IDENTIFICATION OF GROUNDWATER POTENTIAL ZONE BY USING GIS AND REMOTESENSING IN SUTEN TO TORA SUB-CATCHMENT, RIFT VALLEY LAKES BASIN, SOUTHERN ETHIOPIA

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This is to certify that the thesis entitled "IDENTIFICATION OF GROUNDWATER POTENTIAL ZONE BY USING GIS AND REMOTESENSING IN SUTEN TO TORA SUB-CATCHMENT, RIFT VALLEY LAKES BASIN, SOUTHERN ETHIOPIA" has been submitted in the partial fulfillment of the requirement for the degree of Master of Science in Water Resources Engineering and Management has carried out by **Aschalew Gurmu Baruda**. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the school.

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DECLARATION

I hereby declare that this M.Sc.thesis entitled as "IDENTIFICATION OF GROUNDWATER POTENTIAL ZONE BY USING GIS AND REMOTESENSING IN SUTEN TO TORA SUB-CATCHMENT, RIFT VALLEY LAKES BASIN, SOUTHERN ETHIOPIA" is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

DEDICATED TO MY GREAT SON

Eden Aschalew Gurmu

This thesis is dedicated to the memory of my beloved daughter Eden Aschalew Gurmu who passed away after starting this Master of Science degree. **Edu** I have no word to say how to beloved you; simply I said that your sweet word is kept in my heart.

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LIST OF ACRONYMS AND ABBREVIATIONS

AHP	Analytic Hierarchy Process
A.M.S.L	Above mean sea level
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
AWCRZ	Available water capacity of the root zone
CBLC	Classified based on Lithological Characterization
CMB	Chloride Mass Balance
CI	Consistency index
CR	Consistency ratio
DEM	Digital Elevation Models
EPM	Equivalent Porous Medium
ERDAS	Earth Resources Data Analysis System
FAO	Food Association Organization
GIS	Geographical Information System
GPS	Global position system
GWFD	Groundwater flow direction
GWP	Groundwater potential
IDW	Inverse distance weight
IRWR	Internal Renewable Water Resources
ITCZ	Inter-Tropical Convergence Zone

K	Hydraulic conductivity
LULC	Land Use Land Cover
Ma	Million years
MCE	Multi criteria evaluation
MER	Main Ethiopian Rift
MoWR	Ministry of Water Resources
OLI	Operational land imager
PCI	Peripheral Component Interconnect
PCP	Precipitation
RH	Relative Humidity
RI	Random index
RS	Remote sensing
RVLB	Rift Valley Lakes Basin
SRTM	Shuttle Radar Topography Mission
SNNPR	South nation nationality people Representative
TIRS	Thermal infrared sensor
TM	Thematic map
VES	Vertical Electrical Sound
WATBAL	Soil water balance model
WWDSE	Water Works Design and Supervision Enterprise

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ABSTRACT

This study was aimed to mapping of Groundwater potential investigation of Suten-Tora sub-catchment in the Rift Valley Lakes basin, Southern Ethiopia. Climate, hydro-geological, land use/land cover, soil, lithology, geomorphology and stratigraphic data were collected, analyzed and inferred. The aquifer characteristics from the well completion reports were used to map the Groundwater flow direction. A Groundwater level contour map; which developed from well completion report is revealed that the Groundwater flows from western towards the center and eastern part of the sub-catchment. The results also inferred from the geological formations show that the Suten-Tora Sub-catchment are mainly covered by partially welded pyroclastic flow, Gash Megal rhyolitic lava flows, Guraghe-Anchor basalt, Nazret welded pyroclastic, Lacustrine sediment, Mesozoic sediment, porphyritic rhyolitic lava domes, Wonji basalts, Precambrian basement complex and recent basalt flows. Moreover, there is also a Geological structure in the study area. The linear feature of these structures are characterized by three distinct interconnected fault trends systems are called in NW-SE, NE-SW and N-S which are more or less affect the availability of Groundwater potential. Among the above listed lithological formations lacustrine sediments, Wonji basalt with scoria deposit and pyroclastic are coincide with high Groundwater potential zone. Similarly a moderate Groundwater potential zone is covered by Geological formations; e.g. Chefe Donsa, un-welded to poorly weld pyroclastic and others small formations. In the other way low and very low potential zones are covered by depositions of Nazret pyroclastic, Gash Megal rhyolite and other similar lithological formations. For the delineation of Groundwater potential zones, the weight over analysis of different factors namely: lineament density, lithology, geomorphology, slope, soil texture, drainage density, rainfall and elevation have been analyzed through the Analytical Hierarchal process (AHP) and ArcGIS 10.3 software. The delineated Groundwater potential zone was categories into four classes namely high, moderate, low and very low potential zone. These delineated Groundwater potential zones class called high, Moderate, Low and very low potential zones are covers an area of around 50%, 20%, 16% and 14% of the total sub catchment area respectively. To conclude that; the center and southeastern parts of the sub catchment have high amounts of Groundwater potential. However the western part has les Groundwater potential. Depend on the validation of output accuracy level; the delineation of Groundwater potential zones by using GIS and remote sensing techniques is important method. Finally it has been recommend that ; the well drillers in this study area suggested to use this Groundwater potential zone map as information.

Keywords: Groundwater level, Groundwater flow system, Groundwater potential zone, AHP, GIS, Overlay analysis,

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1. INTRODUCTION

1.1. Background

Among the precious resources nature has given; water is the most essential for life. Ethiopia is one of a countries gifted with vast water resource. As a third world country, it is not excluded the nations suffering from the negative socio-economic outcomes of potable water shortage. The percentage of the people who had access to adequate and safe water is very minimal. The population has no sufficient clean water supply partly they lacks efficient, equitable and optimum utilization of water for significant socio-economic development in a sustainable basis (Genet Mathewos, 2017). This is because of the problem in exploitation of Groundwater in unsuccessful rate of well production encounter.

It is believed that an intensive water resource development can have a great role in the economic growth of a country and preventing ecological degradation. As compare to surface water resources, Ethiopia has lower Groundwater potential. However, the total exploitable Groundwater potential is high (Seifu Kebede, 2013).The occurrence, movement and chemical constituents of groundwater are dependent on geology/ lithology, Geomorphology /Landforms, drainage density, rain fall, Geological structures/lineaments, slope, Land use/Land cover and soil of groundwater regime (Genet Mathewos, 2017). Based on Groundwater resource affecting parameters; the Groundwater potential zone investigation is important for sustainable management and development of Groundwater systems (Dar et al., 2010). Likewise, identifying the Groundwater flow system is critical for implementing effective strategies Groundwater resource investigate and management (Tweed et al., 2007).

Among several methodologies to locate and map the occurrence and distribution of Groundwater; the use of remote sensing (RS) and Geographic information system (GIS) is efficient and cost effective technique providing valuable data on geology, geomorphology, lineaments and slope as well as a systematic integration of the data for exploration and delineation of Groundwater potential. Satellite data provides quick and useful baseline information on the parameters controlling the occurrence and movement of Groundwater even in inaccessible areas. The information on the input parameters in the above can be acquired and integrated through remote sensing (RS) and geographical information system (GIS) techniques. The concept of RS and GIS has proved to be an efficient in Groundwater studies, in facilitate better data analysis and their interpretations. In addition, the greatest advantages of using remote sensing data for hydrogeological investigations is its ability to generate information in spatial and temporal domain, which is very crucial for successful analysis, prediction and validation (Solomon, 2003; cited as Temesgen, 2018).

The gap of understanding Groundwater potential zone identification is one of the factor in planning water supply from Groundwater resources. Therefore, investigation of Groundwater potential zone and flow direction in the study area is the main approach for improving the use of Groundwater resource. It was addressed to understand Groundwater flow direction and identifying Groundwater potential zone through developing thematic map of various Groundwaters potential affecting parameters; such as rainfall, drainage density, soil texture, geomorphology, land use/Landover, slope, lineament and elevation is essential for sustainable development and improving the use of Groundwater resource.

1.2 Statement of the problem

Currently, there is a rapid urbanization, increase in agricultural production and industrial developments have led to water shortages in many parts of the country including this study area (Karanth, 2009). Suten-Tora sub catchment is the source of domestic water through construction of borehole began more than fifty years back during the Emperor Haile Selassie regime (Spate Irrigation Network, 2015).

But now a day because of a lack of reconnaissance survey for site selection in Suten-Tora sub catchment there has a potential risk of adequate water supply for irrigation, domestic and small scale industrial purpose. The cause of lack of reconnaissance survey for site selection is unavailable Groundwater potential zone identification in GIS and remote sensing techniques; which are powerful tools for the identification and mapping of Groundwater potential zones in time and cost effective manner. Instead of GIS and remote sensing techniques Groundwater development was done based on traditional field studies (using existing water source site as guideline) is also the main problem. So because of these sequential problems and well dryness in short period of time; the communities are exposed to the problem of accessing safe drinking water at acceptable distance. Therefore the primary problems of all these listed things are due to the gap of proper Groundwater potential zone site identification.

1.3. Objectives

1.3.1 General objective

The general objective of this study was investigating the Groundwater potential and identifying the Groundwater flow systems in Suten-Tora Sub-catchment, Rift valley Lakes Basin; South Ethiopia

1.3.2 Specific objectives

The above general objective will be broken down in to three more specific objectives that would together achieve the overall goal of the research are:

1. To identify the Groundwater flow systems in Suten to Tora Sub-catchment
2. To prepare thematic maps of Groundwater potential affecting parameters
3. To delineate the Groundwater potential zone in Suten to Tora Sub-catchment

1.3.3 Research questions

1. Which aquifer parameters are determined the Groundwater flow system in Suten to Tora Sub-catchment?
2. What are the major parameters which affect the occurrence of Groundwater in Suten to Tora Sub-catchment?
3. What does the spatial distribution of Groundwater potential area look like in Suten to Tora sub-catchment?

1.4 Significance of the study

This study expected to improve the different water related problems occurring in the Suten to Tora Sub-catchment. Such study will have a paramount importance to understand the better picture of Groundwater potential zone, Groundwater flow directions and improving the problem of adequate and safe water. In addition to this, any professional interested to work on related issues in the area will be use this Groundwater potential zone identification report as a reference to a detailed study.

1. 5 Scope of the study

This study is geographically limited to the southern part of Ethiopia which is limited between $38^0$12’00”-$38^0$38’00” East and $7^0$50’00”-$8^0$30’00”North. In addition to this, the geographical scope of the area, the study of this research is also bounded to identifying the Groundwater potential zone and its flow systems, together achieve the overall goal of the research called investigating the Groundwater availability in Suten to Tora sub catchment.

2. LITERATURE REVIEW

2.1 Groundwater potential investigation

All water beneath the land surface is referred to as under Groundwater (or subsurface water). The equivalent term for water on the land surface is surface water. The potential of Groundwater is depending on the Groundwater recharge amount. Groundwater recharge is the process by which water percolates down the soil and reaches the water table either by natural or artificial methods to replenish the aquifer with water from the land surface (Yongxin, 2003). The Geological units in Ethiopia fall into three major categories. These are Precambrian basement, late Paleozoic to early tertiary sediments and Cenozoic volcanic and associated sediments (Mengesha et al., 1996). The main Ethiopian Rift developed over a span from the Oligocene to the Quaternary. During this period, major volcanic episodes are recognized in Oligocene, middle Miocene, late Miocene, early-middle Pleistocene and Holocene (WoldeGabriel et al. 1990, cited in JICA, 2012). The oldest volcanic activities are basalt and rhyolite flows in Oligocene, exposed in and around of highland of the rift margins , which formed lava plateau in the surrounding the study area. By middle Miocene, the rift was formed in some parts with containment basaltic flows. In Pliocene, a huge pyroclastic flow covered the study area. This characteristic pyroclastic flow deposit is currently observed at a depth of around 2100 meter in the basin floor by geothermal well, indicates a minimum of 2km of down throw in the rift basin since its eruption (WoldeGabriel et al, 2000).

Groundwater and surface water interactions occur through the fractured mediums which are represented by replacing the primary and secondary porosity. These primary and secondary porosity are affects the hydraulic conductivity distributions with a continuous porous medium of equivalent or effective hydraulic properties.

The equivalent porous medium approach has been frequently applied to estimate the amount of flow in fractured media. This practice results in some severe limitations such as hydraulic head averaging and an inability to handle preferred fluid pathways (Snow, 1969). Groundwater potential and its flow directions of a given catchment were mapped based on different indicators such as; topography, Groundwater flow pattern and static Groundwater levels. Topography is a major factor which has to be considered for delineating the recharge and discharge zone; high land areas are an indicator of recharge areas (Afewerk, 2011).

Identifying Groundwater potential zone using geographic information system(GIS) and remote sensing(RS) is done by considering a nine parameters ; such as drainage density, elevation, geology, geomorphology, land use and land cover, lineaments, dyke, rainfall pattern, slope gradient and soil texture. The selected parameters have been prepared and classified using analytical Hierarchical process, then weighted overlay analysis in ArcGIS used to find out the result. The result of the study has been compared with collected sample data to assess the accuracy of the result (Ramu, 2014, cited in Temesgen, 2018).

2.2 Remote Sensing (RS)

RS is the non-contact recording of information about the earth surface, from the ultraviolet, visible, infrared and microwave regions of the electromagnetic spectrum, by means of instruments such as scanners and cameras, located on mobile platforms such as aircraft or spacecraft followed by the analysis of acquired information by means of photograph interpretation techniques, image interpretation and image processing. The contact between the remote sensor and the target is through electromagnetic energy such as visible, thermal and infrared radiation, force fields that are gravity magnetic. Remote sensors measure the relative variation of these forms of energy that is either emanating from the body or being reflected from it for recognition and detailed studies (Kibrit ,2018).

2.3 Application of GIS and RS in Groundwater potential studies

There are a plenty of works undertaken in GIS and remote sensing techniques. Preparing thematic map of drainage density, geomorphology, lineament density, land use/land cover, soil type, slope and mean annual rainfall are the main activities that done by GIS. The thematic maps of these listed parameters had been ranked depending upon their suitability to hold Groundwater and the rank in turn, had been converted to a probability weight in a characteristics of a given study area (Sar et al, 2015; cited in Kibrit ,2018). Among the literature reviews that shows hint for how to give a rank of the thematic map parameters are shown follow.

In Dulung Watershed, West Bengal, India, used an integrated remote sensing and GIS based methodology to develop and test the groundwater resources of the area. In this study different thematic maps were prepared from conventional survey. And in such terrain, geomorphology played a vital role for groundwater storage followed by slope, geology, lineament density, drainage density and land use (Bandyopadhyay, 2012). Identification of Groundwater potential zones by using GIS and remote sensing application in Keleghai river thematic layers drainage density, geomorphology, lineament density, land use/land cover, soil type, water bodies density, slope and mean annual rainfall. The thematic maps of these listed above had been ranked depending upon their suitability to hold groundwater (Sar et al. 2015). Another groundwater potential mapping study was carried out in Birnbaum district ,West Bengal which concluded that the combined application of remote sensing, GIS and multi influencing factor techniques are found to be an efficient tools in the delineation of groundwater potential zones with respect to cost, efficiency, manpower and time involved in conventional exploration.

In this study, various thematic layers give a rank elevation, land use/land cover, drainage density, geomorphology, lineament density, soil type, water bodies density, slope and mean annual rainfall(Thapa et.al., 2017, cited in Kibrit, 2018)

2.4 Analytical Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a Multi-Criteria Decision Making (MCDM) approach and was introduced by Saaty in 1980s. AHP has attracted the interest of many researchers mainly due to the nice mathematical properties of the method. AHP is a decision support tool which can be used to solve complex decision problems. It uses a multi-level hierarchical structure of objectives, criteria, sub criteria, and alternatives. The data are derived by using a set of pair wise comparisons. These comparisons are used to obtain the weights of importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion (Kousalya et.al. 2012; cited in Kibrit, 2018).

2.5 Factors that Affects Groundwater Potential

Among the types of Groundwater potential affects parameters; the followings are the main one that affects the occurrence and movement of Groundwater potential in this study are describes below:

2.5.1 Elevation

Elevation is one of the main inputs parameters of delineation Groundwater potential zone. It is known that water tends to store at lower topography rather than at the higher topography (Ramu et.al. 2010). Therefore; the elevation increase the Groundwater potential will be decrease. Hence elevation or altitude should be considered in the Groundwater potential studies.

To prepare the elevation, slope and drainage map, either the SRTM or ASTER DEM 30m data could be used. In this study, SRTM DEM 30m was selected since it is more accurate both in its vertical and horizontal accuracy than ASTER DEM (Odutola et al., 2012 ; cited in Kibrit, 2018).

2.5.2 Geological Formation

The Geological formation of the whole Main Ethiopian Rift Valley is the result of the geologic events that took place in the Eastern Africa. At the end of tertiary and early Pleistocene, as a result of the liberation of large amount of magma and the gradual widening of the fractures a continental scale collapse takes place, giving rise to the Rift Valley. In the Pleistocene, most of the graben is filled by deposits of volcanic clouds pouring from the cracks and giving rise to post-rift ignimbrites, ashes and blocks transported by the gases after a violent explosion. In the quaternary alternation of basic outpouring (alkaline basalts) and acidic outpouring (rhyolites, ignimbrites, obsidians, pumices and ashes) are common. The post-rift volcanic activity has often taken place in a lacustrine environment and given rise to rocks with a volcano-lacustrine faces (ignimbrites and rhyolites, hyaloclastites, cinerites, diatomites, pumiceous tuffs, ashes, (M. Raunet, 1977).

In Suten to Tora sub catchment; there are huge pyroclastic flow and lacustrine sediments; which covered a wide area. This characteristic pyroclastic flow deposit is currently observed at a depth of around 2100m in the escarpment of the sub catchment by geothermal well, indicates a minimum of 2km of down throw in the rift basin since its eruption (WoldeGabriel et al, 2000). The hydrological nature of Suten to Tora sub catchment area’s Geology are controlled by the variability of lithological units, different litho-stratigraphy, topography, geological structure, climatic condition, weathered and fractured zone in the rock mass and others. As we know good aquifer must be adequately permeable and transmit that means interconnected porous and sufficiently stored of water (Bereket Fenatw, 2011).

2.5.3 Soil Texture

The type and texture of the soil have an important role on the amount of water that can be infiltrated into the subsurface formation. Soil store rainwater in their pores before it infiltrates to greater depths and recharges the aquifer system. The water stored at the upper layers was evaporated easily, it negatively affects Groundwater potential (Habtamu 2014; cited in Temesgen, 2018). The major soil units in the catchment are categorized as Eutric cambisols, Eutric Vertisols, Eutric luvisols, Leptosols, Luvisols, Alluvial-colluvium originated Eutric cambisols.

2.5.4 Land use Land cover (LULC)

Groundwater potential was affected by different classes of LULC. Forests and agricultural lands increases the Groundwater potential by trapping and holding the water in root of plants, whereas the built and rocky lands affect the recharge of Groundwater by increasing runoff during rainfall (Temesgen, 2018).

The vegetation cover of Suten to Tora sub catchment is varies from east to west, it depends on the altitude and soil type across the sub catchment. Major crops grow in the western parts of the sub catchment are coffee, inset, maize and teffe, however in the southern and eastern parts of the catchment maize, teffe , livestock production is the main activity of the community (Temesgen, 2018).

2.5.5 Drainage Density

Drainage Density is the measure of the total length of the stream segment of all orders per unit area, which is inversely proportional to permeability (Magesh, 2012). When rocks are highly permeable, infiltration to the Groundwater is high and reduce surface runoff while where rocks are low permeable there is low infiltration and high surface runoff which negatively affect the Groundwater potential. The drainage system of the Suten to Tora sub catchment is strongly influenced by the morphology (Halcrow, 2007). The catchment stream network shows dendritic drainage pattern in the upstream areas and sub parallel patterns in the downstream sections. In dendritic system, there are many contributing streams which are joining together to the tributaries of the main river.

2.5.6 Rainfall Characteristic

Rainfall is the major source of recharge Ethiopia; that determine the amount of water would be to percolate into the Groundwater system (Genet Mathewos, 2017). Ethiopia, seasons are classified based on rainfall pattern, Indicates that there are three major seasons; kiremt (main rain season from June to September), Belg (small rain season from February to may) and bega (dry seasons from October to January (Birhanu, 2009). At high rainfall season the amount of Groundwater potential is increased due to increasing Groundwater recharge (Potential et at. 2010). Suten to Tora climate and rainfall intensity in the catchment follows a humid to semi-arid tropical bimodal distributed precipitation pattern; Variability is caused by alternating dry and rain seasons, as well as long term influences which is over lapping with regional orographic (Mandefro, 2016).

2.5.7 Slope

Slope is an important factor for the identification of Groundwater potential zones, higher degree of the slope results in rapid runoff and increase erosion rate which decreases recharge (Magesh, 2012). Surface runoff and rate of infiltration are influenced essentially by the slope of the surface. The study area western parts are dominantly covered by steep and very steep slopes; however, the eastern parts of the catchment are relatively considered as gentle slopes.

3. MATERIAL AND METHODS

3.1 General description of the study area

3.1.1 Location

The location of Suten to Tora sub-catchment is situated in the southern part of Ethiopia which encompasses fourteen Woredas are listed in the following map legend. This study area lies between $38^{0}12'00''$-$38^{0}38'00''$ East and $7^{0}50'00''$-$8^{0}30'00''$North. The area is accessed from Addis Ababa to Suten-Koshe Asphalt road and after Koshe accessed the rest area through weathered and all weathered road. Such distance is measured approximately around 195km. The total area and perimeter are covered as 2175 square kilometers and 282.349 kilometers respectively.

