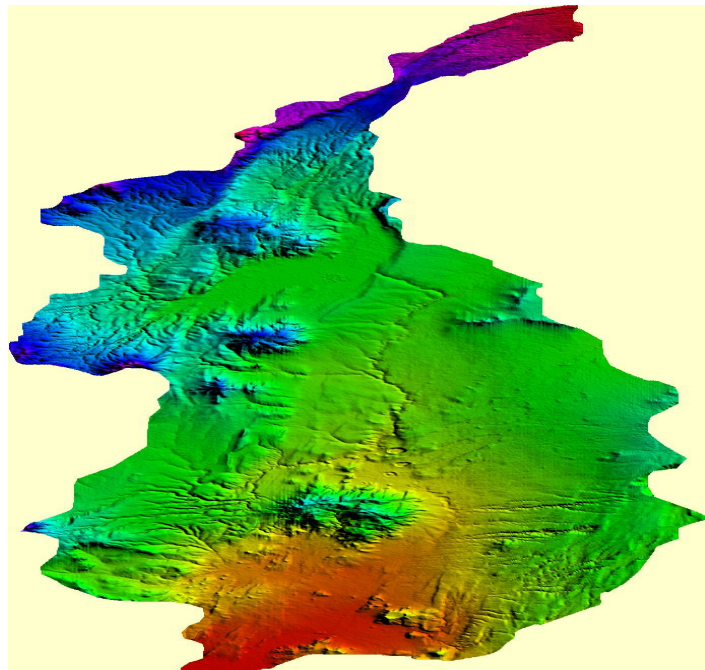


**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES DEPARTMENT OF
EARTH SCIENCES**



**GROUNDWATER POTENTIAL EVALUATION BASED ON
INTEGRATED GIS AND REMOTE SENSING TECHNIQUES, IN
BILATE RIVER CATCHMENT: SOUTH RIFT VALLEY OF
ETHIOPIA**



By Tesfaye Tessema Gintamo

*A Thesis submitted to the School of Graduate Studies of Addis Ababa University In
Partial Fulfillment of the Requirements for the Degree of Master of Science in
Hydrogeology*

June, 2010

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Acknowledgements

Before anything, glory and thanks be to God who gives me full health, peace, knowledge and wisdom to accomplish this thesis work and He is still in my side throughout my life. The secret of my success is Jesus Christ. It the Lord!!

My deepest feeling of gratitude goes to my advisor prof. Tenalem Ayenew, for his worthless advice, and constant encouragement helped me to complete this research work successfully. I never ever forget his admirable patience, work quality, and attractive spirit of friendship as unique personal possessions.

I would like to express my special and sincere appreciation to my instructor Dr. Seifu Kebede and all Addis Ababa University Earth Science Department instructors who support in the knowledge of Hydrogeology. I extend my thanks for secretary office members Roman Kefyalew, Worku, and librarian Eden Wube all of them helped me in providing valuable information and reading materials.

I am thankful to Hadiya Zone Water, Mines and Energy Development Coordination Department, for allowing me to pursue my postgraduate studies. I extend my gratitude to SNNPR Water resources development Bureau for their assistance in providing me relevant data, per diem and Vehicle during field work.

I am also grateful to Ethiopian Water Resources Ministry, National Meteorological Service, Geological survey, Mapping Agency and Water Works Design Enterprise (WWDE) for providing me flow data, meterology data, and relevant documents, which helped me to carry out my research work.

I owe my great respect and love to Ato Nigatu Liranso and his family for their support, appreciation and elderly advice. Ato Nigatu it is your kindness to support me from the very bigging and your good wish to see my upgrade, here is the fruit.

I have the pleasure to thank all my lovely friends, relatives, and supporters who have been in my side encouragement and prayer which made this true. Sintayehu you are model

of hardworking and your support and encouragement is really appreciable. My special thanks go to GIS and remote sensing students (2009/20100), especially Dulla and Sheleke; they enabled me to fully use the GIS and remote sensing techniques, which contributed much to achieve my objective in this thesis work. Mulatu Bufebo, it is in my mind, really God bless u. I would like to thank Afework and Mulatu; you were with me in encouragement and provide relevant information which helped me much to finish my work on time. Afework, I don't forget the lovely time we have spent.

Last but not least I owe my deepest gratitude to my family, who has humble heart, understanding, and courage, each other. My father Tessema Gintamo and my mother Tseganesh Ashebo, they are model for me to life in good social life with people and always think my future bright. My parents, I wish you long live. I would like to appreciate my lovely sisters and brothers Mulunesh, Mihret, Getachew, Tamene, Aklilu, Deneke and Abinet for their support and lovely advice. Tame, it is for my success your being with me. Finally, I become happy in finalizing this work, Praise the Lord!!

Abstract

Groundwater is occurring within different hydrogeology environment, geologic formations and topographic settings that the factors mainly control the groundwater distribution and development for different purposes. A systematic evaluation of groundwater is essential for the proper utilization and management of this precious natural resource. Integrated GIS (geographic information system) and remote sensing are efficient techniques in groundwater studies; in facilitate better data analysis and their interpretations of groundwater potential controlling parameters. In the present study, an attempt has been made to delineate and classify possible groundwater potential zones in the Bilate River catchment of the south Ethiopian rift escarpment, found in SNNPR using integrated remote sensing and GIS techniques. The thematic layers considered in this study are lithology, geomorphology/landform, drainage density, lineament density, rainfall, soil, slope and land use/ land cover were prepared using the Landsat ETM+ imagery and ArcGIS software. All the thematic layers were then assigned weights according to their relative importance in groundwater occurrence and the corresponding normalized weights were obtained based on the Saaty's analytical hierarchy process. These weights were applied in linear summation equation to obtain a unified weight map containing due weights of all input variables. The thematic layers were finally integrated using ArcGIS and IDRIS software to produce a groundwater potential zone map of the study area. Thus, four different groundwater potential zones were identified, namely 'high, 'moderate', 'low' and 'poor'. The high potential zones correspond to alluvial plains, lacustrine sediments, the fracture valleys, and valley fills, which coincide with the low slope and high lineaments density areas. The eastern portion and some small patches in the northern and valley escarpment of Bilate River of the study area fall under moderate groundwater potential zone. The low zones mainly comprise structural hills and escarpments which contributes high run-off. On the other hand, Poor groundwater potential zones are present in the mountain peaks, plateaus and escarpments with steep cliff, where low fractured undifferentiated peralkaline Dino formation, obsidian and pitch stone exist. The resulted groundwater potential zoning map validated based on existing water sources point data of the study area. Finally, it is concluded that the integrated GIS and remote sensing techniques are very efficient and useful for the identification of groundwater potential zones.

