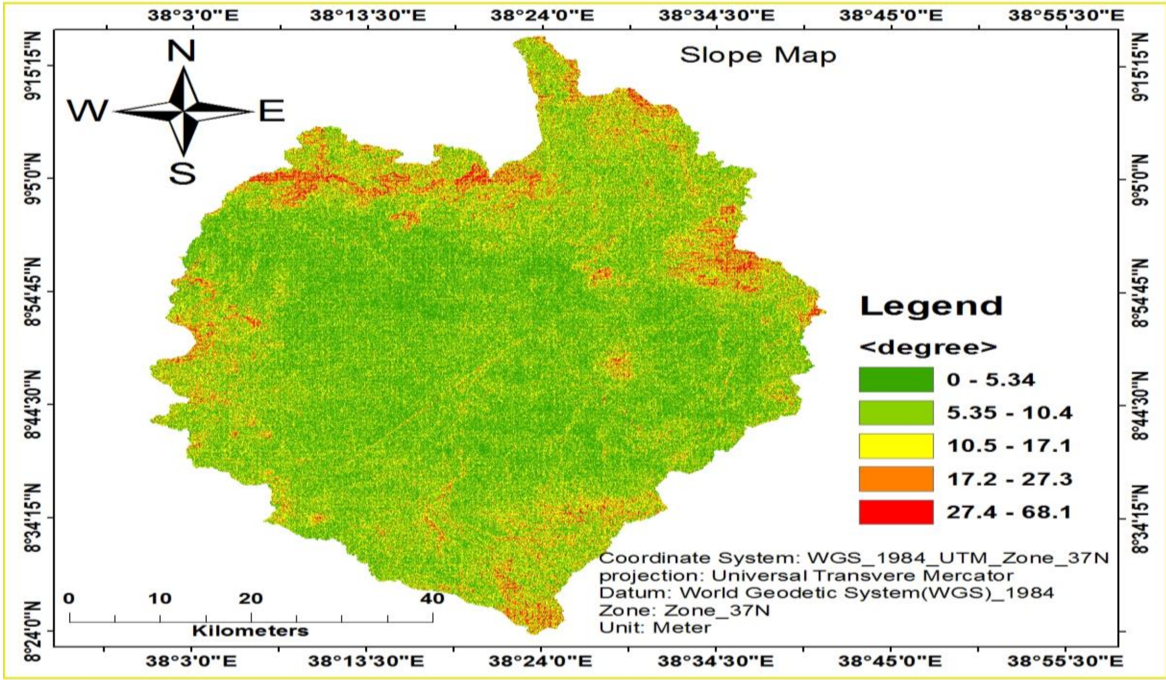


Figure 14: Slope map of Melka kunture Sub-Watershed

Soil map was clipped from soil map Upper Awash River Basin taken from Ministry of Water, Irrigation and Energy. It was polygon (vector) format and clipped to the study area and then converted to raster format to get the final layer of soil.

The study area is composed of five soil types (Figure 15): chromic cambisols, pellic verisols, chromic luvisols, chromic vertisols, eutric nitisols, haplic nitisols, leptic nitisols, umbric leptosols, leptic cambisols, vertic cambisols, and there is a land which have no soil (rocky surface). As indicated on Figure 15 major portion of the study area is composed clay and vertisols soil with black cotton soil which cover 63.1% of the total study area (Table 10). This types of soil consists of expanding clay minerals with very low water transmitting capacity. The detail characteristics of each soil types found the study area and its effect on potential groundwater and recharge occurrences was discussed under Appendix Table 4

Table 10: Soil types and texture of the study area

S.No	Major soil Type	Soil texture	%	Area (km^2)	Area (%)
1	Vertisols	Clay	95	2729.93	63.09
		Clay loam	5		
2	Luvisols	Clay	67.67	739.92	17.1
		Clay loam	5.26		
		Silt Loam	27.07		
3	Leptosols	Loam	100	368.64	8.62
4	Cambisols	Clay	2.7	243.15	5.62
		Clay loam	13.8		
		Sand clay Loam	83.6		
5	Nitisols	Clay	98	240.66	5.56
		Loam	2		
6	Escarpment land	Rocky surface	-	4.64	0.11

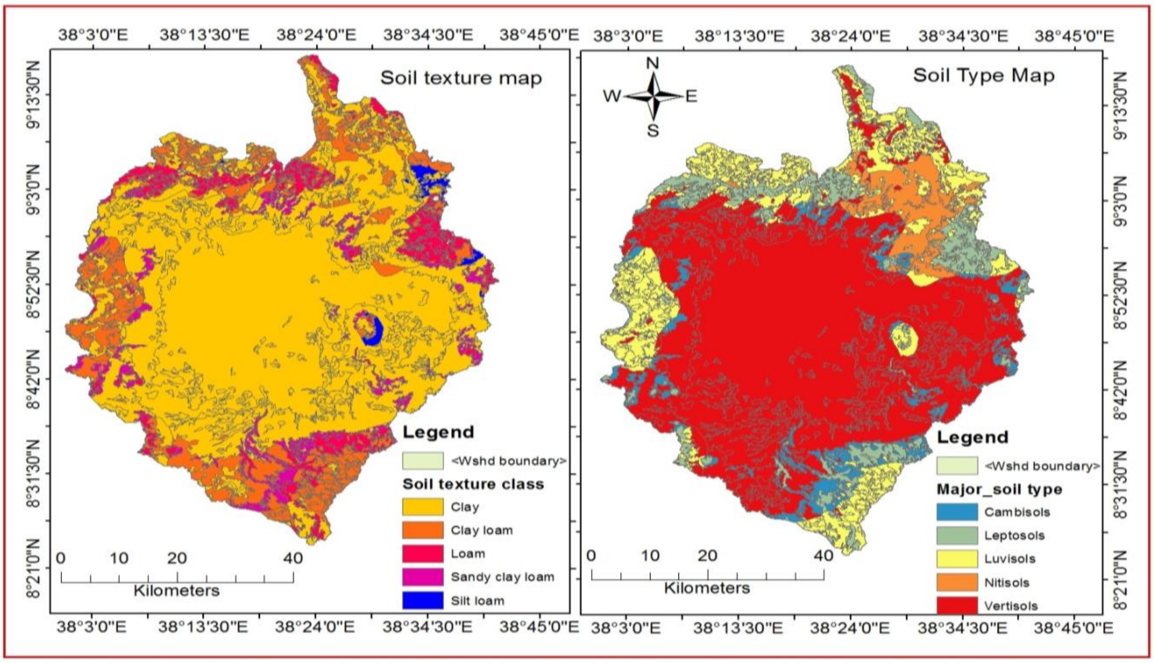


Figure 15: Soil map of Melka Kunture Sub-watershed

After the thematic maps of all factors was prepared, each thematic layers based on their relative influence on the groundwater potential of the study area were weighted, normalized and ranked using AHP by pair-wise comparison matrix. Finally all these prepared thematic layers were integrated using weighted overlay tool in ArcGIS 10.4.1 to generate the groundwater potential and recharge zone map of the study area. The general systematic methodology of the study was illustrated in methodological flow chart shown on Figure 17.

3.5. Method of Data Analysis

Factor influencing the occurrence, distribution and movement of groundwater potential and recharge were identified from different previous literature and combine together by setting selection criteria. Those factor have significant role in identification of groundwater potential and recharge zone.

3.5.1 Theoretical selection of factors

The identification criteria is useful for indicating the main governing and the degree to which suitable to map groundwater potential and recharge zone of the study. This factor were so selected based on past studies or literature review of different scholars and their review were combined by setting criteria of Selection based on: 1) Frequency of usage 2) Criticalness of the factor 3) Ease of data access, which is summarized as matrix form as shown Table 8.

Table 11: Selection criteria matrices for factor influence GW potential and recharge

Factor (F)	Criteria (C)				
	C1	C2	C3	Score	Rank
F1	W_{11}	W_{12}	W_{13}		
F2	.	.	.		
F3	.	.	.		
.	.	.	.		
F8	W_{81}	W_{82}	W_{83}		

Where, C-Criteria, F= factor affecting GWP and Recharge and C1= Frequency of Usage, C2= Criticalness of the Factor, C3= Ease/difficult of data access and W11= weight of factor one by criteria one.

3.5.2 Analytic hierarchy process (AHP) techniques

The analytic hierarchy process (AHP) is a comprehensive, logical and structured mathematical framework, which allows improving the understanding of complex decisions to organize and analyze by decomposing the problem in a hierarchical structure. It is based on the construction of a pairwise comparison matrix, which is assembled for each thematic map using a scale of importance of nine points or 9-point rating scale. Once the matrix is resolved, each weight is assigned to the values or ranges of each thematic map, thus establishing a hierarchy order for those parameters that define the occurrence of groundwater (Figure 16)

The decision hierarchy structure of groundwater potential and recharge consist of the main objective at top, followed by four level of hierarchy. The eight factors affect the occurrence of groundwater and recharge potential used in this research were divided into two major group: Environmental factor and hydrological factor. These two factor again sub-divided into different factors. The examined factors were selected based theoretical selection criteria set on the relevant literature for specific major study area problem. In complete hierarchy, every layer in the lower hierarchical level affect every element in the upper hierarchical level. Therefore, the element in the lower hierarchical level were then compared to each other based on their effect on the major influential layer above.

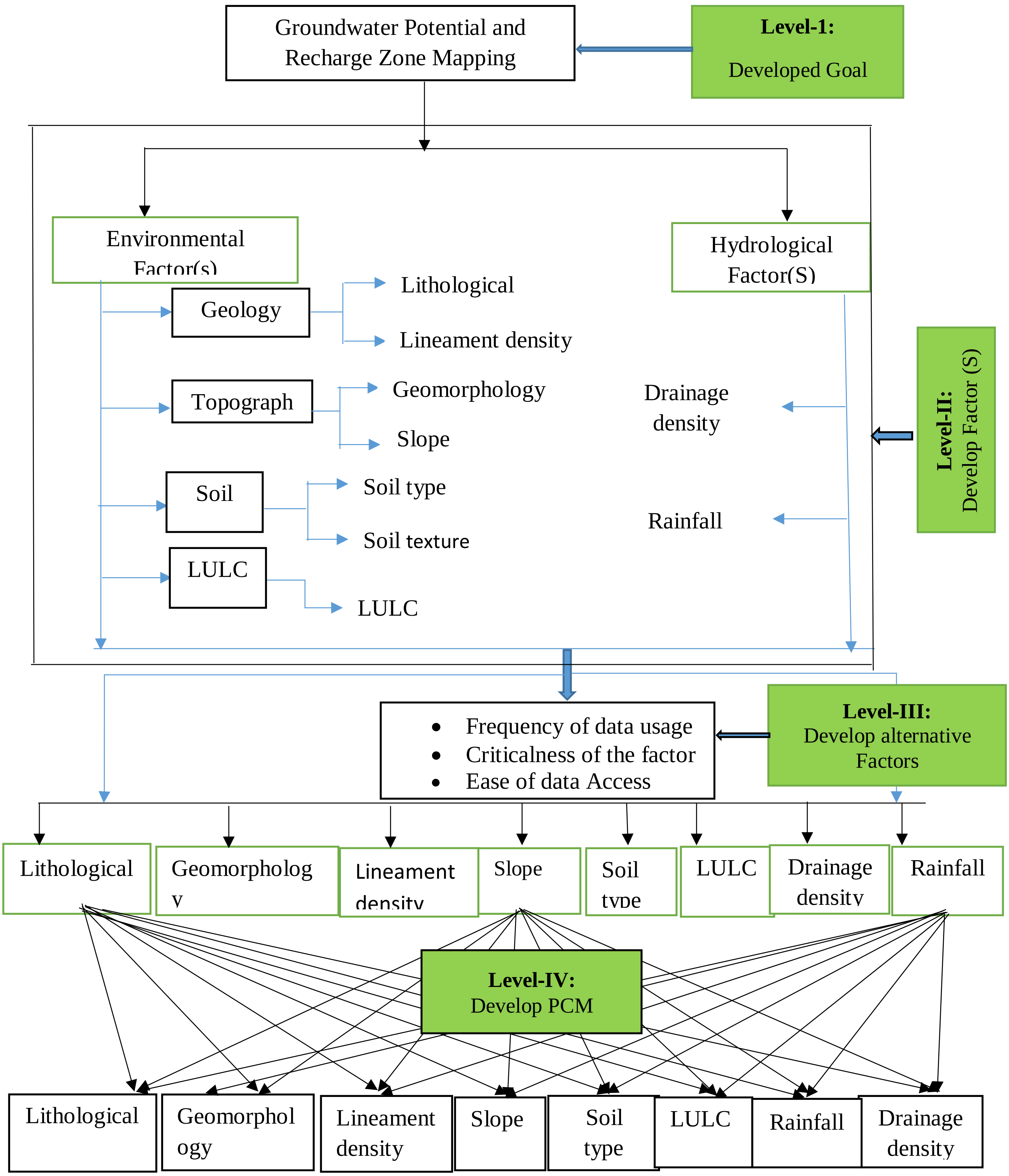


Figure 16: Hierarchical structure of analytic hierarchy process (AHP) techniques

Different thematic map of factor were assigned based on knowledge-based AHP to weight and ranking depending on its significance or interaction to groundwater storage and recharge. The Weightages of each factor were assigned according to Saaty's scale (1–9) of relative importance value give in Table 12. Saaty's scale, 1-9 numbers indicate how many times one factor more important than other factors.

Table 12: Scale of relative importance (9-poin rating scale) (Saaty's, 1980)

Level of Importance and Its Value								
Less Importance ←				Equal Importance			→ More Importance	
Extremely	Very Strong	Strong	Moderate	Equal	Moderate	Strong	Very Strong	Extremely
1/9	1/7	1/5	1/3	1	3	5	7	9

Note: 2, 4, 6 and 8 - are intermediate values denoting compromise.

: Reciprocal no (1/9, 1/7, 1/5 and 1/3) - indicate Values for inverse comparison.

The main steps to decision based on PCMs in the AHP approach are: 1) the determination of the important criteria in the problem 2) the assessment of the relative importance of each criteria to each other (criteria weight and Normalized weight) the assessment of the consistency through PCMs to assign CR. The PCMs constructed by taking relative importance for each elements as shown below (Table 13).

Table 13: Pair-wise comparison Matrix

Factor (F)	F1	F2	F3	…	Fn
F1	a11	a12	a13		a1n
F2	a21	a22	a23		a21
F3	a31	a32	a33		a3n
..	..	..	..		..
Fn	an1	an2	an3		ann

Where, F = factor influence GWP and recharge and aij = relative importance weight value given for each elements by pair-wise comparison. The above PCMs was normalized, by divided each number in the column by the sum of each column (Equation 4).

$$\bar{a}_{ij} = \frac{aij}{\sum_{i=1}^{N} aij} \ldots\ldots (4)$$

Where, ā is the value of matrix, m is column number, j is the row number and i is theme N is the total number of theme. Thematic (criteria) weight (Wj) is calculated from normalized values according to (Equation). The normalized weight were then ranked in descending order.

$$W_j = \frac{\bar{a}ij}{N} \ldots\ldots (5)$$

Since, thematic weight was used to calculate groundwater potential index (GWPI), it is important to check the consistency of pairwise comparison. Consistency check was done by following Saaty (1980) procedure, where

$$\text{Consistency Ratio} = \frac{\text{Consistency Index(CI)}}{\text{Random Index(RI)}} \ldots\ldots (6)$$

$$\text{Consistency Index (CI)} = \frac{\lambda\text{max} - \text{N}}{\text{N} - 1} \ldots\ldots (7)$$

$$\lambda\text{max} = \frac{1}{\text{N}} \left(\sum_{\text{i}=1}^{\text{N}} \frac{\text{aij.Wj}}{\text{Wj}}\right) \ldots\ldots (8)$$

Where, λmax = Principal Eigen Value (which measure the degree of consistency)

RI = Random Index (RI) – is the consistency index of a randomly generated PCMs (Saaty, 1980). RI depend on the number of the factor being compared as shown (Table 14).

Table 14: Random Index value for N ≤ 10

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.88	0.90	1.12	1.24	1.32	1.41	1.45	1.49

(Source: Saaty, 1980)

According to Saaty's, for a good decision there must be CR ≤ 0.1. Here CR shows that the assigning weight for each factor were consistency and the relative weight were appropriate and acceptable for decision making. However, if CR > 0.1 there is an indicator of error when assigning ranks to the criteria/factors. Due to this, it should reevaluate the assigning relative importance of the factors or the assessment of CR should be revised the pairwise weight.

3.5.3 Estimation of missing data

After significant factors influence groundwater potential and recharge would identified, the missed data of the factor (particularly rainfall data) were filled by using simple arithmetic average method and the representative value of areal rainfall depth for the area under consideration could be analyzed by using arithmetic mean and isohyetal method, and the detail of analysis for each method was described in section 3.6 below.

3.6 Data Analysis

Data analysis was cover all procedure for identification of relevant evaluation criteria data sets through data collection, data preparation/organization, data pre-processing and editing, analysis, data validation, data integration, attribute table design and entry, standardizing suitability classification, weightage theme and overlay techniques.

3.6.1 Filling of missing rainfall data

The missing rainfall data of stations that occur at certain rain gauge station for a certain day/period may missed due to absence of observer or instrumental error was estimated using the data of neighboring stations. For this study areas, simple arithmetic average method was used for filling of missing rainfall data because the average annual rainfall of the station differ within 10% of the average annual rainfall of station X using equation 9:

$$P_X = \frac{P1+P2+\cdots+Pn}{n} = \frac{\sum_{i=1}^{n} P}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(9)}$$

Where, P_X: missed rainfall data at station X; P1, P_2, and P_n rainfall at station 1, 2, and n; n: total number of rainfall station.

3.6.2 Determination of areal depth of rainfall

In water budget studies, it is necessary to know the uniformity of average rainfall depth that occur over certain duration at a given catchment in study watershed areas. The rainfall gauges measure the point data at each station in study area should be converted to the averaged aerial rainfall by using some interpolation method to prepare rainfall map. Because, rainfall measurement is a point observation and may not be used as a representative value for the area under consideration. Therefore, using different rainfall depth of different stations found in the study areas, the representative aerial depth of rain fall over the whole area is analyzed. Accordingly Arithmetic mean and isohyetal method was used to estimate aerial depth of rainfall in the catchment, considering the non-uniformity of the land and variation of topographic features of the area.

Arithmetic mean method

This method is the simplest and reliable to calculate the average rainfall over relatively flat topography, for uniformly distributed gauges, and closely and evenly spaced gauging station. It can be calculated using equation 10:

$$P_A = \frac{P1+P2+\cdots+PN}{N} = \frac{\sum_{i=1}^{n} Pi}{N} \ldots\ldots \quad (10)$$

Where, P_A: average rainfall depth of watershed, P_1, P_2 and P_N: mean annual rainfall at station 1, 2 and up to N-station, and N: total number of station in watershed. According to this method the average annual RF depth in the watershed is 961.27mm (Table 15).

Table 15: Average areal rainfall depth of the study area by arithmetic mean method

Gauge station Name	Elevation (m)	Longitude (DD)	Latitude (DD)	Mean annual RF (mm)
Tulu Bolo	2190	38.21	8.65	1087.44
Asgori	2072	38.33	8.79	971.45
Tefki	2063	38.49	8.84	945.87
Boneya	2251	38.64	8.78	834.22
Ginchi	2132	38.13	9.02	1115.82
Sebeta	2240	38.63	8.93	959.91
Teji	2091	38.37	8.83	941.84
Welenkomi	2165	38.25	9	946.27
Bantu Liben	1991	38.12	8.97	707.43
Holeta	2380	442854	100254	1102.4
Average annual rainfall				961.27

Isohyetal method

This method is selected because of the non-uniformity of land and variation of topographic feature of the watershed in study area. This method is analyzed by joining rainfall depth of equal value of precipitation over the area of interest. The area between successive isohyets were calculated using field calculator in arc GIS and multiplied by the average rainfall of that area using spatial analysis tools of interpolation as equation 11.

$$P_A = \frac{P_{12}A_{12+}\ P_{23}\ A_{23+}\ ...+\ P_{n-1,n}\ A_{n-1,n}}{A_T} \quad \text{...} (11)$$

Where, P_{12}: average rainfall depth between 1 and 2; A_{12}: area enclosed by successive contour 1 and 2; A_T: total watershed area of study and P_A: is average rainfall depth. According to this method the average annual rainfall in the watershed is equal to 959.72 mm (Table 16).

Table 16: Average areal rainfall depth of the study area by Isohyetal method

Isohyet (mm)	Estimated average (mm)	Enclosed area (km^2)	Percent of total area (%)	Weighted rainfall (mm)
708-800	754.0	58.84	1.32	9.96
801-900	850.5	365.24	8.20	69.71
901-1010	955.5	3365.54	75.53	721.67
1010-1100	1055	639.54	14.35	151.42
1110-1200	1155	26.84	0.60	6.96
Total		4456	100.00	959.72

Based on the above analysis, arithmetic and isohyetal method gives appropriate value of areal rainfall for the study area. So that the average areal rainfall depth of Melk Kunture Watershed was taken as 960.5mm.

3.6.3 Pairwise comparison Matrix of factors affect GWP and Recharge

The importance of each pair of factors is compared with respect to the goal of the decision problem (groundwater potential and recharge zone in this case). The important thing here is that, considering which criteria are more important than others. Pairwise comparison method was used for the assignment of weight for thematic layers. Pairwise comparison matrices were created for each of the lower hierarchical levels one matrix for each element in the level immediately above. This was done by considering which layer effect is dominant than the other. The pairwise comparison matrices were formed by interviews conducted with various experts and knowledge of the researcher. A pairwise comparison matrix is derived using Satty's (1980) nine-point importance scale (Table 17). The scale for each factor was given by looking real problems and considering the role of each factor for the occurrence of groundwater.

Table 17: Pair-wise comparison matrix and scale (weight) relative of importance

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

3.6.4 Assigning weight for factors affect groundwater potential

Based on the above method of data analysis described in section 3.5, the detail procedures of the relative importance determination and the weight of each factors with another were analyzed based PCM according to relative importance value with 1 to 9 scale (Table 14) using AHP techniques (Das, 2018; Fashae *et al*., 2014; Abdul-Aziz *et al*., 2017) .

As per pairwise comparison matrix, the relative weight matrix, normalized Principal Eigen Vectors and consistency ratio were calculated to determine the relative importance of factor with each other. The eight selected factors influencing groundwater potential were assigned by applying pair-wise comparison ranking method. The final weight calculation require the computation of the principal eigenvector and consistency ratio of the pair-wise comparison matrix to produce a best-fit of the weights. The weighting procedure is based on the AHP. The relative importance of the pair-wise combination of the factors was judged using the following 9-point rating scale:

1/9	1/7	1/5	1/3	1	3	5	7	9
Extreme	Very strong	Strong	Moderate	Equal	Moderate	Strong	Very strong	Extreme
← Less important				↓↑	More important →			
Note: 2,4,6 and 8 are intermediate value								

Therefore, the PCM of factors influencing groundwater potential was computed based on the level of importance by 9-point rating scale through the following procedure:

Pair-Wise Comparison Matrix

Table 18: Pair-wise comparison matrix (relative Weight) for factors influence GWP areas

Factor	Li	Gm	Sl	Lulc	L.D	RF	D.D	S
Li	1	3	4	5	6	7	8	9
Gm	1/3	1	2	3	5	6	7	7
Sl	1/4	1/2	1	2	3	4	4	6
Lulc	1/5	1/3	1/2	1	2	3	4	5
L.D	1/6	1/5	1/3	1/2	1	3	4	4
R.F	1/7	1/6	1/4	1/3	1/3	1	2	3
D.D	1/8	1/7	1/4	1/4	1/4	1/2	1	2
S	1/9	1/7	1/6	1/5	1/4	1/3	1/2	1
Sum Column	2.33	5.49	8.50	12.28	17.83	24.83	30.50	37.00

Where, Li= Lithology, Gm = Geomorphology, Sl = Slope, RF = Rainfall, L.D = Lineament Density, Lulc = Land use/cover, S = Soil and D.D = Drainage density.