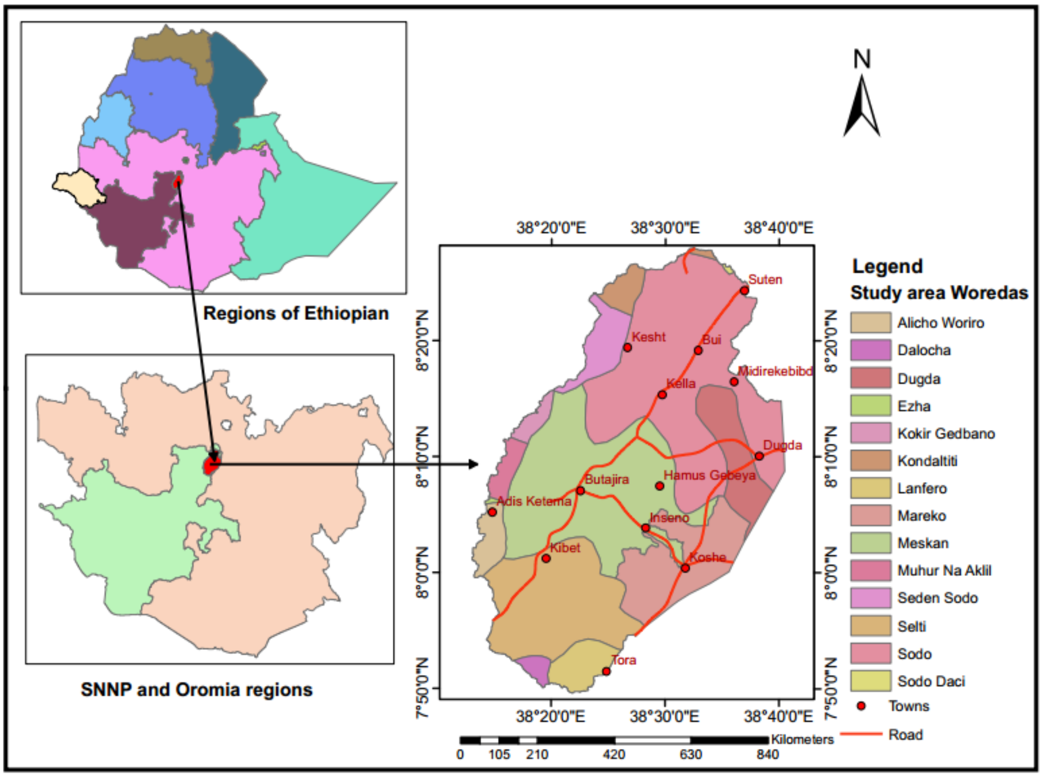


Figure 3. 1 Location map of Suten to Tora sub catchment

3.1.2 Topography

Among Groundwater potential controlling factors topography is one of the main parameters. Topographic configuration and geomorphological development of the study area is closely related to the geological formation and a series of tectonic activities. Depend on these formations the study area topography is represented as highland area which formed by welded to partially welded pyroclastic flows and escarpment area that covered by volcanic origin Lacustrine deposits (Tsegaye Abebe et al., 2005).

3.1.3 Hydrology and Rainfall

Rainfall

Precipitation is water released from clouds in the form of rain, freezing rain, sleet, snow, or hail. It is the primary connection in the water cycle that provides for the delivery of atmospheric water to the Earth and it falls to the earth surface as rain. The agro-climatic zone of the study area is tropical, from June to September being wet season while the dry season extends from November to May (Abebaw, 2012). Knowing the nature and characteristics of precipitation, it can be conceptualized and predicted its effects in runoff, infiltration, and Groundwater recharge. Therefore, for climatically analysis it is important to know the areal distribution of precipitation that may contribute to Groundwater recharge and create potential area(Ramu et.al., 2010; cited in Kibrit, 2018).

The studies of water resources development and management depend heavily on hydro meteorological data. These data should be stationary, consistent, and homogeneous when they are used to compute a hydrological system. If it does not fulfill one of the above criteria, its result wills in a big problem that contradicts the actual situation. Among the approaches that used to estimate missed hydro-metrological data varying is Normal ratio method. This method is done based on orography rain fall distance between the gauged station and the variation of rain fall amount recorded on the station.

Normal ratio method is a method that recommended estimating missing data in a region where unevenly (non-uniform) rain gauge network over the study area and the annual rain fall among stations differ by more than 10%. This method is used to fill in missing data on a rain fall stations in the study area since the difference in annual rain fall between most of the stations exceeds 10%. This is calculated by weighting the observation at n gauges of respective annual average measured values as expressed below:

$P_{X=}\frac{1}{n}[p_{1*}\frac{Nx}{N1}+p_{2*}\frac{Nx}{N2})+p_{3*}\frac{Nx}{N3}\ldots\ldots\ldots.+pn*\frac{Nx}{Nn}]$, where

P_1, P_2, P_3…...P_n are the annual precipitations data

N_1, N_2…….N_n, the normal annual rainfall

P_x and N_x the corresponding values for the missing station X

n is the number of stations

Estimation of Areal depth of Precipitation (PCP)

A measurement of precipitations in metrological stations is a point observation that probably incorrect representative value for the total study area under debate. To avoid this debate in the study area, the real representative data has to be obtained from National Metrological Service Agency (NMSA). The study area meteorological stations are adopted to estimate aerial depth of precipitation by sing normal ratio methods were seen from the following table.

Table 3. 1 Meteorological stations and their elements

No	Stations and Year of Record	Meteorological Elements	Class	Geographical coordinates		
				Easting(m)	Northing(m)	Elevation (m.a.s.l)
1	Buei(1987-2018)	P,T,W,S,H	I	450951	920825	2059
2	Kella(1987-2018)	P,T	II	444472	912526	1921
3	Butajira (1955-2017)	P,T	II	431248	897824	2079
4	Tora(1975-2017)	P	IV	436446	868696	2011

Where, p=Precipitation and T=Temperature, W=Wind speed, S=Sunshine H= Humidity

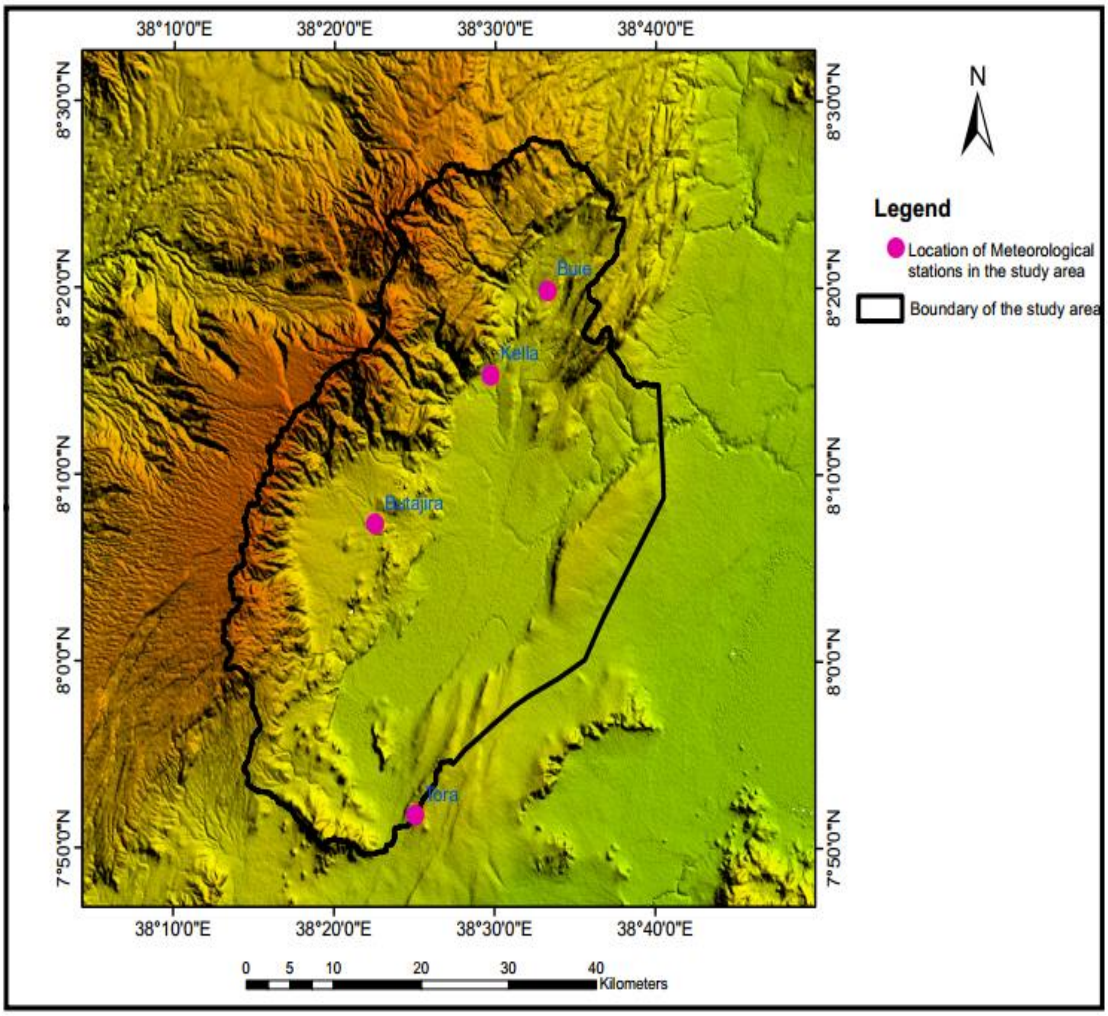


Figure 3. 2 Location of Meteorological stations in the study area

Arithmetic average method

Suten to Tora Sub-catchment and its surroundings seem to have a variation of precipitation due to the uplift of an air mass when it is forced upward against a mountain barrier. If lifted high enough, the air mass cools, water vapor condenses and precipitates out as snow or rain called orographic effect. In order to evaluate and estimate uniform depth of aerial precipitation over the study area, there are using two methods called Arithmetic and Isohyetal polygon methods.

When the rain fall measured at varies stations in a sub-catchment shows little variations, the averaging precipitation over the sub-catchment area is taken as arithmetic means of the station value (K. Subramanya, 2008). This method gives a very satisfactory measure if the area is sampled by many uniformly spaced rain gauges and has no marked diversity in topography (Chow, 1988). The study area is situated at the base of Zebidar Massif Mountain in the Gurage and Silti Zone of the Southern Nations, Nationalities and Peoples' Region. The topography of this area is characterized by plane-undulating slopes to mountainous. And also the altitudinal variations in the study area is extent from 1752m to 3606m, which is not suitable to use this method for estimation of the rainfall depth. However, for this study we use such method for the sake of computing Isohyetal polygon methods. So the mean monthly uniform aerial depth of precipitation which calculated by using arithmetic mean method is shown below.

Table 3. 2 Mean annual areal depth of precipitation (by arithmetic mean method)

Station & Year	Jan.	Fub	Mar.	Apr.	May.	Jun.	Jul	Aug	Sep.	Oct.	Nov	Dec	Annual
Buei(1987-2018)	23	49	85	93	81	121	210	190	110	39	16	13	1030
Kella(1987-2018)	26	45	79.9	95	100	135	236	236	124	50.8	20	6	1154
Butajira(1987-2018)	21	50	51	106	104	132	216	250	114	52	34	28	1158
Tora(1987-2018)	24	43	79	106	87	89	143	124	104	54	12	7	872
Mean(mm/year)	36	57	96	113	104	134	211	198	129	59	30	21	1054

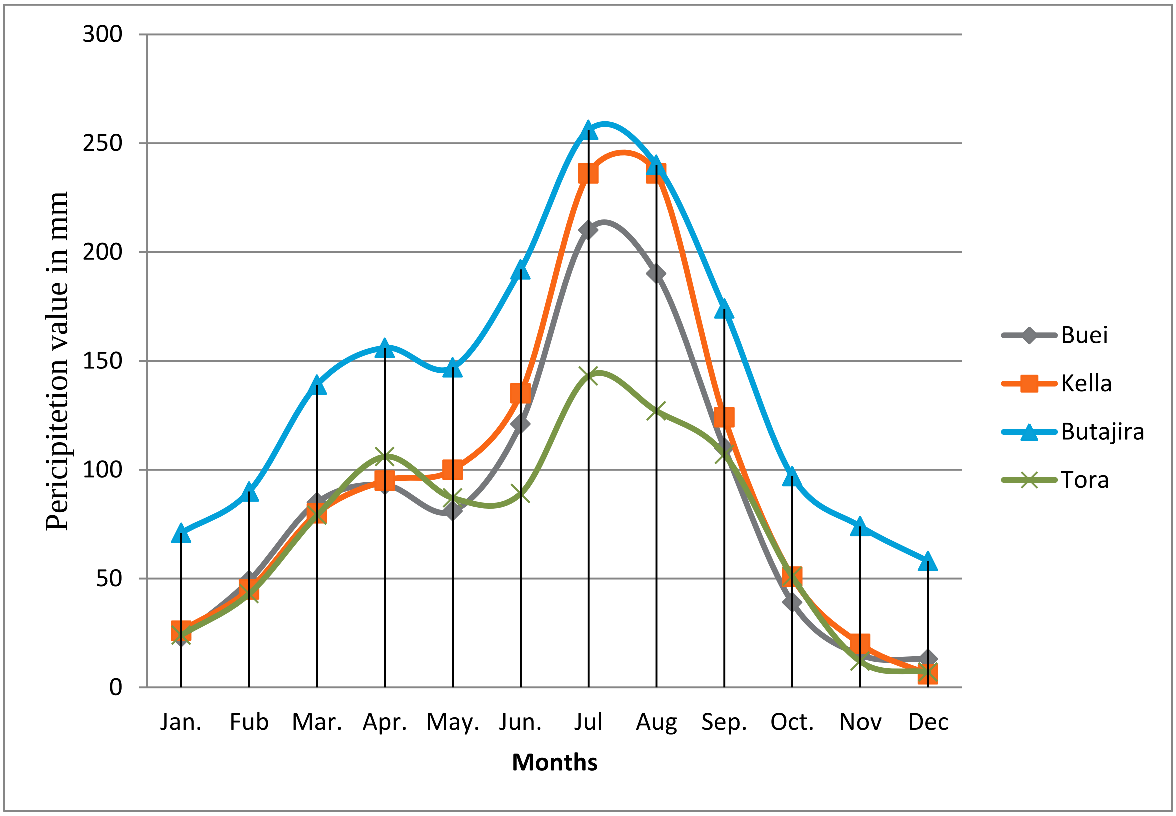


Figure 3. 3 Mean monthly rainfall distributions obtained from arithmetic mean method

Hydrology

The area is situated within the Rift valley drainage basin where it is drained by the rivers called 'Irinzaf', 'Eresha', 'Woja' and 'Meki' with their tributaries. 'Erinzaf' river drains the western and south western catchment areas whereas 'Eresha' drains the northern mountainous parts. Both rivers finally drain into 'Debena' river which in turn flows in the southerly direction to 'Mereche' river. The 'Erinzaf' river originates from the highlands of 'Chinko', 'Imbor' and 'Yetebon' areas. It flows from the west and south west direction towards the town and its name becomes 'Debena' after joining with the stream called Eresha (Abebaw, 2012). Just like of this; Meki river is a river in the study area that emerged from Gurage highland and drains into Lake Ziway at the latitude and longitude of $8^0$4'8" north $38^0$52'53"east.

3.1.4 Geology

According to the base map of Akaki-Beseka and Hosaina map sheet in Geological Survey of Ethiopia, there are 16 lithological units in Suten to Tora Sub-catchment is classified as Pre-rift and Post-rift units:

3.1.4.1 Pre-rift units

The pre-rift units/old formations/ in the study area are listed as the following major categories:

Biotite genies (Pb)

Precambrian basement, Quartz-feldspare-biotite gneiss, cross cut by quartzo-feldspathic pegmatite vein units are outcropped in the northern part of the study area at kella horst(Efrem Beshawered , 2010). This unit covers small area that have a minimum exposed thickness of 150 meters, unconformable overlain by Adigrat sandstone and it is cut by swarms of quarzo- feldspathic pegmatites and minor migmatites. A Biotite gneiss (Pb) rocks are classified under low potential aquifers Groundwater occurrence in the study area (Efrem Beshawered, 2010).

Mesozoic sediment, consists adigrat reddish brown sandstone, shales & marls and yellowish grey Antalo limestone (Ms)

This unit contains three types of lithology, namely Adigrat Sandstone, Shales with Marls and Antalo Limestone (Efrem Beshawered, 2010). All these Mesozoic sedimentary rocks are classified under low aquifers with limited Groundwater occurrence in the study area (Efrem Beshawered, 2010) are listed follow:

Adigrat Sandstone

This unit is exposed to the northeast part of the map area at the base of Kella horst. In most outcrops, it is fine to medium grained, light gray, brown grey to dark-grey in fresh samples to pinkish yellow to reddish brown in weathered ones. It attains in a maximum thickness of 150 meters at Kella horst forming cliff (Efrem Beshawered, 2010).

Shales and Marls

It is exposed to the northern part of the map area at Kella horst. The shale unit is grey in color composed of variable amount of clay minerals and quartz. It shows varying degree of fissility in textural pattern. Marls usually are fine grained and consisting of calcite mixed with silt and clay. This unit attains a maximum of 30 meters thickness at Kella horst (Efrem Beshawered, 2010).

Antalo Limestone

This unit is exposed in the Northern part of the study area. Its color is yellow and greyish yellow having a maximum thickness of 25m. In addition to this Antalo Limestone is mapped with its contact of the lower shale and marl is gradational marked by planner smooth surface and mud cracks. The alteration shows pale green and partially lateritized but still preserving the sedimentary structures(Efrem Beshawered, 2010).

Aiba-Alaje basalts, Scoriaceous and fine grained basaltic lava flows with minor intercalated pyroclastics (Maab)

This unit is one of the pre-rift (mid-Tertiary) volcanic rocks of the area. It contains Basalt, Trachy-basalt, Trachyte and rhyolite. The basalt is highly fractured and aphanitic basalt found underlying the rhyolitic on the river bed. The trachyte is highly weathered, fractured and cut by frequent basaltic dykes. Aiba-Alaje group is found in northern and north-western part of the map area at the base of the major fault escarpment in the western rift margin. It is dark grey hard and compact, medium to coarse grained on fresh sample , but it turns to reddish to yellowish brown up on weathering (Efrem Beshawered, 2010). The permeability of Aiba-Alaje basalt is dependent on vesicles and cracking joints, however the interconnection is not well and sometimes filled by secondary materials.

At the escarpment of Kella horst north of the village there are few springs emerging from Aiba-Alaje basalt through fractures at the topographic break with average yield of 0.3 l/s(Efrem Beshawered, 2010).

Guraghe-Ancher basalt, Aphyric to plag-pyroxene phyric basalt-trachybasalt lava flows with intercalated acid pyroclastics & lava flows (Nab)

Ancher basalt is exposed at the South-West and North-West corner of the study area. It consists of aphyric to plagioclase and pyroxene, phyric basalts and trachy-basalts intercalated with rhyolitic tuffs (Tsegaye et. al., 2005).

The basalts are olivine tholeiites and quartz tholeiites. Radiometric ages range between 11.5 and8.3 Ma (Tsegaye et. al., 2005). Approximately 300 to 600 m thick flood basalts exposed immediately west of Butajira town have been correlated with the anchar Basalts overlapped by Pliocene- pleistocene silicics (Nazret group). The anchar basalts are mildly alkaline (transional) type with transions to hawaeiites and andesine basalts

On this unit there are springs that come out through the fractured unit at the contact with average discharge of 0.05 liter per second (Kazmin et al., 1980; Tsegaye et al., 2005).

3.1.4.2 Syn-Rift units

The Post-rift units in the study area are belongs to the following major categories:

Nazret pyroclastics, welded to partially welded pyroclastic flows (Nnwpp)

It is fine grained, densely welded ignimbrite to poorly welded pyroclastics with developed fiamme and lithic fragments. In most exposures it is associated with rhyolitic lava flows and intercalated with ash and unwelded tuff. The weathering activity changes the light to dark-grey color to reddish yellow to pink. Mostly Nazret pyroclastics, welded to partially welded pyroclastic flows is exposed at the Northern, North-Western and South-Western of the study area.

The Welded to partially weld and welded pyroclastic flow of the Nazret group are affected by faulting and weathering conditions, which produce an average yield of 0.4 L/s.

Pyroclastics, welded pyroclastics interceded with basaltic lava flows (Nnwp)

Welded pyroclastic flow unit mapped as the lower member consists of welded Peralkaline pantelleritic ignimbrites with minor intercalated basaltic lava flows. It is light to dark-grey in fresh sample and reddish yellow to pink up on weathering (Tsegaye Abebe et al. , 2005). Such unit fine grained densely welded rock containing vitrophyric fiamme and lithic fragments with associated rhyolitic lava flows interleaved with ash and tuff (Efrem Beshawered (2010). This unit is exposed at the Northern, North-Western and South-Western of the study area and depend on its transmissivity and yield data these units are believed to have generally they have low productivity aquifers, with limited water supply to the local people.

Nazret pyroclastics, porphyritic rhyolitic lava domes & flows (Nnpr)

It is exposed in the form of unevenly distributed small dome and gently circular to elliptical hills. It has a characteristics color light grey to pink in fresh sample and it identified an intercalation of ash and tuff locally. Based on its transmissivity and yield data these units are also believed to have generally they have low productivity aquifers (Bereket Fenatw, 2011).

Peralkaline silicics, Undifferentiated (Qws)

In the rift escarpments where 500 meters thick and more of silicic rock is locally exposed both Peralkaline silicics and Undifferentiated units are almost certainly present at the southern part of the study area, but in most cases the data is not sufficient to separate them (Basalfew Zenebe, 2012).

Ignimbrites, tuffs, waterlain pyroclastics, occasional lacustrine beds (Qdi)

These units covers southern part of the study area and it comprises a number of flows of compacted fiamme ignimbrites in place intercalated with aphyric basalt and unwelded pyroclastics. The thickness varies from a few meters to 30m (Seife M., 1978). Within the thickness of this lithological unit there are a secondary fractured porosity and well jointed structures, which have an average yield of 10.5 L/s in this unit.

Wonji basalts, scoria fallout deposite (Qwbs)

This unit is outcropped at the center part of the study area by forming volcanic cones and broad- based gentle sloping circular to elliptical hills. It is reddish, black and dark brown vesicular coarse grained consists of volcanic bombs, ropy fragments and varies shapes of pieces of lavas (Tsegaye Abebe et al., 2005). The well completion data from different wells like Boreholes drilled at Butajira town reveals that the discharge of 7.35 l/s.

Wonji basalts, Alkaline to transitional basaltic lava flows with minor hawalites & benmoreites, outcrop along the MER axis (Qwb)

Basaltic lava flow (Qwb) is crop out in the central parts of the map area forming a relatively flat terrain. It is dark color, fine grained mainly composed of alkali to oliven basaltic lava flows (Efrem Beshawered, 2010). Described it as mainly composed of plagioclase, pyroxene and opaque. The products of this volcanic basalt vary from strongly porphyritic to aphyric. Just similar to the unit (Qwbs),this units also give un average discharge of 7.35 l/s.

Lacustrine sediment, composed of sand and silt intercalated with recent pyroclastic deposites, Daitomites & soda-ashe (Qls).

Lacustrine sediment is exposed in the central and southern parts of the map area dominantly on the central. It also forms flat laying topography and swampy areas. It is mainly represented by sand and silt. The major components of the sediments are volcanic origin, pumice , volcanic ash also obsidian, rhyolite and basaltic rock fragments (Tsegaye Abebe et al., 2005).

The intercalation of primary pyroclastic fall deposits and lacustrine deposits are usually common (Tsegaye Abebe et al., 2005).

The permeability of the lacustrine sediment is very variable depending on the grain size, sorting in a uniform recharge conditions. Those with grain size of silt and sand have better permeability and productivity. The geological log of the well shows that an aquifer thickness of 43 meters with yield and transmissivity of 19 l/s, 185.23m^2/day respectively.

Chefe Donsa pyroclastics, unwelded to poorly welded, fine ash flow and fall & deposit with littics, glass shards & some crystals (Ncdp)

Chefe Donsa Pyroclastics Depositions unit is exposed in the eastern and northeastern parts of the mapped area. The rock is fine grained, poorly welded volcanic ash flow and fall deposits with vitriphyric fiamme and lithic fragments with associated pumice and rhyolic lava flows (Efrem Beshawered, 2010).