Key words: Bilate River, Groundwater potential, GIS and remote sensing, western escarpment, thematic maps

Table of Contents

Acknowledgements	I
Abstract	III
1. Introduction	1
1.1 Back ground and Statement of problem	1
1.2. Objectives.....	3
1.2.1 General Objective.....	3
1.2.2 Specific Objectives:.....	3
1.3 .Significance of the study	3
1.4. Literature Review	4
1.5. Approach and Methodology.....	7
1.5.1 Data used/Data sources	7
1.5.2 Methodology	8
2. General overview of the study area.....	11
2.1 Location and Accessibility	11
2.2 Physiography and Drainage	12
2.3 Climate	14
2.4 Land use/ Land Cover	17
2.5 Soil	17
2.6 Geology of the study area.....	18
2.7 Geological Structural set up/Lineaments	22
2.8 Hydrogeology.....	23
3. Preparation of Thematic maps using GIS and Remote sensing techniques	24
3.1 General	24
3.2 Groundwater movement and occurrence controlling input parameters in the study area.....	24
3.2.1 Hydrometeorology	24
3.2 .2 Slope.....	36
3. 2.3 Drainage density map.....	38
3.2.4 Land use/ Land Cover	40
3.2.5. Soil map.....	41
3. 2.6. Geomorphology.....	42
3.2.7 Lithology	43
3.2.8 Lineament density	46
4. Results and Discussions	48
4.1 Data Integration Analysis in GIS Environment	48
4.2 Criteria weights and Map Scores	49
4.3 Output/Groundwater potential zoning map.....	53
4.4 Results Validation	55
4.5 Limitations	59
5. Conclusion and Recommendation.....	60
5.1 Conclusions	60
5.2 Recommendations	60
6. References	61

List of figures

Figure 1-1 Conceptual Flow chart of groundwater potential evaluation methodology.	8
Figure 2-1 Location map of the study area	12
Figure 2-2 Elevation map of the study area	14
Figure 2-3 Mean monthly precipitations in the study area and nearby meteorological stations	15
Figure 2-4 Dino formations with joints downstream Dato ridge to east of Shone town.....	20
Figure 2-5 alluvial plain of Bilate River near Abaya Lake	22
Figure 3-1 Isohytal rainfall map of the study area	25
Figure 3-2 Reclassified Rainfall map of the study area	26
Figure 3-3 Thornthwaite soil water balance of the area.....	30
Figure 3-4 Base flow separations for up to 365 days of Gudar River near Hosanna.....	31
Figure 3-5 Base flow separation for up to 365 days of Bilate River at Weira	31
Figure 3-6 Base flow separation for up to 365 days of Bilate River at Alaba near Kulito town	32
Figure 3-7 Base flow separations for up to 365 days of Bilate River at BilateTena River	32
Figure 3-8 Recharge map of the study area.....	34
Figure 3-9 Groundwater flow direction map of the study area	36
Figure 3-10 Slope map of the study area.....	37
Figure 3-11 Stream order map of the area.....	39
Figure 3-12 Reclassified drainage density map	40
Figure 3-13 Land use/ Land cover map of the area.....	41
Figure 3-14 Reclassified FAO, 1997 Soil map of the area	42
Figure 3-15 Landscape of the Bilate River Basin with prominent topographical features	43
Figure 3-16 Geological map of the area.....	45
Figure 3-17 Lineament density map of the area.....	47
Figure 4-1 Weights of parameters determined using analytical hierarchy principle (AHP)	50
Figure 4-2 weighted Overlay analysis table to produce Groundwater potential zone map	52
Figure 4-3 Groundwater potential map with Woredas in the study area.....	54
Figure 4-4 Distribution of boreholes and springs with discharge in groundwater potential zone	57
Figure 4-5 Hydrogeological map of the study area.....	58

List of Tables

Table 1.1 Ratings on Satty’s 9 – point continues scale 10

Table 2.1 Long term mean monthly values of Tempretture (°c), Relative humidity(%), wind speed(m/s)and sunshine (hrs/ day) 16

Table 3.2 Summary of Computed recharge in the study area 32

Table 4.1 Paired Comparison matrix..... 50

List of Appendices

Annex 1 Arthemetically estimated mean monthly rainfall 65

Annex 2 Thornthwaite soil water balance of the area 66

Annex 3 Mean monthly flow of Bilate River at Bilate Tena 68

Annex 4 Water Point Inventory data..... 75

1. Introduction

1.1 Back ground and Statement of problem

Ground water is the safest and most reliable water source, use in domestic, irrigation, industries, and municipality purposes. Ground water development for water supply purpose is preferable to low discharge springs and dug wells because they are found to be inadequate yield and no longer resistant drought while most of them might be completely dried out and never easily recovered after the prolonged drought time. The occurrence, origin, 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.

It is common to have problem in exploitation of groundwater in that unsuccessful rate of well production encounter and requires huge amount of investment cost to utilize this precious resources. Improper evaluation of groundwater and site selections is mostly expected to pose the problems (Abebe G/H, 2006). Since the groundwater occurs out of our sight, deep in the subsurface, there is no direct method to facilitate observation of water below the surface. Its presence or absence can only be inferred indirectly by studying the groundwater occurrence and distribution controlling parameters.

Thus, in order to ensure wise use of groundwater, a systematic evaluation of groundwater is required.

There are several methodologies to locate and map the occurrence and distribution of groundwater. Satellite data provides quick and useful baseline information on the parameters controlling the occurrence and movement of groundwater even in inaccessible areas (M. Thangarajan, 2007). The information on the input parameters in the above can be acquired and integrated through remote sensing and geographical information system (GIS) techniques. The concept of integrated remote sensing and GIS has proved to be an efficient tool in groundwater studies, in facilitate better data analysis and their interpretations (Saraf, A.K.et.al.1998, Krishnamurthy et. al. 1996 and Murthy, 2000). In addition, the greatest advantages of using remote sensing data for hydrogeological investigations and monitoring is its ability to generate information in spatial and temporal domain, which is very crucial for successful analysis, prediction and validation (Saraf, 1999).

The present study focused on the evaluation of groundwater potential zone in south Ethiopian rift escarpment, the Bilate River catchment in SNNPR, based on integrated Geographical information system (GIS) and remote sensing techniques.

The catchment covers the area between Gurage high lands to Lake Abaya shore, which includes the portion of SNNPRS regional zones; Hadiya, KT, Gurage, Silte, Wolyita, Sidama, and Alaba special woreda and small parts of the South-central Oromiya Regional states and the total area coverage is around 5625 square kilometer.

For the study area is part of the main Ethiopian rift, it is highly affected by the uplift and subsequent rifting phenomena that created localized and regional fractures and faults,(the rift floor and escarpments are highly faulted); the complex spatial and temporal distribution of the volcanic rocks, their different intricate stratigraphic and structural relationships, wide compositional variability, different degree of weathering and topographic position complicate the hydrogeological behavior of the volcanic aquifers and the hydrochemical signature requires systematic and scientific approach of investigation to determine the groundwater potential, (Ayenew et.al, 2008) in the area.

Moreover, most of the area is known in high scarcity of surface water and due to recurrent drought, substantial part of the area water supply comes from groundwater has taken great attention.

Lack of adequate potable and agricultural water supplies inhibits the progress of developing countries and is the cause of considerable hardship to humans world-wide, but a thorough hydrogeologic understanding is often critical for cost effective water development designed to alleviate these hardships, (Timothy B., Jerome A., Matthew M. and Robert B., 1994).

Despite water requirement is increasing very rapidly with the growth of human and animal population, and irrigation in the area, analysis of water resources has been fragmentary.

Thus, as a part of filling the gap, the present study, GIS and remote sensing techniques was used to systematically assess the importance of each input parameters in the evaluation of groundwater occurrence and potential zone in the area

1.2. Objectives

1.2.1 General Objective:-The main objective of this research is to evaluate and delineate ground water potential zones in the Bilate River catchment using integrated geographic Information system (GIS) and Remote sensing techniques.