Normalization of relative weight

According to Satty (1980), the relative weight of PCM was normalized by dividing each value by the total column and subsequently averaging the row total weight or divide the total weight by total number of factor (n) (Table 18). Then thematic normalized weight is calculated from normalized values according to (Equation 5). The normalized weight were then ranked in descending order according to their influence/suitability to GW (Table 19).

Table 19: Normalized weight (Wn) of selected Factors

Factor	Li	Gm	Sl	Lulc	L.D	RF	D.D	S	Total Weight(Wt)	Normalized Weight(Wn)
Li	0.43	0.55	0.47	0.41	0.34	0.28	0.26	0.24	2.98	37%
Gm	0.14	0.18	0.24	0.24	0.28	0.24	0.23	0.19	1.75	22%
Sl	0.11	0.09	0.12	0.16	0.17	0.16	0.13	0.16	1.10	14%
Lulc	0.09	0.06	0.06	0.08	0.11	0.12	0.13	0.14	0.79	10%
L.D	0.07	0.04	0.04	0.04	0.06	0.12	0.13	0.11	0.60	8%
R.F	0.06	0.03	0.03	0.03	0.02	0.04	0.07	0.08	0.35	4%
D.D	0.05	0.03	0.03	0.02	0.01	0.02	0.03	0.05	0.25	3%
S	0.05	0.03	0.02	0.02	0.01	0.01	0.02	0.03	0.18	2%
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	8.00	100%

Weighted Sum

Normalized Weight	0.37	0.22	0.14	0.10	0.08	0.04	0.03	0.02	Weight Sum
Factors	Li	Gm	Sl	Lulc	L.D	R.F	D.D	Soil	
Li	0.37	0.65	0.55	0.49	0.46	0.31	0.25	0.21	3.29
Gm	0.12	0.22	0.28	0.29	0.38	0.26	0.22	0.16	1.93
Sl	0.09	0.11	0.14	0.20	0.23	0.18	0.12	0.14	1.20
Lulc	0.07	0.07	0.07	0.10	0.15	0.13	0.12	0.12	0.84
L.D	0.06	0.04	0.05	0.05	0.08	0.13	0.12	0.09	0.62
R.F	0.05	0.04	0.03	0.03	0.03	0.04	0.06	0.07	0.36
D.D	0.05	0.03	0.03	0.02	0.02	0.02	0.03	0.05	0.25
Soil	0.04	0.03	0.02	0.02	0.02	0.01	0.02	0.02	0.19

Principal Eigen Vectors (λmax)

Principal Eigen vectors is the normalized weight Eigen vectors or the average value of the consistency vector computed in order to check assigned the relative weight (PCM in Table 18) to each factor through PCM is fairly weighted. It is calculated by divide the sum of weighted ratio (R) to the total number of factor selected using to equation 6 (Table 20).

Table 20: Weighed ratio (R) or consistency vector of selected factors

Factor	Li	Gm	Sl	Lulc	L.D	RF	D.D	S	Normalized Weight(Wn)	Weighted Ratio(Ř)
Li	0.37	0.65	0.55	0.49	0.46	0.31	0.25	0.21	0.37	8.83
Gm	0.12	0.22	0.28	0.29	0.38	0.26	0.22	0.16	0.22	8.86
Sl	0.09	0.11	0.14	0.20	0.23	0.18	0.12	0.14	0.14	8.73
Lulc	0.07	0.07	0.07	0.10	0.15	0.13	0.12	0.12	0.10	8.52
L.D	0.06	0.04	0.05	0.05	0.08	0.13	0.12	0.09	0.08	8.27
R.F	0.05	0.04	0.03	0.03	0.03	0.04	0.06	0.07	0.04	8.07
D.D	0.05	0.03	0.03	0.02	0.02	0.02	0.03	0.05	0.03	8.13
S	0.04	0.03	0.02	0.02	0.02	0.01	0.02	0.02	0.02	8.30

From computed weighted ration (R) in Table 20, the principal Eigen Vector is obtained using equation 8 and 12 and presented in Table 21.

$$\text{Principal Eigen Vector } (\lambda\text{max}) = \frac{1}{n}\left(\sum_{i=1}^{n} \frac{aij.Wt}{Wt}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

$$= (R_1 + R2 + R3 + R4 + R5 + R6 + R7 + R8)/n$$

Table 21: Normalized principal Eigen Vectors (λmax) of selected factors

Factor	Li	Gm	Sl	Lulc	L.D	RF	D.D	S	Principal Eigen Vector (λmax)
Weighted Ratio(Ř)	8.83	8.86	8.73	8.52	8.27	8.07	8.13	8.30	8.46

Consistency ratio is important to check (assess) the accuracy or consistency of the relative weight of pair-wise comparison of matrix of factors. In order to calculate consistency ratio (CR), first we compute the consistency index (CI) using equation, then consistency ratio is calculated by dividing consistency index for Random Index(RI) value obtain for n = 8 is 1.41 as equation 13 and 14.

Consistency index (CI) = (λmax – n)/ (n-1)…………………………………….………… (13)

CI = (8.46 – 8)/ (8-1)

= 0.07

Consistency Ratio (CR) = CI/RI ……………………………………………………….. (14)

CR = 0.07/1.41

= 0.05

Where RI for n = 8 is 1.41, which depends on the number of factor being compared (see table 11). According to Satty's, for a good decision there must be CR $\leq$ 0.1. Here CR = 0.05 which is less than 0.1. This shows that the assigning weight for each factor were consistency and the relative weight of pair-wise comparison were appropriate and acceptable for decision making. However, if CR $>$ 0.1 there is an indicator of error when assigning ranks (relative weight) to the factors and it can be reweighted for evaluation.

3.6.5 Assigning weight for factors affect groundwater recharge potential

Groundwater recharge zone was identified and mapped considering the thematic layer (map) which was the same map that were used for groundwater potential zone mapping. The pair-wise comparison matrix of the factors was done as suitability for groundwater recharge or their influence on groundwater recharge. The pair-wise comparison, normalized relative weight and Principal Eigen Vector was calculated as shown in (Table 22, Table 23 and Table 24) respectively and the consistency ratio according to equation 14.

Table 22: Pair-wise comparison matrix (Relative Weight) for factor influence GWRP area

Factor	RF	L.D	Li	Gm	Sl	D.D	S	Lulc
RF	1	2	3	4	5	6	7	8
L.D	1/2	1	2	3	4	5	6	7
Li	1/3	1/2	1	2	3	4	5	6
Gm	1/4	1/3	1/2	1	2	2	3	4
Sl	1/5	1/4	1/3	1/2	1	2	3	5
D.D	1/6	1/5	1/4	1/2	1/2	1	2	3
S	1/7	1/6	1/5	1/3	1/3	1/2	1	2
Lulc	1/8	1/7	1/6	1/4	1/5	1/3	1/2	1
Sum Column	2.72	4.59	7.45	11.58	16.03	20.83	27.50	36.00

Where, Li= Lithology, Gm = Geomorphology, Sl = Slope, RF = Rainfall, L.D = Lineament Density, Lulc = Land use/cover, S = Soil and D.D = Drainage density

Normalization of relative weight

The normalized weight was calculated from relative weight of pair-wise comparison matrix (value) after dividing each relative weight of factor by their corresponding sum column, which are calculated by averaging the total weight or divide the total weight by total number of factor (n) and also gives corresponding ranking of each factor according to their influence/suitability for groundwater recharge (Table 23).

Table 23: Normalized weight (Wn) of selected Factors

Factor	RF	L.D	Li	Gm	Sl	D.D	S	Lulc	Total Weight(Wt)	Normalized weight(Wn)
RF	0.37	0.44	0.40	0.35	0.31	0.29	0.25	0.22	2.63	33%
L.D	0.18	0.22	0.27	0.26	0.25	0.24	0.22	0.19	1.83	23%
Li	0.12	0.11	0.13	0.17	0.19	0.19	0.18	0.17	1.27	16%
Gm	0.09	0.07	0.07	0.09	0.12	0.10	0.11	0.11	0.76	9%
Sl	0.07	0.05	0.04	0.04	0.06	0.10	0.11	0.14	0.62	8%
D.D	0.06	0.04	0.03	0.04	0.03	0.05	0.07	0.08	0.42	5%
S	0.05	0.04	0.03	0.03	0.02	0.02	0.04	0.06	0.28	4%
Lulc	0.05	0.03	0.02	0.02	0.01	0.02	0.02	0.03	0.20	2%
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	8.00	100%

Where, Li= Lithology, Gm = Geomorphology, Sl = Slope, RF = Rainfall, L.D = Lineament Density, Lulc = Land use/cover, S = Soil and D.D = Drainage density

Weight Sum

Normalized weight	0.33	0.23	0.16	0.09	0.08	0.05	0.04	0.02	Weight Sum
Factors	Li	Gm	Sl	RF	L.D	Lulc	S	D.D	
Li	0.33	0.46	0.47	0.38	0.39	0.31	0.25	0.20	2.78
Gm	0.16	0.23	0.32	0.28	0.31	0.26	0.21	0.17	1.95
Sl	0.11	0.11	0.16	0.19	0.23	0.21	0.18	0.15	1.34
RF	0.08	0.08	0.08	0.09	0.16	0.10	0.11	0.10	0.80
L.D	0.07	0.06	0.05	0.05	0.08	0.10	0.11	0.12	0.63
Lulc	0.05	0.05	0.04	0.05	0.04	0.05	0.07	0.07	0.42
S	0.05	0.04	0.03	0.03	0.03	0.03	0.04	0.05	0.28
D.D	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.20

Principal Eigen Vectors (λmax)

Principal Eigen vectors is the normalized weight Eigen vectors computed in order to check assigned the relative weight (in Table 22) to each factor through pair-wise comparison is fairly weighted. It is calculated by divide the sum of weighted ratio (R) (consistency vector) to the total number of factor selected using to equation 15.

Table 24: Weighed ratio (R) of selected factors

Wn	0.33	0.23	0.16	0.09	0.08	0.05	0.04	0.02	Normalized weight(Wn)	Weighted ratio (R)
Fac.	RF	LD	Li	Gm	Sl	DD	S	Lulc		
RF	0.33	0.46	0.47	0.38	0.39	0.31	0.25	0.20	0.33	8.47
L.D	0.16	0.23	0.32	0.28	0.31	0.26	0.21	0.17	0.23	8.51
Li	0.11	0.11	0.16	0.19	0.23	0.21	0.18	0.15	0.16	8.44
Gm	0.08	0.08	0.08	0.09	0.16	0.10	0.11	0.10	0.09	8.38
Sl	0.07	0.06	0.05	0.05	0.08	0.10	0.11	0.12	0.08	8.13
D.D	0.05	0.05	0.04	0.05	0.04	0.05	0.07	0.07	0.05	8.10
S	0.05	0.04	0.03	0.03	0.03	0.03	0.04	0.05	0.04	8.09
Lulc	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	8.14

Where, Li= Lithology, Gm = Geomorphology, Sl = Slope, RF = Rainfall, L.D = Lineament Density, Lulc = Land use/cover, S = Soil and D.D = Drainage density.

From computed weighted ration (R) in Table 24, the principal Eigen Vector is obtained using equation 15 and presented in Table 25.

$$\text{Principal Eigen Vector } (\lambda max) = \frac{1}{n}\left(\sum_{i=1}^{n} \frac{aij.wj}{wj}\right. \ldots\ldots \quad (15)$$

$$= (R_1 + R2 + R3 + R4 + R5 + R6 + R7 + R8)/n$$

Table 25: Normalized principal Eigen Vectors (λmax) of selected factors

Factor	RF	L.D	Li	Gm	Sl	D.D	S	Lulc	Principal Eigen Vector (λmax)
Weighted ratio (Ř)	8.47	8.51	8.44	8.38	8.13	8.10	8.09	8.14	8.28

Consistency Ration (CR)

In order to calculate consistency ratio (CR), first we compute the consistency index (CI) using equation 16, then consistency ratio is calculated by dividing consistency index for Random Index(RI) value obtain for n = 8 is 1.41 as equation 16 and 17.

Consistency index (CI) = (λmax – n)/ (n-1)………………………………………….. (16)

$$CI = (8.28 – 8)/ (8-1)$$
$$= 0.04$$

Consistency Ratio (CR) = CI/RI ………………………………………………….…. (17)

CR = 0.04/1.41, where RI for n = 8 is 1.41 (see table 11)
= 0.03

According to Satty's, for a good decision there must be CR $\leq$ 0.1. Here CR = 0.03 which is less than 0.1. This shows that the assigning weight for each factor were consistency, and the relative weight of pair-wise comparison were appropriate and acceptable for decision-making. However, if CR $>$ 0.1 there is an indicators of error when assigning ranks (relative weight) to the factors and it can be reweighted for evaluation.

3.6.6 Assessing suitability level of factors affect GWP and recharge zone

Suitability analysis of factors affect GWP and recharge zone was performed to assess the suitability or the potentiality level of each factors to groundwater and recharge occurrences on the study area. The suitability class of each thematic layers was examined according to previous studies, expert knowledge, the nature and characteristics of each factors responsible to potential groundwater and recharge zone development. These suitability classification standardized based previous studied or literature. Therefore, in all reclassified thematic map the suitability classification standard was cited.

3.7 Groundwater Potential and Recharge Zone Map Development

The groundwater potential and recharge zones of the study area was developed by using the weighted overlay analysis (WOA) of the eight reclassified of thematic layers (lithology, geomorphology, slope, lineament density, LULC, rainfall, drainage density and soil) with their percentage of influence in ArcGIS (Figure in Appendix 3). GIS and RS technologies were used for the analysis and integrate surface feature of factor influence that are used to indicate groundwater potential and recharge zone. In order to delineate the groundwater and recharge for this study areas all thematic maps were reclassified and changed into raster format and superimposed by weighted overlay method.

3.7.1 Groundwater potential zone map development

Groundwater potential zone map were obtained by weighted overlay method (WOA) of all reclassified thematic layer using spatial analysis tool in ArcGIS (Figure in the Appendix 3). During the weighted overlay analysis, each individual factors affect groundwater potential of the study was adopted to combine all thematic layers, weighted and ranked according to the influence on groundwater potential based on the judgment of past studies carried out by researchers or knowledge of expert gained through similar work on groundwater potential and recharge zone mapping. All factors were reclassified after thematic layers converted to raster format and resampled to the same cell size, the weighted overlay analysis take place in spatial analysis tools in GIS. Groundwater potential zone map was obtain by weighted overlay method of linear combination of thematic layer (Karnataka *et al*., 2011; Kumar *et al*., 2016; Zhou & Wang, 2018) according to equation 18.

$$GWPZ = \{[(Li_w)(Li_r)] + [(Gm_w)(Gm_r)] + [(Sl_w)(Sl_r)] + [(LuLc_w)(LuLc_r)] + [(Ld_w)(Ld_r)] + [(RF_w)(RF_r)] + [(Dd_w)(Dd_r)] + [(S_w)(S_r)]\} \quad \text{.........} \quad (18)$$

Where, GWPZ – Groundwater Potential zone, Li – Lithological, Gm – Geomorphological, Sl– Slope, and LuLc – Land use land cover, Ld – Lineament density, RF – Rainfall, Dd – Drainage density and S – Soil. The subscript "w" and "r" refers to normalized (criteria) weight of theme and reclassified normalized weight of the individual feature of a theme (rank), respectively.

GWRZ is helps to indexing the probable groundwater potential in the area and then used to produce groundwater potential map with five classes (very high, high, medium, low and very low) based on factor influence on groundwater potential development.

3.7.2 Groundwater recharge zone map development

The groundwater recharge zones map of the study area was also identified and mapped by using GIS weighted overlay analysis (WOA) based the eight reclassified of thematic layers (lithology, geomorphology, slope, lineament density, LULC, rainfall, drainage density and soil) with their percentage of influence in ArcGIS. These eight physical factor were used to determine the suitable site for groundwater recharge of the study areas. The result of groundwater recharge potential zone (GWRZP) map was done weighted overlay by linear combination of all thematic maps according to equation 19.

$$GWRZ = \{[(Li_w)\ (Li_r)] + [(Gm_w)\ (Gm_r)] + [(Sl_w)\ (Sl_r)] + [(LuLc_w)\ (LuLc_r)] + [(Ld_w)\ (Ld_r)] + [(RF_w)\ (RF_r)] + [(Dd_w)\ (Dd_r)] + [(S_w)\ (S_r)]\} \quad (19)$$

Where, GWRZ – Groundwater recharge zone, Li – Lithological, Gm – Geomorphological, Sl– Slope, and LuLc – Land use land cover, Ld – Lineament density, RF – Rainfall, Dd – Drainage density and S – Soil. The subscript “w” and “r” refers to normalized weight of theme and reclassified normalized weight of the individual feature of a theme, respectively.

In general, the highest and lowest ranking of factors affecting GW potential and recharge zone was summarized and weight of each factors was analyzed by AHP (Table 26).

Table 26: Rank and suitability classification factors influence GWP and recharge (R)

Factors	Lower rank of GWP and GWR (very poor suitable)	Highest rank of GWP and GWR (very good suitable)
Lithology	Lowest permeability	Highest permeability
Geomorphology	Mountain/hilly landform	Plain landform
Slope	Flat/low slope	Steep/high slope
Lineament density	Lowest lineament density	Highest lineament density
Rainfall	Lowest annual rainfall	Highest annual rainfall
Land use/land cover	Settlement/built up areas	Water body/wetland
Soil	Leptosols (sand)	Vertisols (clay)
Drainage density	High drainage density	Lowest drainage density

3.7.3 Weighted overlay analysis

The GIS overlay process can be used to combine the factors and constraints in the form of a weighting overlay analysis (WOA). The suitability map was the product of the weightage (% of influence) and rank which is developed by using the WOA method and integrate by linear combination. During WOA all reclassified thematic layers was converted to raster (grid format) and resample to the same cell size, then weightage (% influence) done through AHP and rank given during suitability analysis was taken as input factors for each reclassified thematic map and the detail was described Appendix Figure 3. The result is then summed up producing a suitability map as shown by the formula:

$$\text{Suitability map} = \sum(\text{Factor (Weighted) map})) * (\text{Rank of individual Theme})$$

$$= \sum_{n=1}^{N=8} \text{Fw} * \text{Fr}$$

Where, F_w- weightage (% of influence) F factor and F_r- rank given for each individual theme of F factor.

3.8 Validation of Groundwater Potential Map

The groundwater potential zones of this study area were validated based on water source point inventory data of hand dug well, bore well, tube well and spring point obtained from Upper Awash River Basin. For validation, location for groundwater-level (borehole, hand Dug well, Tube well and spring point) observation site was overlain and must be coincide on GWPZ map. The accuracy of the identified potential zones is estimated based on total number of validation data and the total number of disagreement data with their actual yield.

After groundwater potential zone of the study area was validated, the sensitivity of factor influence GWPZ map was done by AHP and checking by removing each thematic layer one by one. If one of the thematic layers was removed at a time and the critical thematic layers in varying the GWPZ validated map of the study area were identified. This shows that the delineated GWPZ map was highly sensitive to the thematic layer having high weight of influence (% Influence). Therefore, the factor that changing the GWP zone highly was considered as the more influential/sensitive factor for identifying and mapping groundwater potential and recharge otherwise less influential factor accordingly

3.9 Groundwater Flow Direction Determination

As discussed under literature review section the flow direction of groundwater can be determined from source of contamination (hydrochemical parameter data analysis), based on surface elevation or groundwater level and fault orientation. But, for this particular study area the flow direction of groundwater was determined from the elevation of groundwater level. The elevation of hydraulic head at different well point were obtained by subtracting the depth to water table/static water level in the borehole from the ground surface elevation with respect to the mean sea level as equation 20:

$$HH = GSE - SWL \quad (20)$$

Where, - HH (hydraulic head) – is the elevation to which water will mutually rise in a well.

- GSE (ground surface elevation) - is the elevation of ground surface elevation with respect to mean sea level
- SWL (Static water level) – is the depth to the water table/static water level in the borehole when no pumping was taking place.

SURFER 17 software package was used for this work (groundwater flow direction mapping). It also used to develop groundwater contour map and flow direction of the study area based on groundwater level data which is organized as xy coordinate for well point and z-elevation of the water table. The format of sample for this parameter used for determining groundwater flow direction was summarized according to Table 27 and detail were described in Appendix Table 4.