The grain size varies from clay to gravel size and hence leads to the poor sorting with less permeability. Dominantly it is composed of pumice fragments with some ash deposit having poor welding. In most cases the occurrence of this unit as intercalated layer in lacustrine sediment act as an impermeable layer. However in some places it develop interconnected pore spaces leading to the good permeability.

Bora-Bericha rhyolites, Per-alkaline thyolitic, obsidian lava flows and domes (Qbbr)

Most of the products of central volcanoes are per-alkaline rhyolites and trachytes of pantelleritic or locally of comendetic affinity (Tsegaye Abebe et al., 2005). In the escarpment area of Suten to Tora sub catchment there are few springs that directly come out from these units with discharge less than 0.12 l/s.

Gash Megal rhyolite, fine graind with some alkali feldspar phyric rhyolite lava flows, pyroclastics and interbeded basic lavas (Ngmr)

Rhyolite unit is outcrop in northern part of the study area, on top of the Guraghe escarpment. It is light grey to pink color. The products of Gash Megal central volcano is mainly per-alkaline comendetic rhyolites. However the presence of exposures of fine ash and unwelded tuff on top and fine grained to alkali–feldspar phyric lava flows and pyroclastic deposits with some interbeded basaltic lava flows at the base of the volcano with a discharge less than 0.12 l/s(Tsegaye Abebe et al. , 2005).

Recent and sub–Recent basalt lava flows and cones (Qwbh)

Anther types of volcanic activity in the Quaternary Volcanics /Wonji Group/was the eruption from fissures of recent basalts (Qwbh) and the bulk of these late basalts are concentrated in the Wonji fault belt. The basalts are clearly controlled by extensional fractures and generally display fresh through surfaces and it locates at the southern part of the study area. Hydraulic conductivity of this unit is largely related to joints, faults, vesicles and fragment size , the unit posse 10m/day to 20m/day permeability value (Tenalem Ayenew, 1998).

3.1.4.3 Structural characteristic of the study area lithological units

The Main Ethiopian Rift (MER) constitutes an area characterized by active extensional tectonics. In the study area most of the structures are affects the volcanic units. The common structures are different types of faults; Geological contacts. The linear features of these structures are characterized by three distinct fault trends systems, which are in NE-SW, NW-SE and N-S direction (Tsegaye, 2005).

Water points in the study area

Existing drilled pump test and spring data has been collected before and during the field work. Throughout a representative place field studies different water points were observed, measured their discharge and collect different hydrogeological data.

Springs

Among field observed water points; spring is very interesting things. Springs of various discharges are observed in a representative place of the study area. The discharge of springs in the study area is ranged from a simple seepage (0.05 l/s) to about 1.5 l/s. The study area springs are emerged through fractured, depression and contact type's spring. Most of such springs are structurally controlled following the N-S, NNE-SSW and E-W major lineaments. These springs are distributed under the lithology of Gurage ancher basalt, lacustrine sediments, Nazret pyroclastic and Bora-Bericha rhyolites units.

Marshy and swampy areas

Based on field investigations were conducted in the study area to determine existing lithological formation at depth; the lacustrine sediment is exposed in the central and southern parts of the sub catchment; dominantly at the central flat laying topography. On this lithological formation of flat topography, there is a formation of small swampy/marshy areas, which is located near to Tora town called Abaya swampy area.

Water wells (Hand Dug well, Shallow well and Deep well)

Most of the study area dug wells are sunk at the bed of intermittent streams and at local depressed land. These dug wells reach up to 3 meter diameter and most of them are unlined and also open used for domestic water supply. When comes to the borehole(shallow and deep wells), the major water bearing units for most of the boreholes in the study area are lacustrine sediment and basalt unit.

Moreover the pyroclastic and fractured trachytes are also significant water bearing layers. The depth of boreholes ranges from 60 to 360 meters. During a representative field work the water level of the wells were tried to measured, despite that most of the wells have no observation pipe for water level measurement. Such wells are installed with submersible pump and some are with hand pump. The collected data from different source show that the yields of boreholes are variable depending on their depth, aquifer type and topographic setup.

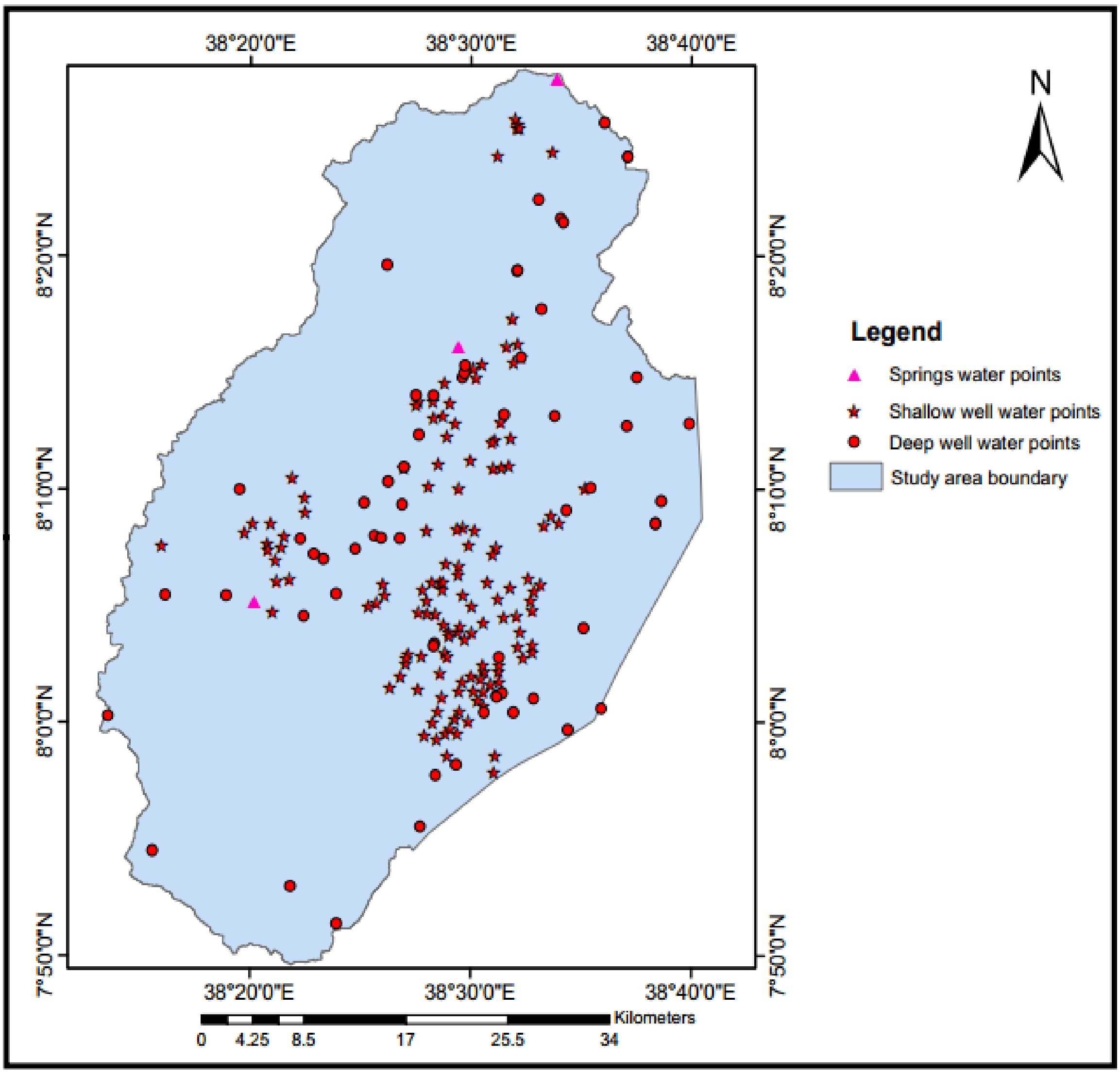


Figure 3. 4 Water points in the study area

Types of aquifers

Depend on the well completion data (pumping test data , time-drawdown measurements and recovery data) of boreholes , Hydrogeological units, the distribution of water points and lithological logs of boreholes in and around the focused area , the study area aquifers have been classified based on the approaches called:

- ❖ Analysis of lithological logs of each borehole distributed within and around the area
- ❖ Observation of seasonal fluctuations in hand dug wells and shallow well level

Analysis of lithological logs of each borehole

Based on the analysis of each borehole logs of the study area; many of boreholes have seen to possess productive aquifer are unconfined layers. So depend on these, the aquifer types which commonly located in the study area are unconfined aquifer. Among the analysis of many boreholes log data; Addele Borobor well is take as an example of unconfined layer with 95meters deep, 18 meters aquifer thickness, 21.85meters static water level and discharge of 6.3 l/sec in a geological logging indicates that the main aquifers are poorly sorted gravel and Ignimbritic origin. However, like Kella town borehole tapping confined aquifer water is also recognized in the study area.

Observation of seasonal fluctuations in hand dug wells and shallow well level

Depth to water level measured in a hand dug well before the commencement of the rain and after the rain measured gives different levels below ground surface for different hand dug wells. For example water level measured in a hand dug well 25m located around Sodo wereda at Addele chelelek kebele are measured before the rain (12/02/2019) is 12.85meter and after continues long period rain (27/06/2019) 11.95 meters below the earth surface shows that this area aquifer is unconfined aquifer. After diligent different representative area assessment of such activities; relatively most of the wide study area aquifer was decided are called unconfined aquifers and also some limited areas are accomplished by confined and leaky aquifers. In addition to this ,due to high erosion processes as a result of slopping topography and low deposition that cause existence of thin layers and freshness of underlying geological units called aquiclude. Finally depend on careful examining of lithological logs of each borehole and Observation of seasonal fluctuations of dug wells level the wide study area aquifer was decided are called unconfined aquifers.

3.1.5 Soil

Soil type, distribution, extent and characteristic in the study area depend on variation in geology, slope gradient, land use and land cover, altitude, climatic conditions, population density and agricultural practice. In most case the Ground water receives the main recharge from precipitation and this precipitation reaching the earth's surface has to be percolate through the upper unsaturated zone of soil layer. Therefore, the effect of soil cover on the Groundwater potential mechanism is paramount proportion.

The most governing factor affecting the water holding capacity, infiltration and runoff characteristics of soils is texture, which is the proportion of clay, silt and sand components clearly indicates how soils behave towards infiltration. If a soil mass is composed of mainly finer particles such as clay, degree of percolation will be too little and most of the incoming precipitation will be lost through surface runoff and evapotranspiration (Halcrow, 1989).

Based on the soil data of Ethiopia (FAO soil) that obtained in MoWIE and using the geo-processing clip tool in Arc GIS 10; the study area has 8 soil types which have unique textural and hydrological characteristic are described below.

Chromic Luvisols: These soils are generally well drained, very deep, dark brown over dusky red and heavy textured clay. These soils are developed on gently undulating to undulating foot slops, with slopes of 2 to 10 %. The soils are formed in basaltic parent rock and colluviums materials.

Luvic Phaeozems: These soil groups are formed on gentle to undulating topographic setting. These soils are generally well drained, deep, dark brown over dusky red.

Eutric cambisols: Eutric cambisols is a soil that developed on elongated escarpment and moderately dissected side slope with piedmont zone steep residual land forms (>15%slope). The main hydrological properties of such soil has somewhat Excessively drain, moderately deep, dark yellowish, brown to very dark brown, Medium textured , moderately calcareous and it found dominantly moderately to very steep topography.

Chromic Vertisols: These soils have high content of clay known as montmorillonite (because it developed from basaltic rock) that forms highly cracks in dry seasons and sticky with spongy when raining. Because of these properties, this soil in the study area less drained and infiltration (initially rapid infiltration but full fill the cracked and infiltration is stopped) of water, slow to very slow permeability

Lithosols: Because of their extreme shallowness(less than 10cm thick), steepness and occurrence of high erosion it is called skeletal soil. It is a mineral soil that developed over hard rock. So due to these and other conditions these soils have no agricultural value and poor hydraulic properties.

Pellic Vertisols: Pellic Vertisols has less moist value throughout the upper 30 cm soil thickness and less dominant soil matrix.

Vertic Cambisols: Vertic Cambisols is found at the top of the study area and it developed from Peralkaline rhyolitic ignimbrite rocks.

Eutric Nitosols (high clay content): Soils have good agricultural potential (good physical and chemical properties, stable structure and high moisture storage capacity).

3.1.6 Lineament density

Lineaments are straight or approximately linear landforms that are widely distributed across the surface of the Earth and are closely related to underground concealed faults. Lineaments are related to fractures and faults in slightly inclined stratigraphic regions. The direction and number of lineaments reflect rock mass fracture patterns and can provide valuable information related to geological structures, tectonics, hazard assessment, and natural resource availability (Temesgen, 2019). Therefore, lineament density of an area can ultimately expose the Groundwater potential.

3.1.7 Land use Land cover

In general the nature of land use-land cover is disturbed by the different activities of human being for sustain their life (cultural, economic, social and other benefit). The land use and land cover is directly or indirectly related to the infiltration, interception and surface runoff. According to these the high growth rate of population in the study area, the local people interfere the environmental stability by doing different activity like deforestation for wooding, ploughing and livestock grazing, which are aggravating surface runoff, evapotranspiration and decreasing infiltration rate of the precipitation.

Depending on the altitude and soil type of the study area, the Land use-land cover of the study area is classified as shrub land, Grassland, intensive cultivated Land, and moderate cultivated Land, Water body and forest**.**

Shrubland: The unique hydrological characteristics of this area are moderately drained, moderately deep and Medium textured. Because of these properties the soil of such land is not comfortable for cultivation except the area that covered by Eutric cambisols which has a proper texture and flat topography**.**

Grassland: Grass land is developed on the soil that derived from geology of Peralkaline silicic and undifferentiated units that mixed with small tress. The main activity of such area is livestock grazing with some browsing. The grasslands land use located at the heel of southern part of the study area.

Intense cultivated land: Mixed Arable area (Maize, Sorghum, Wheat, Pulses, Pepper) with some Grazing, Browsing and wood production activities. Such intensive cultivation land is located at the canter and eastern parts of the study area

Moderate cultivated land : Mixed Upland Arable area (Barley, Wheat, Teff, Maize, Pulses, Potatoes, Inset) activities are mostly developed at the lowest temperature part of north and southwestern parts of the study area.

Water body: Throughout the Sub-catchment a number of small water bodies have been noted. These include Lake Harishetan, Swamp area and Marshlands.

3.1.8 Drainage Density

Drainage density is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin. It is a measure of how well or how poorly a watershed is drained by stream channels. It is equal to the reciprocal of the constant of channel maintenance and equal to the reciprocal of two times the length of overland flow. Soil permeability (infiltration difficulty) and underlying rock type affect the runoff in a watershed; impermeable ground or exposed bedrock will lead to an increase in surface water runoff and therefore to more frequent streams. In Suten to Tora Sub catchment, the highland area is characterized by higher drainage density than the escarpment.

3.1.9 Elevation

The elevation of a geographic location is its height above or below a fixed reference point, most commonly a reference geoid, and a mathematical model of the Earth's sea level as an equipotential gravitational surface (Halcrow, 1989). As surface runoff increases, less rainfall will infiltrate into the ground and Groundwater discharge to the coast will decrease. The link between sea level rise and runoff is critically dependent on the sensitivity of surface runoff to changes in the elevation of the water table (Halcrow, 1989). In this study, SRTM DEM 30m was selected since it is more accurate both in its vertical and horizontal accuracy than ASTER DEM (Odutola et al., 2012).

3.1.10 Slope

Slope is very important in identifying the Groundwater potential zones of the watershed. Because it impacts the runoff speed, runoff retention on the soil surface as well as infiltration capacity. The topography of this sub catchment is close to the Gurage highlands on the west and North West and also low elevation is closed to center and eastern part. The lower slope areas of the flat terrain allows rain fall infiltration and percolation; and higher slope areas correspond to steeper slope generating quick runoff from the terrain(Ramu et.al., 2010; cited in Kibrit, 2018).

3.1.11 Geomorphology

The topographic configuration and geomorphological development of the study area is closely related to the geological formation, a series of tectonic and erosional activities. Depend on these formations the study area topography is represented as:

- **The highland area:** This topography formed by welded to partially welded pyroclastic flows which is fine grained, densely welded ignimbrite to poorly welded pyroclastics with developed fiamme and lithic fragments and others.

- **The Escarpment area:** In this area covered by the major components of the Lacustrine deposites are volcanic origin that combine pumice , volcanic ash, obsidian, rhyolite and basaltic rock fragments (Tsegaye Abebe et al., 2005). The study area is situated at the base of Zebidar Massif Mountain in the Gurage and Silti Zone of the Southern Nations, Nationalities and Peoples' Region.

3.2 Material

To investigate the Groundwater availability in Suten to Tora Sub-catchment the following necessary data were collected from the field and government bodies are shown in the following table 3.3.

Table 3. 3 Data and its sources

No	Collected data	Sources of data	Used to prepare
1	Long term meteorological data	National Meteorological Agency	Areal rainfall map
2	SRTM DEM 30 by 30	https://earthexplorer.usgs.gov/	Delineating Elevation, drainage density , slope, geomorphological and other maps
3	Existing files	GSE and MoWIE	Geology and soil file
4	Existing wells completion/springs data	SWE, SWDE and and MoWIE	For Delineating Groundwater flow system and validation of the Groundwater potential zone map
5	Landsat 8 OLI/TIRS	https://landsatlook.usgs.gov/	Lineament and LuLc map

After the data are collected the following listed tools like; Arc GIS, AHP, Global mapper, Surfer, Stata, and others important softwares are used as a tool for the different collected data analysis throughout the report work. The activities done in such tools are shown below:

Arc GIS: The central function of a geographic information system for this study is to provide a visual representation map of collected data. That means creating and compiling geographic data, analyzing mapped information, like forming different contouring map and delineating Groundwater potential zone.

Global mapper: Provides tools for editing both the geometry and physical appearance of vector objects like DEM with the attributes or information that is associated with each feature.

Surfer: It is a grid-based mapping program that interpolates irregularly spaced XYZ data into a regularly spaced grid. Grids may also be imported from other sources. The grid is used to produce different types of maps including contour, color relief, and 3D surface maps among others.

Stata: It provides mathematical functions, probability and density functions, matrix functions, string functions. Among these functions filling missing time series data is the main uses for this study.

Analytic hierarchy approach (AHP): Analytic hierarchy approach (AHP) is a tool which helps to reduce bias in the Groundwater potential zone judgment by making prioritization of parameters and weighting of each parameter.

3.3 Methods

In order to achieve the overall goal of the research, it should have follow a logical approach and use appropriate input data for all over the progress of the studies. The methodology of this work is based on the application of the Groundwater potential investigate in the whole Suten to Tora sub catchment area. To achieve the objectives, the data required was collected from the field and secondary sources. As described from the above in order to do the overall goal of the thesis, the following methods are applied under each Specific objective:

3.3.1 Identify the Groundwater flow systems in Suten to Tora sub-catchment

- ❖ Collecting well-completion reports (yield, transmissivity, hydraulic conductivities, lithological logging, and others). Based on such data constructing
  - Groundwater level contour map
  - Wellfield location Map

3.3.2 Prepare thematic maps of Groundwater potential affecting parameters

- ❖ Prepare various thematic maps of Groundwater availability controlling factors parameters (Land uses Land cover, Soil, Drainage density, Slope, Geomorphology, lineaments, Elevation, lithological formations and rainfall characteristics).
- ❖ Give weighting for each legends respect to each parameter and reclassify them.

3.3.3 Delineate the Groundwater potential zone in Suten to Tora Sub-catchment

- ❖ Give weighting of the parameters and prioritization of them were computed in Analytic Hierarchy Approach (AHP) software. These were done by the following activity
  - Analysis of pairwise comparison matrix and changed it to decimal form
  - Normalized pairwise comparison matrix
  - Compute a criteria weight values of each Parameter
  - Evaluations of Consistency Ratio (CR)
- ❖ Overlay analysis these various thematic maps were carried out using ArcGIS.
- ❖ Finally, Groundwater potential zone map was generated.

In order to do the above listed activities, the general frameworks that used for investigate of Groundwater potential in study area is illustrated by the following flowchart forms.

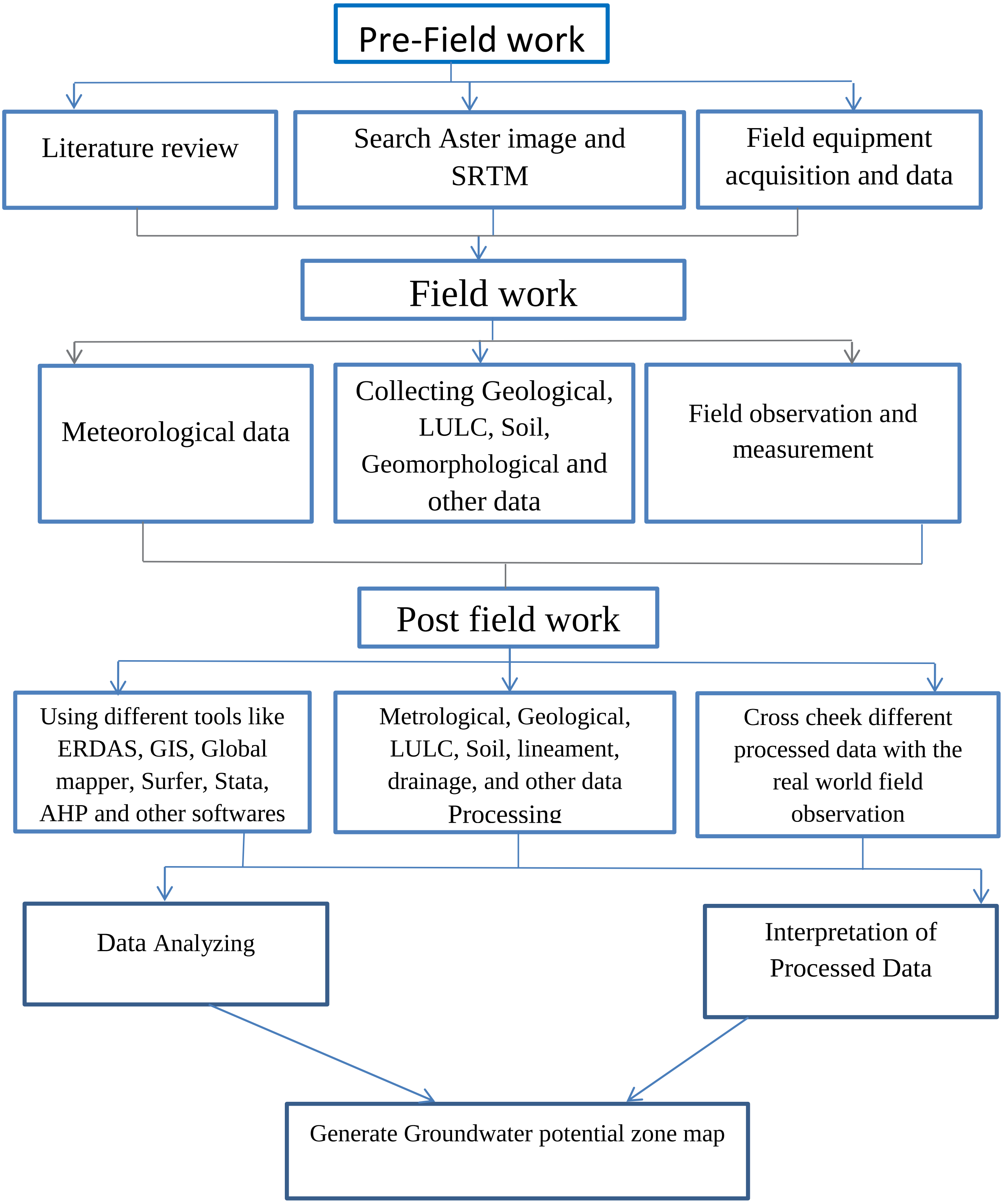


Figure 3. 5 Flow chart of methodological approach

4. RESULT AND DISCUSSION

4.1 Identify the Groundwater flow system in Suten to Tora Sub-catchment

Identification of Groundwater flow systems in the study area is done based on the Groundwater level contour and wellfield area map.