1.2.2 Specific Objectives:

- ❖ To evaluate the ability of currently used GIS and remote sensing techniques to distinguish or delineate target features controlling groundwater occurrence.
- ❖ To produce hydrogeological map of the area based on the available data interpretation and analysis that will be a good basis for detailed groundwater exploitation work
- ❖ To adopt different GIS and remote sensing software as a tools in developing spatial data that help in decision making and planning
- ❖ To identify the degree of role of groundwater occurrence and distribution controlling parameters in the study area and their relationship to each other.
- ❖ To provide information for decision makers enable to retrieve as required for planning and management of water resources for both domestic and agricultural purposes.

1.3 .Significance of the study

The research study is expected to produce a groundwater potential zone map that demarcates the study area into different zones according to their groundwater potential. The resulted detail map of the area can be one input for understanding of hydrogeological systems of the area, and used as data for further research work.

The generated, collected and digitized data organized into the logical groups of entities concerning geological factors (lithology and lineament), drainage density, and physiographic factor (geomorphology, slope, land use/land cover) to produce properly organized Geodatabase which will enable the responsible officers to make decision and review by concerned stakeholders and subsequent researchers to properly use water resources in the area.

1.4. Literature Review

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

M. Thangarajan, 2007, showed the advantage of remote sensing and GIS science in resources management. Satellite remote sensing has become a common tool to investigate different fields of earth and natural sciences (Barret and Kidd, 1987; Barret and Curtis, 1982).

Integration with Geographic Information Systems (GIS) allows a synergistic processing of multi-source spatial data. Using of GIS in hydrogeology is only at its beginning, but there have been successful applications that started to develop (Barton, 1987; Bhasker et al., 1992; Clark, 1998; Gossel et al., 2004). . To improve the information and data feeding the GIS, pressure is put to advance the remote sensing platforms .The development and advancement of remote sensing platforms is crucially needed to improve our knowledge and monitoring ability on natural resources. In addition to targeting the groundwater potential zones, integrated GIS and remote sensing is also important to identify suitable sites for artificial recharge to sustain groundwater systems and avoid their depletion due to over-pumping and/or insufficient natural recharge.

Amaresh Kr.Singh, et al, Map India, 2003, used integrated approach of Remote sensing, geophysics and GIS to evaluation of ground water potentiality of Ojhala Subwatershed, Mirzapur district, Indian. In general, different thematic layers such as; hydro geometry, lineaments, slope, drainage and overburden thickness are used to be integrated without considering aquifer thickness. This proves a broad idea about the groundwater prospect of the area. Then ground water potential zones have been demarcated by integration of aquifer thickness derived from surface electrical resistively survey and drilling data with above thematic layers, using a model developed through GIS techniques. The ground water potential zones map generated through this model was verified with the yield data to ascertain the validity of the model developed and found that it is in agreement with the bore wells yield data. This illustrates that the approach outlined has merits and can be successfully used elsewhere with appropriate modifications. The study has demonstrated the capabilities of using

remote sensing, geo electrical data and geographic Information System for demarcation of different ground water potential zones, especially in diverse geological Set up. This gives more realistic groundwater potential map of an area which may be used for any ground water development and management programme.

In order to produce the ground water potential map of the Langat Basin area, Malaysia, a GIS model has been used ,to integrate thematic maps such as annual rainfall, litho logy, lineament density ,land use ,topographic elevation, slope steepness, drainage density and soil types (Khairul Anam Musa, et al,2000). Each thematic layer consists of a number of polygons, which correspond to different features. The polygons in each of the thematic layers have been categorized, depending on the suitability /relevance to the ground water potential, and suitable weights were assigned. Finally, all the thematic layers were integrated using the ground water potential model (derived from DRASTIC model of groundwater pollution vulnerability assessment) to drive the final derived layers of ground water potential. The output that is produced is capable of being used for further investigations and assessments, especially at larger scale.

Sandeep Goyal et .al,1999, attempted to use remote sensing ,GIS and multi-criteria analysis of decision support for evaluation of groundwater in watersheds of Rawasen and Pili rivers which are the tributaries of Ganga,U.P., India.

The ground water exploration in the study area involved thematic map generation and their integration through GIS. Geology, Land use, Geomorphology and Lineament maps were derived from interpretation of Satellite Images and Aerial photographs supported by selective ground truth verification. Drainage map was prepared using survey of India topo sheet on 1:50,000 scale. Slope map was obtained by creating DEM after interpolation of spot height and contour in GIS. For integration all the maps were converted into digital format in the GIS. Prior to integration of different information, individual class weights and map scores were assessed based on Satty's Analytic Hierarchy processes. In this method a pair wise comparison matrix was prepared for each map using Satty's nine point importance scale and this matrix was solved using Eigon Vector method. This resulted in individual class weights. The map scores were also calculated by same method. These weights were multiplied with map scores

and applied to linear summation equation. This map was further logically classified to arrive at ground water potential zone map.

Ingrid and Gerd, LARS 2007, conducted water Balance Modeling in the Bilate River catchment ;they faced difficult to use standardized hydrological models due to limited data both spatially and temporally. The precipitation runoff model NASIM was used to account the necessary water balance parameters, but strong relief and great variability of the precipitation, as well as the influence of evaporation, are not represented adequately by the number of climatic stations. In addition NASIM does not work on a raster basis at present. Thus they strongly recommended a further use of GIS for the visualization of the simulation results, and more research is required to modify the model and conduct more field work from which initiated to Carrey out further research using GIS in the area.

Stefan and Gerd, 2004, In Water Resources Assessment in the Bilate River catchment – precipitation Variability, observed rainfall variability and intensity in the catchment follows a semi-humid to semi- arid tropical bimodal distributed precipitation pattern. Accordingly, Variability is caused by alternating dry and rainy seasons, as well as long-term influences, which is overlapping with regional orographic effects. The extreme variability of daily and monthly precipitation amounts all over the catchment area essentially limits the exact assessment or even prediction of water resource availability. In addition, the long-term variation of precipitation –over lapping with the seasonal variability cannot be predicted accurately as well, to lack of reliable data.

Timothy B., Jerome A., Matthew M. and Robert B., 1994, used an integrated approach to groundwater exploration in developing countries using GIS and remote sensing within the Afram Plains of central Ghana due to an active drilling program with a large percentage of unsuccessful wells. If fractures can be mapped and correlated with areas of high groundwater potential, well site selection may be improved. Therefore, the objective of the study was to improve the availability of safe and reliable water resources through the installation of hand pumps. The combination of remote sensing and GIS has shown promise for groundwater development in the regions.

Water works design and construction enterprise in association with consulting engineering services (India), Bilate Hydrogeological draft report of Bilate Irrigation Project, 2008, was conducted to observe the feasibility of the project with respect to hydrogeology point of view. The methods used for the investigation was office work, Landsat Imagery and other maps interpretation, hydrogeological field survey, on site water quality testing, water quality analysis, data analysis and reporting.

Integrated hydrogeological investigation was carried out in the upper Bilate River catchment, Legesse S. 2009, to assess hydrogeological system and groundwater potential investigation. In the investigation both hydrological and hydrogeological parameters was included in detail ,which shows the western and northern part of the area is recharging zone and the central and southern part is discharge zone while the area just southeast of Boyo plain is categorized under deep groundwater zone due to the damming effect of Ambericho fault. Thus, he recommended detailed hydrogeological especially remote sensing and geophysical investigation should be conducted to delineate major water bearing zones, aquifer thickness and aquifer depth in the volcanic and alluvial formation particularly in the northern part of the study area.