Table 27: Parameters for determination of groundwater flow direction

Water Point Location	Longitude (Easting) (UTM)	Latitude (Northing) (UTM)	Elevation E (m)	Static Water Level SWL (m)	Hydraulic head (H) = E – SWL (m)

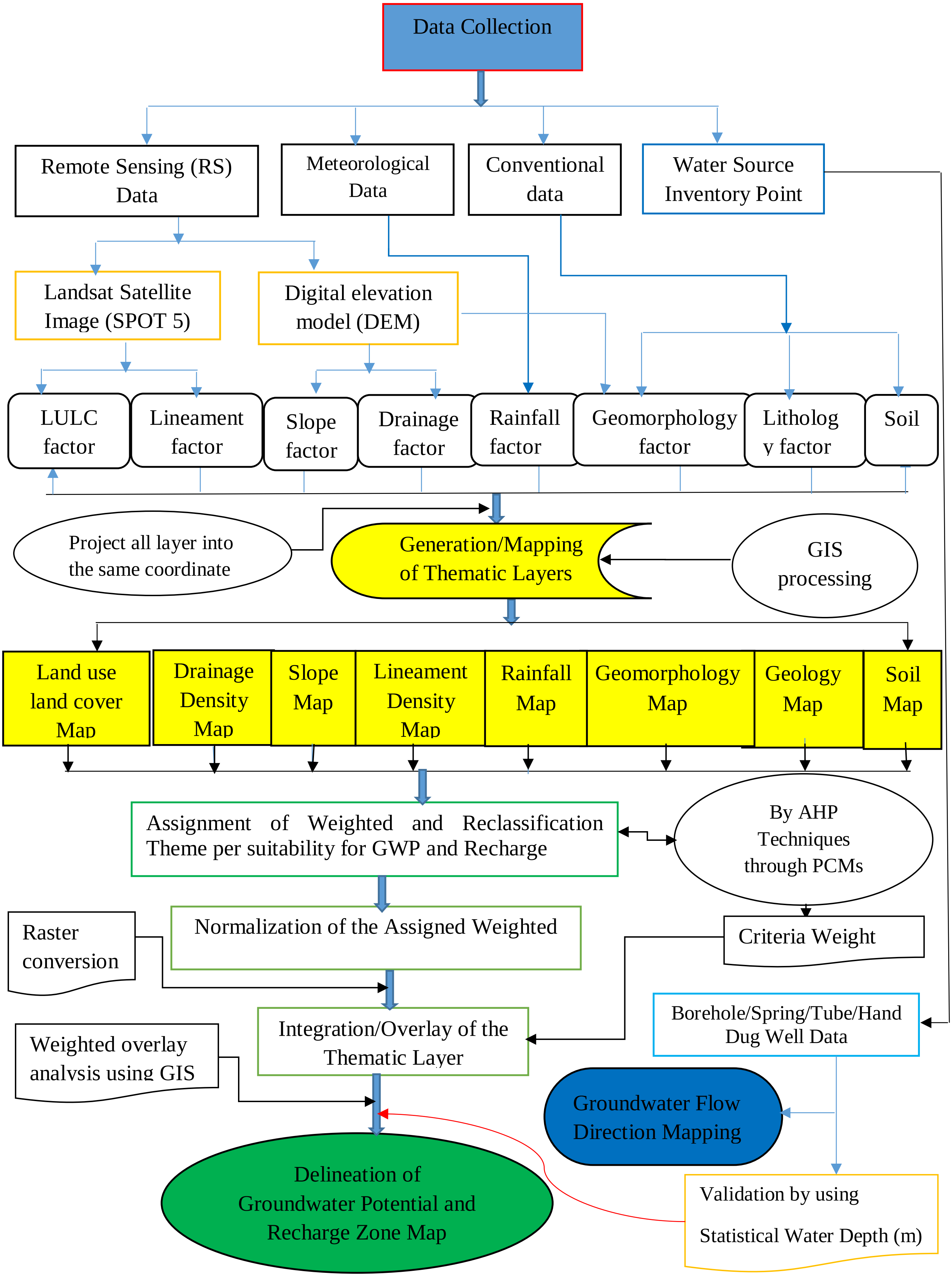


Figure 17: Conceptual framework of the general methodology used for the study

4. RESULTS AND DISCUSSION

This chapter describe the results of the application of GIS and remote sensing methods in mapping groundwater potential and recharge zones in Melka Kunture Watershed area. The result of AHP process used to assign weights for each factor considered to be influence GWP occurrence were discussed. Suitability class and reclassified thematic maps produced for each factor were also discussed her. Finally, Weighted overlay analysis carried out to map groundwater potential and recharge zone and validation of the final result that reveal the capability of GIS and RS in delineation of GWP and recharge zone was done.

4.1 Identification of Factor Influence Groundwater Potential and Recharge Zone

Selecting the most appropriate factor for groundwater occurrence is an important consideration for mapping groundwater potential and recharge site. Factor influence the occurrence of the groundwater potential and recharge were identified from different previous literature and selected based theoretical selection criteria. The identified factor were combined together as pair-wise comparison by setting theoretical selection criteria as:

- Frequency of usage (C1),
- Criticalness of the factor (C2),
- Ease/difficult of data access (C3), according to their significant role in groundwater occurrences. This criteria were identified as:

1) Frequency of usage (C1): 30 different past studies/literature were selected and reviewed. Among these 22 studies are from different countries in worldwide out of Ethiopia and around 8 studies are selected from local studies in Ethiopia. The frequency value of their usage is given in Percent (%) n-times, out of 30% (Table 28). For example, Geology was taken 25-times which get 25% out of 30%.

2) Criticalness of the factor (C2): based on past scholar studies and basic scientific concept, the most significant role for the influence the groundwater occurrence is given in the range of (1-5) %, where, 1= very low importance, 2= low importance, 3= medium importance, 4= high importance and 5= very high importance (Table 28).

3) Ease/difficult of data access (C3): based data availability or ease of data access their pair comparison value is given in the range of (1-5) %, where, 1= very difficult, 2= difficult, 3= medium, 4= ease and 5= very ease (Table 28).

Table 28: Theoretical Selection criteria weight for factor identification

		Criteria (%)				
S.No	Factor	C1 (30%)	C2 (5%)	C3 (5%)	Score	Rank
1	Geology	25	5	4	34	1
2	Geomorphology	23	5	2	30	2
3	Lineament. D	19	4	3	26	5
4	Slope	23	3	3	29	3
5	Soil	18	1	4	23	8
6	Drainage. D	19	2	3	24	7
7	Lulc	22	3	3	28	4
8	Rainfall	17	3	5	25	6

Where, C= Criteria, C1= Frequency of Usage, C2= Criticalness of the Factor and C3= Ease/difficult of data access.

According to this analysis, eight (8) factor that have score in the range of (20-40) % were selected (Table 28). Therefore, this eight factors are the most significant factor affect groundwater occurrence and considered as the main factor responsible for groundwater resource development and identifying optimal site that prospect groundwater potential and recharge zone for this study area.

4.2 Suitability Level of Factors and Reclassified Thematic Map

Groundwater potential and recharge zone mapping in the study area involves eight thematic layers such as lithology, geomorphology, slope, soil, land use/cover, rainfall lineament density and drainage density were weighted, normalized, reclassified and ranked, and integrate by weighed overlay analysis (WOA) in a GIS environment. WOA was used develop groundwater potential and recharge zone map by integrate reclassified thematic layers of eight inputs factors.

All thematic layers were reclassified, weighted and ranked according suitability standardized to groundwater potential and recharge occurrence. For this study the reclassified map was ranked into five qualitative classes (1-5) described as very low, low, moderate, high and very high. Hence, the higher value were given for high groundwater potential and lowest value were given for class causes the existence of low groundwater potential.

4.2.1 Lithology

Lithology is one of most important role in the occurrence and movement of the groundwater. Identification of the lithological units of the study areas helps to determine the infiltration capacity, permeability and its ability to discharge and store water. The study area was composed from seven major geological formation control the occurrence and movement of groundwater and recharge highly. Those lithological found in study were; Tarma ber basalt, Addis Ababa Ignimbrite, Weliso Ambo basalt, central volcanic of (Wechecha, Furi, and Yerer), Akaki basalt and alluvial deposits are the major litho-units of the area (Table 26).

The reclassified lithological map was generated from lithological map of the study area (Figure 12), and then reclassified into five classes as shown on Figure 18 and its classes were ranked as suitability for existence of groundwater potential and recharge zone. As seen from reclassified lithological map of the study shown on Figure 18, the higher rank was given for alluvial deposit which cover 0.6% and Addis Ababa ignimbrite which cover 49.4% (Table 29). These geology allow high to moderate infiltration of water to ground and their aquifer produces high yield.

This result of suitability classification of the study area is within the range of other research finding such as (Abdul-Aziz *et al.*, 2017; Shekhar and Pandey, 2015; Yitbarek *et al.*, 2012) which conducted on geology, hydrogeology and in hard rock of terrain for the delineation of groundwater. Therefore, this suitability classification of lithology for delineation of groundwater potential and recharge zone are acceptable when compared with those and other finding.

Table 29: Lithology suitability classification for GWP and Recharge zone identification

Factor	Geological type	Area(Km^2)	Area (%)	Rank	Suitability classification
Lithology	NcvTy	824.71	19.0	1	Very low
	QwaB/NebRy	537.36	12.4	2	low
	NakB/PNtbB	807.95	18.6	3	Moderate
	NadI	2144.01	49.4	4	High
	Qal	25.81	0.6	5	Very high

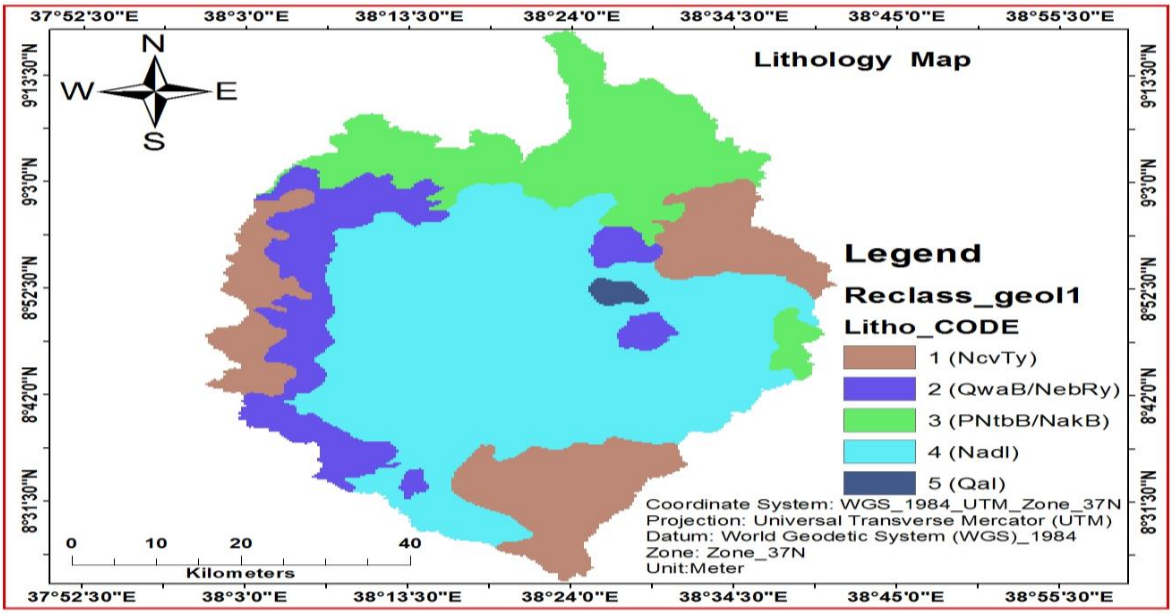


Figure 18: Reclassified lithological map of the study area

4.2.2 Geomorphology

Geomorphological map of the study shows the various landforms and geomorphic unit that play fundamental role in groundwater occurrence and movement. Volcanic terrain of Ethiopia comes in a variety of landforms that has a significant importance to groundwater occurrence and movement (Seifu Kebede, 2013). The geomorphological unit in the study area includes escarpment, hilly, level piedmont plain, level plain, level plateau, mountain, rolling and undulating plateau has been identified and mapped based on topographic (slope) difference and landforms (Figure 9).

The reclassified map of geomorphic feature/landform of the study areas as per suitability rank of groundwater potential and recharge zone was presented in Figure 19. It shows that this study is dominated by undulating plateau and level plateau/semi-plain which covers

48.7% and 31.6% (Table 30) of the study area at west, east, south, north and central which classified as an area of low and high groundwater potential and recharge zone respectively (Figure 16). High rank (4) and (5) was given for level plateau/semi-plain and flat/plain land which covers 6.3% and 0.03% (Table 30) of the study area at north, north-east and central which classified as an area of high and very groundwater potential and recharge zone, because of low runoff and high infiltration (Figure 19). Lower rank (1) was given for mountain/hilly/escarpment land areas which cover 13.3% of the study area which classified as an area of very low GWP and recharge zone, because it has steep land of high slope which produce high runoff and low infiltration (Figure 19).

Therefore, this suitability classification was agreed/acceptable since the result was within the range of finding of different researchers such as (Sisay, 2007; Zende *et al.*, 2012; Abdul-Aziz *et al.*, 2017) which they conducted on evaluation of groundwater potential and recharge zone based on RS and GIS techniques in different areas of their study. So, this study is acceptable in suitability classification and ranking of groundwater potential and recharge zone of the study as compared those and other finding.

Table 30: Geomorphology suitability classification for GWP and R zone identification

Factor	Geomorphic/landform type	Area (km^2)	Area (%)	Rank	Suitability classification
Geomorphology	Mountain/hilly/escarpment	575.15	13.30	1	Very low
	Undulating plateau/rolling	2106.87	48.73	2	Low
	Piedmont plain/foot slope	271.89	6.29	3	Moderate
	Level plateau/semi-plain	1368.38	31.65	4	High
	Level plain	1.16	0.03	5	Very high

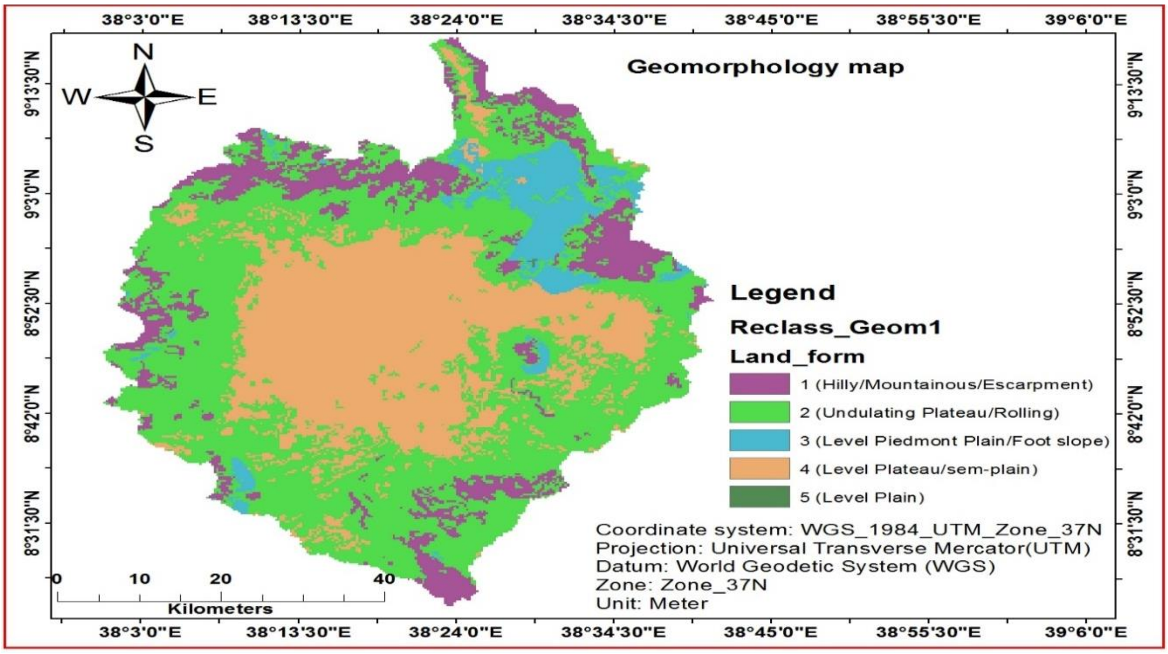


Figure 19: Reclassified Geomorphological map of the study area

4.2.3 Slope

Slope of the study highly indicate characteristic of groundwater occurrence and movement in watershed that govern is capable of holding water by infiltration or it may promotes runoff (Argaz *et al*., 2019). For this research the lower slope value indicate the terrain flatter (gentle slope) which causes high groundwater occurrence and recharge because the lower slope of the area gives enough time to infiltrate rainwater to the ground table which result in higher chance getting high groundwater potential and recharge whereas the higher slope value indicate steeper slope of the terrain which falls into low groundwater potential and recharge because the higher slope cause high runoff/rapid flow of water and prevents the infiltration of water into the ground. The slope in the study area ranges from 0 to 68.1% (Figure 14).

Here, the slope map of the study area given on Figure 15 was reclassified and ranked as shown on Figure 20 based suitability for groundwater occurrence and recharge. The highest rank/weight is assigned to lowest slope value (i.e. nearly level and gentle slope) which give highest contribution for groundwater occurrence and recharge and lowest rank is assigned to highest slope value (i.e. hilly to steep slope) which give highest groundwater potential and recharge zone. as seen from reclassified slope map the suitability identification for groundwater potential and recharge, the slope of the study was reclassified into five classes 0 to 5.34%, 5.35 to 10.4%, 10.5 to 17.1%, 17.2 to 27.3% and 27.4 to 68.1% which cover 2.8%, 44.8%, 36.7%, 13.4% and 2.3% of the study areas respectively (Table 31). Therefore, most of this study areas was dominated with slope 5.34 to 10.4% which cover 44.8% of the areas were considered as gentle slopes which is good for groundwater potential and recharge occurrence because moderate slope causes moderate infiltration of rainwater and runoff as shown on Figure 20.

According to different finding of research such as (Fashae *et al.*, 2014; Abdul-Aziz *et al.*, 2017; Sisay, 2007; Waikar and Nilawar, 2014) this suitability classification result of the study was acceptable in classification of slope for mapping groundwater potential and recharge zone because the result fall in the range of those finding as compared with them.

Table 31: Slope Suitability classification for GWP and Recharge zone identification

Factor	Slope (%)	Description	Area(km^2)	Area (%)	Rank	Suitability classification
Slope	0-5.34	Flat to gentle	1500.42	34.56	5	very high
	5.35-10.4	gentle to high slope	1608.18	37.04	4	High
	10.5-17.1	High to hill slope	813.71	19.16	3	moderate
	17.2-27.3	Steep	314.47	7.24	2	Low
	27.4-68.1	Very steep	86.47	1.99	1	very low

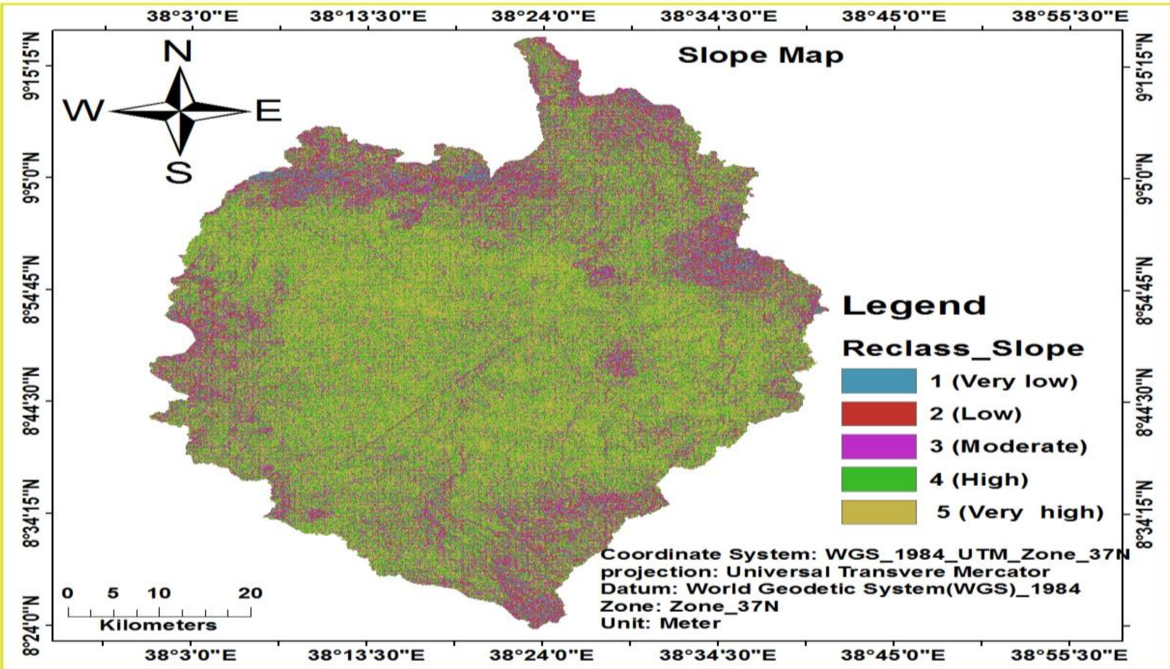


Figure 20: Reclassified slope map of the study area

4.2.4 Land use/cove map

Land-use/land-cove of the study area includes both manmade and natural land that play vital role in groundwater occurrence because it gives the necessary information on infiltration, soil moisture, surface water, rate of recharge from precipitation, runoff and evaporation. As seen from land use/cover image (map) indicated on Figure 10, major types of land-use/cover classes of these study area includes urban land/ settlement, barren land, agricultural/Cultivated land), forest and woodland, and wetland and water bodies which cover 1.0%, 7.4%, 85.8%, 5.7% and 0.1% of the study area respectively (Figure 10). As shown on this map, the study area is dominated by agricultural land where as wetland and waterbody cover small land when compared with others (Figure 10).

Different types of LULC have a different rate of groundwater occurrence due to different rate of infiltration capacity. Considering this, LULC of the study area was reclassified based the suitability rank as shown on Table 32. Lower rank (1) was given for settlement/urban areas because it cause high runoff and low infiltration which result in very low groundwater potential and recharge zone whereas higher rank (5) was given for wetland and water bodies because it cause high recharge may exist over a long period of time due to low runoff and high infiltration which result in very high groundwater potential and recharge zone (Figure 21). The reclassified LULC map result on Figure 21 showed that highest area of coverage (85.8%) of the total study area is moderately suitable for identification of groundwater potential zones.

This suitability classification result of the study is agree with finding of different studies such as; (Mesfin, 2011; Nilawar, 2015; Tesfaye, 2015; Bane, 2017) which they conducted on groundwater potential and recharge zone assessment by using GIS and RS. Therefore, LULC classification and ranking of the current study area was acceptable for mapping of groundwater potential and recharge zone as we compared with them.

Table 32: Land use/cover suitability class for GWP and recharge zone identification

Factor	LULC Types	Area (Km2)	Area (%)	Rank	Suitability Classification
Land use/land cover	Urban/Settlement/ land	41.69	1	1	Very low
	Bare land	322.69	7.4	2	Low
	Agricultural/cultivation and grass land	3720.95	85.8	3	Moderate
	Forest and woody land	276.71	5.7	4	High
	Wetland and water bodies	4.07	0.1	5	Very high

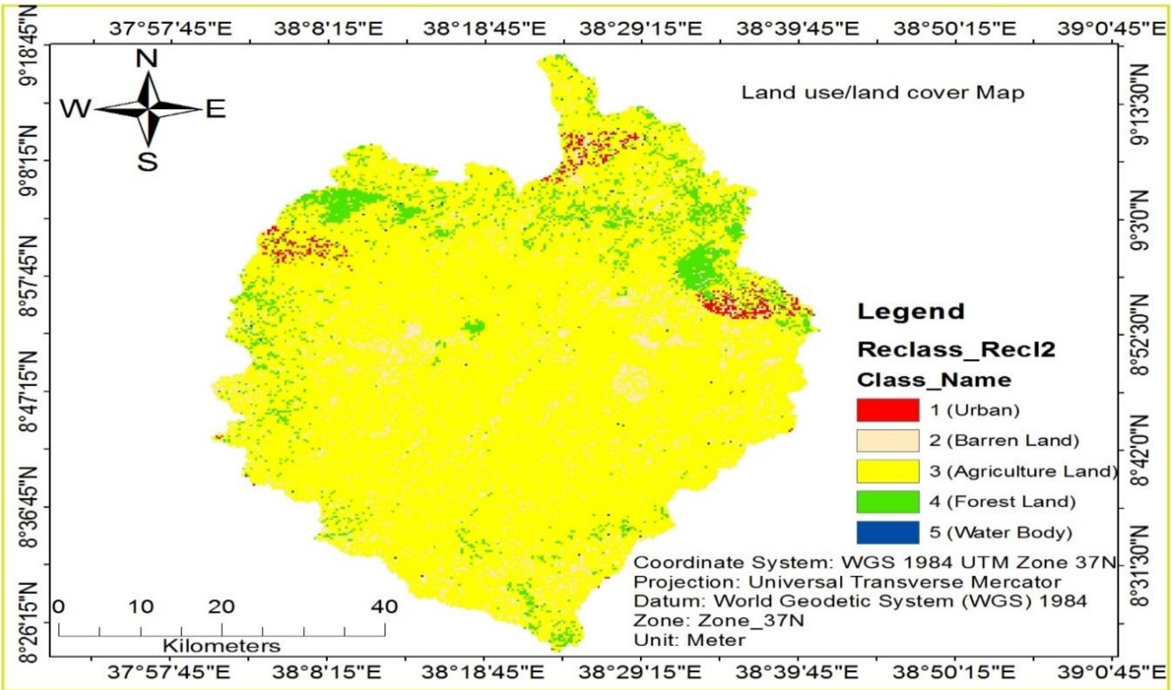


Figure 21: Reclassified land use/land cover map of the study *area*

4.2.5 Lineament density map

Lineament density of the study area was very important in groundwater potential and recharge zone identification because those lineament structure are served as a conduit for groundwater movement (increase infiltration capacity and have high water holding capacity). According to Jhariya *et al*. (2016) it was correlated with faults, fractures, joints, bending plane and geological contact that describe the groundwater potential and recharge zone of the study area. The lineament density map of the study area was mapped as shown on Figure 11.