4.1.1 Groundwater level

To determine Groundwater flow directions in Suten to Tora sub catchment; the Groundwater level value of different borehole in each lithological unit are calculated as, the elevation(z value) which read from GPS on the borehole location minus the static water level of that borehole. Generally in addition to listed on the Annex 1 ; The hydrogeological properties of different boreholes in the study area are shown by the following table.

Table 4 1 Hydrogeological properties of different boreholes in the study area.

Site	Symbol	Lithological Symbol	X	Y	Static water level(m)
Tora2	BH1	Qls	433726	868414	74
Adele/Borbor(Mirt)	BH2	Qls	431024	892728	71
Hospital Well #4	BH3	Qls	452897	901064	22
Gogete	BH4	Qls	458031	929019	170
Kela	BH5	Qls	432663	897234	54
Koshe Akababi	BH6	Qls	431867	897635	13
Shanka Tuffa	BH7	Qls	430742	898821	7
Merit Meteja	BH8	Qls	441837	910128	7
Gose salen	BH9	Qls	443700	880968	220
Shershera Ele	BH10	Qls	414732	884875	200
Netsa Sefer Well #1	BH11	Qwbs	418390	874188	188
Bonosha2	BH12	Qwbs	444472	912526	19
Eresha Well # 2	BH13	Qwb	460335	900046	244

Agede Anshebeso	BH14	Qdi	440733	876079	2
Shirinto2	BH15	Qdi	446043	885112	11
Luke Feka	BH16	Qdi	429902	871358	14
Dugda Geriyo	BH17	Ncdp	454955	902825	34
Tach Gembela	BH18	Ncdp	449138	913155	26
Suten 1	BH19	Nnwp	447710	908637	20
Tach Anati	BH20	Nnpr	437480	898874	26
Edo 2	BH21	Nnwpp	452660	923864	7
Addis ketema	BH22	Nab	419493	894429	285
Dobi kebele	BH23	Nnwp	425689	902748	247
Keshit kebele	BH24	Nnwpp	437995	920492	89

The map of contour lines is much like a topographic contour map, but it states the distribution of Groundwater level in the Groundwater system. Each contour, or equipotential line, represents a line of equal head. In addition to this , the fact that; areas with uniform Groundwater flow, the portions having wide water table contour spacing. Depend on many past and current drilled boreholes Groundwater level data indicate and Tenalem Ayenew, 2001 descriptions, the Groundwater also flows in the direction of the steepest gradient, meaning that the water flow perpendicular to equipotential lines. So based on the above table Groundwater level value the following Groundwater level contour lines map is formed for determining the Groundwater flow systems of Suten to Tora sub-catchment area.

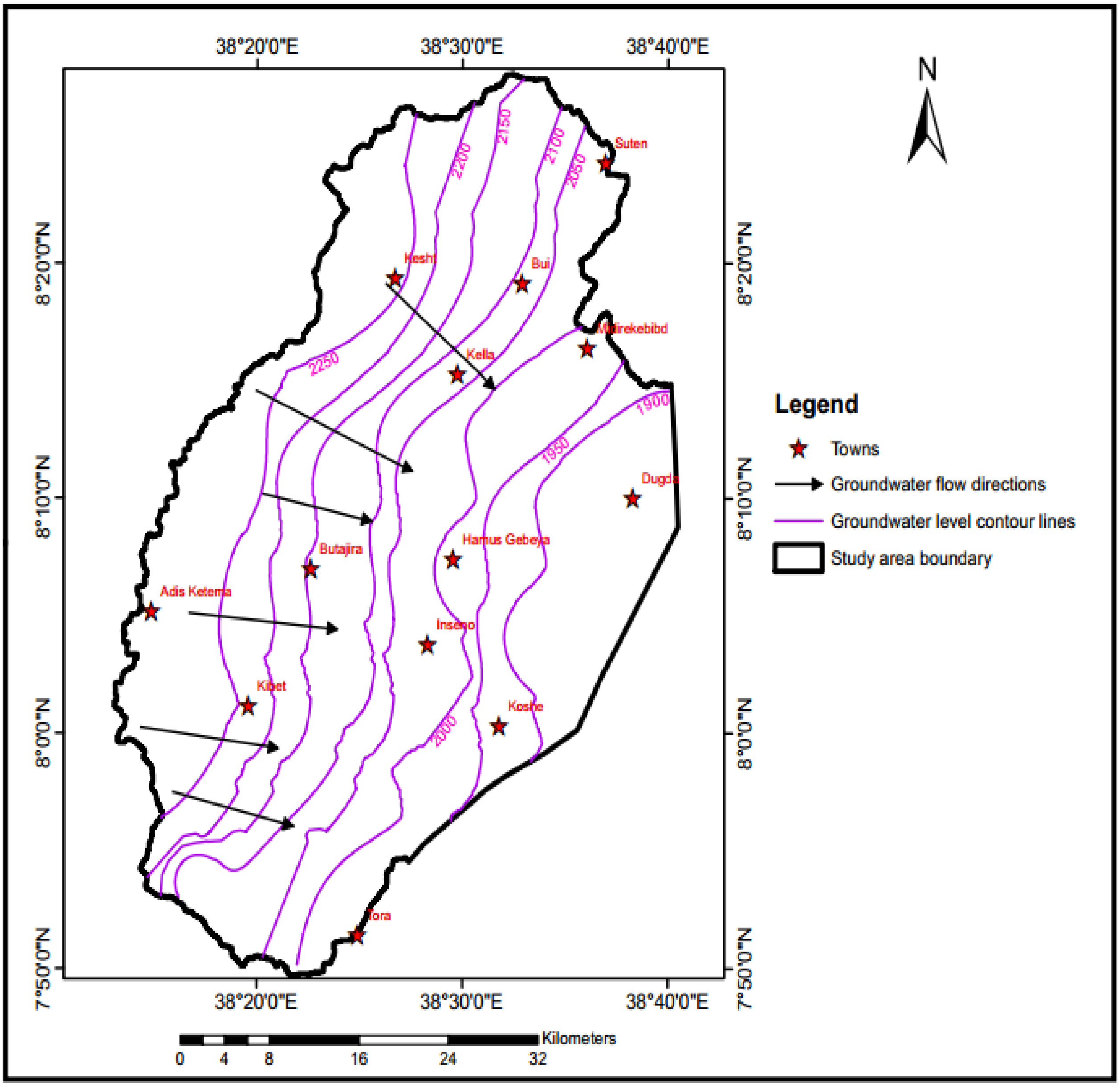


Figure 4. 1 Groundwater level contour map of Suten to Tora sub catchment area

Depend on the above Groundwater level value contour map; the Suten to Tora sub catchment area revealed that the Groundwater flows downward from the west in a higher hydraulic gradient towards east located within the location close to hamus Gebeya and Inseno.

This is confirmed by the theorem of Groundwater flows from the highest Groundwater level contour elevation to the lowest in the direction perpendicular to the contour line(Julius and Merrious ,2010; cited in Genet Mathewos, 2017).

4.1.2 Groundwater flow direction indicator well field location

In addition to Groundwater level line contour map; the well field area is also indicate the Groundwater flow direction of Suten to Tora sub catchment. Means that under pumping situation the Groundwater flow path is followed to the well field area. This is due to the cone of depression created by high pumping rate at the well field area. Therefore Groundwater coming from the western part of the study area is trapped in to the well field area. Due to the high cone of depression, the recharged water from the western part of the sub catchment is also trapped in the well field area.

This is confirmed by the general truth; under pumping situation the Groundwater flow path towards the well field locations. This is due to the cone of depression created by high pumping rate at the well field area because of this the water fails to the well field area (Tenalem Ayenew, 2008).

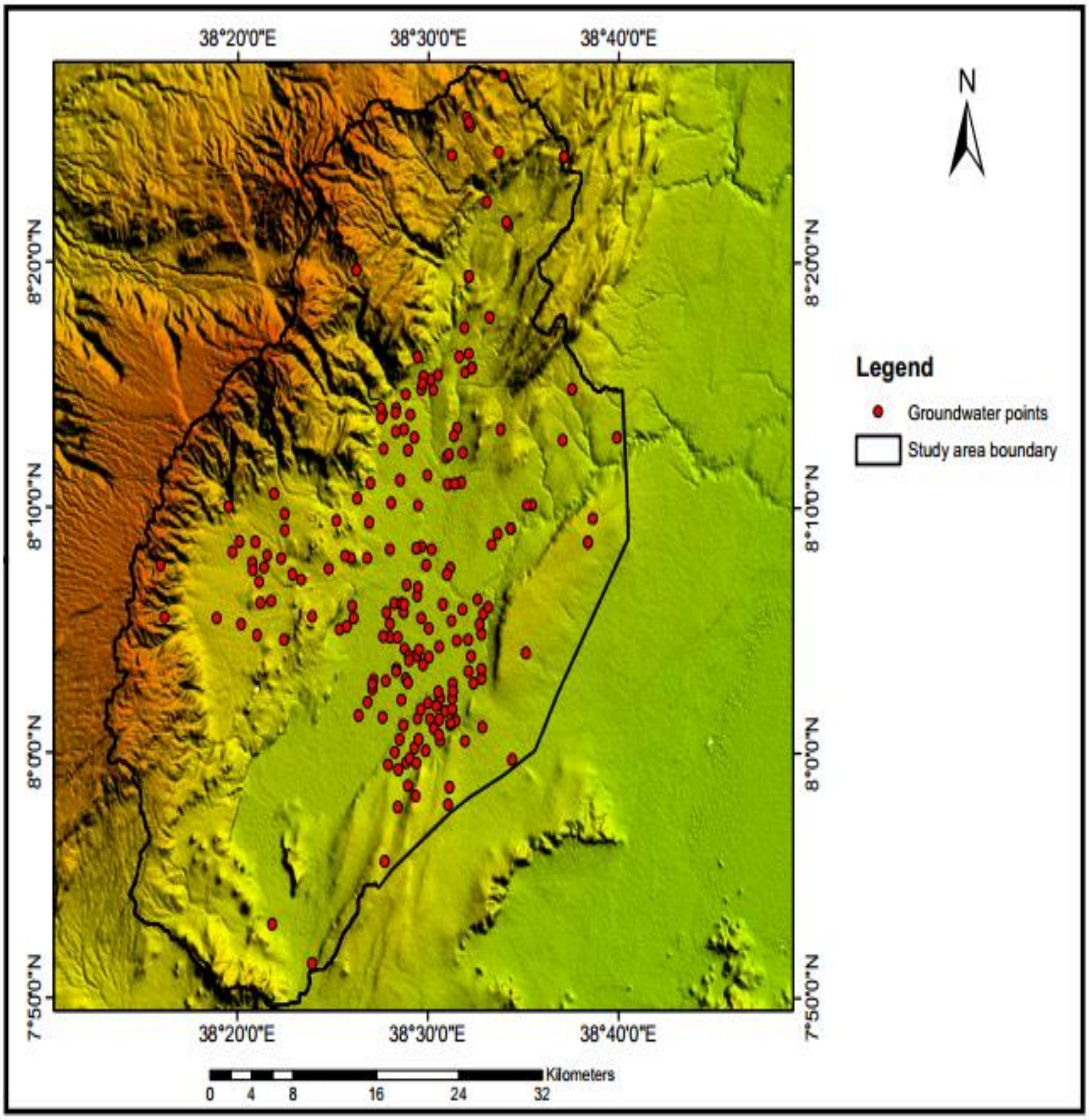


Figure 4. 2 Groundwater flow direction indicator well field location

4.2 Prepare thematic map of Groundwater potential affecting parameters

4.2.1 Rainfall

As we seen from the study area description part, there are four metrological stations which can measure only point data. Because of this it should be converted to the areal rainfall system by using Isohyetal polygons interpolation techniques to prepare the mean areal rainfall value map of the study area. The following four meteorological stations in the study area are adopted to estimate areal depths of precipitation.

Table 4 2 Mean annual areal depth of precipitation done by arithmetic mean method

No	Stations and Year of Record	Mean annual Precipitation
1	Buei(1987-2018)	1030
2	Kella(1987-2018)	1154
3	Butajira (1955-2017)	1158
4	Tora(1975-2017)	872

Based on the above table; the following Isohyetal Polygon map was formed. Because, computing of areal average precipitation in isohyetal polygon method is superior to the Arithmetic average method. In isohyetal polygon method once the weightage factors are determined, the calculation of average precipitation is relatively easy for a fixed network of stations. The relative weights for each gauge are determined from the corresponding areas created in an isohyetal polygon network.

4.2.1.1 Isohyetal method

An Isohyetal method is a method of lines drawing which have equal magnitude of rain fall and joining those points in the Isohyetal map. Isohyetal maps can be produced by using computer programs for automated contouring. Once the isohyetal map is produced, the area (a_i) between each pair of isohyets, within the Catchment under consideration, is measured and multiplied by the average of each precipitation(Chow, 1988). To compute the areal average precipitation by using Isohyetal method is shown as the following formula:

$$\text{Avg. Precipitation (P)} = \sum (a_i/A)\, P_i,\ i = 1\text{-}n$$

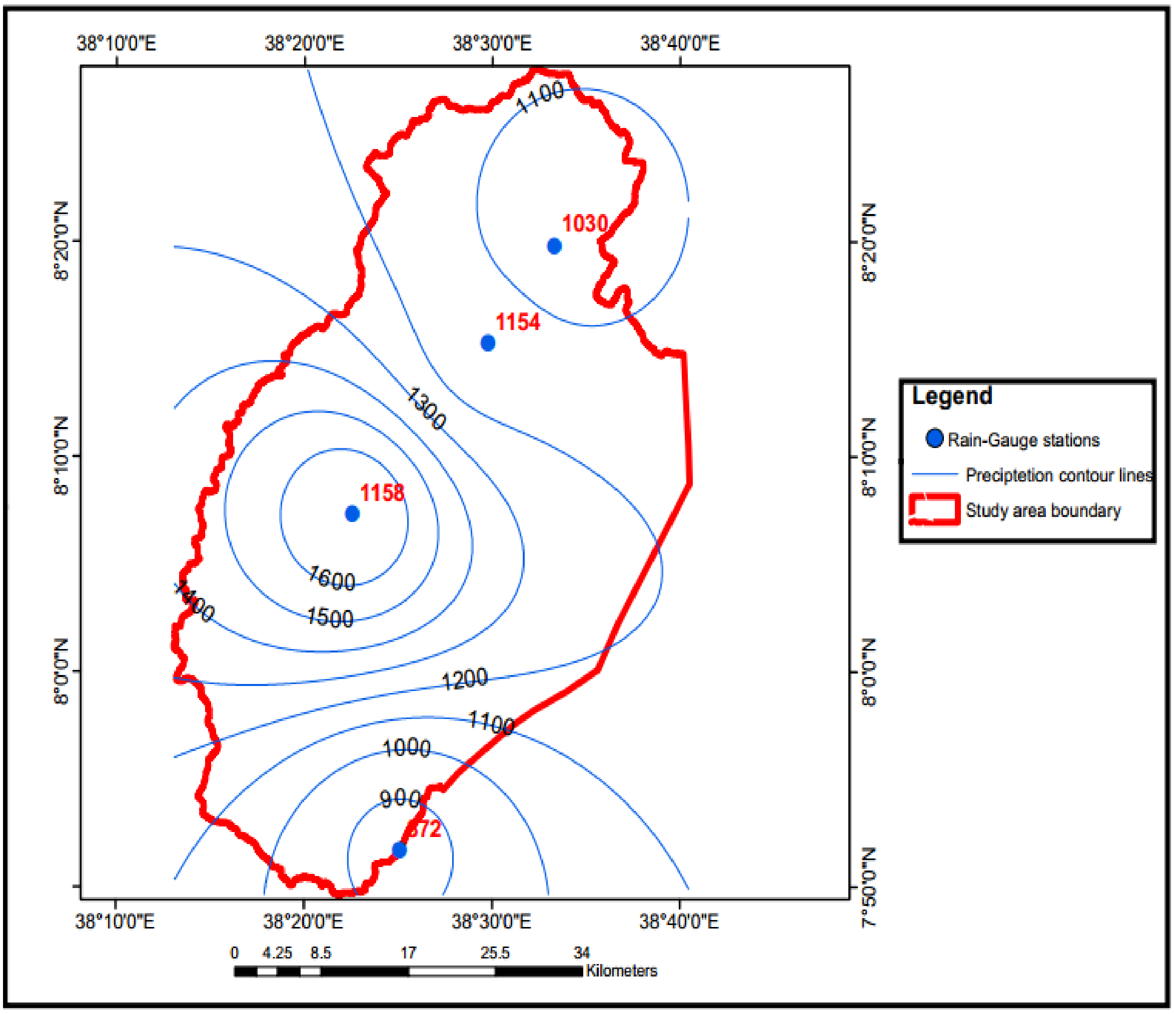


Figure 4. 3 The rainfall depth of Isohyetal map for the study area

For the Isohyetal Polygon method, If there is i gauge and P_i is the Average of the two Contour; a_i is the area between the two Contour created by using the Isohyetal method corresponding to the precipitation P_i , A is the total area of the catchment, i refers to the i^{th} precipitation gauge. So depend on the average precipitation value and the area between the two Contour created by using the Isohyetal method corresponding to the precipitation P_i, the following tabulated value was formed.

Table 4 3 Mean annual depth of precipitation obtained from Isohyetal method.

Contour interval(mm)	Average of the two Contour(p_i)	a_i	A	a_i/A	p_i	$(a_i /A)*(p_i)$
800-900	850	110.96	2175	0.051	850	43.36368
900-1000	950	177.155	2175	0.081	950	77.37805
1000-1100	1050	175.155	2175	0.081	1050	84.55759
1100-1200	1150	204.655	2175	0.094	1150	108.2084
1200-1300	1250	472.655	2175	0.217	1250	271.6408
1300-1400	1350	295.655	2175	0.136	1350	183.51
1400-1500	1450	291.655	2175	0.134	1450	194.4367
1500-1600	1550	255.155	2175	0.117	1550	181.8346
1600-1700	1550	191.955	2175	0.088	1550	136.0705
Sum of mean annual areal Pcp						**1281**

In Suten to Tora Sub-catchment, Mean annual areal depth of precipitation are one of the main inputs for the Groundwater recharge estimations, which requires performing a rainfall frequency analysis that involves several steps. Among these steps the isohyetal map for mean annual areal depth of precipitation in the above map shown that the precipitation decreases from North west to the South east and the highlands get high rainfall as compared to the escarpments, indicating the presence of orographic influence in the sub-Catchment. Depend on this method the mean areal precipitation in the Sub-catchment is 1281mm/year

4.2.2 Soil

Soil type and textural characteristics in the study area is depend on variation in geology, slope gradient, land use and land cover, altitude, climatic conditions, population density, and agricultural practice. Depend on this the soil map of Suten to Tora sub catchment was clipped from soil map of Ethiopia (FAO soil) that obtained in MoWIE using the geo-processing clip tool in Arc GIS 10.3. Based on this, the study area has 8 soil types which have unique textural and hydrological characteristic are described below.

Table 4 4 Soil types and their textural properties in the study area (FAO, 2003)

No	**Soil type**	**Area coverage(km^2)**	**Area (%)**	**Textural properties**
1	Chromic Luvisols	376	17.29	Clay loamy texture
2	Chromic Vertisols	434	19.95	Clay texture
3	Eutric Cambisols	641	29.47	Sandy loam texture
4	Eutric Nitosols	105	4.83	Clay texture
5	Lithosols	182	8.37	Sandy clay
6	Luvic Phaeozems	153	7.03	Silty sand
7	Marsh	55	2.53	Water body
8	Pellic Vertisols	105	4.83	Sandy clay
9	Vertic Cambisols	124	5.70	Silty sand

The textural classes for the above identified soils types of Suten to Tora sub catchment were obtained from Soil User Manual. As we shown from the following soil map; clay textures soils were majorly found around highland area (Eutric Nitosols, Chromic Luvisols and Pellic Vertisols etc), which has fine texture. The finer the texture is the greater the available moisture holding capacity (SCI, 2005). Clay soil has high water storage with low infiltration rate. Because of this; such soils are given low priority for Groundwater potential. On the other hand Sandy loam texture soil (Eutric Cambisols) which located around the center and southern parts of Suten to Tora sub catchment is highly permeable, light texture, well drained and the rate of infiltration is excellent. Because of these characteristics, Sandy loam texture soil (Eutric Cambisols) is gives high weights for Groundwater potential zone.