1.5. Approach and Methodology

1.5.1 Data used/Data sources

The following data were used for the hydrogeological and ground water potential study

- Metrology data and River flow data obtained from Ethipian Metrological Agency and Water Resources Ministry.
- Water sources inventory data from SNNPR Water Resours Development Bureau and zonal water offices.
- Topographic maps of 1:50,000.scale coverage of Bilate water shade from Ethiopian Mapping Agency:

Here are different top sheets used (37° to 38° East and 06° to 07° North)

1. Hossana (0737B4), 2. Welbareg(0738A3), 3 Angecha (0737D2), 4 Kulito (0738C3), 5 Shone (0737D4),6.Sodo(0637B2),7.Tebela(0737B4),8.Kilisa(0638A3),8.Chericho(0638A1),9 Ropi(0738C3)

- Geological Maps prepared by Geological Survey of Ethiopia
- Published and non published literatures and maps
- Landsat ETM+ (with path and row of 055/168, 054/169 and 055/169 scenes) from the year 2001 image.
- Different software's such as ArcGIS 9.2, Global Mapper 7, ERDAS Imagine 9.1, Surfer 8, 3DEM, IDRISI 15.0, GPS
- Personal fieldwork experience in the area and field visited to verify ground truth data

1.5.2 Methodology

The study was carried out in several stages to delineate potential groundwater zones that reveal the capability of using remote sensing and GIS in groundwater exploration study as presented schematically and described in the following steps.

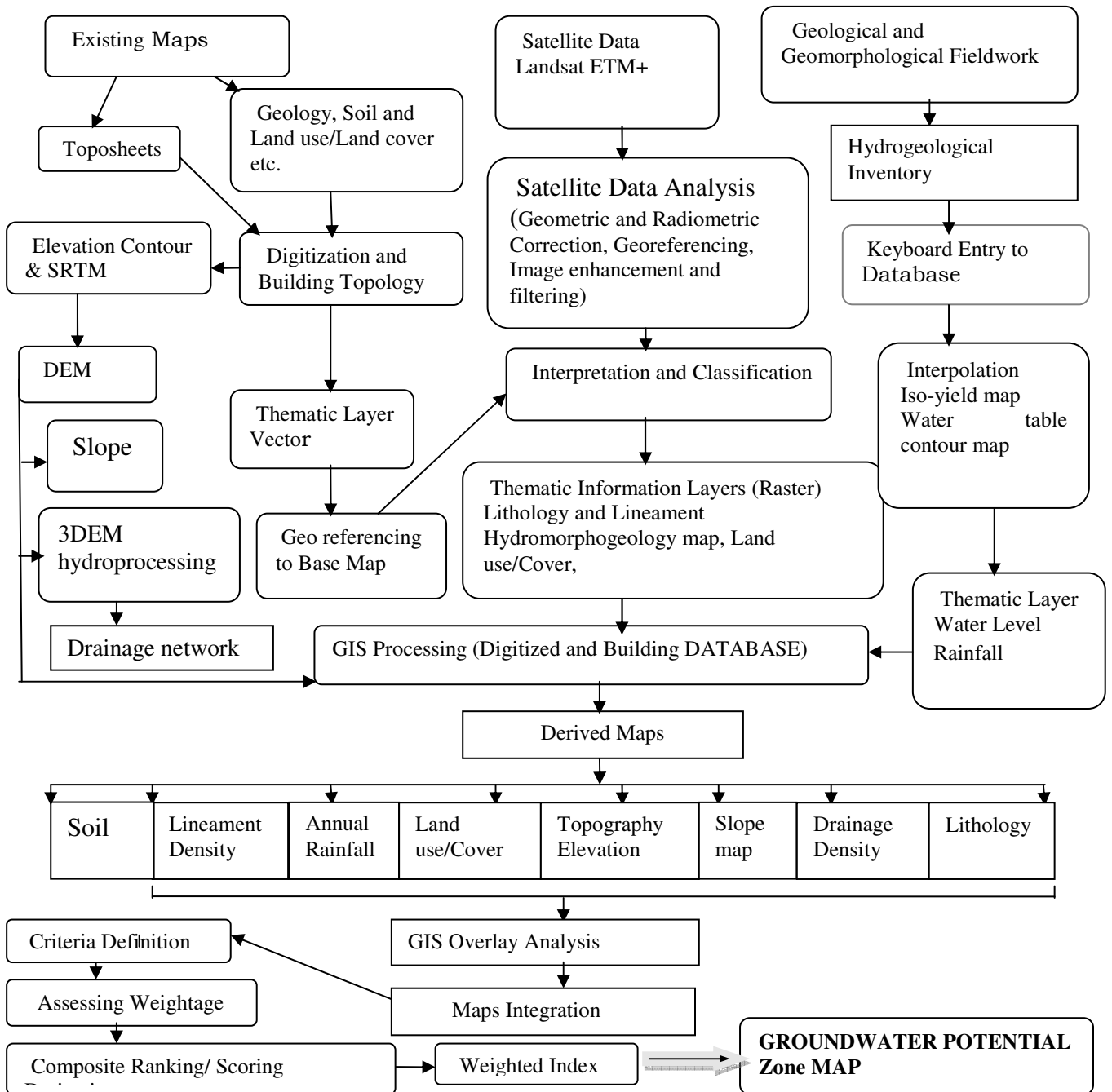


Figure 1-1 Conceptual Flow chart of groundwater potential evaluation using GIS and remote sensing mapping methodology applied on the Bilate River Catchment.







1.5.2.1. Dataset Identification

The occurrence and movement of ground water controlling factors, such as (geology (lithology and lineaments), rainfall, geomorphology/landform, slope, drainage, and land use/land cover, and soil) generated primarily from satellite imageries through digital image processing techniques and existing data.

The collected relevant data, in the initial stage of GIS spatial database development various analogue maps, which were in different scales obtained from different organizations, converted into digital format by using manual digitization method using ARCGIS 9.2 software.

1.5.2.2. Building the Research Geodatabase

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

-  In order to demarcated the groundwater potential zones of study area different thematic maps on 1:700,000 scales and 30m pixel size prepared from remote sensing and topographic maps.
-  Drainage density map prepared from SRTM data 3DEM Hydro processing.
-  Elevation map prepared from SRTM and topo sheets.
-  Slope map prepared using Digital Elevation Model (DEM)
-  Land use/land cover map prepared using supervised classification in IDRIS 9.1 software for Landsat ETM⁺ image 2001.
-  Groundwater potential zone map prepared using overlay analysis using IDRIS and ArcGIS software's.

1.5.2.3. Data Analysis

In this stage, digital image processing of the satellite data carried out for extraction of pertinent information. The groundwater exploration in the study area involved thematic map generation and their integration through GIS.

Prior to integration of different information, individual class weights and map scores was assessed based on Satty’s Analytic Hierarchy process where a pair – wise comparison matrix prepared for each map using a nine point important scale.

The result unified weight map containing due weights of all input variables. The weight values this final map further logically was classified to arrive at groundwater potential zone map. This provides a broad idea about the groundwater prospect of the area.

Table 1.1 Ratings on Satty’s 9 – point continues scale.