Reclassified lineament density map of the study area generated was extracted from lineament map shown on Figure 11 and their suitability were ranked into five class as their influence on the groundwater and recharge as indicated on Figure 22. As seen in figure 22 lineament density in the study area ranges from 0 to 0.76 km/km^2. In the study area, very high lineament density was 0.45-0.76 km/km^2, high was 0.32-0.44 km/km2, moderate was 0.2-0.31 km/km^2, low was 0.07-0.19 km/km^2 and very low was 0-0.069 km/km^2 which covers 2.7%, 6.7%, 15.9%, 9.9% and 64.9% respectively (as coverage indicated in Table 33). Lineament orientation analyzed by creating rose diagram using Rockworks 17 software. From hydro-geological point of view, groundwater flow direction follows the orientation of lineament direction. In this study the most dominant of the lineament structural densities direction are found in N-S and NW-NE part of the study area and few are aligned towards E-W, NE-SW and NW-SE direction (Figure 22). Therefore, N-S and NW-NE region were expected to have high groundwater potential and recharge because the presence of lineament denotes as permeable zone.

According to Suganthi *et al*. (2013) high lineament density value indicate high weight value or suitability for GWP and recharge zone whereas the low weight value for groundwater potential area is low lineament density area. So, in case of this study, the highest lineament density shows the highest groundwater potential and most suitable for recharge because it has more joints and faults that infiltrate water to groundwater table and the lowest lineament density shows the lowest groundwater potential and the least suitable for groundwater recharge because those area has very low joints and faults for permeability of water to groundwater table, so lineament density has direct relationship with groundwater potential and recharge zone. Therefore, the suitability classification) of the study is acceptable because the result under the range of finding stated above. The lineament density map was reclassified into five classes as per suitability rank for groundwater occurrences (Figure 22).

Table 33: Lineament density suitability class for GWP and recharge zone identification

Factor	Lineament Density. Km/km2	Description	Area (km2)	Area (%)	Rank	Suitability Classification
Lineament density	0-0.069	Very low density	2817.1	64.9	1	Very low
	0.07-0.19	Low density	428.81	9.9	2	Low
	0.2-0.31	Moderate density	690.50	15.9	3	Moderate
	0.32-0.44	High density	289.29	6.7	4	High
	0.45-0.76	Very high density	115.59	2.7	5	Very high

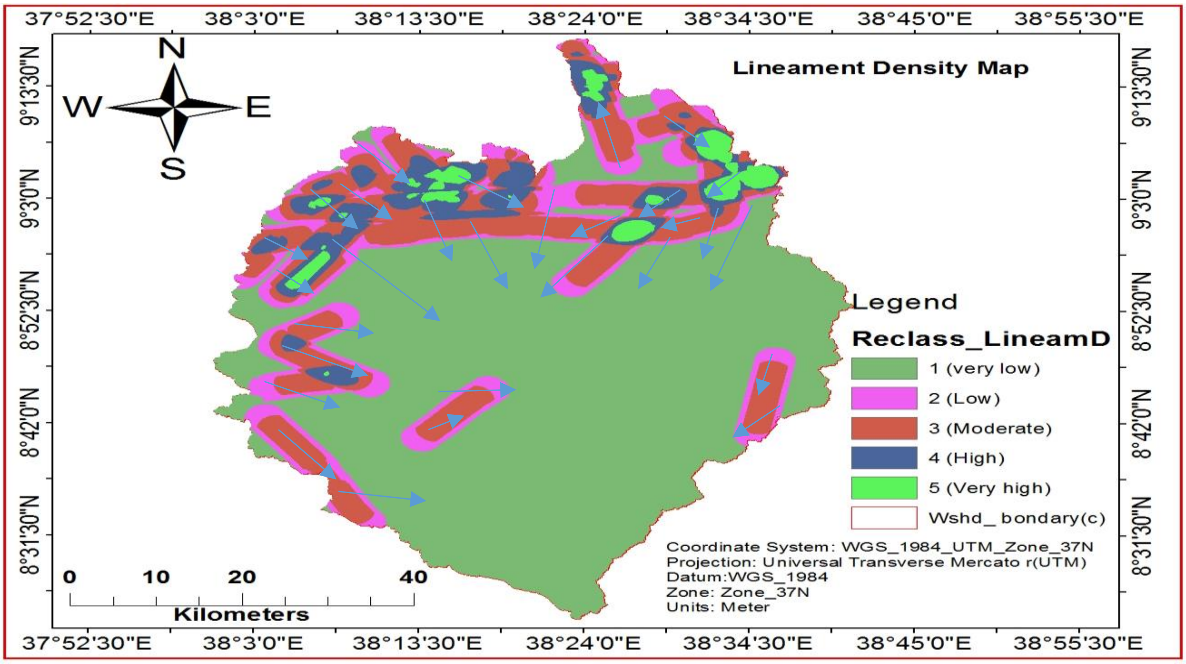


Figure 22: Reclassified Lineament density map of the study area

4.2.6 Rainfall map

Rainfall is the most dominant factor for existence of groundwater recharge and considered as the major water source for groundwater recharge in the study area. As provided in methodology part, the mean annual rainfall of the study area was calculated by mean arithmetic mean method which ranges from 1050mm in upland (plateaus) areas at which Awash River emerge and 850mm in lowland (rift) areas. Most the study areas was dominant with medium average annual rainfall 960mm within the range of (870-1050)mm especially in central, north and south west of the study areas but high rainfall areas usually found in highland (i.e. south west and north west) which cover small land (part) of the study (Figure 13).

As seen from reclassified rainfall map of Figure 23 higher rank (5), high rank (4), moderate rank (3), low rank (2) and lower rank (1) were given for the classes of 1110 to1200mm, 1010 to 1100mm, 901 to 1100mm, 801 to 900mm and 708 to 800mm which covers (as shown in Table 34) 0.1%, 14.2%, 77.0%, 7.9% and 0.8% of the study area and considered as; very high, high, moderate, low and very low groundwater potential and recharge zone respectively because, the higher rainfall result areas; the higher suitability for recharge and the higher chance to develop groundwater potential whereas the lowest rainfall area; the lowest recharge and the lowest groundwater potential. Here, according rainfall characteristics the higher groundwater potential is found to be at moderate rainfall class which covers 77.0% of the study areas however groundwater is less affected by rainfall than other factors affect groundwater of the areas.

The suitability classification of rainfall map classified and result agreed within and according different research studies such as; Abdul-Aziz *et al.* (2016) which conducted on evaluation of groundwater potential using geospatial techniques at northern Ethiopia, Wollo zone, in Gerardo river catchment and (Thapa and Gupta, 2017) which conducted on assessment of groundwater potential using MIF in India, West Bengal, Birbhum district. Therefore, the result of the this study was acceptable for mapping groundwater potential and recharge zone based on suitability rank; the high rainfall areas were reclassified as very high to moderate zones for groundwater potential and recharge, and small rainfall areas were reclassified very poor zone.

Table 34: Rainfall suitability class for GWP and recharge zone identification

Factor	Mean Annual RF (mm)	Area(km^2)	Area (%)	Rank	Suitability Classification
Rainfall	708-800	35.8	0.8	1	Very low
	801-900	342.2	7.9	2	Low
	901-1010	3342.5	77.0	3	Moderate
	1010-1100	616.5	14.2	4	High
	1110-1200	3.8	0.1	5	Very High

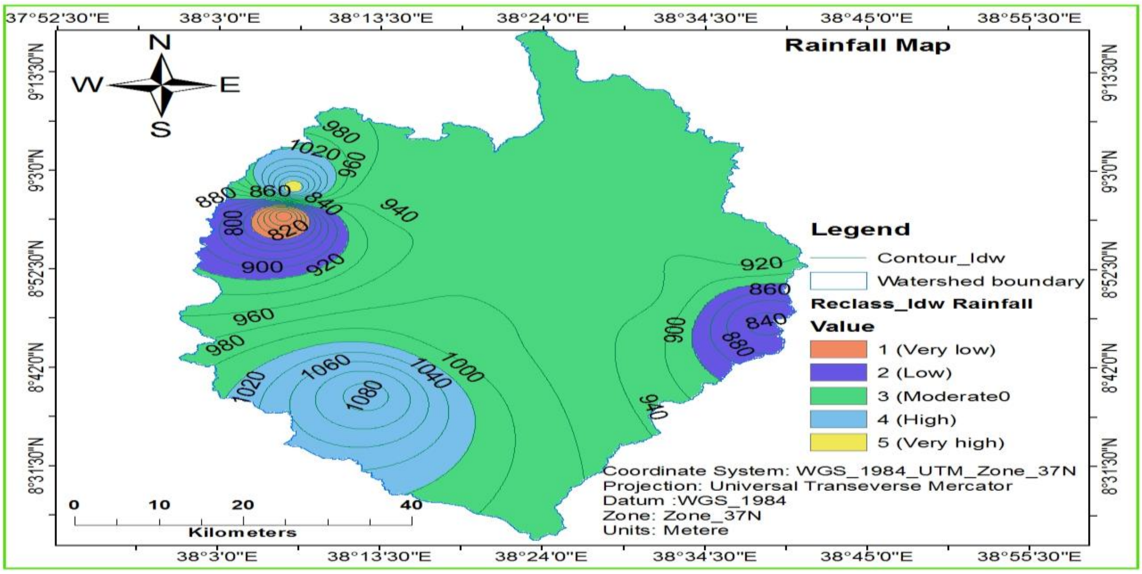


Figure 23: Reclassified rainfall map of the study area

4.2.7 Drainage Density

Drainage density is the hydrological parameter which is extracted from stream network in order to generate drainage density map of the study (Figure 8). As provided in methodology part, the density of drainage was calculated by divide total length of the stream network of the whole watershed to total watershed areas then after mapping drainage density by using line density tool in spatial analysis tool. The drainage density of the study area ranges from 0 to 0.89 km/km^2 (Figure 8).

Hence, as indicated on Figure 24 the delineated drainage density map of the study area was reclassified into five class as per suitability rank for potential groundwater and recharge zone. These were; 0-0.2 km/km^2 was cover 74.5%, 0.36-11 km/km^2 was cover 10.5%, 12-30 km/km^2 was cover 7.9%, 21-33 km/km^2 was cover (as shown in Table 35) 5.7% and 34-60 km/km^2 was cover 1.4% of the study area and considered as very low, low, moderate, high and very high drainage density which is classified as very good, good, moderate, poor and very poor respectively based on the suitability of groundwater (Figure 24). Here the lowest drainage density reduce the runoff potential and enhance infiltration capacity of water to groundwater and causes the occurrence of highest groundwater potential and recharge whereas the highest drainage density increase the runoff and decrease infiltration of water to the ground which causes the low suitability groundwater occurrence and recharge of the areas.

This suitability classification of the drainage density of the study was acceptable as compared with other finding done by (Salwa, 2015; Bereket, 2017) which conducted on groundwater potential mapping in weito sub-basin, Ethiopia and an overview of integration of GIS and RS for groundwater potential mapping in Egypt, respectively and all result agreed with them as within the range. Therefore, it's acceptable for mapping groundwater potential and recharge zone of the study areas.

Table 35: Drainage density suitability class for GWP and recharge zone identification

Factor	Drainage density. km/km^2	Description	Area (km2)	Area (%)	Rank	Suitability classification
Drainage density	0-0.18	Very low density	2786.2	64.2	5	Very high
	0.9-0.36	Low density	983.40	22.7	4	High
	0.37- 0.54	Moderate density	391.05	9.0	3	Moderate
	0.55-0.71	High density	151.06	3.6	2	Low
	0.72-0.89	Very density	29.67	0.7	1	Very low

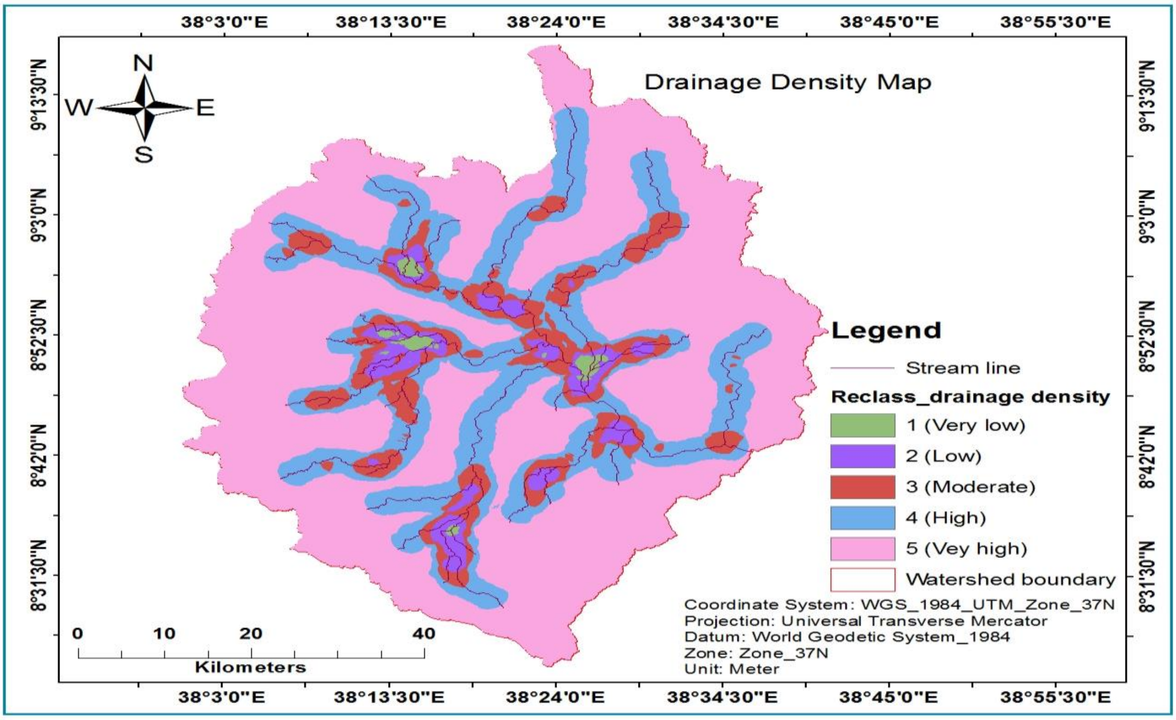


Figure 24: Reclassified drainage density map of the study area

4.2.8 Soil

Soil plays an important role in the occurrence and movement of groundwater in the study area. For this study both soil types and texture were consider comparatively. Soil types affect the water holding and infiltration capacity of soil while the texture of the soil particularly plays an important role in determining the infiltration which control the penetration of surface water into aquifer and run-off on surface and sub-surface of the land in the study area. Soil types and textural class map of the study area was mapped as Figure 15.

As shown on Figure 25 the reclassified soil types and texture map was found around northern, western and southern part of the area have a coarse grain soil type (sandy clay loam and silt loam) with nitisols, leptosols and luvisols soil types, which is suitable for water infiltration (groundwater recharge). The clay soils texture and vertisols soil types in the middle and eastern part of the study area are poor and moderately suitable for groundwater recharge. But there is high groundwater potential here due to ground flow from sloped areas because of geological characteristics, high lineament density and other factor. As described in Table 36 from the total study area the very poor zone has highest area of coverage which is cover around 63.1% and the moderate, good and very good classes which cover 5.62%, 17.1% and 8.62% of the total study area as classified as suitability class for groundwater recharge respectively.

Table 36: Soil types and texture suitability class for GWP and Recharge zone identification

Factor	Soil Types	Soil texture	Rank	Suitability classification
Soil types and texture	Vertisols	Clay	1	Very poor
	Nitisols	Clay Loam	2	Poor
	Leptosols	Loam	3	Moderate
	Cambisols	Sandy clay loam	4	High
	Luvisols	Silt loam	5	Very high

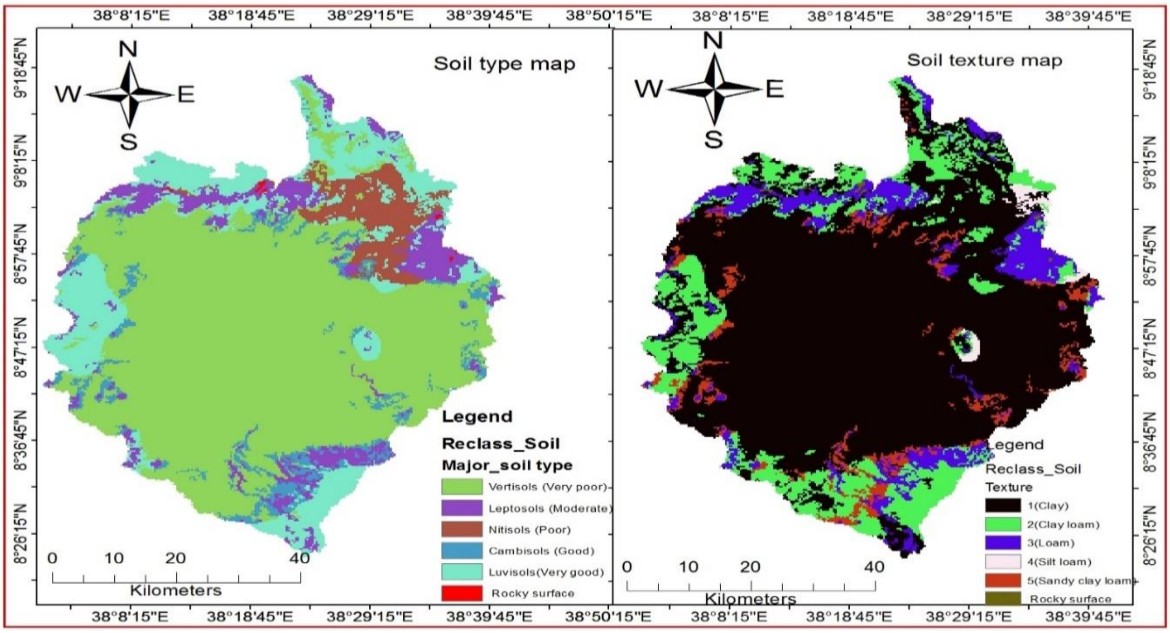


Figure 25: Reclassified map of soil type and texture

4.3 Groundwater Potential Zone Map

The groundwater potential zone were delineated by weighted, normalized and finally overlaid the reclassified thematic layers. The factors used to generate groundwater potential zone map were lithology, geomorphology, slope, lineament density, land use/cover, rainfall, drainage density and soil. The delineated the groundwater potential zone map (GWPZ) is developed by weighted overlay by linear combination of all thematic layers (map) affect groundwater potential of the study according to equation 21:

$$GWPZ = 37\%*Lir + 22\%*Gmr + 14\%*Slr + 10\%*LuLcr + 8\%*Ldr + 4\%*RFr + 3\%*Ddr + 2\%*Sr \quad (21)$$

Where, GWPZ = groundwater potential zone, 37%, 22%, … and 2% = normalized weight of thematic map and r_i = reclassified normalized weight of the individual feature of thematic map (rank).

The result of overall integration of thematic layers revealed that the study area can be categorized into four suitability classes of GWP zone described as very low (1), low (2), moderate (3), and high (4) (Figure 26) which cover 1. 1%, 20. 5%, 53. 7% and 25. 7% of the total study areas (Table 37) respectively. From the total study area, the very low zone has the smallest area of coverage (47. 8 km^2) and the moderate zone has the highest area of coverage (2308.0 km^2) relative to others (Table 37) and (Figure 26). The overall areal coverage of groundwater potential zone maps of the study area are summarized in Table 35.

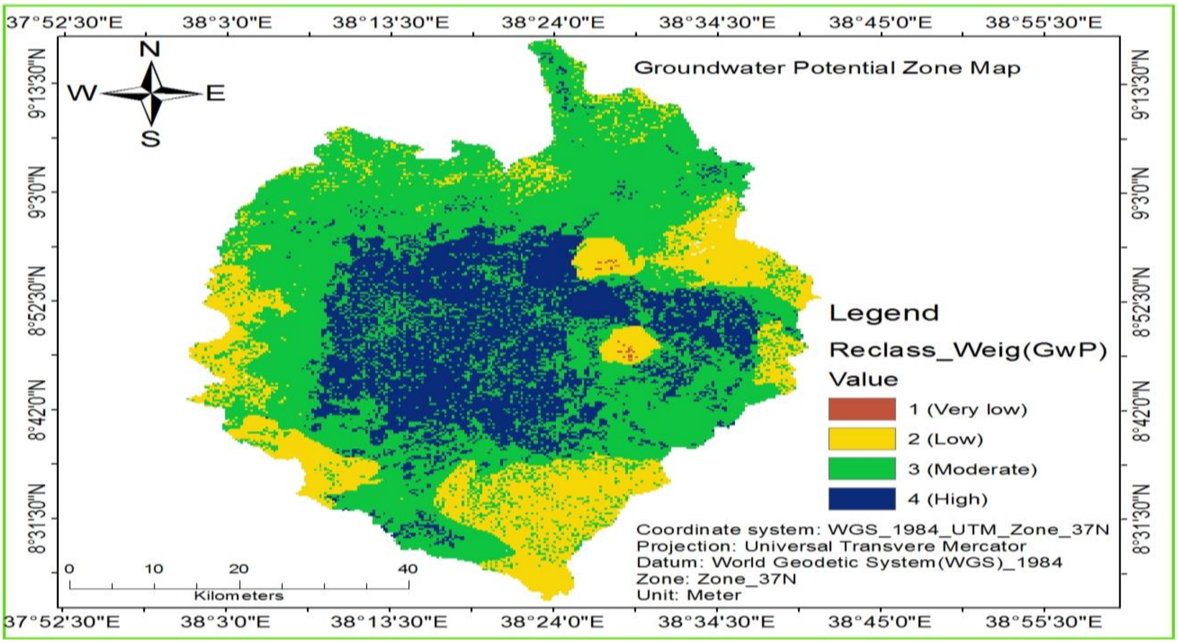


Figure 26: Groundwater Potential Zone map

Table 37: Suitability class and areas of Groundwater Potential Zone

No.	GWP rank/index value	Groundwater Potential Zone (Suitability class)	Area (km^2)	Area (%)
1	1	Very Low	47.8	1.10
2	2	Low	880.0	20.49
3	3	Moderate	2308.0	53.73
4	4	High	1105.6	25.74

4.4 Groundwater Recharge Potential Zone Map

The reclassified factors affecting the existence of groundwater recharge zones were weighted, normalized and finally overlaid to generate groundwater potential map. The parameters used for delineation of groundwater potential zones were; slope, soil, land use/cover, drainage density, lineament density, geomorphology, lithology and rainfall. The delineated the groundwater recharge zone map (GWRZ) was developed by weighted overlay by linear combination of thematic layers of factors affect groundwater recharge potential of the study area as equation 21.

$$GWRZ = 33\%*RFr + 23\%*Ldr + 16\%*Lir + 9\%*Gmr + 8\%*Slr + 5\%*Ddr + 4\%*Sr + 2\%*LuLcr \quad (22)$$

Where, GWRZ = groundwater recharge potential Zone, 33%, 23%, …. and 2% = normalized weight for thematic map and r_i = reclassified normalized weight of the individual feature of thematic map (rank).