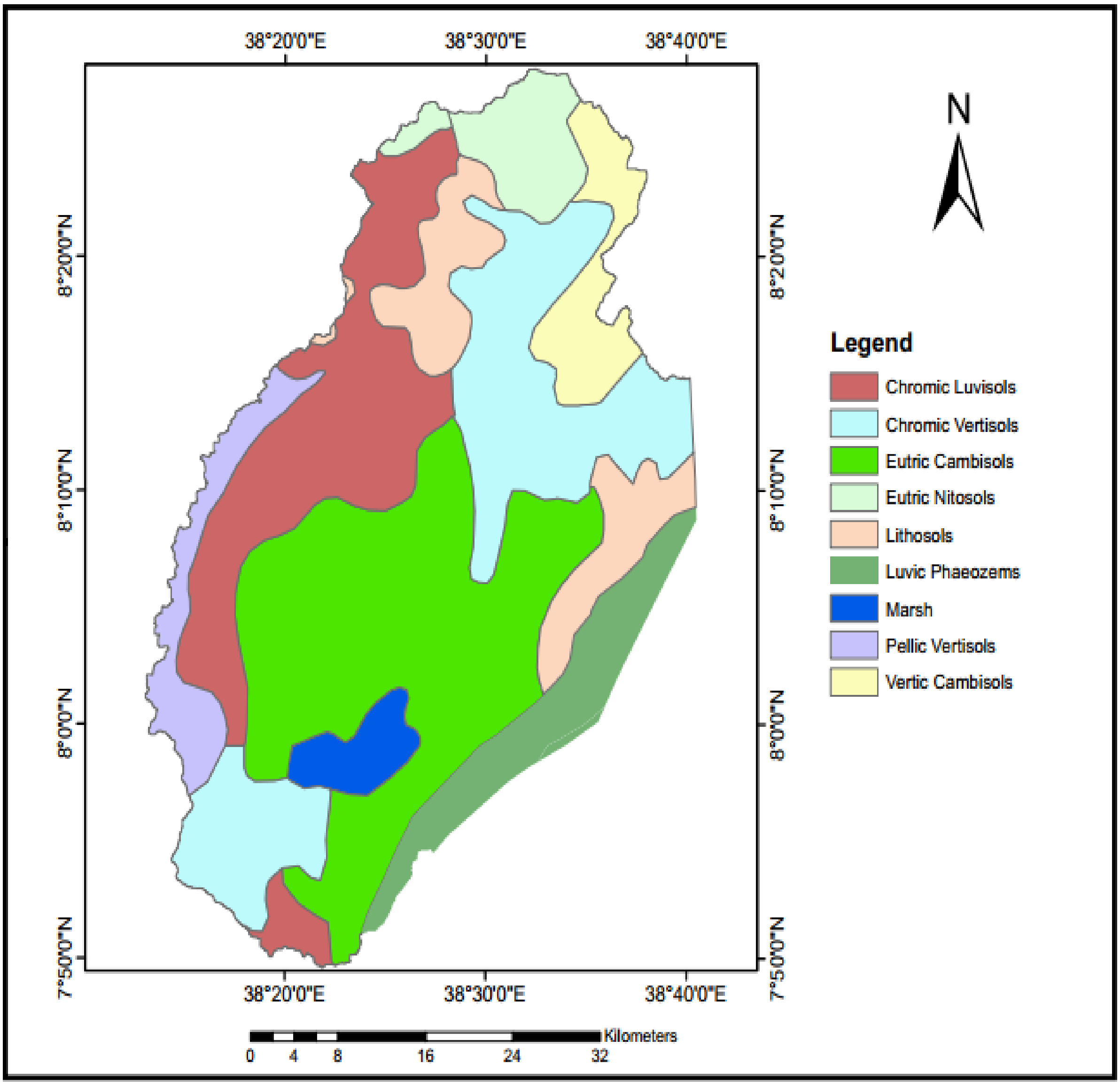


Figure 4. 4 Soil map of Suten to Tora sub catchment (FAO, 2003)

4.2.3 Geomorphology

Among controlling factors of Groundwater potential; geomorphology is also a major role in controlling Groundwater availability. The topographic configuration and geomorphological development of the study area is closely related to the geological formation, a series of tectonic and erosional activities. Depend on the geomorphological map of Suten to Tora sub-catchment there are major land forms including open high mountains, smooth plains with same local relief, irregular plains with moderate relief, open hills, low hills, mountains, plains with hills, open moderate hills and moderate hills.

Land units, such as valley fills, plains and terrace have been associated with high Groundwater potential; while peak mountains and ridge have been associated with poor Groundwater potential (Solomon, 2003). The southwestern and northwestern part of the Suten to Tora sub-catchment which occupied by hills, mountains, open high hills and open high mountains, shows poor potentiality for Groundwater occurrence; while smooth plains with moderate relief shows moderate potentiality for Groundwater occurrence. Similarly a low elevation flat and near to flat plains with moderate relief land form, found at center and southeastern part of the sub-catchment gives that a high weighted for Groundwater potential occurrence.

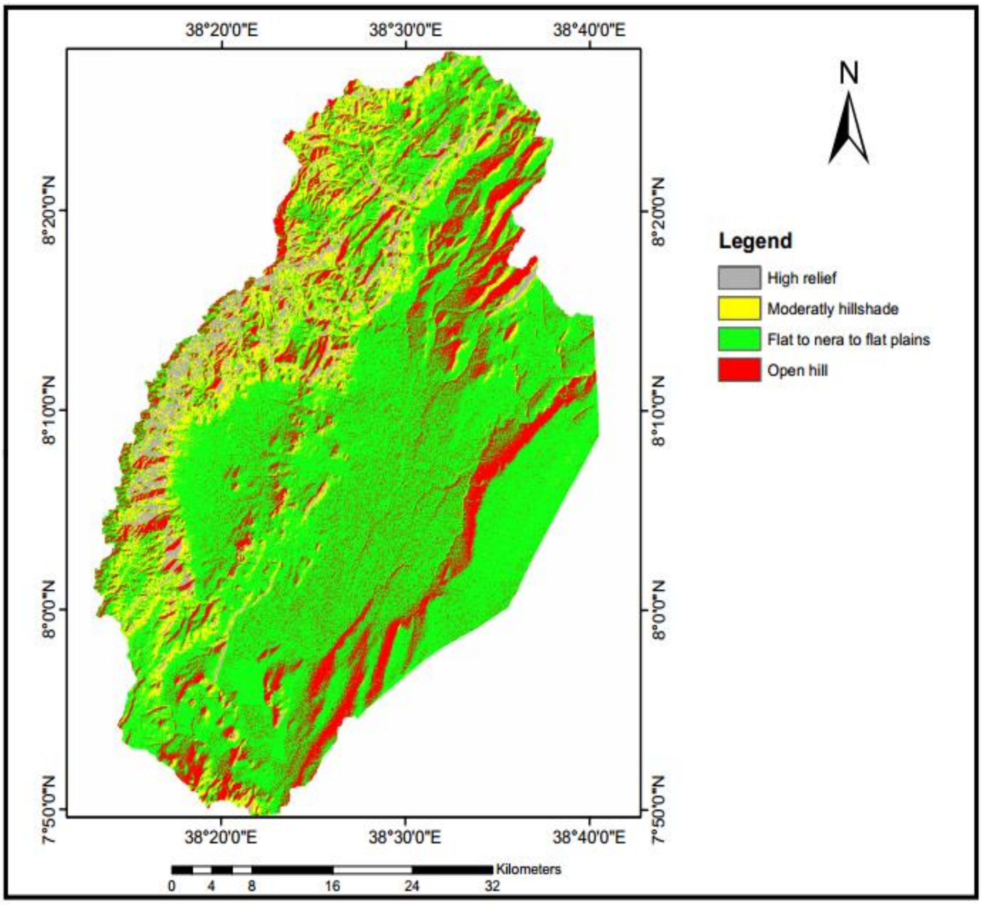


Figure 4. 5 Hill shade/Geomorphological map of Suten to Tora sub catchment

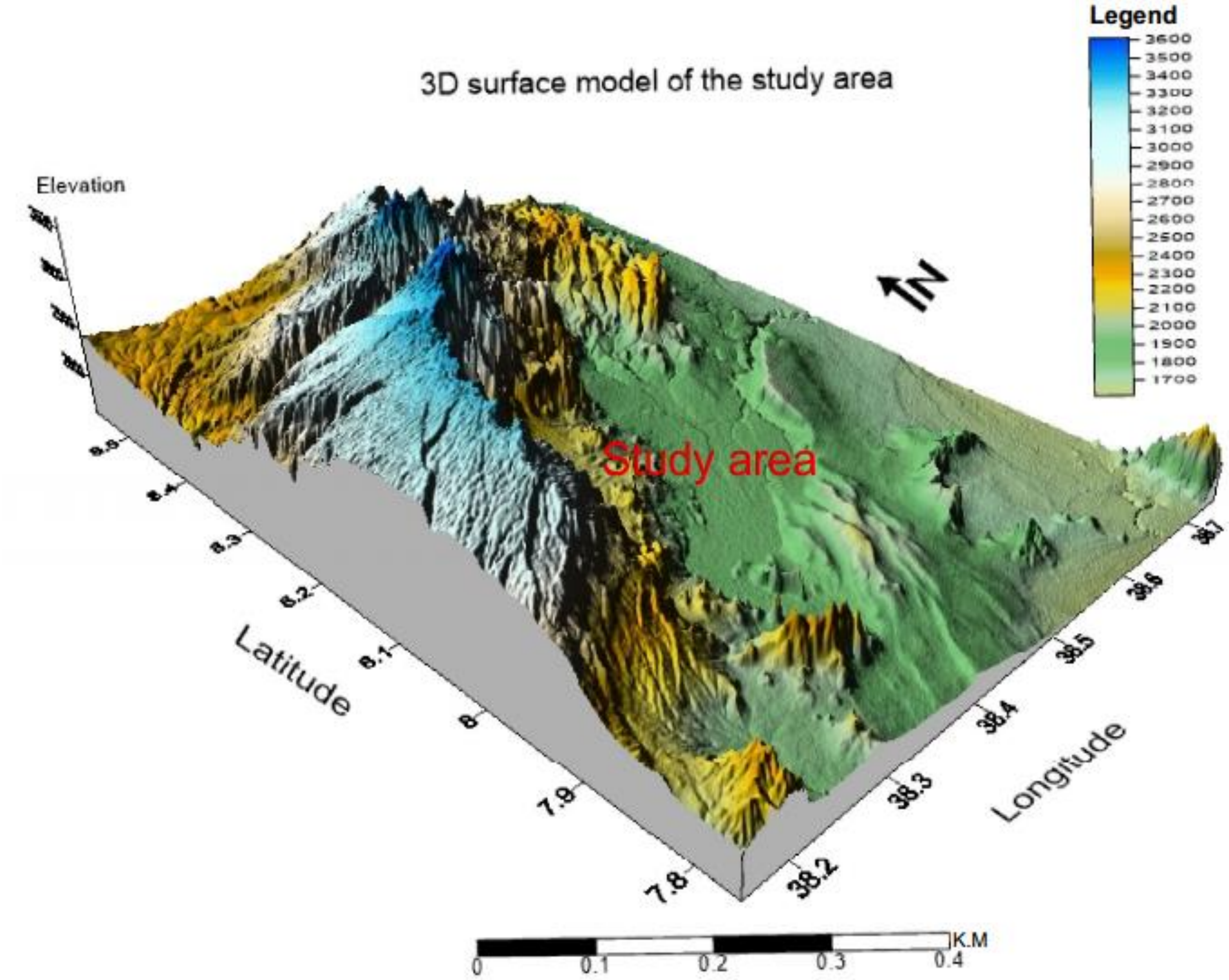


Figure 4. 6 The 3D view surface model of Suten to Tora sub catchment

4.2.4 Geology

The main geological formation obtained in this catchment is shown in Table 4.5. The wide area of the catchment was covered with lacustrine sediment and Basaltic formations, which were found at northern, central and southeastern part of the catchment. The main geological structures of the area were resulting from the main Ethiopian rift activity (MER), which is more or less affecting the Groundwater infiltration. Volcanic Sediments such as alluvial deposits and lacustrine sediments were assigned highest weightage due to higher porosity.

Pleistocene basalt, highly fractured Ignimbrites, pyroclastic deposits were assigned moderate weightage and the least weightage were assigned for hard volcanic rock and basement complex/metamorphic rocks. This is due to less affecting of fracture and faulting which decreases Groundwater infiltration.

Table 4 5 Description of lithological formation

No	Lithological units	Symbol
1	Nazret pyroclastics, welded to partially welded pyroclastic flows	Nnwpp
2	Ignimbrites,tuffs,waterlain pyroclastics,occasional lacustrine beds	Qdi
3	Guraghe-Ancher basalt, Aphyric to plag-pyroxene phyric basalt-trachy basalt lava flows with intercalated acid pyroclastics & lava flows	Nab
4	Lacustrine sediment composed of sand and silt intercalated with recent pyroclastic deposites. Daitomites & soda ashe	Qls
5	Wonji basalts, Alkaline to transitional basaltic lava flows with minor hawalites & benmoreites, outcrop along the MER axis	Qwb
6	Chefe Donsa pyroclastics, unwelded to poorly welded, fine ash flow and fall & deposit with littics, glass shards & some crystals	Ncdp
7	Bora-Bericha rhyolites, Peralkaline thyolitic, obsidian lava flows and domes	Qbbr
8	Wonji basalts,scoria fallout deposite	Qwbs
9	Nazret pyroclastics, welded pyroclastics interbeded with basaltic lava flows	Nnwp
10	Aiba-Alaje basalts, Scoriaceous and fine grained basaltic lava flows with minor intercalated pyroclastics	Maab
11	Gash Megal rhyolite, fine graind with some alkali feldspar phyric rhyolite lava flows, pyroclastics and interbeded basic lavas	Ngmr
12	Nazret pyroclastics, porphyritic rhyolitic lava domes & flows	Nnpr
13	Peralkaline silicics, Undifferenciated	Qws
14	Recent and sub – Recent basalt flows and cones	Qwbh
15	Mesozoic sediment, consistes adigrat reddish brown sandstone, shales & marls and yellowish grey Antalo limestones	Ms
16	precambrian basement, Quartz-feldspare-biotite gneiss, cross cut by quartzo-feldspathic pegmatite vein	Pb

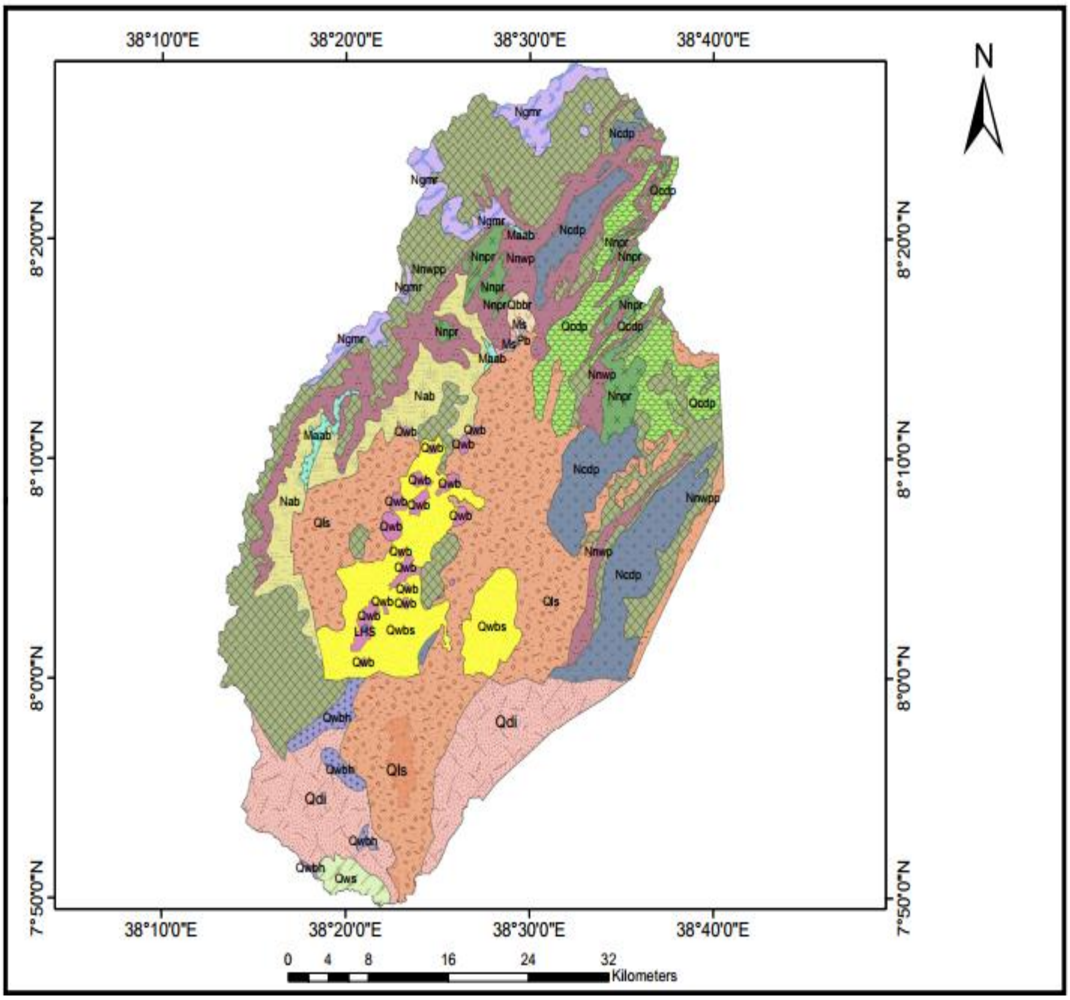


Figure 4. 7 Geological map with their symbols of Suten to Tora sub catchment

Legend

- Aiba-Alaje basalts, Scoriaceous and fine grained basaltic lava flows with minor intercalated pyroclastics(Maab)
- Bora-Bericha rhyolites, Peralkaline thyolitic, obsidian lava flows and domes(Qbbr)
- Chefe Donsa pyroclastics, unwelded to poorly welded, fine ash flow and fall & deposit with littics, glass shards & some crystals(Ncdp)
- Chefe Donsa pyroclastics, unwelded to poorly welded, fine ash flow and fall & deposit with littics, glass shards & some crystals(Qcdp)
- Gash Megal rhyolite, fine graind with some alkali feldspar phyric rhyolite lava flows, pyroclastics and interbeded basic lavas(Ngmr)
- Guraghe-Ancher basalt, Aphyric to plag-pyroxene phyric basalt-trachybasalt lava flows with intercalated acid pyroclastics & lava flows(Nab)
- Lacustrine sediment,composed of sand and silt intercaliated with recent pyroclastic deposites. Daitomites & soda ashe(Qls)
- Lake Haro Sheytan(LHS)
- Mesozoic sediment, consistes adigrat reddish brown sandstone, shales & marls and yellowish grey Antalo limestones(Ms)
- Nazret pyroclastics,porphyritic rhyolitic lava domes & flows(Nnpr)
- Nazret pyroclastics,welded pyroclastics interbeded with basaltic lava flows(Nnwp)
- Nazret pyroclastics,welded to partialy welded pyroclastic flows(Nnwpp)
- Wonji basalts, Alkaline to transational basaltic lava flows with minor hawalites & benmoreites, outcrop along the MER axis(Qwb)
- Wonji basalts,scoria fallout deposite(Qwbs)
- precambrian basement, Quartz-feldspare-biotite gneiss, cross cut by quartzo-feldspathic pegmatite vein(Pb)
- Ignimbrites,tuffs,waterlain pyroclastics,occasional lacustrine beds(Qdi)
- Peralkaline silicics, Undifferenciated(Qws)
- Recent and sub – Recent basalt flows and cones(Qwbh)

4. 2.5 Land use Land cover

Based on supervised classification of land use land cover map of the study area, which prepared from the satellite sensed images, is reclassified as shrubland, grassland, intensive cultivated land, moderate cultivated land, water body and forest.

Table 4 6 Area coverage of each land use land cover map in the study area

Soil type		Area coverage(km^2)	Area (%)
1	shrub land	143	6.57
2	Grassland	18	0.83
3	Intense cultivated land	1200	55.17
4	Moderate cultivated land	584	26.85
5	Water body	80	3.68
6	Forest	150	6.90

The area covered by forest and swampy water body area gives a great contribution on increasing Groundwater potential of the sub catchment. Similarly grass land and shrub land have moderate effects on the Groundwater potential of the catchment. The dominant land use land cover units called intensively cultivated lands which cover 55.17 % from the total area is reclassified under high Groundwater potential contribution of the sub catchment. This is done because of Groundwater flows from the highland area is stored at and around the high storativity properties of the lithology called lacustrine sediments. Similar conditions happen for moderate cultivated land contributes moderate Groundwater potential for the sub catchment. Finally the rests are very low and low contribute for the Groundwater potential. The map of the Land use land cover classification of the catchment is given in the figure 4.8 below.

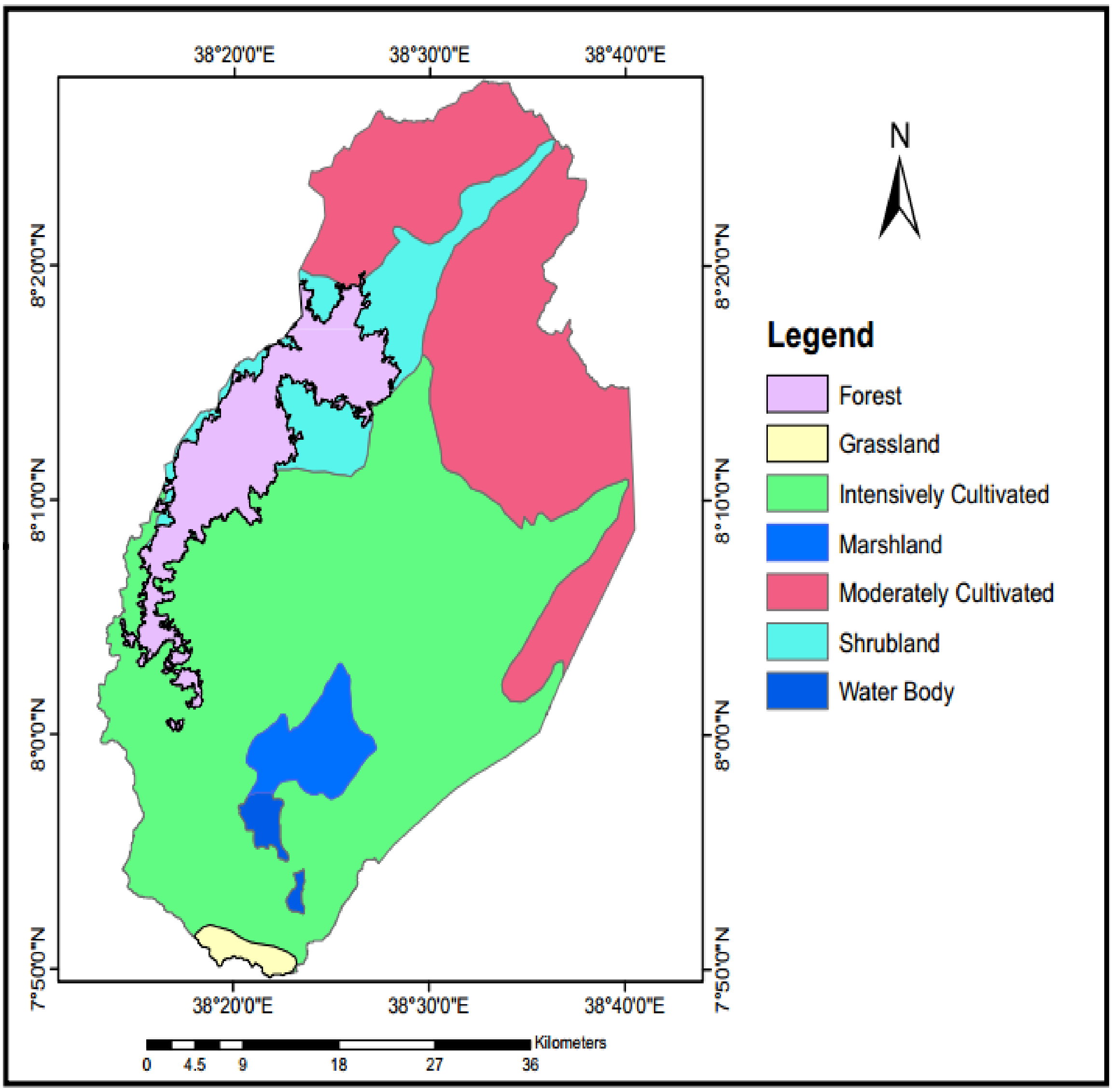


Figure 4. 8 Land use land cover map of Suten to Tora sub catchment

4.2.6 Elevation

In this study, SRTM DEM 30m was selected; since it is more accurate both in its vertical and horizontal accuracy than ASTER DEM (Odutola et al., 2012). Based on this dem, there is high elevation variation in the study area with the highest about 3606 meters above sea level (a.s.l.) around Guraghe highland and the lowest 1752 meters a.s.l. nearby the center of the study area. Such elevation variation in the study area is reclassified in to high elevated from 286 to 3606 meter, moderate elevated from 2365 to 2862 meter, low elevated from 2007.5 to 2365 meter, and very low elevated from 1752 to 2007.5 meter. One of the most criteria for delineation of Groundwater potential zone is depending on the topographical elevations variations. That means Groundwater flow from high elevation to low elevation, low storage of Groundwater with high amount of rainfall recharge in elevated area and vis-versal. So the following map shows that; the lowest elevated area (most part of the green and blue color) is represented by a good Groundwater potential zone.