Rating	1/9	1/7	1/5	1/3	1	3	5	7	9
Qualitative description	Extra mely	Very Strong	Strongly	Moderatel y	Equally	Moderate ly	Strongl y	Very Strongly	Extrem ely
	Less Important					More Important			

To achieve the final target of the study, delineation of groundwater potential zones, different thematic layers; lithology, lineament density, drainage density, geomorphology, slope, soil, and land use/land cover and rainfall integrated.

1.5.2.4. Data Interpretation

The different polygons in the thematic layers labeled separately and then they were converted to raster and registered. In the final thematic layer initially each one of the raster qualitatively the final potential groundwater map visualized into one of the categories like (I) high (ii) moderate (iii) low (iv) poor in terms of their importance with respect to groundwater occurrence and suitable weights was assigned.

1.5.2.5. Result Validation

Thematic layers converted in to grid with related item weight and then integrated and analyzed, using weighted aggregation method. The grids in the integrated layer were grouped into different ground water potential zones by a suitable logical reasoning and conditioning. Second groundwater potential map produced using existing water sources data and actual well yield data which reflects the actual groundwater potential and water flow dynamics verified the first groundwater potential map generated by GIS analysis to ascertain the validity of the model develop. Besides, recommendation for a sustainable use of water resources and planning of new water facilities in a dynamic perspective was provided.

2. General overview of the study area

2.1 Location and Accessibility

The study area Bilate River catchment is situated in South Western Escarpment of the Main Ethiopian Rift at about 130 Km North West of the regional town Awassa and 340km from Addis Ababa through the asphalt road from Addis Ababa to the Arbaminch town that passes via towns of Shashemane, Alaba Kulito, Wolayta Sodo of SNNPR. It can be also accessible through 230Km asphalt road from Addis Ababa –Hossana in Northern part and Inter site accessibility is possible by currently made dry weather roads in the and other feeder dry-weather access roads that connect different parts of the study area. But during rainy seasons especially starting from June through October most part of the catchment area is inaccessible.

The River catchment includes the portion of SNNPRS regional zones; Hadiya, KT, Gurage, Silte, Wolyita, Sidama, and Alaba special woreda and small parts of the South-central Oromiya Regional states. It covers an area of about 5625 kilometer square. It is bounded in geographic coordinates of 365483W to 426838E at Abaya Lake in southern part Woliya Zone to 726037S to 896469N at Gurage and Silte zones border in the Northern part Figure 2.1

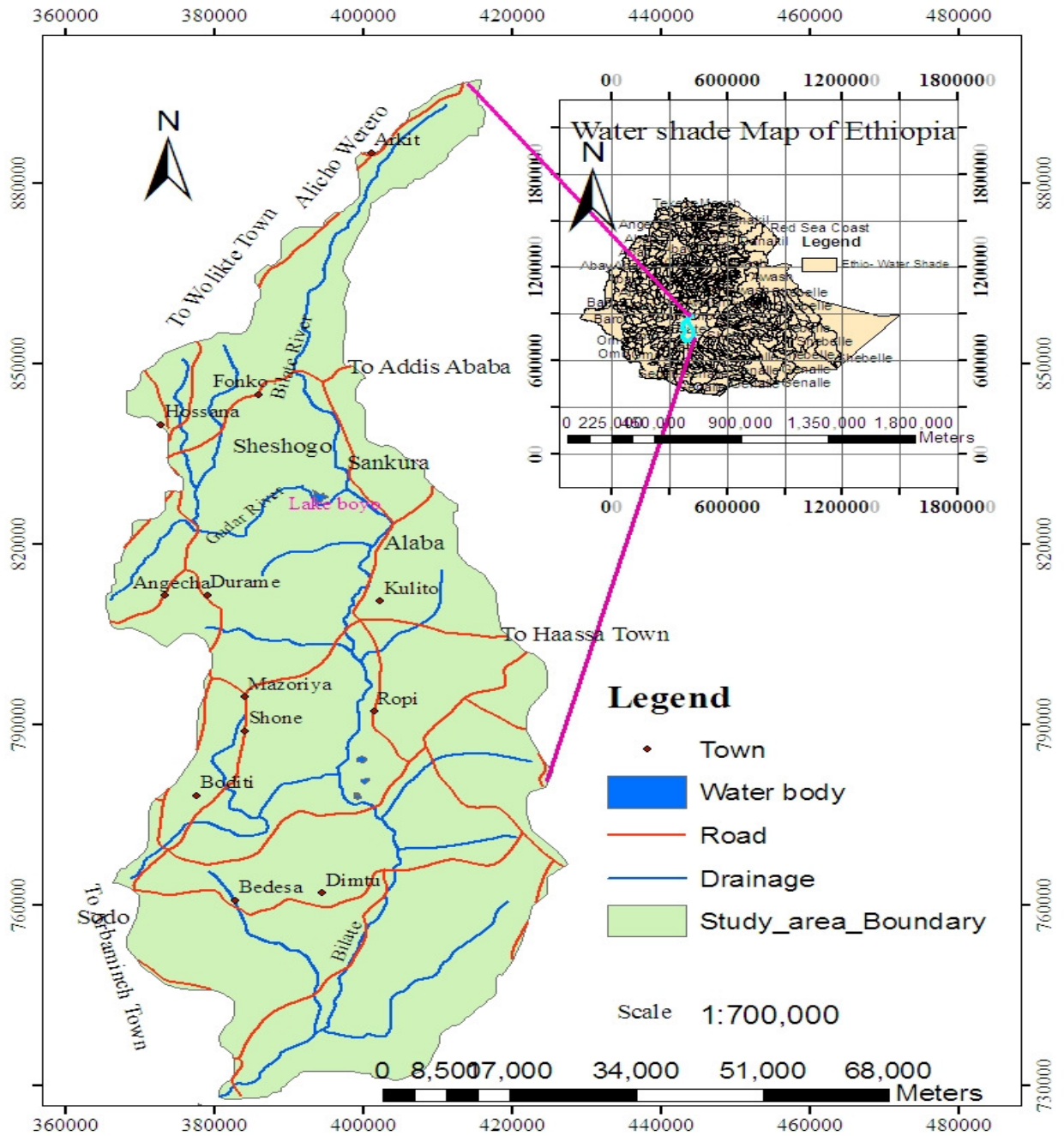


Figure 2-1 Location map of the study area

2.2 Physiography and Drainage

Physiographically the Bilate River basin is a tectonic valley along its length much of the valley is bounded by fault scarps or steep slopes on either side. The floor of the valley is mostly flat plain and appears to be in part a remnant of the depositions floor of ancient large water basin.

For the study area is part of the western rift margin which is characterized by chain ridge, hills, deep and wide valleys of small and large streams, and narrow flat lands between the valleys having gentle slopes. It is due to the uplift and subsequent rifting phenomena that created localized and regional fractures and faults, (the rift floor and escarpments are highly faulted); (Ayenew, Demlie and Stefan, 2008). The set up is also caused by erosion, deposition processes, and land use practices. .

The altitude of the catchment ranges from 1177 meter at Lake Abaya to 3328meter at Mt. Ambaricho and at Alichu Wiriro Woreda above sea level. This indicates that the topography of the area ranges from lowland plain areas to highly rugged and mountainous elevated terrains. Due to the effects of these elevated and other mountains around the area such as Duguno Fango ridge, Mt. Dato, and Mugo ridge that made the morphology of the study area is quite complex, starting from the edge of the North West and South-west part of the area characterized by steep slopes .Towards the centre and the South, the morphology changes to quite gentle slopes though there are some steep slopes along the river courses and hilly features. The catchment is bounded by Omo – Gibe basin to the south west, Ziway – Abijata – Shala, Lakes basin to the east and Lake Abaya to the south.