The result of overall integration of reclassified thematic layers revealed that the groundwater recharge potential zone of the study area was classified into three suitability classes described as low (2), moderate (3), and high (4) which cover 10. 2%, 84. 0% and 5. 8% of the total studying areas respectively as shown on Figure 27 and Table 38. The delineated groundwater recharge zone map shows that the most part of this study area has moderated groundwater recharge zone which 3369.6 km^2 of total studying areas. The remaining areas were reclassified as the high, and low groundwater recharge zone which cover 304.3 km^2 and 110.98 km^2 of total studying areas. The overall areal coverage of groundwater recharge zone maps are summarized in Table 38.

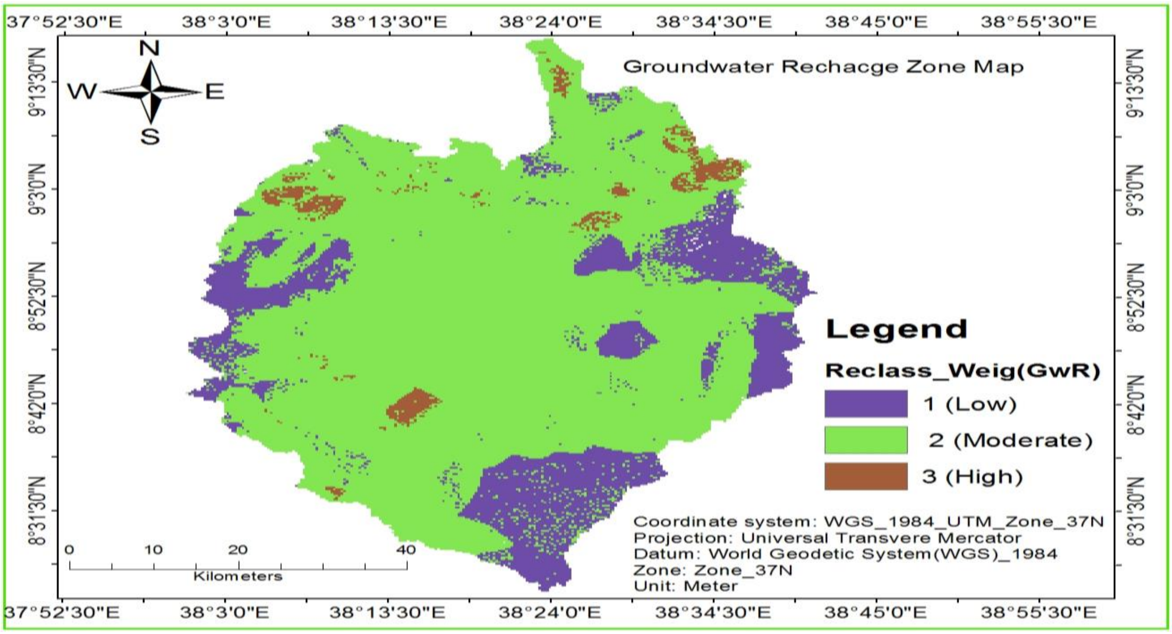


Figure 27: Groundwater Recharge Potential Zone Map

Table 38: Suitability class and areas of groundwater recharge potential zone

No.	GWR rank/ index value	Groundwater Recharge Zone (Suitability Class)	Area (km^2)	Area (%)
1	2	Low	443.5	10.2
2	3	Moderate	3647.9	84.0
3	4	High	250.2	5.8

4.5 Validation of Groundwater Potential Zone Map

Mapping of groundwater potential zone by using GIS and remote sensing techniques with existing conventional data was validated when existing water inventory point was a close agreement with groundwater potential zone delineated. For this validation, more than one hundred or (around 109) water inventory point was collected from OWWDSE and MoWIE as shown by Appendix Table 8. The point data of borehole (shallow and deep well depth), and springs were overlaid on the result of groundwater potential zone map (Figure 26 above) and they coincide with the expected result. Those are 52 water point from shallow borehole well, 46 from deep borehole well and 11 from spring water source (Appendix Table 4).

As viewed on the validation map (Figure 28), most water point data (validation data) were found in high and moderate groundwater potential zone and few of them were found in low groundwater potential zone. However, in very low groundwater potential zone no water point data are found. This indicates the suitability of such area for groundwater potential and recharge is very low as characterized above in factor influence groundwater potential and recharge zone occurrence which is resulted in very low possibility of getting groundwater.

Table 39: Total number of water inventory point in different GWPZ

S.No		Groundwater potential zone suitability class				
	Expected GW potential	High	Moderate	low	Very low	Total
1	Total number of validation under different GWPZ	44	49	16	No data (dry well) -	109
2	No of valid under agree	40	42	14	-	96
	No of valid under disagree	4	7	2		13
2	In present (%)	91%	86%	88%	-	-
3	Well yield (l/s) (average)	87.5	35.5	16.7	1.8	-
4	Transmitivity (m^2/d)	1523.5	1470	127	-	-

Prediction accuracy(%) = $\left(\frac{\textbf{No of valid under agreement}}{\textbf{Total no of validation under different GWPZ}}\right)*100 = 88\%$

Therefore, from the total water inventory point (validation data) 91% data was overlaid on high groundwater potential zone, around 86% were overlaid on moderate groundwater potential zone and 88% of the total validation data was overlaid on low groundwater potential zone. However, no water point is found on very low groundwater potential, this shows the possibility of getting groundwater potential here is very low. In generally, as shown on Figure 28 the number of water inventory point on low groundwater potential zone are also few number which indicates the possibility of groundwater occurrence is low.

Generally, groundwater depth is varying from place to place due to variation of physiographic characteristic, rainfall and geologic type. High potential zone characterized by high yield and low potential characterized by low yield. Accordingly as indicated in Table 39, groundwater well yield less than 1.8.L/s very low, 16.7-35.5l/s low, 35.5-87.5l/s moderate, greater than 87.5l/s high and groundwater zones relative to groundwater wells yield data found in the watershed even there is no general classification of groundwater potential zones.

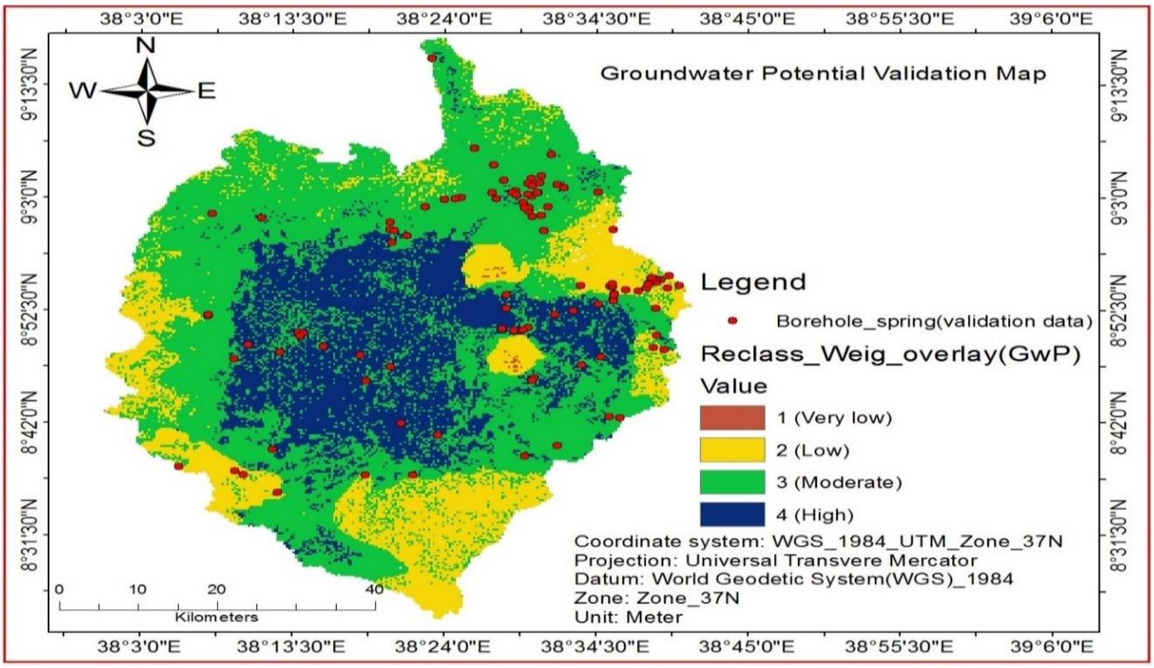


Figure 28: Validation map of Groundwater potential zone map

4.6 Sensitivity of Factor Influence GWP and recharge

The sensitivity analysis was performed to assess the difference in the effect of each factor on the groundwater potential zone of study area. It was done by AHP and checking by removing each thematic layer one by one. If one of the thematic layers was removed at a time and the critical thematic layers in varying the output map (GWP validation map) of the study area were identified. This shows that the generated output map was highly sensitive to the thematic layer having high weight of influence (% Influence).

In this particular study, lithology was the first influential thematic layer (% Influence = 37%) to determine the output map of the GWP zone of the study area. Geomorphology and slope were also the 2nd and 3rd influential thematic layers which account 22% and 14% of influence. On other hand, the least influential factor for the output map determination of this study were drainage density and soil which account 4% and 2% of influence respectively (Table 40).

Table 40: Weight (Percentage of influence) of factors influence GWP and recharge

S.No.	Factors	GW potential		GW recharge	
		Weight (Wn)	Weight (%)	Weight (Wn)	Weight (%)
1	Lithology	0.37	37	0.16	16
2	Geomorphology	0.22	22	0.09	9
3	Slope	0.14	14	0.08	8
4	Land use/land cover	0.10	10	0.02	2
5	Lineament density	0.08	8	0.23	23
6	Rainfall	0.04	4	0.33	33
7	Drainage density	0.03	3	0.05	5
8	Soil	0.02	2	0.04	4
	Sum	1.00	100	1.00	100

Also, for GWR prospect map delineated for the study area, rainfall was the first influential thematic layer (%influence = 33%), and lineament density and lithology were the 2nd and 3rd influential thematic layers which account 23% and 16% of influence. On other hand, the least influential factors were drainage density, soil and land use/cove which account 5%, 4% and 2% of influence respectively (Table 40).

4.7 Groundwater Flow Direction of the Study Areas

The direction of flow of groundwater is shown from groundwater contour map. Hence, groundwater contour map for the shallow and deep aquifer system of the study area is generated from well point of static water level (SWL) in order to understand the flow direction. In most parts of the area groundwater level distribution is similar to the topography (slope), which follows the elevation variation. Accordingly, the inclination of the topography (slope) factor, geomorphology and aquifer (lithological) characteristic and lineament density and alignment are the most important factor control groundwater flow direction because this factor are more susceptible for groundwater flow system occurring .

The groundwater flow direction in melka kunture watershed area tends to be towards the becho plain and surrounding areas, and main Awash River. Generally, it is possible to say the topographically highlands (some ridges) are considered as recharge areas whereas lowlands (flat to gentle) are groundwater storage potential and/or discharge areas (Figure 29) and also the detail was described in Appendix Figure 4 and 5 in both 2D and 3D.

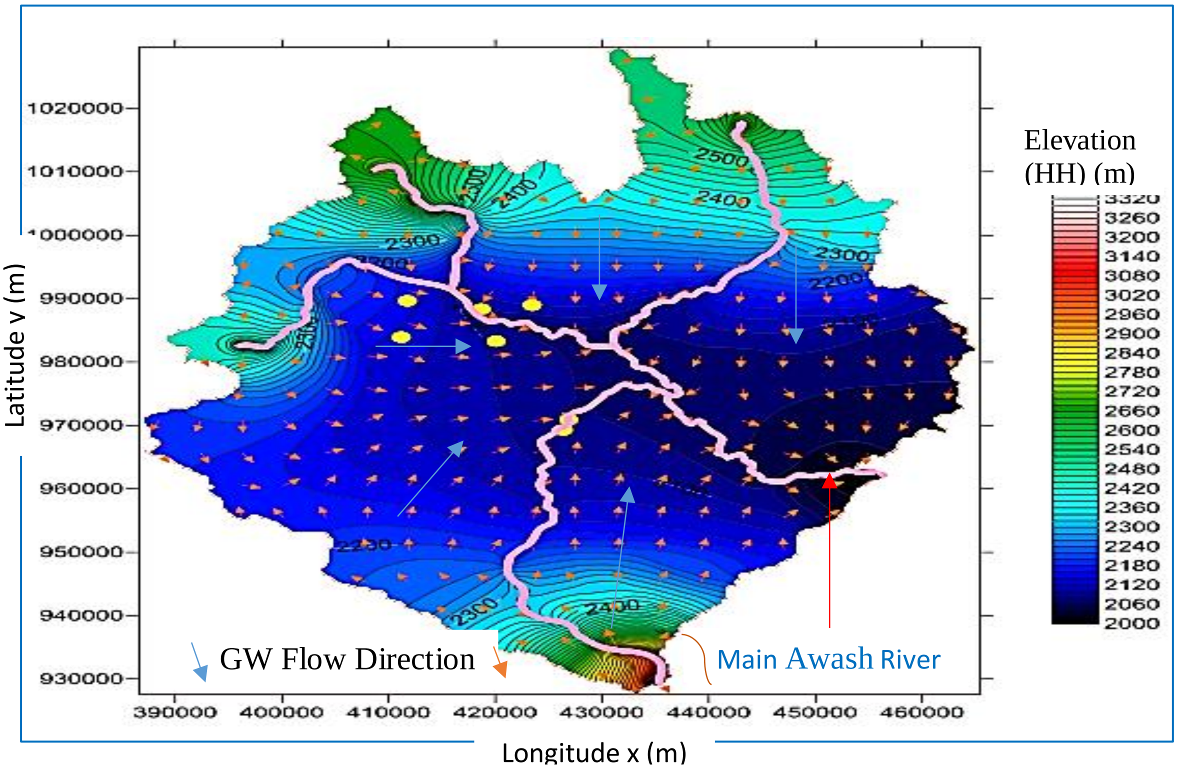


Figure 29: Groundwater flow direction of the study areas (Melka Kunture Watershed)

4.8 Discussions

4.8.1 Identified factors influence GWP and recharge and suitability level

The occurrence and movement of groundwater controlled by various factor, and each factor has its own weight depending on their influencing on the groundwater storage and movement. Those factor influence groundwater potential and recharge zones were identified (selected) depend on past studies and knowledge based studies with experts considering three criteria: Frequency of factor usage, criticalness of factor and ease/difficult of data access. According to these criteria, eight factors were selected or identified and considered as the main factor influence GWP and GWR of the study area. Those factors are includes lithology, geomorphology, slope, lineament density, rainfall, land use/cover, drainage density and soil. All those factors do not have equal importance in governing groundwater occurrence and movement. Due to this, weighted value determination through AHP techniques be very important after all factors affect groundwater are selected, and organized in pair-wise Comparation matrix (Fashae *et al.*, 2014; Tesfaye, 2015; Abdul-Aziz *et al.*, 2017; Das, 2018). In this study, lithology, geomorphology and slope are the main control (influence) of groundwater occurrences and movement (GW potential site) while rainfall, lineament density and lithology are the main cause of GW recharge occurrences, and potential site selection according to percentage of influence (weight). Their assigned weight are 37%, 22% and 14% for GW potential zone respectively and 33%, 23% and 16% for groundwater recharge zone respectively. According to Satty (1980) the consistency of weighted comparison analysis (in pair-wise comparison) of those factors are checked, which should be less than 0.1. While deriving the weight of each factor for the present study, the CR value was 0.05 for GWP and 0.03 for GWR which is less than 0.1 and it’s acceptable for further analysis of those factor influence groundwater.

4.8.2 Delineated suitable groundwater potential and recharge zone map

The delineated suitable groundwater potential zone map shows that the study area was classified into four suitability class such as high (4), moderate (3), low (2), very low (1) which covers 25.74%, 53.75%, 20.49% and 1.1% of total study areas respectively (Table 39). High groundwater potential zone in this study was identified around level plateau/semi-plain landforms with slope of 0º to 5.34º (degree) overlaid in Addis Ababa ignimbrite, basalt and in the alluvial deposit due to its primary porosity which is dominated around central part of the study area. The moderate groundwater potential zone was observed in irregular plain (undulating plateau, level piedmont and foot slope) landform with slope 5.35º to 10.4º (degree), at a moderate rainfall and around moderate to a very high fracture overlaid in Tarmaber basalt and Weliso Ambo basalt are found.

Low and very low groundwater potential zone in the study area was observed in Central volcanic geological unit that comprises Wechecha, Furi, and Yerer trachytic and porphyritic lavas and Entoto ridge. The others cause of this low to very low potentiality of groundwater occurrence in this study area is in hilly/mountain with slope of greater than 17.1º (degree) and high drainage density found in the area which is resulted in low to a very low groundwater potential zone. Because the higher drainage density here resulted in lower infiltration and higher runoff, which is result in the occurrence of lower groundwater potential.

The delineated groundwater recharge zone map was similarly another map which shows groundwater recharge potential of the study areas. According to suitable for groundwater recharge, this map was also classified as high (4), moderate (3) and low (2) which covers 5.8%, 84.0% and 10.2% of total study areas respectively (Table 39). High GWRP zone were characterized by high lineament density, lowland areas, plain to semi-plain geomorphic features and moderate precipitation areas which cover only 5.8% of the total study areas in the northern and from central to south part of the study areas. Moderate groundwater recharge zone areas were distributed in the most central part of the study areas which cover 84.0% of the total study areas. It were found at central, northern and some southern part of the study areas at moderate to low sloped, semi-plain with having moderate to high precipitation distribution and cultivated/agricultural areas. Low groundwater recharge zone were also characterized by highly slope (sharp land) which have low precipitation distribution, high runoff and heavy clay soil because such areas causes runoff rather than enhancing infiltration/recharge to groundwater.

In this study areas, the highest rainfall is observed in highland (hilly/mountain and steep slope), which is the main source of recharge in areas. This recharged rainfall flow to lowland (flat/semi-plain areas) due to topographic effect and structural discontinuity or through interconnected pore, open joints and fissures. So, this is the reason why gave high weight for rainfall (33%) in the analysis of factor influence groundwater recharge. Therefore, due to topographic effect, and other thematic layers, this high rainfall areas were resulted in low to high groundwater recharge zone. Next rainfall, high groundwater recharge zone is in the study area was observed around where high lineament density are found. Here, high lineament density is indicated the existence of high pore space (secondary porosity), open joints, fissures and fractures which is highly responsible (facilitate) for high infiltration rate or recharge from precipitation and decrease runoff which resulted in high groundwater recharge potential zone occurrences. Therefore, this is the reason why gave high weight assigned to lineament density (23%) next rainfall factor in the weighted comparison analysis of factor influence groundwater recharge zone. The land use/land cover of this study have also significant role in the existence of high groundwater potential and recharge. The existence of wetland and water bodies (e.g. Becho swamp) at becho plain indicate existence of high groundwater potential whereas, the place where land coved by forest/woody land and cultivation land, the occurrence of groundwater recharge is high because it more susceptible for infiltration and it also intercepts surface runoff which result in high groundwater recharge zone of the areas.

Table 41: Suitability Level class of factors for identifying potential site for GWP and recharge

Factor	Suitability class				
	5	4	3	2	1
Li	Qal	NadI	NakB/PNtbB	QwaB/NebRy	NcvTy
Gm	level plain	level plateau/ semi-plain	piedmont plain/foot slope	undulating plateau/rolling	mountain/hill y/escarpment
S	0-5.34	5.35-10.4	10.5-17.1	17.2-27.3	27.4-68.1
Lulc	wetland/ water bodies	forest /woody land	agriculture/culti vated/grass land	bare land	urban/settlem ent land
L.D	0.45-0.76	0.32-0.44	0.20-0.31	0.07-0.19	0-0.069
R.F	1110-1200	1010-1100	901-1010	801-900	708-800
D.D	0-0.18	0.9-0.36	0.37-0.54	0.55-0.71	0.72-0.89
Soil	course	medium and course	fine and medium	medium	fine

4.8.3 Capability of GIS and RS technology in mapping GWP

From objective aspect of the study, GIS, RS and AHP techniques have been shown to be powerful for preparing, analysis and integration of thematic layers of surface feature for mapping groundwater potential and recharge site, and are economic and time effective. In this study GIS technology was used in thematic layer preparation, spatial integration or overlay into one layer and analysis for each factor influence GWP and recharge and has an ability to demarcate the study area (site) into different groundwater potential. On the other hand, RS was the major source of hydrological and geographical information on the study area by constructing fundamental data base to complete each objective of the study. To verify the accuracy of the proposed method, the location of GWP map delineated was checked against the existing water resource inventory point which was performed by using overlay analysis tool implemented in ArcGIS software. Therefor GIS has been the most powerful techniques in assessing the suitability analysis and good tools to delineate GWP and recharge by integrate different thematic layers.

In this study, the identified groundwater potential were validated by using water source inventory data in GIS environment. The validation result showed that the method applied (GIS and RS techniques) for this research analysis and integrate different factors in details and produced significant, reliable and precise groundwater potential zone. All works fully completed in GIS and RS to successfully carry out all the objective of the study, this study has demonstrated the capabilities of a GIS and RS techniques for delineated groundwater potential zone in the given areas.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Groundwater is the most valuable natural resources for sustainable development of the country. The identification, delineation and evaluation of these resources were so the most desirable and the main work in this study. The identified and delineated groundwater potential and recharge zones of the present study area was the result of integrated GIS and remote sensing techniques with multi-criteria decision analysis (MCDA)–analytic hierarchy process (AHP) method. In this study GIS is the most appropriate tool for the mapping of groundwater potential and recharge zones effectively with more accurate, low cost and short period. The thematic map of the factors were prepared after identifying the main factors influence groundwater potential and recharge based on appropriate selection criteria set. The identified factors for this study area was includes geology, geomorphology, slope, lineament density, land use/land cover, rainfall, drainage density and soil. These eight parameters were weighted and ranked by AHP method in pair-wise comparison matrix (PCM) based on their influence on groundwater potential and recharge zone. The weighted comparison analysis by AHP were accepted after consistency ratio are checked by normalization and become less than 0.1, otherwise reevaluated. For this study, the consistency ratio are 0.05 and 0.03 for factor used to delineate groundwater potential and recharge zone respectively. In this study the highly weighted were assigned for geology, geomorphology, slope and lineament density for groundwater potential, whereas, rainfall, lineament density, geology and geomorphology for groundwater recharge in consecutive decreasing order and which were considered as the most factor influencing groundwater potential and recharge zone.