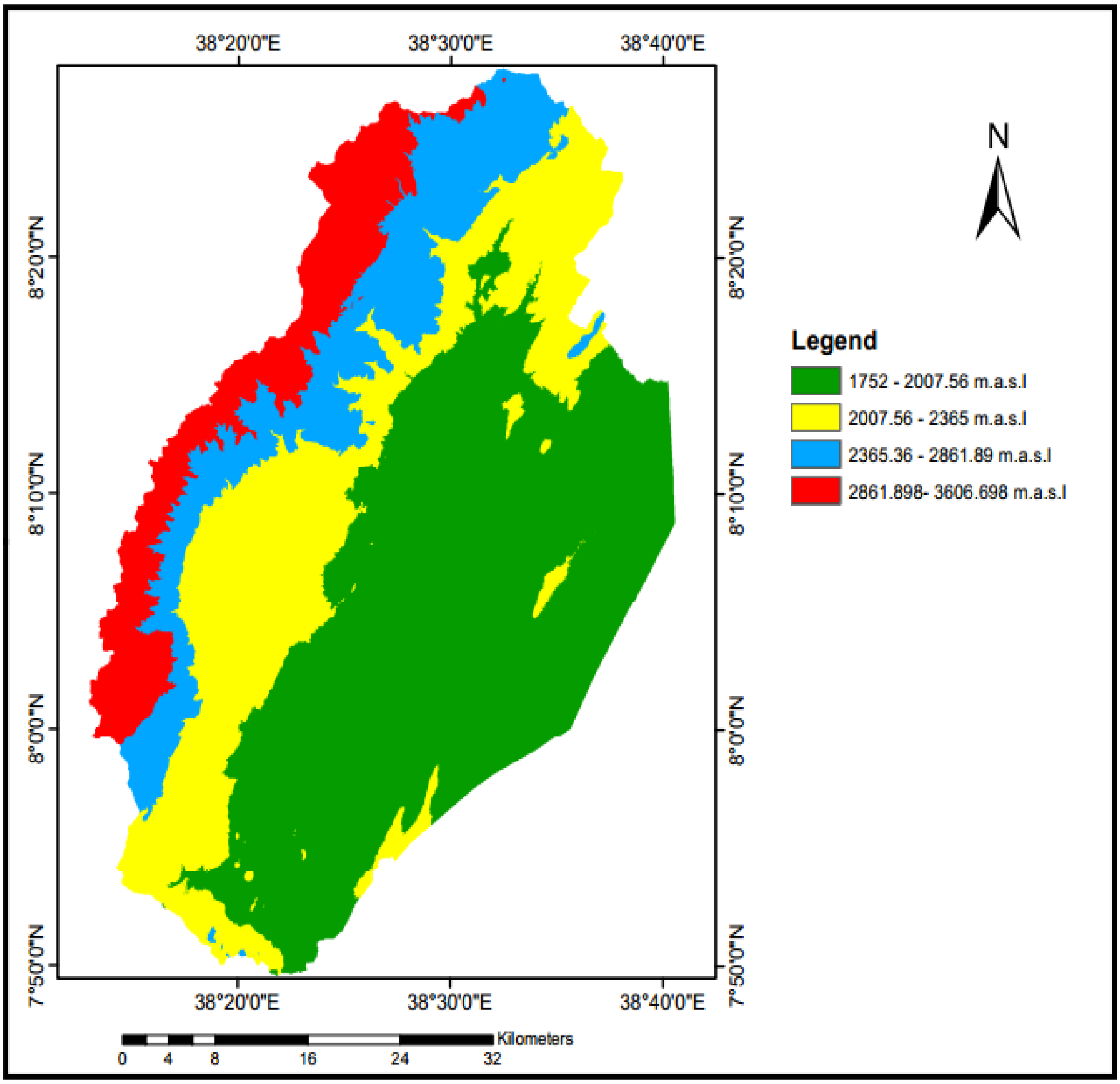


Figure 4. 9 Elevation map of Suten to Tora sub catchment

4.2.7 Slope

In Suten to Tora sub catchment there are four well known slope class called flat or gentle (0-6.2^0), moderate slope (6.2^0-14.8^0), high sloppy area (14.8^0-26.95^0), steep slope (26.95^0-68.73^0). The higher degree of the slope results in rapid runoff and increase erosion rate which decreases the Groundwater potential because of less recharge (Magesh, 2012). From this general truth of Groundwater potential delineation; the study area with high surface runoff and less infiltration occurred in the high and steep slope area that located around western highland areas. And also an area which occupied flat or gentle and moderate slope represents the high Groundwater potential zone because of less surface runoff and high infiltration rate with high storage.

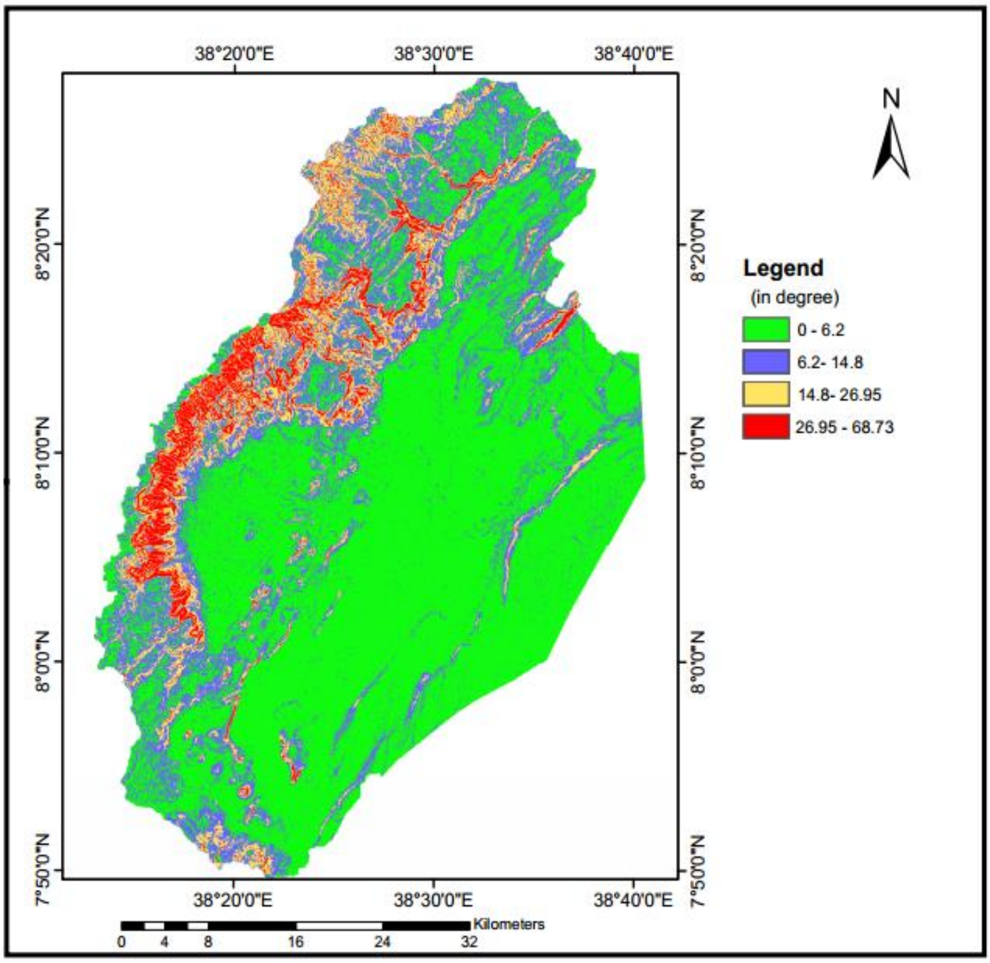


Figure 4. 10 Slope map of Suten to Tora sub catchment

4.2.8 Drainage Density

The figure 4.11 shows that; the general drainage density of Suten to Tora sub catchment are reclassified as very low (0-0.185km/km^2), low (0.185-0.50 km/km^2), moderate (0. 50-0.896 km/km^2) and high (0.896-1.681 km/km^2). High drainage density represent less infiltration , which is not favor much Groundwater potential; while low drainage density characterized high infiltration which is positively affect the Groundwater potential (Tesfaye,2010). Based on the following drainage density map legend value, the drainage density class called very low drainage density are responsible for high weight assigned Groundwater potential zone; while high drainage density are subjected for low weight assigned Groundwater potential zone.

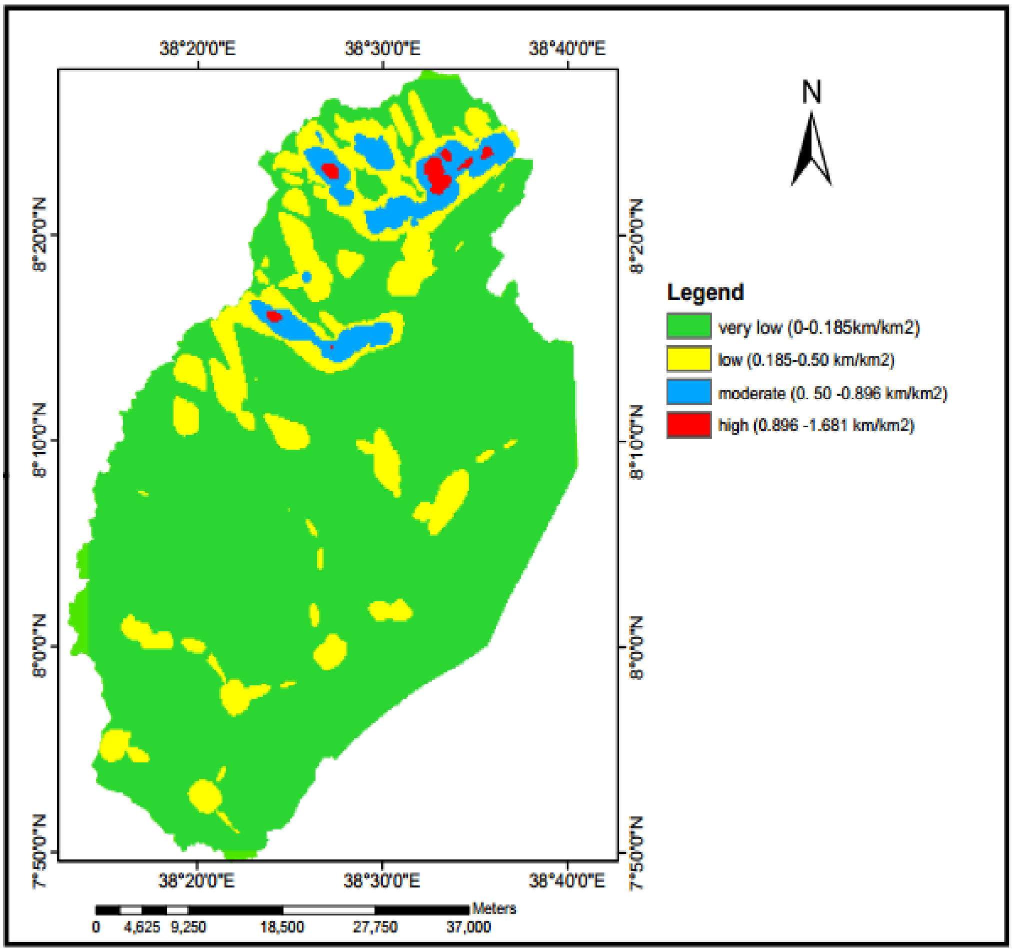


Figure 4. 11 Drainage density map of Suten to Tora sub catchment

4.2.9 Lineament Density

To compute the lineaments density in Suten to Tora sub catchment area there should be downloaded Landsat 8 OLI which has 7 bands. From this Landsat 8 OLI image; the lineaments were extracted from band 4 were taken due to its quality and the highest number of lineaments generated. Based on this the lineament density map of Suten to Tora sub catchment was reclasified into four catagories as very low (0-0.344) km/km^2, low (0.345-0.688) km/km^2, modarete (0.689-1.03) km/km^2, high lineaments density (1.04-1.38) km/km^2. As a general truth areas with high lineament density are good for Groundwater potential zones (Temesgen,2019). But this is not allways true; that means in western part of Suten to Tora sub catchment area; the basaltic flows is erupted along a regional fault acts as barrier or low permeability zone resulting into less groundwater potential and infiltrations (Dereje Birhanu, 2011).

So in the study area Groundwater flow in Western highlands of Gurage Mountain is influenced by topography, because the basaltic flows, which erupted along a regional fault acts as low permeability zone. Because of such conditions the northern part of the study area’s lineament zone has low permeability and low storage coefficient, which represents low Groundwater potential zones priority. However the other part of the study area’s lineaments act as postive impact for the ocurance of high Groundwater potential.

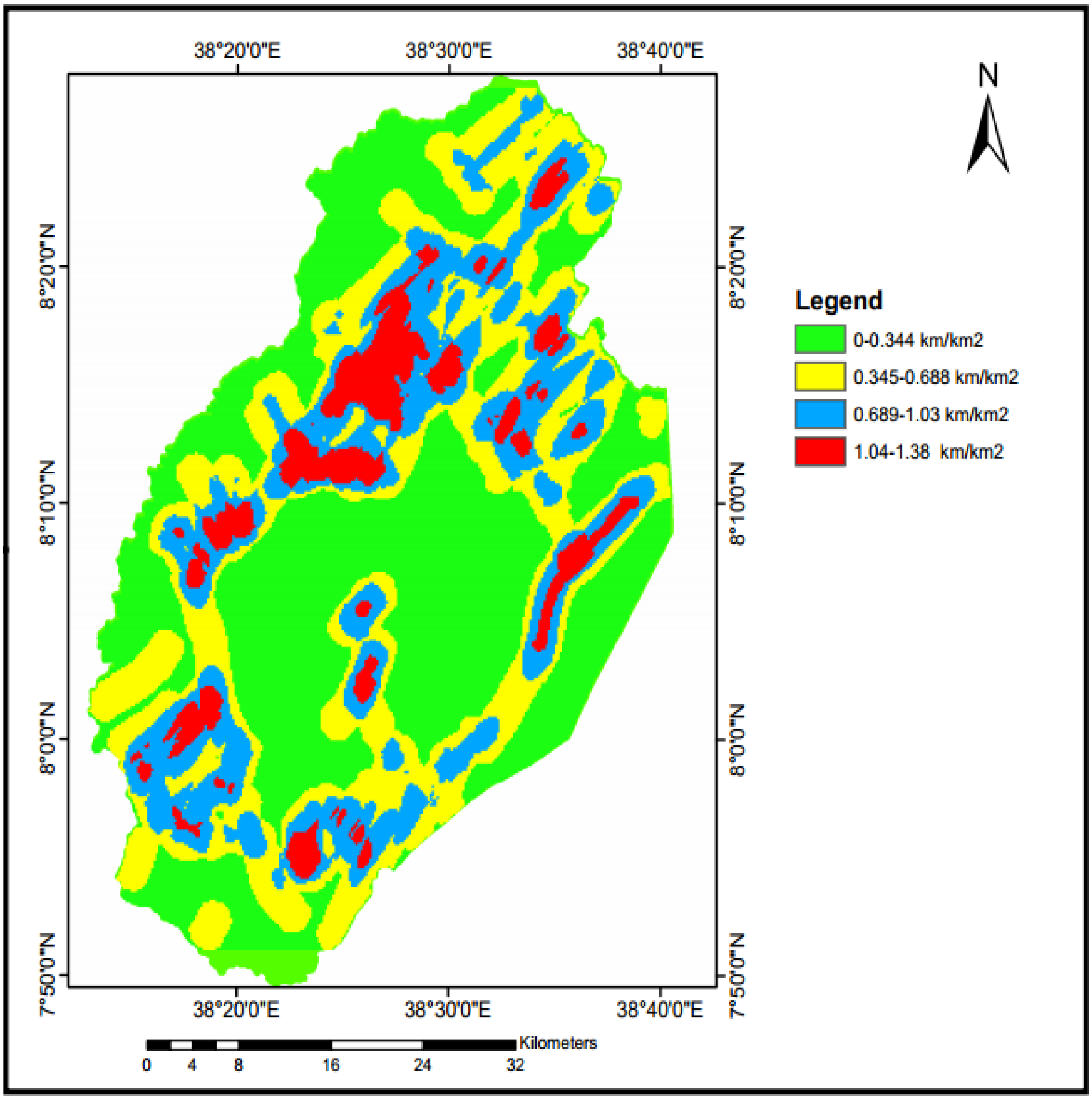


Figure 4. 12 Lineament density of Suten to Tora sub catchment area

4.3 Delineate the Groundwater Potential Zone in Suten to Tora Sub-catchment

Based on Groundwater potential zones identifications conditions, there are nine physical criteria that used for delineating Groundwater potential zones, which include the rainfall, slope, drainage density, lineament density, Land use land cover, geology, soil texture, elevation and Geomorphology. The process of implementing the Groundwater potential zones identifications technique includes prepared and standardizing the thematic maps, assigning weights of relative importance to the thematic maps, then combining the weights and the standardized thematic maps and obtaining a suitability map. These thematic maps were converted into raster data set having the same pixel and different weightage as per their Groundwater potential controlling capacity. Computing of Pair wise comparison method is used to estimate the overall weight of individual criteria or element and also their consistency of generated matrix were checked by using the integration of AHP.

4.3.1 Analytical Hierarchy Process (AHP) to Weight Parameters

Every thematic map was assigned for employing is a knowledge-based ranking of significance to groundwater occurrence. Depend on the knowledge and the previous work which listed under literature reviews part indicates how to give ranking the thematic map parameters. So based on these the rank of Suten to Tora sub catchment's Groundwater potential determinate parameters are Elevation, Lineament, Geomorphology, slope, lithology, soil, rainfall, drainage density and land use/land cover.

In addition to this; before determining the final score, the AHP method has steps to cheek the given relative importance of weights on each criterion/parameters. Among these steps pair wise comparison method is a first step which used to estimate the overall weight of each criteria or element is shown in table 4.7

Table 4 7 Pairwise comparison matrix

Parameters	Elevati	Lin	Geomo	Slope	Litho	Soil	Rainfall	Drain.d	lulc
Elevati	1	2	2	3	4	6	8	9	9
Lin		1	2	3	4	6	7	9	9
Geomo			1	2	3	4	5	7	8
Slope				1	2	3	5	6	7
Litho					1	3	5	6	7
Soil						1	1	2	3
Rainfall							1	1	4
Drain d								1	2
lulc									1

The establishment of the above triangular matrix was done based on the saat (1980) principles, which filled by comparing the row and columns of the generated matrix with respect to assigning level of priority for each parameters.

Where:

Soil = Soil
Lin =lineament density
Litho = lithology
Rainfall = rainfall
Geom = Geomorphology
elevati = Elevation
Drain d = Drainage density
Lulc = land use land cover
Slope = slope

Table 4 8 Ratings on satty's 9-point continuous scale

Intensity of the values	**Interpretation**
1	parameters in raw and columns have equal preferred
3	parameters in raw has slightly more important than columns
5	parameters in raw has strongly more important than columns
7	parameters in raw has strongly most important than columns
9	parameters in raw has the most important than columns
2, 4, 6, 8	Intermediate values between two adjacent judgments
Reciprocals this value	if the parameters in raw has low important than in columns

Just like of the above table 4.7; the lower triangular matrix was filled by using reciprocal theorem, that means the lower triangular matrix values is the reciprocal of the upper diagonal matrix values.

Table 4 9 Analysis of pairwise comparison matrix

Parameters	Elevati	Lin	Geomo	Slope	Litho	Soil	Rainfall	Drain.d	lulc
Elevati	1	2	2	3	4	6	8	9	9
Lin	1/2	1	2	3	4	6	7	9	9
Geomo	1/2	1/2	1	2	3	4	5	7	8
Slope	1/3	1/3	1/2	1	2	3	5	6	7
Litho	1/4	1/4	1/3	1/2	1	3	5	6	7
Soil	1/6	1/6	1/4	1/3	1/3	1	1	2	3
Rainfall	1/8	1/7	1/5	1/5	1/5	1	1	1	4
Drain d	1/9	1/9	1/7	1/6	1/6	1/2	1	1	2
lulc	1/9	1/9	1/8	1/7	1/7	1/3	1/3	1/2	1

To change the above pairwise comparison matrix to a normalization form, there should follow step wise techniques.

Step 1

The above Table 4.9 fractional analyzed pairwise comparison matrix changed to decimal form:

Table 4 10 Pairwise comparison matrix changed to decimal form

Parameters	Elevati	Lin	Geomo	Slope	Litho	Soil	Rainfall	Drain.d	lulc
Elevati	1	2	2	3	4	6	8	9	9
Lin	0.5	1	2	3	4	6	7	9	9
Geomo	0.5	0.5	1	2	3	4	5	7	8
Slope	0.33	0.33	0.5	1	2	3	5	6	7
Litho	0.25	0.25	0.33	0.5	1	3	5	6	7
Soil	0.166	0.166	0.25	0.33	0.33	1	1	2	3
Rainfall	0.125	0.143	0.2	0.2	0.2	1	1	1	4
Drain d	0.111	0.111	0.143	0.166	0.166	0.5	1	1	2
lulc	0.111	0.111	0.125	0.143	0.143	0.33	0.33	0.5	1
Sum	3.093	4.611	6.548	10.339	14.839	24.83	33.33	41.5	50

Step 2

The above Table 4.10 each pairwise comparison decimal matrix divisible by each columnar sum value gives normalization of pairwise comparison matrix.

Example from the above table 1÷3.093=0.323 is shown below.