The Bilate River flows from the Gurage Mountain in the north towards the south in to the Lake Abaya. It is one of the three main perennial rivers such as Bilate, Gidabo and Gelana that flow into the Lake Abaya. Generally many small streams drain towards Abaya Lake along with Bilate River. Most of its tributaries as well as large volume of water comes from Gurage, Silte, Hadiya, kambata and Wolyita zone high lands of the catchment. The increase downstream could be influenced by the corresponding low rainfall, high evapotranspiration, relatively slow drainage and thermal springs that join the river downstream.

The drainage density is high in the plateau and escarpment area and very low in the rift floor. It is due to intensive faulting and volcanic activities in the area. In many places small stream disappear in the floor, before reaching the major drainage system (Ayenew 1998).In general the area is characterized by dendritic and rectangular drainage pattern (Figure 3.10).

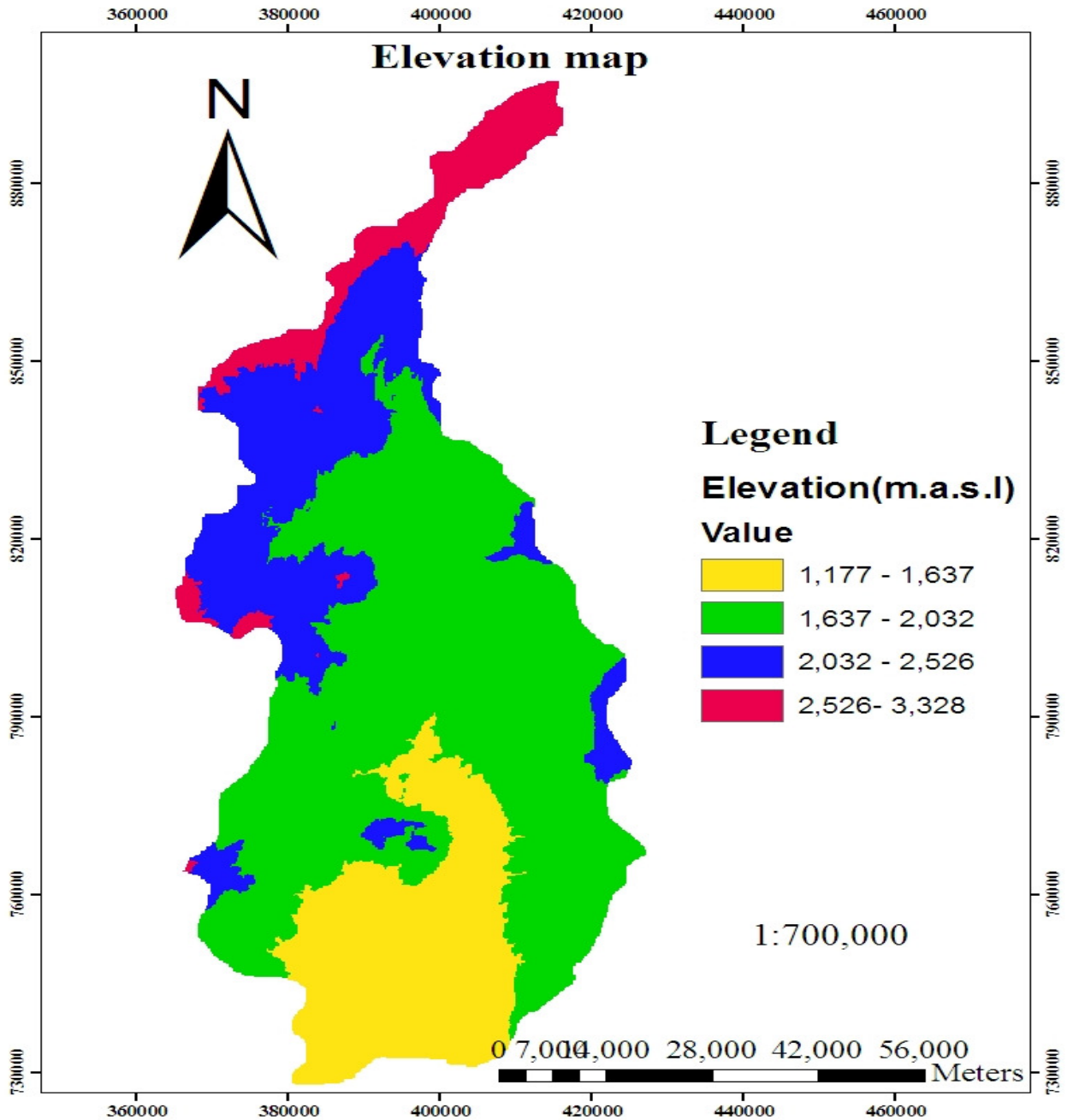


Figure 2-2 Elevation map of the study area

2.3 Climate

Precipitation Variability, Climatically, rainfall variability and intensity in the catchment follows a humid to semi- arid tropical bimodal distributed precipitation pattern. Variability is caused by alternating dry and rainy seasons, as well as long-term influences, which is overlapping with regional orographic effects (Stefan and Gerd, 2004).

The analysis of data of 21 meteorological stations in the area and nearby stations shows the area receives an average rain fall of 1145.82mm per year. From the analysis result observed that two rainfall pattern exist in the area, unimodal in the northern and north western part which receives relatively higher precipitation amount (1366.92mm) and that of bimodal rainfall pattern in the Southern and South Eastern receives relative precipitation amount of 998.16mm. The climate of the area is humid to sub – humid in the highlands and semi – arid to arid in the rift valley.