The eight thematic layers were overlaid by weighted overlay analysis (WOA) in ArcGIS after extract/export raw data from reclassified each thematic layers, converted vector data to raster, resample to the same cell size, and projected all layer on the same projected coordinate system. The overlaid thematic layers were reclassified groundwater potential zone into four suitability classes or zones which named as very low, low, moderate, and high, and groundwater recharge into three classes which named ass low, moderate, and high. Therefore, the study has resulted the groundwater potential and recharge zone map for Melka Kunture Watershed of Upper Awash River Basin which delineated in four classes (zones) with very low, low, moderate and high, and three classes (zones) with Low, Moderate, and high respectively. The delineated groundwater potential zone map was cover very low (1.1%), low (20.5%), moderate (53.7%) and high (25.7%) and the delineated groundwater recharge zone map was cover low (10.2%), moderate (84.0%) and high (5.8%) of the total study area.

High groundwater potential zones were represented by ignimbrite lithological unit and alluvial deposits, flat and semi-plain, which coincide with low slope, very low drainage density and very high and high lineament density. The moderate groundwater potential zones were found in Tarmaber basalt and Akaki basalt lithological unit, undulating/rolling, level piedmonts and foot slope, which coincide with the gentle slope, low drainage density and high and moderate lineament density. The very low and low groundwater were found around central volcanic of Wechecha, Furi and Yerer, and Weliso ambo basalt and Entoto becho-rhyolite lithological unit, in hilly/mountain, which coincide very high and steep slope, high drainage density and low lineament density.

In addition to groundwater potential zone, the groundwater recharge zone were identified based the thematic layers prepared from factor influencing groundwater recharge because all factors has no equal significant for delineating groundwater recharge zone. Groundwater recharge zone highly influenced by rainfall coincide with high lineament density. The high groundwater recharge zone is found in high lineament density. Finally, it can be concluded that integration of GIS and remote sensing techniques are very efficient and useful, time and cost effective tools for identification and mapping of groundwater potential and recharge zone.

5.2 Recommendations

Based on the results of the study found and challenges faced during this pieces of work, the following recommendation are forwarder:

- The integration of GIS and RS techniques with MCDA-AHP method is a very powerful tool in mapping of groundwater potential and recharge zone.
- Considering many types factor (thematic layers) influencing groundwater potential and recharge occurrence have significant importance for detailed groundwater potential and recharge zone identification.
- It is recommended to use the current or more resent conventional existing data with high resolution of satellite image for effective identification and preparation of thematic layer for factor influence groundwater potential and recharge and mapping of groundwater potential zone.
- Any water expert can use this map for further geophysical investigation before well drilling (exploration) as guide line to minimize the cost and time wasted to excavate and misplaced of geophysical investigation.
- Detail study on hydrogeological condition of the area in such study is important.
- For further validation to promote these techniques, well drilling or pump test using geophysical investigation is important and advisable on identification of groundwater potential and recharge zone

REFERENSES

Abdel Rahman Rakad Al-shabeeb. 2015. *A* Modified Analytical Hierarchy Process Method to Select Sites for Groundwater Recharge in Jordan Thesis Submitted for the Degree of Doctor of Philosophy at the University of Leicester.

Abdul-Aziz Hussein, Vanum Govindu, and Amare Gebre Medhin Nigusse. 2017. "Evaluation of Groundwater Potential Using Geospatial Techniques." *Applied Water Science* 7(5): 2447–61.

Abel Abeba. 2017. "Evaluation of Recharge and Shallow Groundwater Dynamics in the Upper Awash Basin, Central Ethiopia." Unpublished M.Sc.Thesis, Addis Ababa University, Addis Ababa, Ethiopia.

Anbazhagan, S., and A. Jothibasu. 2016. "Geoinformatics in Groundwater Potential Mapping and Sustainable Development: A Case Study from Southern India." *Hydrological Sciences Journal* 61(6): 1109–23..

Andualem Eshetu. 2008. "Evaluation of Ground Water Resources Potential of the Teji River Cathment South West Shoa Zone, Oromia Region,

Argaz, A et al. 2019. "Application of Remote Sensing Techniques and GIS-Multicriteria Decision Analysis for Groundwater Potential Mapping in Souss Watershed, Morocco." *J. Mater. Environ. Sci* 10(5): 411–21. http://www.jmaterenvironsci.com.

Arulbalaji, P., D. Padmalal, and K. Sreelash. 2019. "GIS and AHP Techniques Based Delineation of Groundwater Potential Zones: A Case Study from Southern Western Ghats, India." *Scientific Reports* 9(1): 1–17.

Badamasi, Sani, B A Sawa, and M L Garba. 2016. "Groundwater Potential Zones Mapping Using Remote Sensing and Geographic Information System Techniques (GIS) in Zaria , Kaduna State , Nigeria." 2: 51–63.

Bane Lammesa. 2017. Groundwater Potential and Recharge Zone Mapping Using GIS and Remote Sensing Techniques in the Case of Middle Awash River Basin, Ethiopia: Unpublished M.Sc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia.

Bereket Bezabih Bashe. 2017. "Groundwater Potential Mapping Using Remote Sensing and GIS in Rift Valley Lakes Basin, Weito Sub Basin, Ethiopia." *International Journal of Scientific & Engineering Research* 8(2): 43–50. http://www.ijser.org.

Das, Biswajit, Subodh Chandra Pal, Sadhan Malik, and Rabin Chakrabortty. 2018. "Modeling Groundwater Potential Zones of Puruliya District , West Bengal , India Using Remote Sensing and GIS Techniques." *Geology, Ecology, and Landscapes*

00(00): 1–15. https://doi.org/.

Das, Goutam Kumar. 2018. “A Geo-Spatial Analysis and Assessment of Groundwater Potential Zones by Using Remote Sensing and GIS Techniques-A Micro Level Study of Bhagwanpur-I CD Block in Purba Medinipur Dist ... A Geo-Spatial Analysis and Assessment of Groundwater Potential Zones B.”

Das, Sumit, and Sudhakar D Pardeshi. 2018. “Integration of Different Influencing Factors in GIS to Delineate Groundwater Potential Areas Using IF and FR Techniques : A Study of Pravara Basin, Maharashtra, India.”*Applied Water Science* 8(7):1–16. https://doi.org/.

Demeke Sewnet, Hasan Raja Naqvi and Mohamed Abdul Athick. 2016. ’’Zonation of Potential Groundwater and Its Spatial Correlation with Indices and Boreholes: Western Region of Blue Nile Basin, Ethiopia’’. Journal of Remote Sensing and GIS (JoRSG). 1-13. www.stmjournals.com.

Dereje Adeba, M.L. Kansal and Sumit Sen. 2015. ’’Assessment of Water Resource Scarcity and Its Impact on Suistainable Development in Awash Basin, Ethiopia’’. International Journal of Sustaible Resource Management 1:71-87.

Dessalegn Worku Ayalew. 2018. “Theoretical and Empirical Review of Ethiopian Water Resource Potentials, Challenges and Future Development Opportunities.” *International Journal of Waste Resources* 08(04).

Elbeih, Salwa Farouk. 2015. “An Overview of Integrated Remote Sensing and GIS for Groundwater Mapping in Egypt.” *Ain Shams Engineering Journal* 6(1):1–15. http://dx.doi.org/.

Fashae, Olutoyin A., Moshood N. Tijani, Abel O. Talabi, and Oluwatola I. Adedeji. 2014. “Delineation of Groundwater Potential Zones in the Crystalline Basement Terrain of SW-Nigeria: An Integrated GIS and Remote Sensing Approach.” *Applied Water Science* 4(1): 19–38.

G. Sreenivasa Reddy, Dr.G. behera and Dr.S.K. Subramaniam. 2011. ’’Groundwater Prospect Maps - User Manual’’. Distribution: ISRO/DOS Center, Ministry of Dring Water and Sanitagtion, State Remote Sensing Application Center, State Line Depts, Govnt. of India: 1(1): 01

Gumma, Murali Krishna, and Paul Pavelic. 2012. “Mapping of Groundwater Potential Zones across Ghana Using Remote Sensing , Geographic Information Systems , and Spatial Modeling.”

Hussen Ender. 2006. “Water resource potential evaluation of berga river catchment, west shewa zone, oromiya regional state.” Unpublished M.Sc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia

Jhariya, D. C. et al. 2016. “Assessment of Groundwater Potential Zone Using Remote Sensing, GIS and Multi Criteria Decision Analysis Techniques.” *Journal of the Geological Society of India* 88(4): 481–92.

Karnataka, North, Basavaraj Hutti, and R Nijagunappa. 2011.“Identification of Groundwater Potential Zone Using Geoinformatics In.” 2(1): 91–109.

Kidanewold, Belete Berhanu, Yilma Seleshi, and Assefa Melesse. 2014. “Surface Water and Groundwater Resources of Ethiopia : Potentials and Challenges of Water Resources Development.

Kumar, Pankaj, Srikantha Herath, Ram Avtar, and Kazuhiko Takeuchi. 2016. “Mapping of Groundwater Potential Zones in Killinochi Area , Sri Lanka , Using GIS and Remote Sensing Techniques.” *Sustainable Water Resources Management* 2(4): 419–30.

Kumari, Laulina. 2018. “Delineation of Potential Groundwater Zone Using RS and GIS : A Review.” 7(12): 196–203.

Malczewski, Jacek. 2006. “GIS-Based Multicriteria Decision Analysis: A Survey of the Literature.” *International Journal of Geographical Information Science* 20(7): 703–26.

Manna Moumita*., Gujar Ashwini., Joy Liji., Singh Shweta and Mutkure Swapnil. 2017. “Assessment of Knowledge Regarding Post Natal Care Among Antenatalmothers.” 8: 17475–80.

Mesfin Tessema. 2011. “Integrated Remote Sensing(RS) and Geographical Information System (GIS) Techniques for Groundwater Potential Zone Assessment: A Case Study of Borkena River Basin, Northern Ethiopia.” Unpublished M.Sc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia.

MoWR. 2012. “Ground Water Management in Ethiopia.” (Agricultural Water Solutions improved livelhood for smaalholder farmers).

Mulugeta Mussie. 2007. " Groundwater Circulation and Hdrochemistry of the Corridor (Upper Gidabo River and Lake Hawassa Catchments), Sidama Zone, SNNPRS. Unpublished M.Sc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia.

Murasingh, Surajit, and Ramakar Jha. 2013. “Conference Paper: Identification of Groundwater Potential Zones Using Remote Sensing and GIS in A Mine Area of Odisha Identification of Groundwater Potential Zones Using Remote Sensing and GIS in A Mine Area of Odisha.”

Musa, Z N, I Popescu, and A Mynett. 2015. "A Review of Applications of Satellite SAR , Optical , Altimetry and DEM Data for Surface Water Modelling.": 3755–69.

Nilawar, Aditya. 2015. "Identification of Groundwater Potential Zone Using Remote Sensing and GIS Technique."

Oborie, Ebiegberi, and Hycienth Ogunka Nwankwoala. 2017. "Determination of Groundwater Flow Direction in Yenagoa , Bayelsa State , Nigeria."

Preeja, K.R., Sabu Joseph, Jobin Thomas, and H. Vijith. 2011. "Identification of Groundwater Potential Zones of a Tropical River Basin (Kerala, India) Using Remote Sensing and GIS Techniques." *Journal of the Indian Society of Remote Sensing* 39(1): 83–94.

Puertas, DG et al. 2015. "Status and Potential of Groundwater Use in Ethiopian Floodplains.": 1–24. www.spate-irrigation.org.

Rahul V. Chaudhar. 2018. "Weighted overlay analysis for delineation of ground water potential zone: a case study of pirangut river basin first." *Manager* (June): 243–50.

Sar, Nityananda, Ansar Khan, Soumendu Chatterjee, and Arosikha Das. 2015. "Hydrologic Delineation of Ground Water Potential Zones Using Geospatial Technique for Keleghai River Basin , India." *Modeling Earth Systems and Environment* 1(3): 1–15.

Seifu Kebede. 2013. *Groundwater in Ethiopia*. Features, Number and Opportunities: Springer Hdrology, Ethiopia.

Shamuyarira, K.K. 2017. "Determination of Recharge and Groundwater Potential Zones in Mhinga Area , South Africa."

Shekhar, Shashank, and Arvind Chandra Pandey. 2015. "Delineation of Groundwater Potential Zone in Hard Rock Terrain of India Using Remote Sensing , Geographical Information System (GIS) and Analytic Hierarchy Process (AHP) Techniques." *Geocarto International* 30(4): 402–21. http://dx.doi.org.

Siebert, S. et al. 2010. "Groundwater Use for Irrigation - A Global Inventory." *Hydrology and Earth System Sciences* 14(10): 1863–80.

Sileshi Gobena. 2010. "Daily Rainfall-Runoff Modelling of Upper Awash Sub Basin Using Conceptual Rainfall Runoff Models." Dissertation. Addis Ababa University, Addis Ababa, Ethiopia.

Sisay Libasse. 2007. "Application of Remote Sensing and GIS for Groundwater Potential Zone Mapping in Northern Ada'a Plain (Modjo Catchment). Dissertation. Addis Ababa University, Addis Ababa, Ethiopia.

Suganthi, S., L. Elango, and S. K. Subramanian. 2013. "Groundwater Potential Zonation by Remote Sensing and GIS Techniques and Its Relation to the Groundwater Level in the Coastal Part of the Arani and Koratalai River Basin, Southern India." *Earth Sciences Research Journal* 17(2): 87–95.

Tesfaye Tessema Gintamo. 2015. "Ground Water Potential Evaluation Based on Integrated GIS and Remote Sensing Techniques, in Bilate River Catchment: South Rift Valley of Ethiopia." *American Scientific Research Journal for Engineering, Technology, and Sciences (asrjets) issn (Print)*: 2313–4410. http://asrjetsjournal.org/.

Thapa, Raju, and Srimanta Gupta. 2017. "Assessment of Groundwater Potential Zones Using Multi-Influencing Factor (MIF) and GIS : A Case Study from Birbhum District , West Bengal." *Applied Water Science* 7(7): 4117–31.

Thapa, Raju, Srimanta Gupta, Shirshendu Guin, and Harjeet Kaur. 2017. "Assessment of Groundwater Potential Zones Using Multi-Influencing Factor (MIF) and GIS: A Case Study from Birbhum District, West Bengal." *Applied Water Science* 7(7): 4117–31.

Venkateswaran, S Deepa S, R Ayyandurai R Kannan, and M Vijay Prabhu. 2016. "Groundwater Recharge Potential Zones Mapping in Upper Manimuktha Sub Basin Vellar River Tamil Nadu India Using GIS and Remote Sensing Techniques." *Modeling Earth Systems and Environment*: 1–13.

Waikar, M L, and Aditya P Nilawar. 2014. "Identification of Groundwater Potential Zone Using Remote Sensing and GIS Technique." 3(5): 12163–74.

Yitbarek, A., Razack, M., Tenalem, A., Zemedagegnehu, E., and Tilahun, A. 2012. "Journal of African Earth Sciences Hydrogeological and Hydrochemical Framework of Upper Awash River Basin , Ethiopia : With Special Emphasis on Inter-Basins Groundwater Transfer between Blue Nile and Awash Rivers." *Journal of African Earth Sciences* 65: 46–60. http://dx.doi.org/.

Zende, Abhijit M, R Nagarajan, and K R Atal. 2012. "Assessment of Groundwater Potential Zones by Using GIS Techniques in Yerala River Basin, Western Maharashtra, India." *I. Journal of Advance Civil Engineering* 2(1): 9–17.

Zhou, Yongzhang, and Shugong Wang. 2018. "Remote Sensing and GIS Based Groundwater Potential Zone Mapping in Ariyalur District , Tamil Nadu." 92: 484–90.

APPENDICES

Tables in the Appendix

Appendix Table 1: Meteorological Data (Mean Monthly Rainfall) in the Study Area (17 Years)

1. Ginchi

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual RF
2002	113	76.5	88.7	40.5	38.2	182	209.4	158.1	79.9	0	0	61.4	1047.4
2003	19.6	61.2	107	162.5	15.4	148	227.8	207	117.7	0	2.1	14.9	1082.8
2004	108	6.7	21.4	214.1	57.9	124	198.4	200.4	178	19.1	4.9	1	1133.3
2005	65.6	2.5	119.5	45.6	85.5	116	260.5	241.6	185.8	12.8	12.5	0	1148.3
2006	0	15.3	320.4	191.5	134	238	434.2	629.2	157.1	19.5	0	14.1	2152.6
2007	19.9	24.1	37.3	31.6	157	248	232.3	182.6	122.1	35.3	0	0	1090.7
2008	0	5.7	0	18.1	101	153	294.9	236.6	111.2	41.7	62.6	0	1024.1
2009	57.5	5.3	11.4	50.9	43.6	101	210.6	274.2	144.8	0	0	41	940.4
2010	45.5	74.5	90.5	136.5	68	162	262.3	213.5	103.5	17.5	14.2	37.9	1225.6
2011	8.5	12.3	60.4	11.2	94.5	182	144.1	243.4	52.9	0	52.3	0	861.67
2012	0	0	5	67.7	22.7	102	221.3	188.8	215.1	0	0	0	822.4
2013	0	0	0	102.6	119	146	232.4	257.9	114.8	146	0	0	1118
2014	0	56.4	53.4	47.5	169	112	156	232.1	93.4	41.2	0	0	961.1
2015	0	0.175	45.2	35.5	152	151	154	208.1	192.2	0	28.5	4.1	970.86
2016	32.2	19.83	51.8	153.9	122	111	292.58	187.6	107.1	10.7	6.97	0.38	1096
2017	0	54.4	102.8	77	135	136	245.51	203.3	179.9	5.3	17.5	0	1157.6
2018	4.06	6.5	51.9	83.55	73.5	297	264.1	260.9	38.26	29.7	25.7	1.2	1136.2

2. Tulu Bolo

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual RF
2002	46.3	9.1	41.7	60.6	43.3	225	236.8	241	77.2	0	0	40.6	1021.5
2003	40	11.7	49.1	94.3	23.8	127	315.1	219.1	91.5	0	0	7.7	979.4
2004	52.5	0	10.8	92.9	44.7	271	330.6	185	163.8	0	2.2	5.2	1158.6
2005	26	0	53.9	180.9	165	208	211.07	203.2	83.8	18.3	5.5	0	1156.1
2006	0	13.3	106.4	63.2	91.4	198	260.8	138.2	162	5.5	0	0.3	1039
2007	6.8	12.9	40.6	49.4	122	258	206.2	216.7	147.2	13.1	0	0	1072
2008	0	0	7.4	48.4	124	234	281	306	90.8	47	0	0	1139.1
2009	41.4	0	16.2	9.4	67.1	59.2	264.1	331	75.6	89.1	0	25.6	978.7
2010	0	103.9	81.6	82.2	186	282	349.2	157.4	108.1	0	10.2	34	1394.8
2011	3.4	17.8	53.1	14.5	75.5	189	111.1	237.1	152.4	0	0	0	853.7
2012	0	0	23	90.6	97.7	107	218.2	253	122.4	7.5	0	0	919.6
2013	0	0	34.1	71.7	129	252	411.9	454	217.1	112	0	2	1683.6
2014	0	32.1	53.6	22	77.5	95.2	310.9	333.9	79.8	14.2	0	0.05	1019.3
2015	0	1.6	18.93	0	128	114	207.2	209.8	93.2	0.2	15.8	21.3	809.63
2016	21.8	10.7	62.4	100	158	111	241	191.7	107.1	11.5	7.61	0	1022.9
2017	0	49.5	51.3	43.4	137	70.8	255.33	204.5	180.8	2.01	2.65	0	996.85
2018	4.05	6.5	51.88	83.55	73.5	293	232.8	295.7	37.9	137	23.5	1.74	1241.8

3. Asgori

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual RF
2002	27.7	41.4	48.1	41	52.2	97.3	258.4	252.7	93.4	0	0	20.7	932.9
2003	45.1	24.5	65.2	119.8	43.9	170	264.8	272	107.9	2	1.3	10.5	1126.6
2004	30.8	4.5	44.6	172	24.6	152	183.6	173.8	74.3	57.1	0	0	917.1
2005	28.9	2.4	77.2	57.9	141	149	164.2	146.8	123.2	10.5	0	0	900.9
2006	0.2	11.5	99.59	92.39	69.8	122	300.03	249	79.1	2.7	0	1.2	1027.9
2007	8.7	16.79	83	143.5	64.6	198	212.2	179.7	141.7	11	0	0	1059.2
2008	0.77	0	0.9	60.9	103	140	283.2	190.2	74	22.6	65	0	941.07
2009	31.1	1.5	1	26.2	64.7	95.4	205.9	266.2	67.8	64.3	59.1	27.4	910.56
2010	5.69	89.2	91.6	104.4	57.6	158	272.8	150.3	98.6	10.5	34.7	16.4	1090.1
2011	14.8	5.2	37.5	15.1	61.8	171	155.6	256.1	189.9	0	3.1	0	910.1
2012	0	0	1.2	60.7	41.5	135	211.3	230.3	83.6	2.7	0	7.6	773.6
2013	2.7	0	391.6	103.5	77.4	111	228.7	165.2	129	74.7	8	0	1291.9
2014	0	54.2	38	57.4	118	101	213.5	205.6	195.8	8.7	2.9	0	995.5
2015	0	0	11.7	0.8	120	128	196.3	226.7	110.9	0.4	0	3.66	798.57
2016	33.7	7.7	26	134.1	123	111	287.48	182.3	70.6	0.7	3.9	0.38	981.21
2017	0	117.9	23.7	21.9	133	97.3	147.9	201.3	163.8	2.1	2.43	0	911.03
2018	3.94	11.8	28.7	82.8	138	180	216.9	217.6	23.4	24.6	17.2	1.74	946.49

4. Tefki

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual RF
2007	0	31.3	0	33	84	241	215.12	198.6	125.5	15	10.9	0	954.67
2008	0	1.736	1.433	32.4	84	238	253.91	198.6	108.5	46.6	96.7	0	1061.4
2009	16.3	0	21.7	25.8	35	115	168.3	228.2	111.5	68.8	0	40.7	831.4
2010	4.2	108.5	45.3	95.1	43.3	132	204.5	147.4	104.8	8.9	23.2	14.1	930.89
2011	0.5	3.4	31.7	35.7	76.2	138	162.2	310.1	148.9	0	20.9	0	928
2012	0	0	6.4	86.1	41.5	121	176.2	269.4	140.9	4.8	0	0	846.1
2013	2.3	2.8	20.1	70.3	84.8	176	191.4	227.3	131.7	37.4	31.5	30.7	1006.5
2014	11.6	67.2	44.8	41.8	46.6	46.6	156.3	190.2	115.2	17.9	8.9	0.6	747.7
2015	0	0	8.6	1.7	96.8	107	226.5	201.4	77.9	28.4	3.5	0	752.2
2016	38.1	31.8	22.2	118.9	166	115	294.94	191.7	126.9	17.4	5.7	0.38	1128.7
2017	0	128	62.9	34	191	82.3	245.51	204.9	173.1	2.01	0	0	1123.7
2018	4.05	6.5	51.88	83.55	73.5	216	259.4	378.2	25.2	16.5	17.5	0	1132.6