Table 4 11 Compute the weights of each parameter/ Criteria weights

Parameters	Elevati	Lin	Geomo	Slope	Litho	Soil	Rainfall	Drain.d	lulc	Criteria weights
Elevati	0.323	0.434	0.305	0.290	0.270	0.242	0.240	0.217	0.18	0.278
Lin	0.162	0.217	0.305	0.290	0.270	0.242	0.210	0.217	0.18	0.233
Geomo	0.162	0.108	0.153	0.193	0.202	0.161	0.150	0.169	0.16	0.162
Slope	0.107	0.072	0.076	0.097	0.135	0.121	0.150	0.145	0.14	0.116
Litho	0.081	0.054	0.050	0.048	0.067	0.121	0.150	0.145	0.14	0.095
Soil	0.054	0.036	0.038	0.032	0.022	0.040	0.030	0.048	0.06	0.040
Rainfall	0.040	0.031	0.031	0.019	0.013	0.040	0.030	0.024	0.08	0.034
Drain d	0.036	0.024	0.022	0.016	0.011	0.020	0.030	0.024	0.04	0.025
lulc	0.036	0.024	0.019	0.014	0.010	0.013	0.010	0.012	0.02	0.018

4.3.2 Evaluations of Consistency Ratio (CR)

Once the pairwise matrix and relative weights are calculated; the consistencies of the original generated pairwise matrix or the preference ratings should be cheeked.

Table 4 12 Evaluations of Consistency Ratio (CR)

Criteria weights	**0.278**	**0.233**	**0.162**	**0.116**	**0.095**	**0.04**	**0.034**	**0.025**	**0.018**
Parameters	Elevati	Lin	Geomo	Slope	Litho	Soil	Rainfall	Drain.d	lulc
Elevati	1*0.278	2*0.233	2*0.162	3*0.116	4*0.095	6*0.04	8*0.034	9*0.025	9*0.018
Lin	0.5*0.278	1*0.233	2*0.162	3*0.116	4*0.095	6*0.04	7*0.034	9*0.025	9*0.018
Geomo	0.5*0.278	0.5*0.233	1*0.162	2*0.116	3*0.095	4*0.04	5*0.034	7*0.025	8*0.018
Slope	0.33*0.278	0.33*0.233	0.5*0.162	1*0.116	2*0.095	3*0.04	5*0.034	6*0.025	7*0.018
Litho	0.25*0.278	0.25*0.233	0.33*0.162	0.5*0.116	1*0.095	3*0.04	5*0.034	6*0.025	7*0.018
Soil	0.166*0.278	0.166*0.233	0.25*0.162	0.33*0.116	0.33*0.095	1*0.04	1*0.034	2*0.025	3*0.018
Rainfall	0.125*0.278	0.143*0.233	0.2*0.162	0.2*0.116	0.2*0.095	1*0.04	1*0.034	1*0.025	4*0.018
Drain d	0.111*0.278	0.111*0.233	0.143*0.162	0.166*0.116	0.166*0.095	0.5*0.04	1*0.034	1*0.025	2*0.018
lulc	0.111*0.278	0.111*0.233	0.125*0.162	0.143*0.116	0.143*0.095	0.33*0.04	0.33*0.034	0.5*0.025	1*0.018

Table 4 13 Evaluations of Consistency Ratio (CR) of Weighted sum value

Parameters	Elevati	Lin	Geomo	Slope	Litho	Soil	Rainfall	Drain.d	lulc	Weighted sum value
Elevati	0.278	0.466	0.324	0.348	0.380	0.240	0.272	0.225	0.162	2.695
Lin	0.139	0.233	0.324	0.348	0.380	0.240	0.238	0.225	0.162	2.289
Geomo	0.139	0.117	0.162	0.232	0.285	0.160	0.170	0.175	0.144	1.584
Slope	0.092	0.077	0.081	0.116	0.190	0.120	0.170	0.150	0.126	1.122
Litho	0.070	0.058	0.053	0.058	0.095	0.120	0.170	0.150	0.126	0.900
Soil	0.046	0.039	0.041	0.038	0.031	0.040	0.034	0.050	0.054	0.373
Rainfall	0.035	0.033	0.032	0.023	0.019	0.040	0.034	0.025	0.072	0.313
Drain d	0.031	0.026	0.023	0.019	0.016	0.020	0.034	0.025	0.036	0.230
lulc	0.031	0.026	0.020	0.017	0.014	0.013	0.011	0.013	0.018	0.163

Table 4 14 Evaluations of Consistency Ratio (CR) value

Para meters	Elevati	Lin	Geomo	Slope	Litho	Soil	Rainfall	Drain.d	lulc	Weighted sum value	Criteria weights	Weighted sum value ÷ criteria weights
Elevati	0.278	0.466	0.324	0.348	0.380	0.240	0.272	0.225	0.162	2.695	0.278	9.694
Lin	0.139	0.233	0.324	0.348	0.380	0.240	0.238	0.225	0.162	2.289	0.233	9.824
Geomo	0.139	0.117	0.162	0.232	0.285	0.160	0.170	0.175	0.144	1.584	0.162	9.778
Slope	0.092	0.077	0.081	0.116	0.190	0.120	0.170	0.150	0.126	1.122	0.116	9.672
Litho	0.070	0.058	0.053	0.058	0.095	0.120	0.170	0.150	0.126	0.900	0.095	9.474
Soil	0.046	0.039	0.041	0.038	0.031	0.040	0.034	0.050	0.054	0.373	0.040	9.325
Rainfall	0.035	0.033	0.032	0.023	0.019	0.040	0.034	0.025	0.072	0.313	0.034	9.206
Drain d	0.031	0.026	0.023	0.019	0.016	0.020	0.034	0.025	0.036	0.230	0.025	9.200
lulc	0.031	0.026	0.020	0.017	0.014	0.013	0.011	0.013	0.018	0.163	0.018	9.056

- Then depend on the above tables, the value of lamda max (ƛmax) and consistency index (CI) are 9.47 and CI=0.059 respectively.
- In similar manor after calculating the value of Consistency index (CI)**,** then find Random index (RI). Random Index (RI) is the mean value of the consistency index depending on the computed matrix order given by Saaty (1980) that has shown in Table 4. 15

Table 4 15 Random index (RI) value

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	**1.45**	1.49

For this study the number of parameters which affect the Groundwater potential zone determination are nine, then the respective Random Index (RI) value of the number nine is 1.45 and finally the value of consistency ratio (CR) was **0.040.**

Depending on consistency ratio (CR) rule, If the value of CR>0.10, then the criteria weight values of the matrix indicates inconsistencies and the method (AHP) may not give a meaningful result (Saaty1980). In the present study the calculated CR value was **0.040** which is under acceptable limits and the computed weight values are valid. So for further study, the computed criteria weight values are used for weighted overlay analysis in GIS software, which used to delineate the Groundwater potential zone is shown below.

Table 4 16 A criteria weight values of each Parameter

No	Parameters	Criteria weight values	% of criteria weighted value
1	Elevati	0.278	27.8
2	Lin	0.233	23.3
3	Geomo	0.162	16.2
4	Slope	0.116	11.6
5	Litho	0.095	9.5
6	Soil	0.040	4.0
7	Rainfall	0.034	3.4
8	Drain d	0.025	2.5
9	Lulc	0.018	1.8

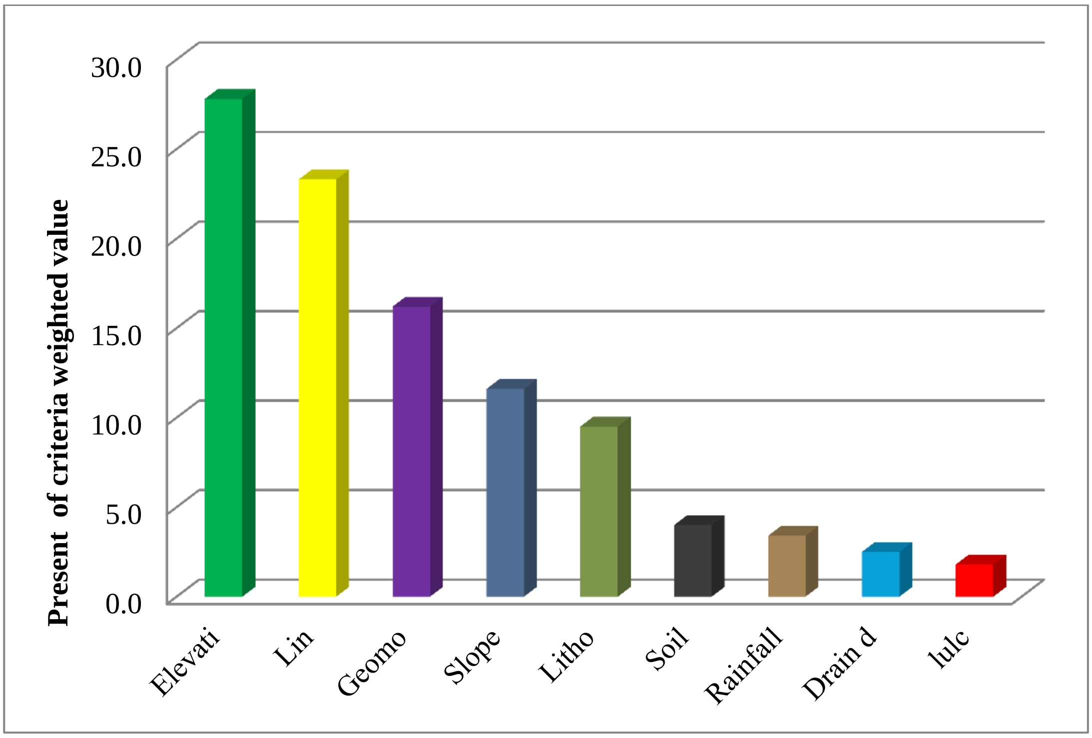


Figure 4. 13 Weight of Groundwater potential affecting parameters

As we seen from the above graph; the study area Groundwater potential is highly affected by parameters called elevation, lineament, Geomorphology, slope, lithology, soil, rainfall, drainage density and lulc respectively.

4.3.3 GIS overlay analysis

The study area Groundwater potential map delineated was done based on the Groundwater potential affected parameters (lineament, Geomorphology, land use land cover, slope, lithology, soil, rainfall, drainage density and elevation). Generally low Groundwater potential zone was located in the mountains peaks and plateaus formation and also high Groundwater potential zones were found at rift escarpment near to low elevated areas (Tesfay, 2010). The Groundwater potential zone map of a given sub catchment was developed by linear summation of each parameters (Tesfay, 2010).

When come to this study area; the linear summation of these parameters and weight overlay all their thematic maps by a spatial analyst tools in ArcGIS gives delineation of Groundwater potential zone map in Suten to Tora sub catchment. According to this delineation; the Groundwater potential map is classified as; high, moderate, low and very low potential zones.

The area of high Groundwater potential zone which covered by lithological formations called lacustrine sediments, Wonji basalt with scoria deposit and pyroclastic coincide with low elevation. Similarly a moderate Groundwater potential zone is covered by Geological formations; like Chefe Donsa un-welded to poorly weld pyroclastic. In the other way low and very low potential zones are covered by depositions of Nazret pyroclastic, Gash Megal rhyolite and other small lithological formations with hills and sloppy environments which contribute high surface runoff.

High potential zone which found at escarpment area is due to Groundwater flow directions from the western, southwestern and northwestern to the center and eastern part of the study area. This Groundwater potential zone has minimum elevation, flat (gentle) slope, and good geomorphological setup with some parts of swamp land feature.

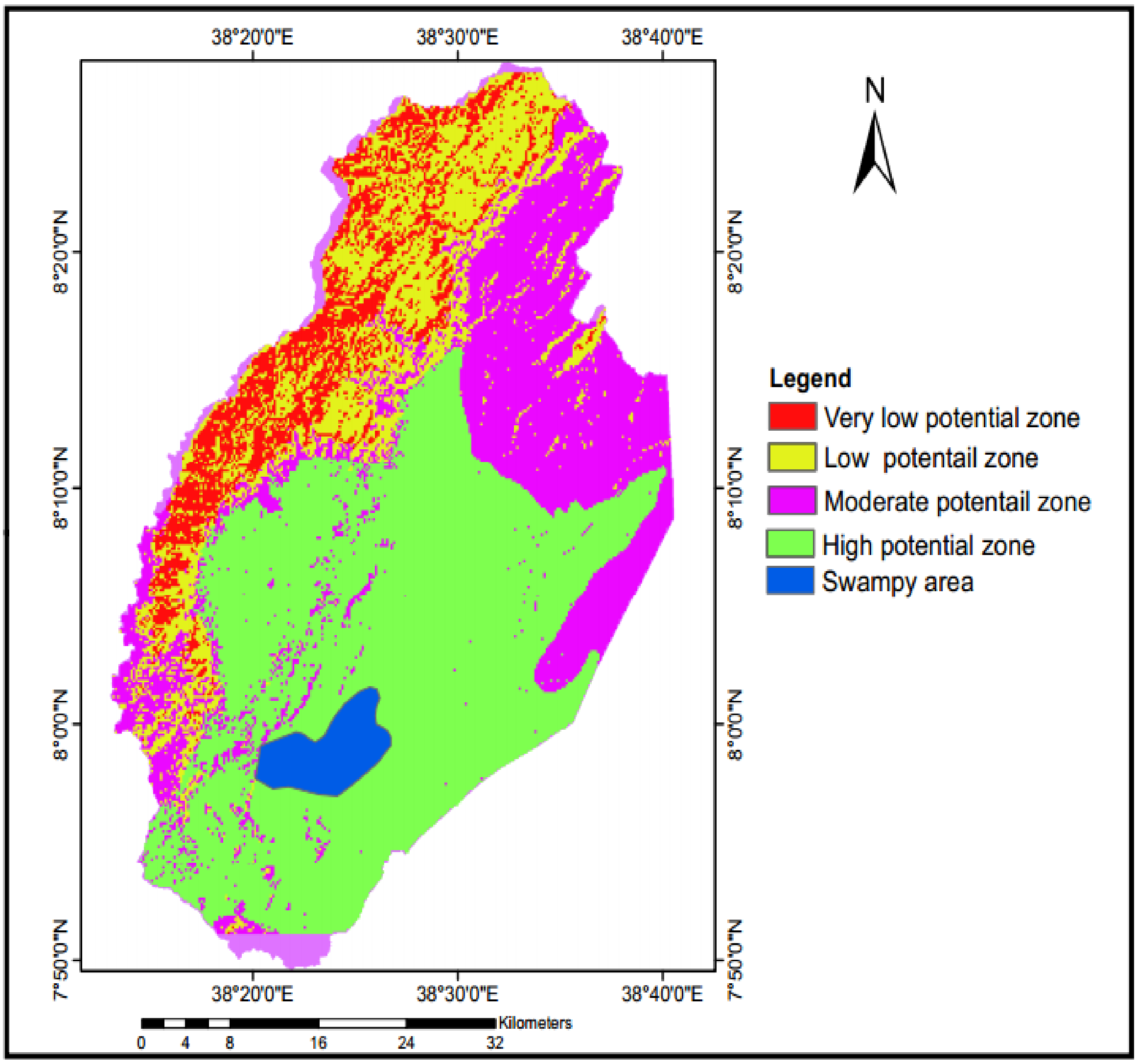


Figure 4. 14 Delineated Groundwater potential zones

The above delineated Groundwater potential zones map shows that the area which have high amount of Groundwater potential zones located at the central and southern part of the sub catchment is covered around 50% of the total sub catchment area. In similar manor moderate Groundwater potential zones is mostly found at northeast part of the sub catchment which covers around 20% of the total sub catchment area. Finally low and very low Groundwater potential zones are distributed around northwest, southwest and northeast parts of Suten to Tora sub catchment which covers around 16% and 14% of the total sub catchment area respectively.

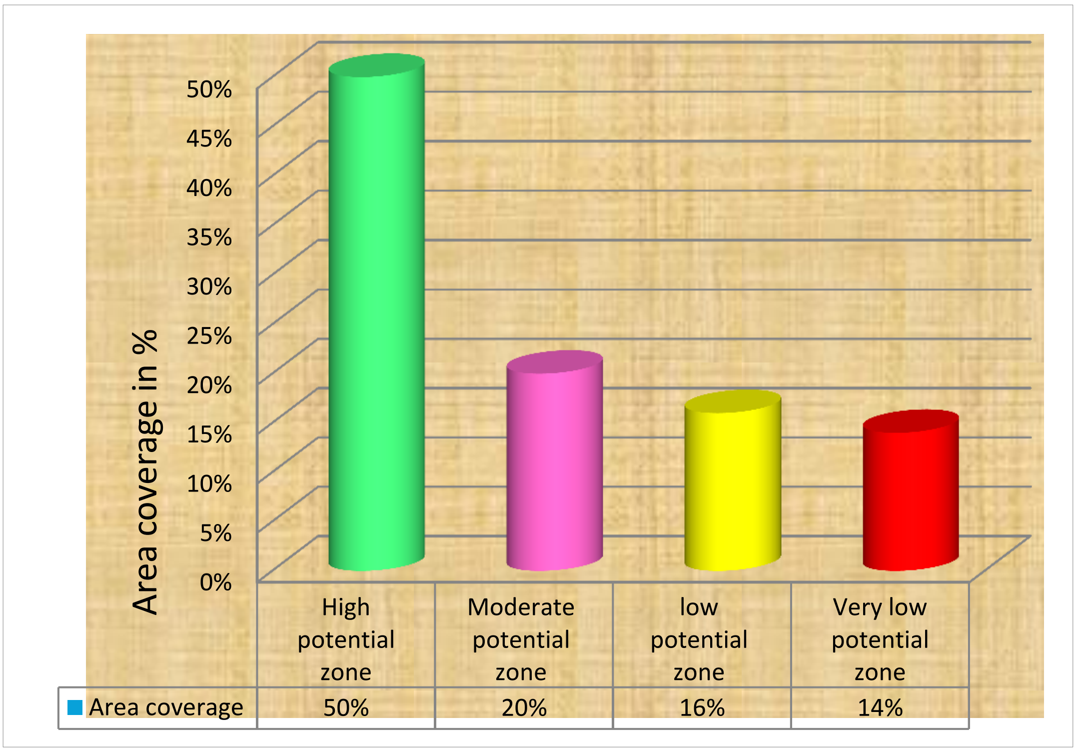


Figure 4. 15 Area coverage of each Ground water potential zone

4.4 Validation

In order to validate the delineated Groundwater Potential Zone classification in Suten to Tora Sub-catchment, it was necessary to collect a well completion data of deep well, shallow well, dug well, spring and other necessary data from respective governments; like SNNPR Water, Mine and Energy Office, South Water Work Construction Enterprise and Gurage Zone Water, Mine and Energy office. The classification of each lithological units in the hydrogeological map of Ethiopia and Akaki beseka map sheet, which estimated optimum yield in liter/second is classified as very low potential (<0.05 l/s), low potential (0.05-0.5 l/s), moderate potential (0.5-2 l/s) and high potential from 2-25 liter per second (Bereket, 2011 and Tesfay, 2010).

Table 4 17 Validation of the delineated Groundwater potential zone discharge value

Standard		Available data	
Aquifer classification rule	Discharge value bounding rule(l/s)	Delineated Groundwater potential zone Classifications	Average discharge value(l/s) that fall on each potential zone Class
Very low potential	<0.05	Very low potential zone	0.041
Low potential	0.05-0.5	Low potential zone	0.43
Moderate potential	0.5-2	Moderate potential zone	1.066
High potential	2-25	High potential zone	2.202531

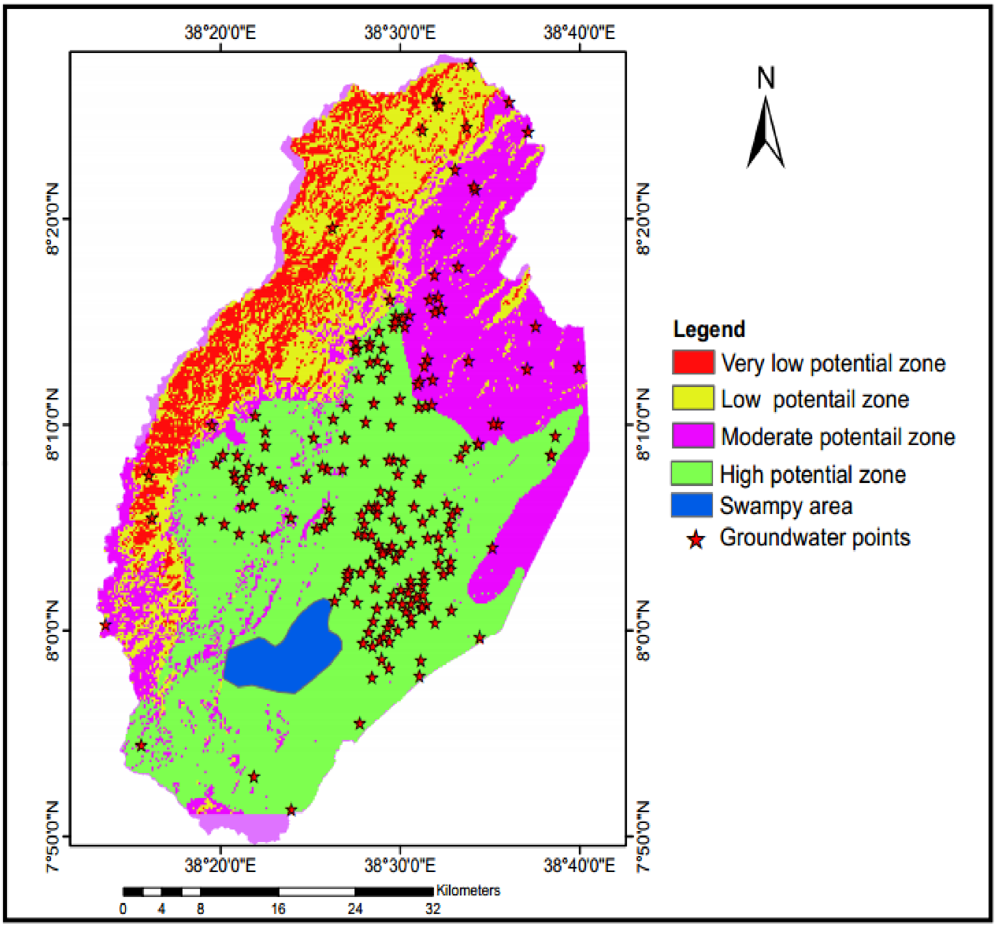


Figure 4. 16 Validity map for developed Groundwater potential zones

Generally, the validation analysis revealed that there is a good agreement between the Groundwater point data and Groundwater potential zones delineated using GIS and RS technique. So GIS and remote sensing techniques were best techniques, for Groundwater exploration.

4.5 Limitation of the study

The lack of data and financial support are concerning factors that affected this research and development in the study area. So the followings are some of the limitations for this study.

- It reminds that, because of different limitations like secondary data and economy, the Groundwater quality aspect of Suten to Tora Sub-catchment was not part of this study.
- Shortage of hydrological data, inaccurate representation of the spatial distribution of hydrological stations. Because of these; delineation of Groundwater recharge zone is not include for this study
- Inadequate well completion data, which is caused by improper document handling

5. CONONCLUSION AND RECOMMENDATION

After conducting a systematic Groundwater potential investigation, the following conclusion and recommendations were arrived.