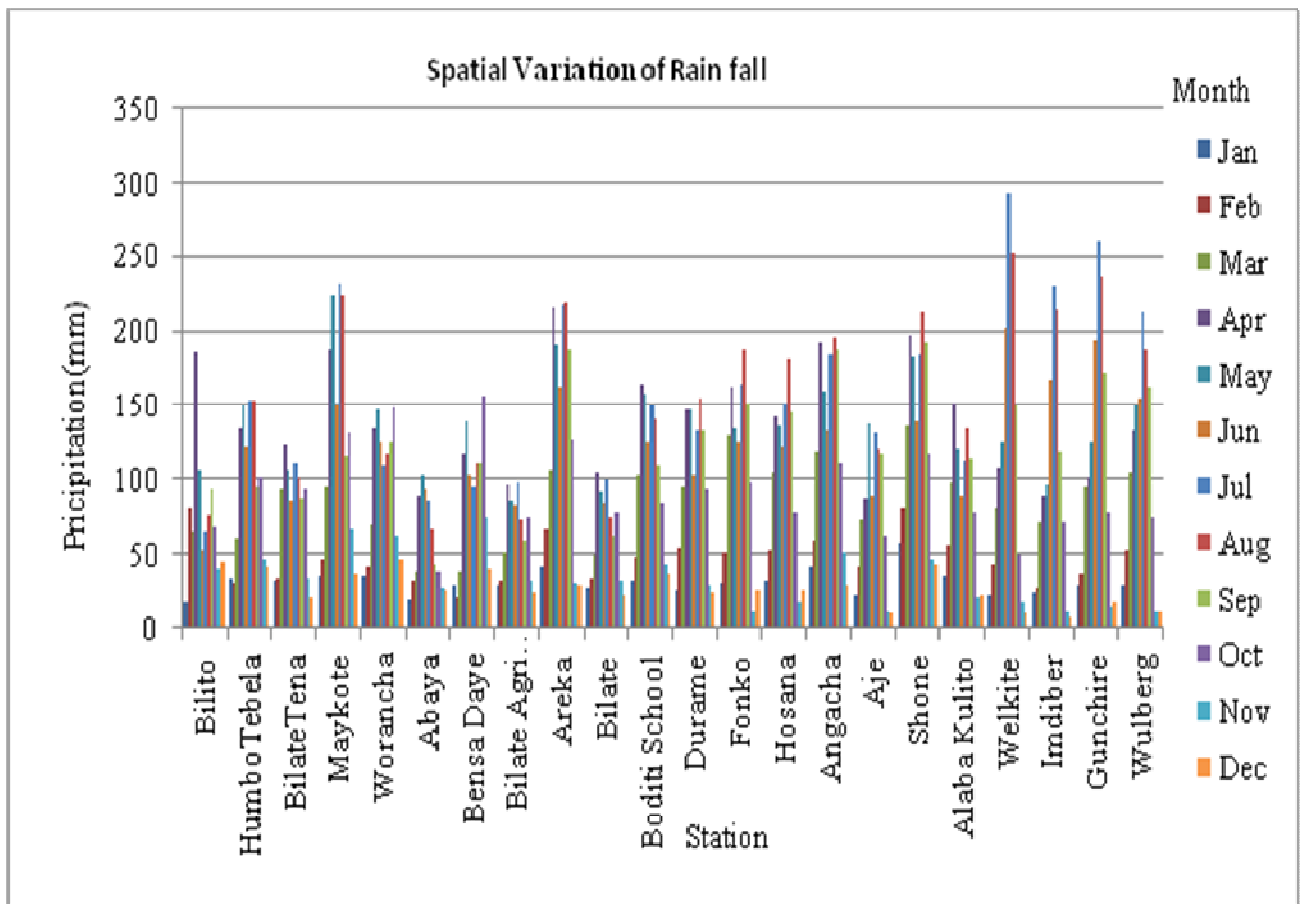


Figure 2-3 Mean monthly precipitations in the study area and nearby meteorological stations

The long term mean annual temperature vary widely, it ranges from 16.65⁰C in the highlands and around 22.10⁰C in the lowlands. The maximum and minimum relative humidity of the area is estimated as 81.17 % during the month July and 56.10 % during the month February respectively. The long term mean annual wind speed at 2m above the ground leve is 1.55 m/s(table 2.1).The potential and actual evaptranspiration of the area are 1162.48 mm and 966.318mm respectively(Figure3.2).

Table 2.1 Long term mean monthly values of Temperature (°c), Relative humidity(%), wind speed(m/s)and sunshine (hrs/ day)													
Mean Monthly Temperature (Oc)													
Stations	Jan	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Age	18.43	20.31	19.76	19.61	19.5	20.33	19.58	19.49	19.35	19.26	19.68	19.35	19.55
Alaba Kulito	19.07	19.59	19.82	19.48	19.99	18.99	18.1	18.06	18.55	18.63	18.34	18.15	18.9
Bilito	19.03	19.32	19.24	19.32	19.22	18.66	16.82	17.22	18.07	17.55	16.67	19.31	18.37
Sodo (Wadu)	20.03	20.48	21.6	20.26	18.31	17.59	16.54	16.39	17.52	18.35	18.65	19	18.73
Worancha	18.15	18.8	19.5	18.85	18.85	18.39	17.5	17.7	17.85	17.75	17.15	17	18.12
Areka	20.74	21.4	21.37	20.56	22.02	21.3	17.88	18.28	19.24	19.56	19.93	20.32	20.22
Bilate	23.97	24.48	24.35	23.79	19.68	18.98	21.07	21.45	22.45	22.39	19.36	22.89	22.1
Boditi School	18.86	19.66	19.73	19.07	18.47	17.26	16.29	16.5	17.51	17.94	18.23	18.4	18.16
Hossana	16.9	17.78	17.78	17.58	16.98	16.11	15.38	15.58	15.96	16.48	16.82	16.4	16.65
Indibir	18.79	19.45	19.53	19.5	19.11	18.61	18.15	17.75	18.16	18.17	18.77	18.9	18.74
study Area	19.4	20.13	20.27	19.8	19.21	18.62	17.73	17.84	18.47	18.61	18.36	18.97	18.95
Mean Monthly Relative Humidity (%)													
Stations	Jan	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Bilate	50.4	52.8	60.5	69.4	71.3	72.4	73.5	70.6	71	67	57.1	51.8	63.9
Hossana	70.2	62.2	67.9	71.6	75.7	82.9	86	86.7	84.1	77.07	69.2	67.5	75.1
Wolyita Sodo	57.7	53.29	61.37	71.55	78.29	80.13	84.02	81.86	78.51	71.01	57.75	54.95	69.2
Mean	59.43	56.1	63.26	70.85	75.1	78.48	81.17	79.72	77.78	71.69	61.35	58.08	69.4
Mean Monthly Wind Speed (U) 2m above ground level (m/s)													
Stations	Jan	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Wolyita Sodo	2.4	2.34	2.03	1.71	1.47	1.42	1.32	1.37	1.37	1.71	2.61	2.62	1.86
Bilate	1.5	1.7	1.4	1.2	1.3	1.3	1.1	1	0.9	0.8	0.9	1.5	1.22
Hossansa	1.6	1.7	1.6	1.7	1.4	1.5	1.6	1.4	1	1.7	1.8	1.8	1.56
Mean	1.83	1.91	1.68	1.54	1.39	1.41	1.34	1.26	1.09	1.4	1.77	1.97	1.55
Mean Monthly Sunshine Hour (hour/day)													
Stations	Jan	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Hossana	8.4	8.1	8	7	7.4	5.7	3.9	4.1	5.8	8.5	9.5	9.6	7.2
Bilate	7.8	8.4	7.8	6.4	7.6	6.1	4.8	5.4	6.3	7	8.8	8.5	7.1
Mean	8.1	8.2	7.9	6.7	7.5	5.9	4.4	4.7	6.1	7.7	9.2	9	7.2

2.4 Land use/ Land Cover

For Land use/ land cover highly control the runoff and evapotranspiration, identification and interpretation of land use pattern of the area, was prepared based on satellite images and various land use/ land cover classes delineated includes, cultivated land, bare land, grass land, plantation, shrub land, riparian plantation, wood land, exposed surface, marshy land and water body (Figure 3.12) because of high population density in the area most part is covered by cultivation land.

2.5 Soil

Soil properties influence the relationship between runoff and infiltration rates which in turn control the degree of permeability, the principal factor in hydrogeology that determines the groundwater potential.

Soil is a good indicator of the influence of soil parent material and the spatial variability in the degree of weathering, the secondary porosity of hard rock which governs the permeability of the rocks. It is formed on account of the climate, physiographic, geology and other factors responsible for soil formation and development. Those soils associated with lacustrine sediments, river alluvium and pumice are weakly developed and unconsolidated which are high permeable and likely to generate little surface runoff (Ayenew, 1998). Unconsolidated sediments are common below the rift shoulder slopes and at the foot of volcanic mountains. Many areas bordering the rift bear well – developed soils overlying weathered ignimbrite and pumice.