5. Sebata

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual RF
2002	25.4	47.2	100.1	31.8	30.6	120	173	251.1	113	0.6	0	21.1	914.07
2003	3	5.8	52.1	76.4	13.6	123	274.9	327.4	118.2	1.2	0	39.2	1034.5
2004	17.2	15.2	46.3	122.8	19.4	137	261.5	189.7	166	55.9	0	0	1030.6
2005	38.4	24.5	61.3	135.3	193	91.5	157.2	161.6	69.6	3.2	9.3	0	945.13
2006	0	13.8	53	84	51.5	81.1	288.2	273	185.4	13.1	0	0.3	1043.4
2007	23.6	28.2	31.7	100.1	68.4	125	83.6	242.5	128.2	3.6	0	0	835.3
2008	0	0	0.6	21.5	56.6	135	239.4	313.4	201.2	41.5	83.7	0	1092.6
2009	30.1	0	4.2	65.3	22	62.8	297	246.9	115.3	20.2	0	47.8	911.6
2010	5.31	33.3	72.3	94.3	86.7	110	233.56	176.2	79	4.07	13.1	19.7	927.4
2011	0.9	13.5	61.12	26.63	59.9	155	102.6	250.5	99.5	0	9.9	0	779.34
2012	0	0	19.8	204.9	51.8	88.6	247.57	174.9	196.7	0	21.4	3.28	1009
2013	0	6.5	75.1	106.1	92.8	97.5	155.7	239.3	124.5	36.6	33.3	0	967.4
2014	0	35.8	18.1	30.2	119	79.4	160.1	243.6	129.9	38.4	3.1	0	858
2015	0	0	18.12	3.4	87.8	128	190.58	229.1	110.2	4.07	9.54	3.67	784.25
2016	46.5	34.3	22.7	165.3	131	113	266.65	142.4	96.4	10.7	7.55	0.38	1035.9
2017	0	52.01	48.2	48.2	163	111	294.58	191.1	234.9	3.9	1.33	0	1148.5
2018	4.06	6.5	51.9	83.55	73.5	183	245.87	260.9	64.4	11	17	0	1001.4

6. Teji

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual RF
2002	14.3	10	63.1	38	45.7	140	210.5	214.3	48.9	0	0	26.5	811.1
2003	29.3	21.1	80.6	153.7	48	158	229.8	267.4	84.3	0	0.2	9.6	1082
2004	20.1	6.4	22.2	129.5	28.5	168	209.2	216.9	72.6	68.5	0	0	941.9
2005	21.9	8.1	72.6	55.2	179	214	238.1	235	72.9	15.7	0	0	1112.6
2006	0	9.8	97.6	90.1	107	124	333.5	242.6	147.9	18.4	0	0.7	1170.9
2007	8.2	11.4	92	27.7	106	185	174	248.2	104.2	11.8	0.2	0	969.3
2008	0	0	0	49.3	53.9	85.8	279.7	139.5	123.2	15.4	59.7	0	806.5
2009	7.7	0	15.6	10.9	46.5	79.7	222.5	271.4	75.3	32.5	2.7	44.8	809.6
2010	2.1	66.9	114.9	65	151	243	258.4	182.9	110.2	8.4	13.1	14.1	1230
2011	2.6	0	47.6	12.5	53.5	179	213.2	233.3	159	0	2.2	0	902.5
2012	0	0	5.7	75.7	42.6	95.6	161.9	215.6	95.8	17.1	9.4	8.9	728.31
2013	2	10.7	13.8	83.3	61.7	202	212.8	217.7	125.5	29	6.8	0	965.4
2014	0.4	47.5	38.6	37.2	96.7	99.5	126.4	209.8	123.8	64.2	0.7	0	844.8
2015	0	0.5	22.8	7.5	94.7	168	200.5	209.1	121.7	0	6.7	4.1	835.1
2016	30.1	19.83	27.5	136.6	136	122	224.1	199.4	113.8	10.7	11	0.38	1031.4
2017	0	49.5	49.05	26.3	122	43.3	135.1	200.2	179.9	5	3.1	0	813.8
2018	4.12	6.5	52.03	83.55	73.5	168	245.87	260.9	40.64	4.2	14.6	1.74	956.07

7. Welenkomi

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual RF
2002	38	16.8	43.8	32.2	34.5	196	224.2	175.9	45.2	2	0	97.7	905.8
2003	22.2	0	103.5	130.3	14.9	178	315.8	185.1	61.8	0	2.3	2.4	1015.9
2004	49.4	2.4	22.8	173.1	22.4	104	249.3	198.7	164.4	10	0	0	996.49
2005	62.8	0	81.5	126.8	111	152	264.3	118.2	77.3	3.4	2.5	0	999
2006	0	25.4	87.2	70	67.6	120	276.53	237.4	119.7	17.2	0.62	10.5	1031.8
2007	30.2	28.7	29.2	58.48	93.8	167	219.1	190.3	85.3	20.7	2.16	0	925.38
2008	0	1.736	0	21.6	114	124	133.4	251.8	129.2	32.5	70.7	1.53	879.87
2009	20.1	1.033	29.2	25.3	39.4	71.2	215.47	266.8	64.1	39.1	10.4	14.9	797.05
2010	19.6	29.7	84.6	72	84.7	143	254.1	195	102	0	31.7	22.8	1039.2
2011	3.23	5.227	57.04	26.63	81.8	182	194	202	87	0	27.7	0	866.08
2012	0	0	0	63.5	24.8	107	285.66	296.6	168.3	19.7	5.72	3.79	975.41
2013	4.7	0	26	69.2	75	170	195.6	123.3	141.4	28.2	25.9	0	859.4
2014	0	47.1	28.7	58.9	88.5	67.7	155.6	239.3	110.7	46.9	12.2	0.05	855.65
2015	0	0	19.63	6.211	135	139	168.8	118.7	108.1	0.2	4	3.7	703.45
2016	32.2	5.4	40.8	236.5	91.4	117	309.2	85.3	74.1	13.6	3.5	0.35	1009
2017	0	30.2	56.4	159.6	292	65.4	245.51	203.3	179.9	2.03	2.46	0	1236.8
2018	4.06	6.5	51.9	83.55	73.5	181	245.87	260.9	40.27	26	16.7	0	990.29

8. Boneya

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual RF
2002	21.5	11.1	18.3	15.1	24.8	75.6	144	122.2	46.1	0	0	14.7	493.4
2003	14.2	7.5	34.1	48.5	5.8	66.8	146.7	124.8	108.4	0	0	8.8	565.6
2004	25.1	0	35.2	80.4	18.3	70.1	84.2	68	6	1.1	0	0	388.4
2005	29.2	0	32.8	34.2	64.1	71.8	97.7	72.1	42.4	0.2	9.6	0	454.1
2006	3.1	33.8	29.6	116.1	31.1	131	295.3	305.6	91.9	8.2	0	13.2	1059.1
2007	0	27.1	27.1	85.2	84.4	173	218	228.4	177	8.4	0	0	1028.5
2008	0	4.6	7.5	38.5	82.5	111	139.1	219.2	125.7	5.3	57.2	0	790.8
2009	24.2	0	10.2	45.6	74.9	53.2	231.9	295.7	72.3	46.9	6.57	59.4	920.87
2010	0	40.3	111.3	103.5	153	135	208.3	203.1	69.3	4.7	14.4	24.1	1067.1
2011	0	10.6	92.2	18.4	138	68.8	184.8	264	98.1	0	0	0	875.2
2012	0	0	20.6	92.8	0	74.3	254.16	291.2	145.8	0.2	0	3.28	882.36
2013	0	0	49.8	51	78.4	120	231.5	243.4	82.1	39	0.9	0	896.2
2014	0	42.4	37.8	26.7	64.7	17.8	164.3	309.1	171.3	61.9	14.2	0	910.2
2015	0	0	17.99	0	121	114	177	221.5	77.7	3.77	0	0	733.56
2016	59.1	32.3	6	77.7	159	111	292.58	187.6	58.7	3.2	6.92	0.38	994.2
2017	0	49.5	49.05	38.89	26.1	104	351.5	217.3	179.9	0	0	0	1016.2
2018	4.06	6.5	51.9	83.55	73.5	195	368.6	260.9	19	26.3	17.2	0	1106

9. Bantu Liben

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual RF
2002	38.8	0	26.7	11.6	39	105	144.3	159.3	33	0	0	13.7	571.4
2003	25.2	44.8	66.5	149	19.5	107	310.4	175.5	36.7	0	0	63.4	998.2
2004	49	0	16.6	112.2	3.4	65.8	135.4	101.1	42.5	5.3	5.6	0	536.9
2005	62.9	0	79.7	94.9	72.1	97.7	256.2	57.6	125.8	3	3.6	0	853.5
2006	1.4	64.1	98.1	139.4	35	153	260.4	122.3	65.8	0	0	4.9	944.3
2007	41	6.1	54	24.8	65.5	75.8	302.1	188	136.9	19.5	2.3	0	916.0
2008	0	0	0	34.7	48.1	55.6	148	209.8	89.1	17.4	44.2	0	646.9
2009	42.5	0	3.2	52.1	13.4	32.6	76	122.8	11.1	46.6	2.1	41.4	443.8
2010	0	75.4	60.4	87.2	0	23.3	60	135.6	92.9	0	0	0	534.8
2011	0	0	74.5	47.1	62.3	50.2	131.8	166.1	94.6	0	7.6	0	634.2
2012	0	0	0	23.8	34.4	70.6	104	298	215.5	216	0	9.8	971.6
2013	4.4	0	16.1	63.5	50.1	140	90.8	43.7	11.8	0	0	0	420.4
2014	0	20.9	61.5	26.2	93.6	66.7	219.9	262.4	264.7	35	1.7	0	1052.6
2015	0	0	27.2	15	109	214	217	309.9	148.9	0	7.7	0.1	1049
2016	69.3	11	4.7	59	42.5	54	56.7	53.9	39.9	9.3	0	0	400.3
2017	0	6.8	0	0	36.6	48	157.1	150.4	8.4	0	0	0	407.2
2018	19.7	13.5	34.7	55.3	22.5	75.7	157.1	150.4	83.4	20.7	4.4	7.8	645.1

Appendix Table 2**:** Meteorological Station (Mean Monthly Temperature Data) of the study area

station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean.A.T
Tulu Bolo	min	8.7	9	9.9	10.2	10.1	10.1	10.1	10.2	9.7	8.9	8.2	7.8	9.4
	max	25	25.6	26.2	26.2	26.3	25	23.5	23.5	23.8	24.2	24.3	24.1	24.8
	average	16.9	17.3	18.1	18.2	18.2	17.6	16.8	16.9	16.8	16.6	16.3	16.0	17.1
Tefki	min	7.5	9.1	11.3	12.1	12.3	12.1	12.7	12.7	11.4	7.7	7.4	6.3	10.2
	max	27.5	28.5	28.8	29.1	28.4	26.9	24.7	24.2	25.3	26.8	27.7	26.9	27.1
	average	17.5	18.8	20.1	20.6	20.4	19.5	18.7	18.5	18.4	17.3	17.6	16.6	18.6
Holeta	min	3.7	5.4	7.3	8.5	7.9	7.7	9	9	7.5	4.6	2.2	2.2	6.3
	max	23.2	24.1	24.1	23.6	24	22.3	19.6	19.4	20.4	21.8	22.5	22.8	22.3
	average	13.5	14.8	15.7	16.1	16.0	15.0	14.3	14.2	14.0	13.2	12.4	12.5	14.3
Addis alem	min	7.4	8	9.3	9.4	9.6	10	9.9	10.3	9.9	9.2	7.4	6.9	8.9
	max	24.7	25.2	25.4	25.4	25.4	24.2	21.9	21.2	22.4	23.8	23.9	24.3	24.0
	average	16.0	16.9	17.8	18.1	18.0	17.3	16.5	16.4	16.3	15.8	15.4	15.1	16.6
Asgori	average	17.6	18.3	19.3	19.6	19.5	19	18.1	18.1	18	16.2	15.9	16.2	18.0
Boneya	average	11.2	12.3	13.7	14.1	14.1	13.5	13.3	13.3	12.9	11.7	10.6	10.2	12.6
Ginchi	average	11.2	12.3	13.7	14.1	14.1	13.5	13.3	13.3	12.9	11.7	10.6	10.2	12.6
Sebeta	average	15.5	16.8	17.9	18.1	18.2	17.1	16.1	16	16.2	15.7	14.8	14.6	16.4
Teji	average	16.1	16.6	17.4	17.4	17.5	17.1	15.9	15.8	16.2	16.5	15.7	15.6	16.5
Welenkomi	average	14.9	15.8	16.8	17.0	17.1	16.5	15.6	15.5	15.6	15.1	14.3	14.1	15.7
Bantu Liben	average	14.9	15.8	16.8	17.0	17.1	16.5	15.6	15.5	15.6	15.1	14.3	14.1	15.7
	av.min	6.8	7.9	9.5	10.1	10.0	10.0	10.4	10.6	9.6	7.6	6.3	5.8	8.7
	av.max	25.1	25.9	26.1	26.1	26.0	24.6	22.4	22.1	23.0	24.2	24.6	24.5	24.5
average(min&max)		15.0	16.0	17.0	17.3	17.3	16.6	15.8	15.8	15.7	15.0	14.3	14.1	15.8

Appendix Table 3**:** Description of the lithological Unit of the Study Area

S.No	Litho_code	Code and lithological description
1	PNtbB	**Tarmaber basalt (**PNtbB) - This rock types are the lower basaltic aquifer with a large amount of scoraceous lava flows and cover dominantly northern part of the study areas around Ambo and Holeta areas (Figure 13). The permeability of this aquifer is highly dependent on the degree and intensity of fracturing, the enhancement of jointing and interconnection of primary porosity. The scoraceous nature of this aquifer is favorable for groundwater storage and movement. It is high productive fissured/or porous aquifer.
2	QwaB	**Weliso Ambo basalt (**QwaB) - Weliso Ambo basalt rock unit is upper basaltic aquifer that distributed in Western and Northern part of the study area around Ginchi and some part of Weliso (Figure 13) and found overlain by Ignimbrites and tuffs in Becho areas. It is a quaternary volcanic rocks and encompasses of confined and unconfined aquifer formed from porphyritic basalt, breccia and tuff. The thickness of this aquifer highly variable and less than 50m in the Becho Plain.
3	NcvTy	**Central volcanic of Wechecha, Furi, Yerer** (NcvTy) - This rock unit is exposed in southern, northeast and northwestern part of the study area which contain porphyritic trachytic lavas (Figure 13). Most part of trachytic lavas are visible at Wechecha, Furi and Yerer, northwestern and southern narrow hill top of the study area forming a lift to higher or mountain peaks. It has low permeability except along weathered and fractured zone and act as local Aquiclude by compartmentalizing upper basaltic aquifer. It is the low productive fissured/or porous aquifer and minor aquifer/aquitard with limited groundwater occurrence.
4	NadI	**Addis Ababa Ignimbrite (**NadI) - Addis Ababa Ignimbrite rock unit is the most dominant unit of rock types of the study areas which cover north-central, south-central, central and eastern part of flatter surface of watershed (Teji, Tulu bolo and Asgori) and around Addis Ababa and Becho plain (Figure 13). It is act as regional Aquiclude types of aquifer made up of welded tuff (Ignimbrite) deposits and poorly welded pyroclastic. Ignimbrite and tuff covering around rift floor (Becho plain) and they are well joints, fractured, weathered and have a high or moderate permeability. In the area of Melka Kunture site the thickness of this unit stretches up to 282-200m (exploration drilling data). In addition to ignimbrite unit, black cotton soil outcrops are mainly dominated the becho area. Black cotton soil is recent soil regolith and alluvial deposits. It is dominated by a rare silt, gravel, interlaid with reworked and weathered pyroclastic.
5	NebRy	**Entoto Becho rhyolite (**NebRy) - The Entoto Ridge is one part of central volcanoes unit which forms watershed divide of Abay and Awash River basins. The Entoto ridge forms steep slope in the direction of the Abay basin steep to gentle slope towards the awash river basin. It contain Obsidian reach rhyolites. It is found around Becho Plain and southwest part of the study areas.
6	NakB	**Akaki basalt (**NakB) - Akaki basalt unit is the visible (outcropped) at Akaki, Abasamuel dam and Dukem which is made up of Scoria and

		spatter cones with associated basaltic lava flows. It found at eastern part of the study area which cover small land around Boneya area. The layer (thickness) of this Akaki basalt unit around Akaki is 202m (drilling data). The water bearing characteristics of this aquifer is highly depend on the secondary permeability which is the result of fracturing and weathering activity. This aquifer is recharged from direct precipitation of the area.
7	Qal	**Quaternary (Alluvial) Deposit (**Qal) - Alluvial deposits are also common in the rift, in connection with flood plain and at some places mixed with volcanic clastic or alluvial bars and swamp areas surrounded by volcanic. The alluvial cover mainly outcropped in Becho Plain and its surrounding areas and composed of regolith reddish brown soils, talus and alluvium with maximum thickness of about 7 meter (from area hand dug well data). It consist mainly sand, silt and clay soil texture. This unit is one of the most important source for shallow groundwater and has relatively good permeability and productivity with sand to gravel size as well as with some fine undifferentiated grains.

Appendix Table 4: Major Soil Types Characteristics of the study area

Sr.No	Soil Type and characteristics
1	**Leptosols**: Leptosols are very shallow soils over continuous rock and are extremely gravelly and/or stony with various kinds of continuous rock or of unconsolidated materials with less than 20 percent (by volume) fine earth. Leptosols have a resource potential for wet-season grazing and as forest land. Erosion is the greatest threat to Leptosols areas, particularly in mountain regions in the temperate zones where high population pressure (tourism), overexploitation and increasing environmental pollution lead to deterioration of forests and threaten large areas of vulnerable Leptosols. Steep slopes with shallow and stony soils can be transformed into cultivable land through terracing, the removal of stones by hand and their use as terrace fronts. The excessive internal drainage and the shallowness of many Leptosols can cause drought even in a humid environment.
2	**Fluvisols**: Fluvisols accommodate genetically young, azonal soils in alluvial deposits. They develop in alluvial plains, river fans, valleys and tidal marshes on all continents and in all climate zones; many Fluvisols under natural conditions are flooded periodically. A dry period also stimulates microbial activity and promotes mineralization of organic matter. Many dry land crops are grown on fluvisols as well, normally with some form of water control
3	**Luvisols**: Luvisols are soils that have a higher clay content in the subsoil than in the topsoil as a result of processes (especially clay migration) leading to an argic subsoil horizon. Luvisols have high activity clays throughout the argic horizon and a high base saturation at certain depths. Pedogenetic differentiation (especially clay migration) of clay content with a lower content in the topsoil and a higher content in the subsoil without marked leaching of base cations or advanced weathering of high-activity clays. Most Luvisols are fertile soils and suitable for a wide range of agricultural uses.
4	**Cambisols:** Cambisols combine soils with at least an incipient subsurface soil formation. Transformation of parent material is evident from structure formation and

	mostly brownish discoloration, increasing clay percentage, and/or carbonate removal. They are soils with at least the beginnings of horizon differentiation in the subsoil evident from changes in structure, color, clay content or carbonate content. Cambisols are characterized by slight or moderate weathering of parent material and by the absence of appreciable quantities of illuviated clay, organic matter. Cambisols with groundwater influence in alluvial plains are highly productive paddy soils.
5	**Vertisols**: Vertisols are churning, heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks from the surface downward when they dry out, which happens in most of the years. The name Vertisols (from Latin vertere, to turn) refers to sediments that contain a high proportion of swelling clays, or products of rock weathering that have the characteristics of swelling clays. Their physical soil characteristics and, notably, their difficult water management cause problems. Buildings and other structures on Vertisols are at risk. The vertical root system of cotton can resist damage by cracking of vertisols but tree crops cannot resist the cracking. The heavy soil texture and domination of expanding clay minerals result in a narrow soil moisture range between moisture stress and water excess. Excess water in the rainy season must be stored for post-rainy season (water harvesting) on Vertisols with very slow infiltration rates
6	**Nitisols:**

Appendix Table 5**:** Water Source Inventory Point (Validation Data)

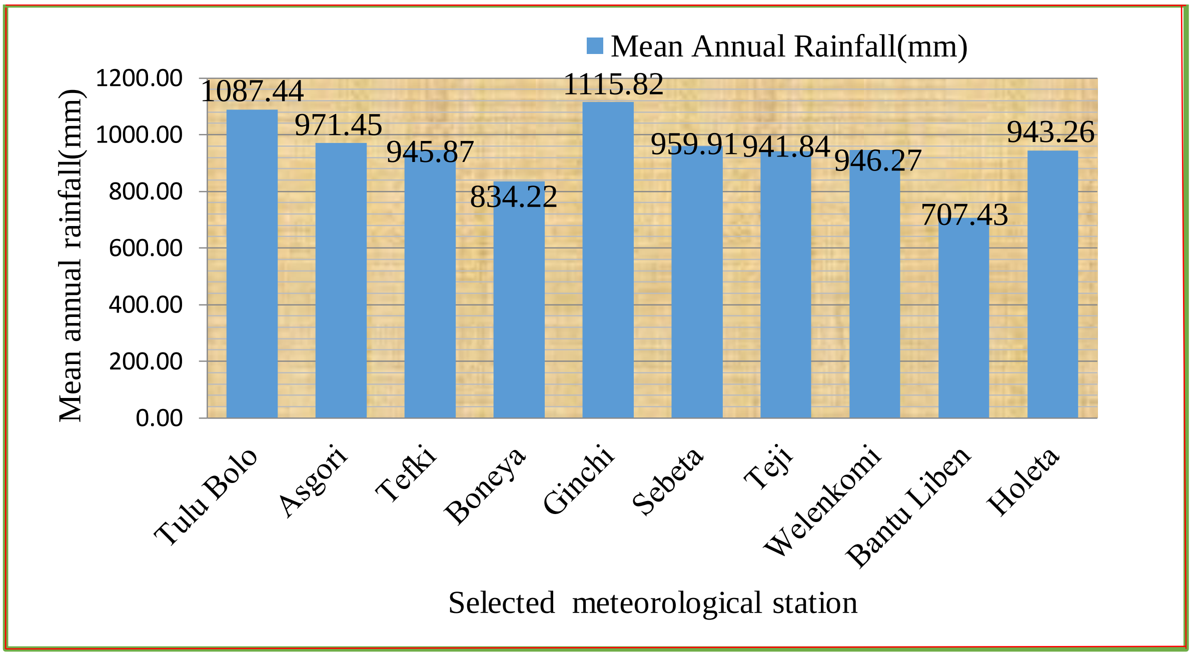
Water point Location	longitude(UTM)	Latitude (UTM)	Elevation (m)	Well depth	SWL (m)	Hydraulic head (m)	well Type
AdBh0150	448290	1002698	2412	0	10	2402.1	Spring
AdBh0152	449177	1002158	2477	0	0	2477.2	Spring
Adbh0153	447200	998889	2295	126	0	2294.7	Deep well
AdBh0154	446338	997431	2259	125	13	2245.4	Deep well
AdBh0155	446632	994813	2242	80	1	2241.1	shallow well
AdBh0156	453522	1001474	2568	115	58	2510.2	Deep well
AdBh0159	446266	1004147	2391	148	37	2354.5	Deep well
AdBh0160	446155	1003073	2389	90	7	2382	Deep well
AdBh0161	444997	1000718	2360	91	38	2322.1	Deep well
AdBh0162	444626	1001034	2386	0	40	2346.5	Spring
AdBh0163	444168	998992	2294	98	7	2286.3	Deep well
AdBh0165	445168	997226	2239	98	0	2238.6	Deep well
AdBh0166	445942	1001323	2395	99	0	2394.5	Deep well
AdBh0167	445773	1001323	2388	75	30	2358.1	shallow well
AdBh0168	445099	1003816	2400	130	30	2370.5	Deep well
AdBh0169	443050	1001649	2407	130	24	2383.3	Deep well
AdBh0170	442635	1001366	2409	220	25	2384.5	Deep well