5.1 Conclusion

Suten to Tora sub catchment is comprised the north-western and south-western highlands and the escarpments area. The objectives of these study was achieved by collecting a data from the field and secondary sources in Minister of Water, Irrigation and Energy, Ethiopian Mapping Agency, South Water Works Construction Enterprise ,Gurage and Silte Zone Water Mine, Energy Bureau. Depend on these collected data, Geological units in the study area are affected by Geological structures. The linear features of these structures are characterized by three distinct interconnected fault trends system is in NE-SW, NW-SE, and N-S which are more or less affect the Groundwater flow directions. Means that higher hydraulic conductivity zones are mapped at or near fractured regions and their values are decreasing away from the structures. The geological formations like lacustrine sediments, Wonji basalt with scoria deposit and pyroclastic are coincide with high Groundwater potential zone. Similarly a moderate Groundwater potential zone is covered by Geological formations called Chefe Donsa un-welded to poorly weld pyroclastic. In the other way low and very low potential zones are covered by depositions of Nazret pyroclastic, Gash Megal rhyolite and other similar lithological formations.

Based on existing well completion reports the Groundwater flows downward from Southwestern and Northwestern towards the center and eastern part of the area. Developing and overlaying Groundwater potential affecting parameters in GIS software (like lineament density, lithology, land use land cover, geomorphology, slope, soil texture, drainage density, rainfall and elevation) were generated from different systems. Among these; Lineament and land use land cover maps were generated from land sat 8 using PCI Geometrics and ERDAS software respectively. The rest other thematic layers were developed by using ArcGIS 10.3. Weights were assigned to each thematic maps based on their characteristics and water potential capacity through analytic hierarchy process (AHP). The thematic layers were subjected to weight sum overlay in ArcGIS spatial analysis tool box and delineate Groundwater potential zone map.

The resulted Groundwater potential zone was categories into four classes namely high, moderate, low and very low potential zone. These delineated Groundwater potential zones class called high, Moderate, Low and very low potential zones are covers an area of around 50%, 20%, 16% and 14% of the total sub catchment area respectively. The center and southeastern parts of the sub catchment have high amounts of Groundwater potential. However the western part has leas Groundwater potential. Depend on the validation; delineation of Groundwater potential zones by using GIS and remote sensing techniques is a best alternative method.

5.2 Recommendations

- As we know the hydraulic properties like hydraulic conductivity, transmissivity, storage coefficient are depend on a well completion reports. But among many drilled boreholes in the study area, most of them have not full well completion reports. So most of the water bureaus has to make a close follow up to have a complete well drilling and pumping test reports for the further schemes.
- The well driller enterprises in Suten to Tora sub catchment recommended to use the Groundwater potential zone map as information to save their time and economy in searching the best Groundwater site for well drillings.
- In addition to the methodology of this study; Geophysical investigations for Groundwater potential site is recommended.

6. REFERENCES

Abebaw Getachew. (2012). Assessment of water supply coverage and water quality

Afewerk. (2011). Groundwater recharge amount in arid and semi-arid areas applied Geochemistry approach – An application of engineering education. Mathematica Aeterna, 2 ,no. 10

Bandyopadhyay, D. J. (2012). Ground Water Potential Mapping in Dulung Watershed using Remote Sensing & GIS techniques, West Bengal,using Remote Sensing & GIS techniques, West Bengal,using Remote Sensing & GIS techniques, West Bengal,India. International Journal of Scientific and Research Publications, 2(12, December 2012 1ISSN 2250-3153,www.ijsrp.org).

Basalfew Zenebe. (2012).BASIC GEOSCIENCE MAPING DIRECTORET GEOLOGY

Bereket Fenatw. (2011).Hydrogeology and hydrochemistry of The Akaki-BesekaSheet (NC 37-14)

Birhanu Debisso. (2009). Groundwater resource assessment in the Gidabo River Butajira Town, southern region, Ethiopia Catchment in the southern main Ethiopia rift province./Yirgalem-Wonago/

Dar. (2010). Deciphering Groundwater potential zones in hard rock terrain using

Dereje Birhanu. (2011). Numerical Groundwater Flow Modeling of the Meki River Catchment, Central Ethiopia discharge areas in salinity prone catchments, southeastern Australia.

Earth Syst. (2012).Environ., DOI 10.1007/s40808-015-0024-3.

Efrem Beshawered. (2010).Geological map of the Northern Main Ethiopian Rift

Genet Mathewos, Supervision Core, and Addis Ababa. (2017). "Groundwater Flow Direction, Recharge and Discharge Zones Identification in Lower Gidabo Natural Resources Conservation Service.

Halcrow.(1989). Master Plan for the Development of Surface Water Resources in the rift

Julius and Merrious.(2010).Groundwater flow direction

K. Subramanya, 2008.Enginerring hydrology, third edition

Kazmin, V. (1975). Explanation of geological map of Ethiopia, GSE

Kibrit. (2018). Identification of Groundwater potential zones using GIS and remote sensing : The case of Megech watershed, Ethiopia

Kousalya, P., Reddy, G. M., Supraja, S., & Prasad, V. (2012). Analytical Hierarchy Process

M. Raunet. (1977).The Geological formation of the main Ethiopian Rift Valley

Magesh, Chandrasekar, and John Prince Soundranayagam. (2012). Delineation of Groundwater Potential Zones in Theni District, Tamil Nadu, Using Remote Sensing, GIS and MIF Techniques. Geoscience Frontiers.

Mandefro Ararso. (2017). Application of Geophysical methods for delineating deep along Ziway-Butajira and Meki-Medrekebed

Mengesha (1996).Geology of Ethiopia Midrekebed traverses

Odutola, C. A., Prof.Beiping, W., & Yao, Y. Z. (2012). Assessing vertical accuracy of SRTM Ver 4.1 and ASTER GDEM Ver 2 using differential GPS measurements – Case Study in Ondo State, Nigeria. International Journal of Scientific & Engineering Research,Volume 4 potential zones using geospatial technique for Keleghai river basin, India. Model.

Ramu, Mahalingam B. and Vinay. (2014). "Identification of Ground Water Potential Zones Using GIS and Remote Sensing Techniques : A Case Study of Mysore Taluk - Karnataka." International Journal of Geomatics and Geosciences.

Sar, N., Khan, A., Chatterjee, S., & Das, A. (2015). Hydrologic delineation of ground water

SCI. (2005). Potential Survey, Identification of Opportunities and Preparations of Projects Profiles and Feasibility Studies Sciences (ASRJETS), Volume 10, 85-120

Seifu kebede (2005). Ground water recharge, circulation and geochemical evaluation in shallow Groundwater flow systems

Snow. (1969)."Anisotropic Permeability of fructured Media." Water Resource Research

Solomon, and Quiel. (2003). Integration of Remote Sensing and GIS for Groundwater Assessment in Eritrea.

Tenalem Ayenew.(2001). Principles of hydrogeology. Addis Ababa University Press

Tesfaye. (2010). Ground Water Potential Evaluation Based on Integrated GIS and Remote Sensing Techniques, in Bilate RiverCatchment: South Rift Valley of Ethiopia. American Scientific Research Journal for Engineering, Technology

Thapa, R., Gupta, S., Guin, S., & Kaur, H. (2017). Assessment of groundwater potential zones using multi-influencing factor (MIF) and GIS: a case studyfrom Birbhum district, West Bengal. Appl Water Sci., DOI10.1007/s13201-017-0571-z.

Tsegaye Abebe (2005). Geological Maps of TheNorthern Main Ethiopian Rift.

Tweed. (2007). Remote sensing and GIS for mapping Groundwater recharge and valley lakes Basin.

Ven Te Chow. (1988).Applied hydrology

WoldeGabriel. (1990). Distribution of Volcanoes in Central Main Ethiopian Rift valley

Yongxin. (2003)Groundwater recharge assessment the Makutupora basin, Dodoma Tanzania

ANNEXES

Annex.1 Borehole's Characteristics which obtained from well completion reports

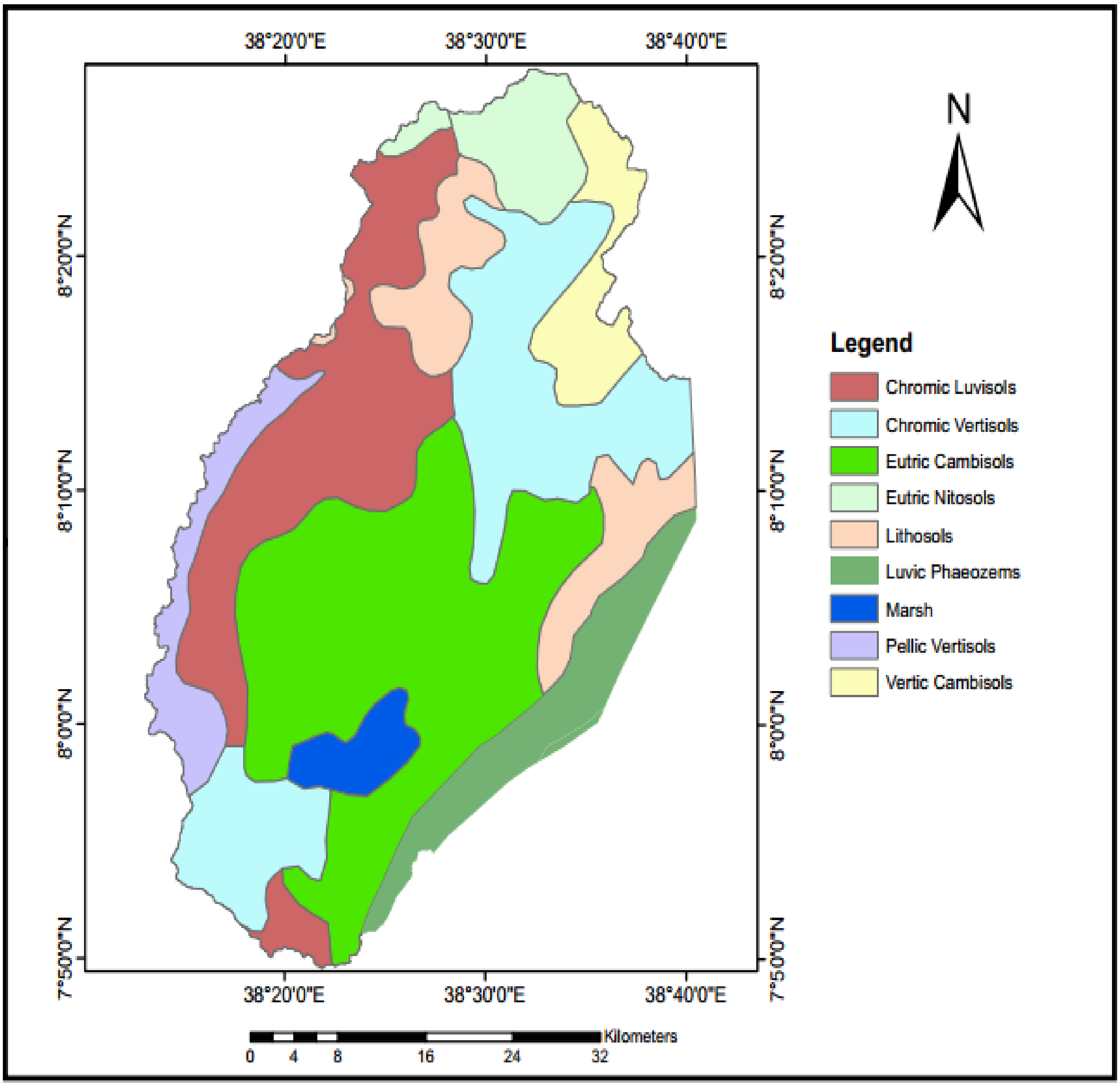
Site name	Symbol	X	Y	Z	Yield(l/s)
Tora2	BH1	433726	868414	1860	8
Bonosha2	BH2	431024	892728	2074	9
Adele/Borbor(Mirt)	BH3	452897	901064	1824	6
Netsa Sefer Well #1	BH5	432663	897234	2081	8.6
Eresha Well # 2	BH6	431867	897635	2060	14
Hospital Well #4	BH7	430742	898821	2085	4.4
Gogete	BH8	441837	910128	1911	13
Shirinto2	BH9	443700	880968	1890	9
Kela	BH10	444472	912526	1921	4
Dugda Geriyo	BH11	460335	900046	1934	3.5
Luke Feka	BH12	440733	876079	1995	12
Koshe Akababi	BH13	446043	885112	1818	27
Shanka Tuffa	BH14	429902	871358	1837	25
Shershera Ele	BH18	437480	898874	1880	5.03
Keshit kebele	BH22	437995	920492	2651	0.5
Silte Sefer	BH23	433740	894488	2032	3.12
Kebele Tsifet Bet	BH24	435312	898037	1998	2.78
Ile	BH25	439012	898849	1897	6
Mesjide Gibi	BH26	441886	890544	1840	8
Atit Sefer	BH27	441842	890340	1837	5.5
Mikael Sefer	BH28	440636	907073	1919	3.47
Kechaber	BH29	424547	894351	2183	6.5
Got-3	BH30	439243	901557	1906	3.4
Mechimena	BH31	439372	904504	1917	4.1
Sheh Sefer	BH32	436932	899045	1959	4.6
Gote 2	BH33	438070	903351	1938	7.3
Mirt	BH36	452897	901064	1824	2.7
Qulqle	BH37	436064	901691	2018	3.4
Qiltu	BH41	460347	900045	1936	2.65
Barka	BH42	460789	901805	1926	6.93
High School	BH46	444247	911555	1907	5.5
Amrach	BH47	444408	911952	1902	5.2
Ketena 3	BH51	447548	886649	1819	20
Ketena 5	BH52	447091	886337	1817	3.55
Ketena 2	BH53	448481	885118	1874	0
Ketena 2	BH54	441990	880139	1926	5.08
Ketena 2	BH55	450165	886176	1879	4
Ketena7	BH56	447093	886426	1823	2.71
Ketena 1	BH57	454324	891742	1925	6.18
Ketena 3	BH58	447285	889440	1831	2.4
Ketena 3	BH59	453014	883708	1813	4.33
Wosile	BH60	444970	893556	1830	0.12
Sodo	BH61	447696	892655	1832	0.13
Mesjide	BH62	448770	892717	1832	0.13
Wurib	BH63	449029	891507	1831	0.12
Saya	BH65	450068	893155	1840	0.2
Meskan	BH66	436396	893497	1849	0.13
Mender 2	BH67	437095	893727	1840	0.13

Gediye	BH68	437597	895255	1845	0.13
Meskan	BH69	437750	894350	1852	9
Fego	BH70	426741	900134	2161	0.13
More	BH71	428443	893076	2014	0.3
Gohina	BH72	426066	899341	2159	0.25
Inseno Usme	BH73	441274	892897	1833	8
Mender 2	BH74	440579	893001	1843	0.13
Gola	BH75	442217	904750	1885	0.14
Megazen Sefere	BH76	443939	902815	1858	0.13
Limech	BH77	427968	898513	2108	0.33
Budikesa	BH78	428032	897945	2107	0.33
Mekiche	BH79	428270	900072	2126	0.22
Budikesa	BH80	429123	898152	2083	0.33
Mekiche	BH81	429420	899051	2090	0.25
Meden	BH82	428647	897106	2100	0.3
Atu	BH83	428747	895512	2090	0.37
Atu	BH84	429806	895651	2089	0.23
Geneme	BH85	446318	895395	1827	0.25
Mesjid	BH86	447187	894131	1837	0.25
Misrake Gode	BH87	430076	903678	2187	0.16
Konkir	BH88	448213	895007	1830	8
Beshiro Sefer	BH89	449678	895736	1833	0.12
Senga Gasha	BH90	450217	894697	1836	0.13
Tayewane	BH91	450717	895179	1831	0.13
Sefere Selam	BH92	449893	893895	1829	9
Elena	BH93	431103	902179	2124	0.33
Elena	BH94	431122	900955	2094	6
Adem Lalega Sefer	BH95	445241	899506	1875	0.33
Soda Mender	BH96	441241	899506	1871	0.25
Kedo Merere	BH97	441381	903003	1891	0.22
Mender 3	BH98	444243	899705	1841	0.25
Delelsa	BH99	442755	911158	1913	0.37
Abasodo1	BH106	447028	898131	1849	0.35
Abasodo2	BH107	446732	897642	1836	0.24
Kobo	BH108	451608	900684	1836	0.57
G/Tesma	BH109	451043	899863	1844	0.32
Misrta	BH110	443621	907925	1900	0.31
Agelglot	BH111	442602	908541	1922	0.2
Sibisto	BH112	440543	909653	1973	0.3
Chelelk	BH114	446815	904384	1861	0.365
Malnajire	BH115	447473	904430	1863	0.275
Ketena2	BH117	443187	909622	1908	0.32
Wenegasha	BH118	441761	909755	1938	0.11
Gurambar	BH124	444881	905079	1869	0.35
Sibisto	BH125	440394	909429	1971	0.3
Mehakel	BH126	441826	908367	1932	0.31
Ybekelni	BH127	442975	906991	1894	0.32
Chefa	BH132	448794	931369	1932	0.52
Ketena2	BH136	444431	890844	1838	0.33
Ketena1	BH137	443767	899591	1830	0.22
Ketena3	BH138	444975	891422	1825	9
Ketena3	BH139	445998	892206	1836	0.2
Ketena2	BH140	446852	880325	1821	0.3

Ketena3	BH141	446969	881655	1821	0.5
Ketena2	BH142	449268	889458	1827	0.33
Ketena2	BH143	450055	889804	1834	0.3
Ketena2	BH144	450059	890524	1826	0.4
Ketena3	BH145	441060	883303	1831	0.25
Ketena2	BH146	441716	884262	1844	0.25
Ketena2	BH147	442801	883468	1855	0.3
Ketena2	BH148	443178	883825	1845	0.25
Ketena1	BH149	443774	883437	1855	0.2
Ketena1	BH150	442980	881762	1858	0.2
Ketena 1	BH151	446564	887337	1819	0.24
Ketena 2	BH152	446043	888341	1825	0.33
Ketena1	BH153	445935	888821	1833	0.24
Ketena 2	BH154	447228	888338	1824	0.2
Ketena 2	BH155	447252	887500	1819	0.2
Ketena 2	BH156	447320	888853	1830	0.4
Ketena 3	BH157	448822	890343	1829	0.5
Ketena 1	BH158	438215	887057	1827	0.25
Ketena 1	BH159	440845	889612	1845	0.28
Ketena 3	BH160	439530	889018	1832	0.25
Ketena 1	BH161	439679	889744	1838	0.2
Ketena 2	BH162	439531	889394	1837	0.2
Ketena 3	BH163	439079	888019	1840	0.28
Ketena 1	BH164	440509	886921	1826	0.3
Ketena 3	BH165	442361	888205	1837	0.25
Ketena 1	BH166	443912	886827	1835	0.3
Ketena3	BH167	444943	887965	1832	0.4
Ketena2	BH168	445106	886771	1828	0.27
Ketena 1	BH169	445471	886068	1826	0.33
Ketena 3	BH170	445701	887748	1827	0.17
Ketena 1	BH171	445966	885601	1820	0.5
Ketena 3	BH172	444238	887505	1836	0.25
Ketena 2	BH173	445979	886750	1825	0.33
Ketena 3	BH174	442189	885242	1837	0.25
Ketena 3	BH175	443595	884614	1840	0.25
Ketena 2	BH176	443975	885256	1840	0.33
Ketena 1	BH177	444702	884396	1835	0.2
Ketena 2	BH178	442518	886299	1836	0.17
Ketena 1	BH179	442060	882957	1861	0.28
Askale	BH180	442859	896859	1855	0.16
Bamo	BH181	443872	896046	1850	0.33
Sode	BH182	443959	896660	1853	0.16
Hamus Gebeya	BH183	444729	898356	1836	0.25
Basha Gebre	BH184	441244	893941	1845	0.13
Yetebon	BH185	441995	892880	1841	0.13
Aborat Mender	BH186	442673	892045	1836	0.13
Hycho Mender	BH187	443809	891516	1837	0.14
Fasilo	BH188	440930	894789	1853	0.12
Amirach Gote	BH189	441681	895478	1851	0.13
Mesjide	BH190	442338	895467	1854	0.14
Gubiraro	BH191	442566	894800	1851	0.12
Goybn Sefer	BH192	442621	895404	1850	0.13
Ocha	BH193	444267	894348	1837	0.13

Mender 1	BH194	442753	889796	1836	0.13
Mender 1	BH195	442963	889508	1832	0.12
Antuso	BH196	443069	891524	1833	0.13
Jahiro	BH197	443106	891173	1836	0.12
Usme	BH198	444037	891967	1833	0.14
Sibisto	Csp1	440371	910162	1971	0.3
Kela zuria kebele	Csp4	443904	913966	2185	0.08
Tekelehaymanot	Csp7	426923	893898	2120	1.5
Suten 1	BH4	458031	929019	2130	0.12
Merit Meteja	BH15	454955	902825	1825	0.31
Gose salen	BH17	447710	908637	1884	0.32
Tach Anati	BH19	452660	923864	2035	1.9
Soleke	BH34	458777	911576	1936	1.53
Bochesa1	BH38	451946	908529	1959	2
Wulawla	BH39	457915	907709	1875	1.75
Shuke	BH40	463149	907916	1820	2.71
Guchimotebe	BH43	450850	916972	1975	2.5
Dachi	BH44	450580	925603	2153	2.05
Keranyo	BH45	458031	929019	2130	1.71
Meki1	BH48	448822	919998	1985	2.91
Meki2	BH49	448857	920045	1980	2.5
Tach Anati	BH50	452474	924129	2035	1.9
Sefera	BH100	445403	911535	1916	0.5
Mucha	BH101	445888	912610	1901	0.35
T/Bet	BH102	448248	906777	1901	0.275
Tere Warka2	BH104	447413	908026	1885	0.32
Muslim1	BH105	446710	906422	1849	0.56
M/Ketena	BH113	454450	902808	1831	0.31
Mehal Jire	BH116	448143	904561	1874	0.175
Tume Abado	BH119	448509	912813	1914	0.65
Lemen	BH120	449134	913164	1930	0.32
Kere	BH121	448825	914220	1960	0.25
Galo	BH122	447933	914018	1942	0.26
Alkakase	BH123	448421	916182	1943	0.32
Meki	BH135	445167	912286	1917	1.74
Mukarbi1	BH103	446947	906646	1875	0.35
Tach Gembela	BH16	449138	913155	1923	0.32
Addis ketema kebele	Csp2	419493	894429	2865	0.5
Tiya zuria kebele	Csp5	452157	935084	2464	0.61
Dobi kebele	Csp6	425689	902748	2347	0.11
Maksengo	BH128	448648	931981	2600	0.45
Chefa	BH130	448794	931369	2584	0.24
Denshe	BH131	451721	929376	2739	0.87
Kechin Dugda	BH133	447203	929118	2553	0.57
Gereno	BH134	448994	931322	2579	0.21
Chefa	BH129	448885	931602	2580	0.24
Denka	BH64	419149	898349	3135	0.5
Keshit kebele	Csp3	437995	920492	2841	0.041

Annex.2 Soil map of Suten to Tora sub catchment



Soil map of Suten to Tora sub catchment (FAO, 2003)