AdBh0171	443132	1000869	2386	116	30	2355.9	Deep well
AdBh0172	444677	998215	2288	100	6	2282.2	Deep well
AdBh0173	444677	998808	2309	100	21	2288	Deep well
AdBh0174	444642	1002960	2426	66	49	2376.3	shallow well
AdBh0175	443984	999625	2311	70	10	2300.5	shallow well
AdBh0176	444209	998733	2286	98	7	2278.5	Deep well
AdBh0177	441584	1003445	2456	50	11	2444.7	shallow well
AdBh0178	437892	1008952	2591	13	4	2587.4	shallow well
AdBh0187	404656	997733	2232	81	22	2210.5	shallow well
AdBh0190	427193	994953	2125	0	2	2122.7	Spring
AdBh0191	427164	996290	2157	37	0	2156.8	shallow well
AdBh0193	434015	1000129	2341	147	5	2335.9	Deep well
AdBh0194	440110	1001337	2422	153	37	2384.9	Deep well
AdBh0196	460810	981473	2229	102	67	2162.1	Deep well
AdBh0197	460464	974637	2093	61	38	2054.8	shallow well
AdBh0200	454852	962780	2005	56	2	2003.5	shallow well
AdBh0208	448328	957872	2130	139	85	2044.9	Deep well
AdBh0212	444245	956023	2219	158	96	2122.2	Deep well
AdBh0249	455450	983014	2110	120	15	2095.2	Deep well
AdBh0250	455426	982736	2105	150	16	2088.7	Deep well
AdBh0253	453850	973096	2055	59	56	1998.7	shallow well
AdBh0254	451420	971692	2066	60	58	2008.2	shallow well
AdBh0255	444624	978143	2064	65	10	2054.1	shallow well
AdBh0257	445354	969451	2092	71	39	2053.1	shallow well
AdBh0258	445144	969045	2088	86	45	2043.3	shallow well
AdBh0259	453538	982154	2088	80	8	2080	shallow well
AdBh0300	442842	977555	2067	100	14	2053	Deep well
AdBh0301	442811	977625	2065	179	10	2055.1	Deep well
AdBh0312	408475	952876	2271	50	10	2260.7	shallow well
AdBh0313	407460	953526	2276	36	9	2267.4	shallow well
AdBh0314	404050	980200	2225	99	10	2215.2	Deep well
AdBh0315	404051	980357	2222	83	4	2218.3	shallow well
AdBh0318	407400	972711	2134	172	19	2114.9	Deep well
AdBh0323	447966	980422	2064	80	54	2010.1	shallow well
AdBh0324	461412	986324	2277	145	45	2232.2	Deep well
AdBh0325	459676	984947	2204	96	28	2175.6	Deep well
AdBh0326	460937	986565	2277	114	46	2230.5	shallow well
AdBh0329	463742	985378	2363	125	18	2344.3	Deep well
AdBh0334	427635	994816	2119	125	7	2112	Deep well
AdBh0335	429252	993949	2110	45	15	2095.4	shallow well
AdBh0339	436160	1000453	2360	153	37	2322.9	Deep well
AdBh0340	435382	1000251	2356	206	10	2345.7	Deep well
AdBh0357	445180	1002459	2390	101	23	2366.6	Deep well

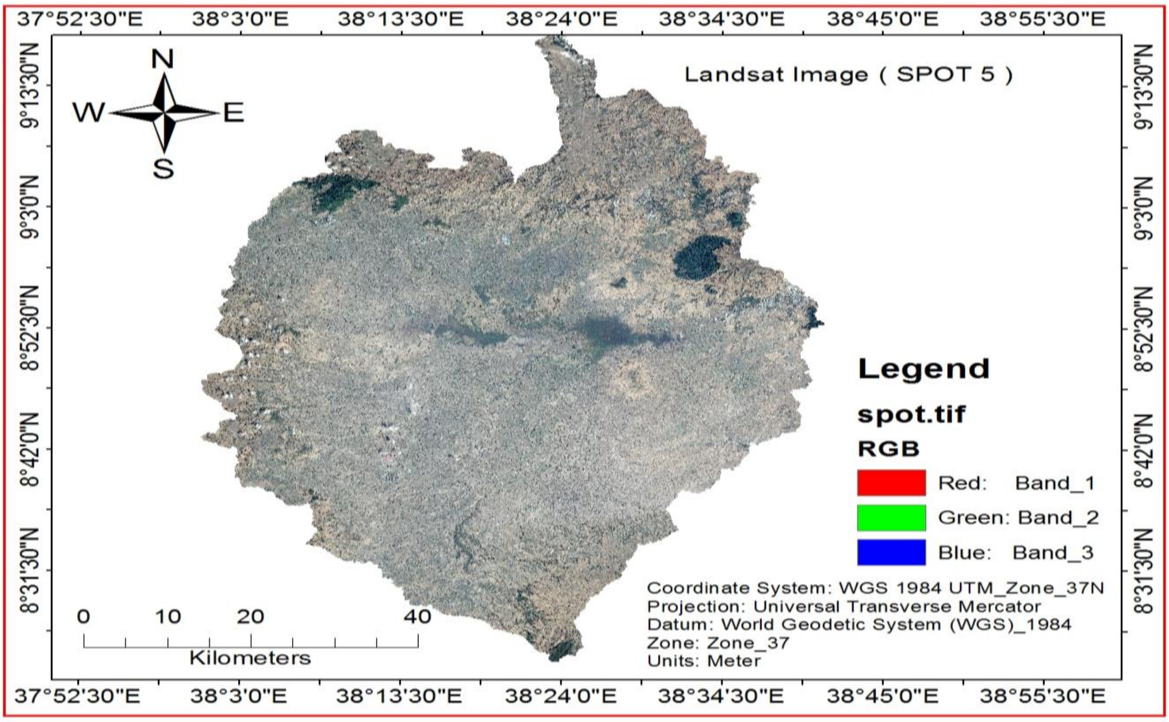
AdBh0362	432432	1024464	2607	161	11	2595.2	Deep well
AdBh0398	412826	949736	2261	50	0	2261.4	shallow well
AdBh0399	424094	968971	2099	24	22	2077	shallow well
AdBh0400	428566	961644	2134	24	22	2113	shallow well
AdBh0401	429969	952736	2161	0	0	2160.8	Spring
AdBh0402	409122	975187	2103	15	14	2088.5	shallow well
AdBh0403	415528	977263	2075	8	7	2068.4	shallow well
AdBh0404	416140	977209	2074	8	7	2067.9	shallow well
AdBh0405	415715	976666	2076	7	6	2070.7	shallow well
AdBh0406	418707	974898	2077	12	10	2066.9	shallow well
AdBh0407	423375	973439	2086	20	19	2067.3	shallow well
AdBh0408	441366	977899	2062	10	8	2054	shallow well
AdBh0409	441901	981393	2064	7	6	2058.3	shallow well
AdBh0410	441831	983807	2078	50	6	2072.2	shallow well
AdBh0426	440595	1000333	2386	170	81	2305	Deep well
AdBh0434	400409	954207	2374	48	22	2352.4	shallow well
AdBh0444	424000	952736	2176	112	5	2170.5	Deep well
AdBh0723	455000	985200	2238	126	51	2187.6	Deep well
AdBh0738	462500	987000	2309	137	84	2225.4	Deep well
AdBh0739	461900	974300	2127	0	38	2089.4	Spring
AdBh0884	455475	994995	2838	152	61	2777.3	Deep well
AdBh0888	455350	985100	2188	128	70	2118.3	Deep well
AdBh0889	455300	985250	2198	101	38	2160.8	Deep well
AdBh0890	455525	984000	2146	124	63	2082.5	Deep well
AdBh0891	455550	983750	2138	181	47	2090.7	Deep well
AdBh0892	444000	977700	2068	100	17	2050.7	Deep well
AdBh0895	460850	985850	2251	106	43	2208.1	Deep well
AdBh0896	460500	986500	2296	100	27	2269.1	Deep well
AdBh0981	460121	985966	2254	120	40	2214	Deep well
AdBh1037	457030	984617	2218	140	89	2129.6	Deep well
AdBh1044	458646	984363	2190	161	44	2145.9	Deep well
AdBh1103	462260	984901	2284	180	83	2201.5	Deep well
AdBh1152	460295	986769	2314	158	31	2282.8	Deep well
AdBh1153	447549	1007893	2509	203	24	2484.7	Deep well
AMW14	450359	981037	2076	280	11	2065.3	Deep well
AMW18	433200	959670	2112	194	0	2111.8	Deep well
AMW2	440274	1006055	2530	300	12	2517.5	Deep well
AMW20	413137	973900	2086	311	10	2076.5	Deep well
AMW26	427395	992768	2101	220	6	2094.6	Deep well
AMW3	427126	971361	2084	308	4	2079.8	Deep well
AMW4	456314	962592	2019	290	0	2018.7	Deep well
Adsp06	431584	998853	0	0	0	2319.1	Spring
Adsp07	431584	998853	0	0	0	2319.1	Spring

Adsp08	410870	997013	0	0	0	2191.4	Spring
adsp11	459831	985582	0	0	0	2226.5	Spring
Adsp12	455287	985619	0	0	0	2234.4	Spring
Adsp44	412197	957215	0	0	0	2173.4	Spring
Adsp45	451249	985378	0	0	0	2153.3	Spring
Adsp59	460950	976800	0	0	0	2110.1	Spring

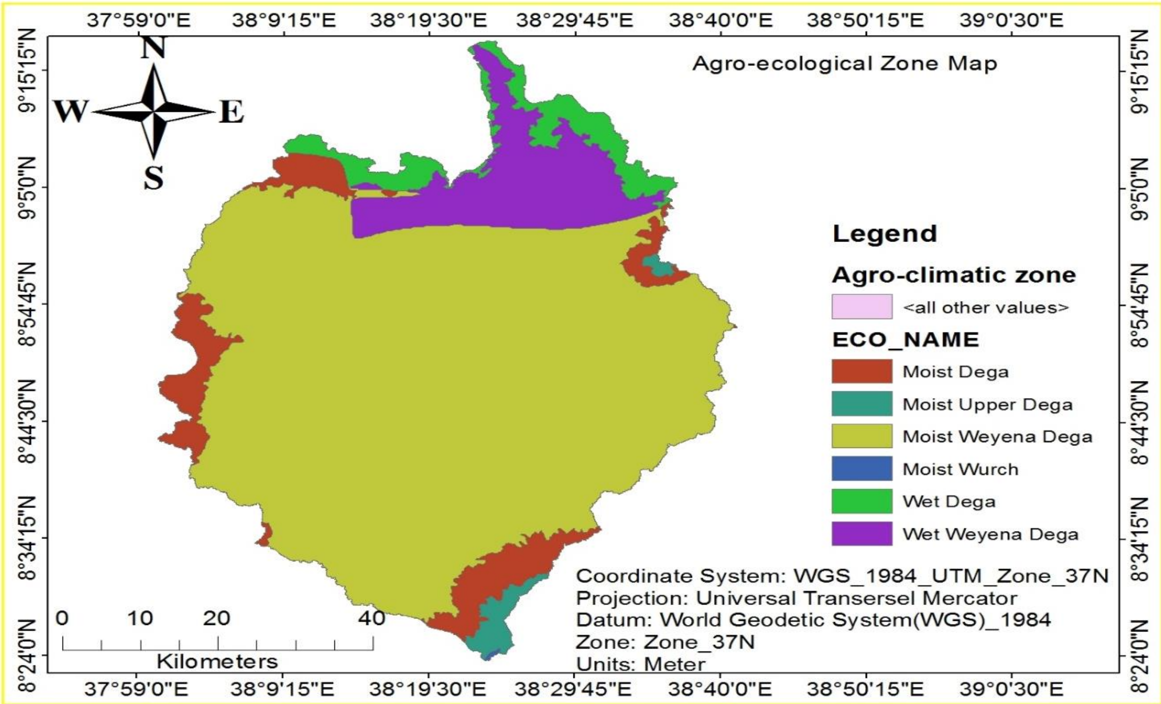
Figure in the Appendix



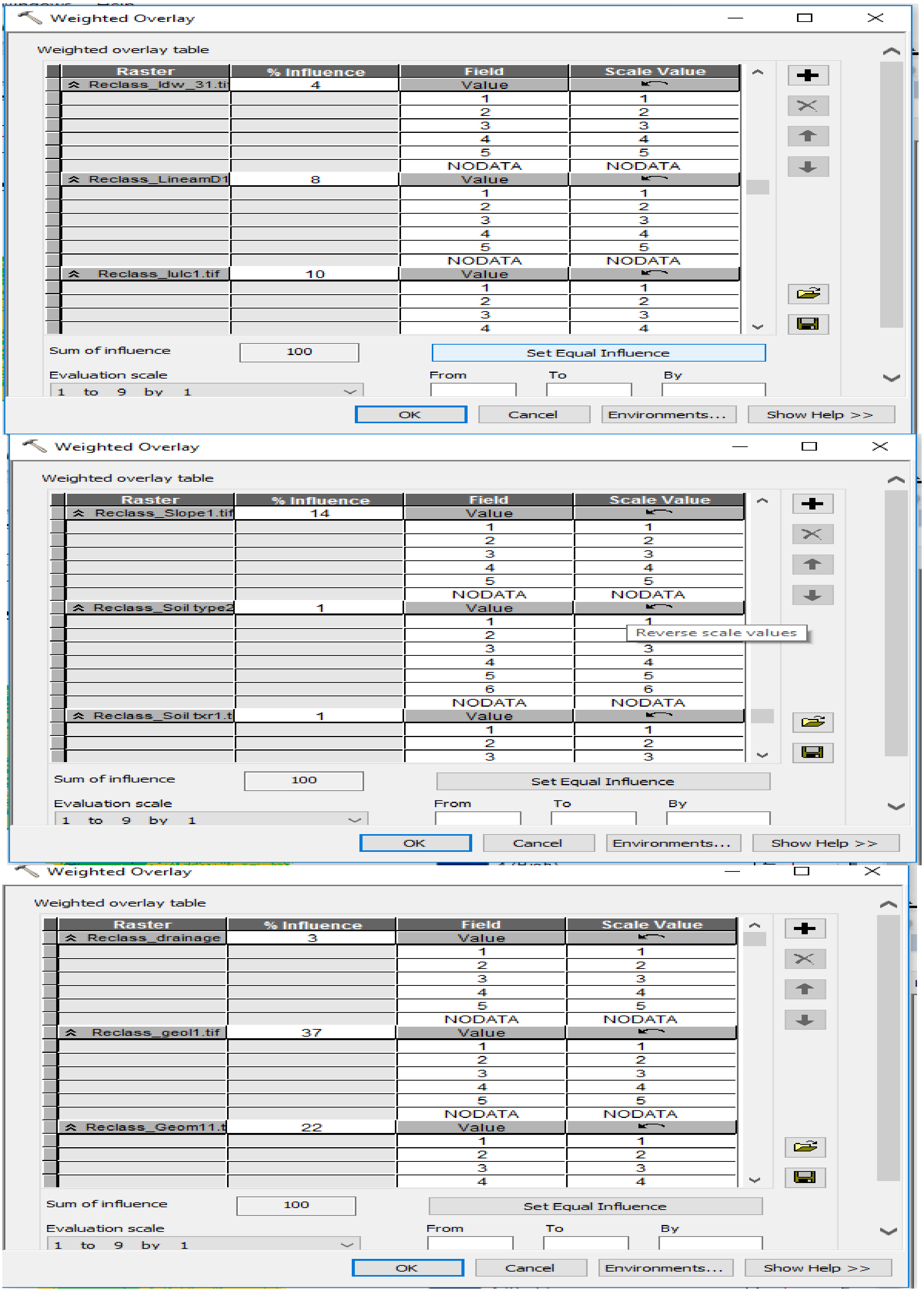
Appendix Figure 1: Long-Term Distribution of Mean Annual Rainfall of Stations (Month/Years) (2002-2018), Source: NMAE, 2019



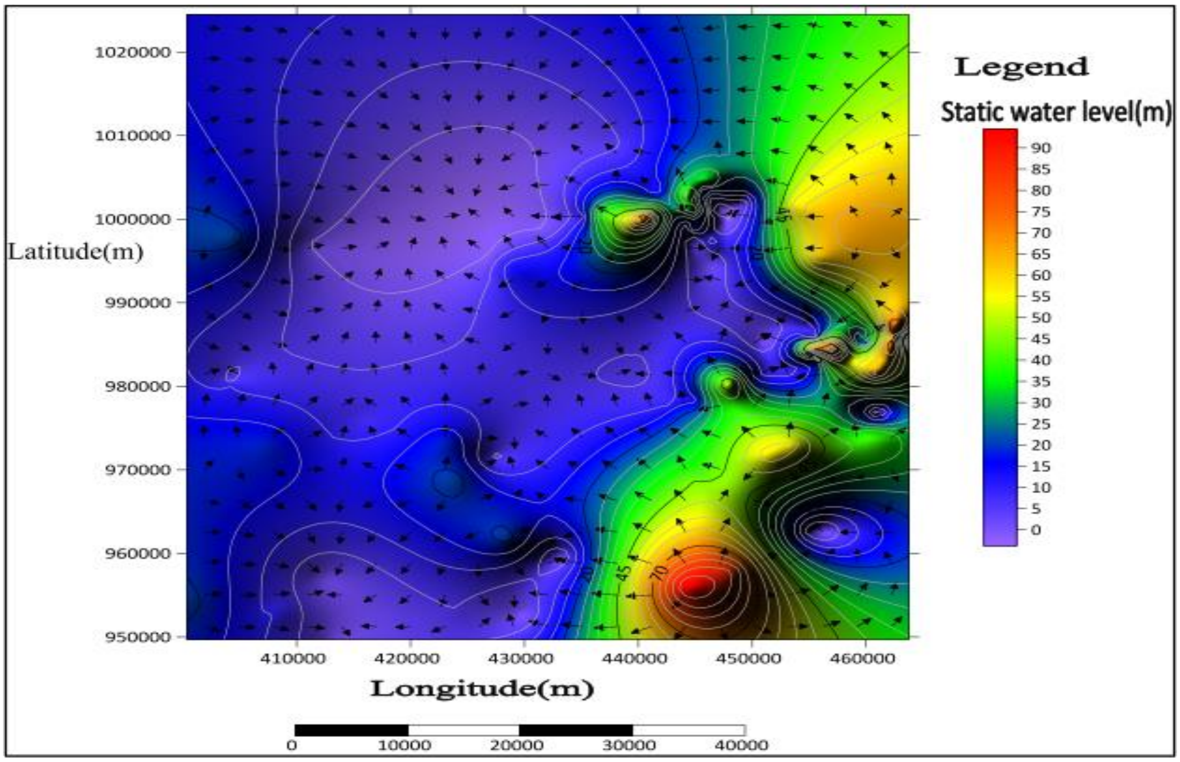
Appendix Figure 2: Landsat satellite image (SPOT 5) of the study area



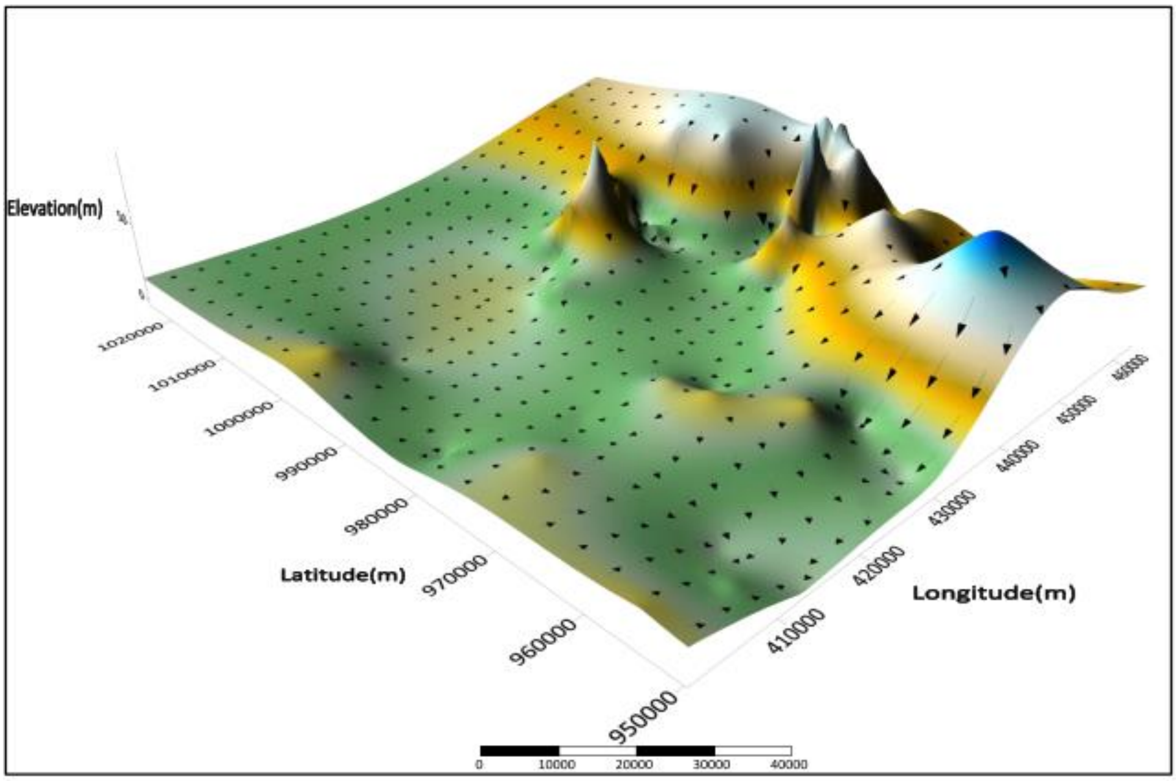
Appendix Figure 3**:** Distribution of Agro-Climatic Zone Map of the Study Area, Source: AWBA, 2018



Appendix Figure 4: Reclassified Thematic Layers Weighted Overlay Analysis (WOA) Workspace



Appendix Figure 4: 2D-Groundwater Flow Direction of the Study Area



Appendix Figure 4: 3D-Groundwater Flow Direction of the Study Area