Based on FAO textural soil classification (FAO 1997) and the Land use/land cover practice of the area, the soil of the basin is reclassified into four classes (see Figure 3.13).

Class –1(clayey- soil): It covers the highland and escarpment of the rift. The area classified under this class is extensively cultivated and moderately deep rooted crops such as corn and cereals are grown. It has a well developed soil profile except in a few areas of the rift, floor and in hill slopes and volcanic ridges where the soil cover is typically thin.

Class – 2(Fine sandy loam): The floor of the rift is covered with this class soil. It is conquered by fine sandy loam soil with moderately deep rooted crops dominantly corn. As compared to class – 1 it is not extensively cultivated. The weathering product of volcanic ash and pyroclastic deposits is also the major source of this class soil.

Class – 3(clay loam soil): texturally these soils are the same as clayey soil, but the degree of cultivation and vegetation practice differ. Due to the presence of wood the degree of cultivation is less than that of class one.

Class – 4(silt loam): These are predominantly silt loam texture soils which have fine – grained unconsolidated parent materials and have thin surficial material and alluvial deposits. Their topographic position and low coherence of matrix materials make these soils sensitive to erosion. Bare land and gully are common with this incoherence behavior of the soil. In this part of the area deep rooted crops such as postural grass and shrubs are commonly grown.

2.6 Geology of the study area

Groundwater inevitably occurs in geological formations that require knowledge of how these earth materials formed and the changes they have gone to understanding the distribution of geologic materials (Fitter, 1994).

The general stratigraphy of the Bilate basin which has been investigated by the Ethiopian Geological survey and verified in the field and satellite images comprises volcanic and sedimentary units. The stratigraphic summary from the oldest to the youngest are as follows:-

A.Pre-rift basaltic succession (Qwbp): they are with minor sialic members (Jima volcanic – Tertiary volcanic) and well exposed on the plateau and escarpments adjoining the Bilate River Valley which rests unconformable on the Precambrian basement. The basalt flows form an unbroken succession and several hundred meters thick in some places.

They are intensely jointed, hydrothermally altered and spheroidally weathered basalt outcrop in the western escarpments of the Lake Abaya graben (Mengesha et.al, 1996). Tertiary volcanic succession has been down faulted into rift floor which in part is covered by the rift valley lakes like Lake Abaya.

B.Nazareth-Group (Nn): The name Nazareth Series was given to a thick succession of welded ignimbrites with fiamme, pumice, ash and rhyolite flows and domes with rare intercalations of basalt flows which occur in the MER, rift margins and adjacent plateaus (Meyer et al.1978 as cited Mengesha et.al., 1996). In composition the ignimbrites are sub-alkaline rhyolites and trachytes with rare peralkaline varieties. The Nazareth formation widely covered the northern and some part of western part of the study area

C.Chewkare Ignimbrite: It is exposed at the west Abaya fault, which forms western escarpment and group of hot spring emerging from the base of the scarp.

The chewkare ignimbrites are brownish and grayish green, crystal rich ignimbrites locally showing cooling joints. On the road to Abaya plantation descending the fault scarp the ignimbrites are overlain by the lacustrine sediments, which is intervened by quaternary basalts.

The ignimbrites of NW Abaya fault is vertically jointed laterally fissured and fractured with thermal manifestations along the weak zones. Moderate weathering has changed the original grey color of the rock to brownish grey color.

D.Dino Formation (Qdi, Qdp, Qws and NQs): These units are coarse unwelded pumiceous pyroclastics mainly of light tuff and ignimbrite outcropped in most part of Sheshogo and Aleba woredas to the southwest, west and north of the woreda. The ignimbrite outcropped along the River bed of Bilate and Bishangurach near Alaba town contains coarse quartz grains with joints displayed categorized under this formation (see Picture below).



Figure 2-4 Dino formations with joints downstream Dato ridge to east of Shone town

E. *Quaternary ignimbrites (Qwi)*: this formation comprises of Quaternary bimodal transitional basalt/peralkaline felsic volcanic products of Wonji Group. The volcanic products of Wonji Group (including those from axial volcanic centres) are intimately associated with lacustrine sediments related to ancestral lakes in the rift floor (in the fluvial periods of Pleistocene). The mappable out crop is observed near Hossana town. Also In the river valleys forming tributary to the Hamesa River (in the vicinity of Humbo town), this ignimbrite is exposed.

F. *pumaceous pyroclasts (Qwpu)*: They are grey and yellowish colored and poorly sorted consisting of accidental fragments of rhyolite and basalts. These pumaceous pyroclastics belong to the explosive episodes of the older rhyolitic volcanic centers. It has extensive outcrop at the Western, North Eastern and Eastern flanks of Dugna-Fango complex. They are generally fresh, grey and yellowish in color.

G. *Abaya rhyolites (Qwa)*: This unit mainly characteristics the surrounding escarpment near Wolyita Sodo town. They are composed of ash and pumice deposits. Trachytic lava flows from the shield volcanic centers of Danota, are exposed rocks of light greenish gray, porphyritic trachyte which show cooling joints and more weathering near the flanks of the shield.

H. *Lower quaternary (Tena Bilate) Basalts (Qwh)*: The NNE trending fault along the axis of the rift floor has been a conduit for basaltic eruptions with lines of scoria cones making fault traces. They are interstratified with the earlier succession of lake sediments. They are exposed over a broad area between lake Abaya and Dugna-Fango, and all along Bilate river bed and banks (hence the name Tena Bilate Basalts) with adjoining rift floor being covered by the overlying, intensely denuded lacustrine sediments.

I. *Recent Basalt*: The younger episodes of basaltic eruption outcrops along an axial zone of more recent volcano-tectonic activity of NW Abaya hydrothermal field.

J. *Recent Rhyo-Obsidian Flows (Qwo)*: They form a composite volcanic cone at Mount Seluwa and Duguna. It outcrop on top mount Korke overlying quartz, the Salwa –Dore-Hako rhyolitic center has produced very recent obsidian and pitchstone flows probably representing the youngest rhyolitic activity in the area.

K. *Volcanical Lacustrine –Sediments (Ql)*: Mainly cover the floor of the depression. Most of the volcanic origin: tuff, pumice, ash, with small amounts of diatomite. They are essentially lacustrine sediments of mainly volcanic origin and were related to the existence of large lakes during Pleistocene times (Mohr, 1967). They are generally yellowish-gray colored, horizontally bedded and poorly sorted with fragments of rhyolite, obsidian and basalt in a matrix of ash and silty clay.

L. *Alluvium and Fluvial deposits (Qa)*: the lower course of Bilate River covered with fluvial deposits along its gentler slope. There are also lacustrine deltas on the northern part of Lake Abaya which are a few kilometers wide. Colluvial and outwash debris is found widespread in the area particularly along the foothills of the major fault scarps. Recent deposits in the area include soils and alluvial sand deposits. The soils are mainly residual weathering deposits, whose composition is controlled more by the physical condition of formations than by the type of rock form which they were derived. On the older basaltic area dark brown cotton soil is common while the soil outcrop of the ignimbrites is red lateritic.



Figure 2-5 alluvial plain of Bilate River near Abaya Lake

2.7 Geological Structural set up/Lineaments

Because, the main geologic structures characterizing to the area to be fractures, resulting from the MER system. Being within the Main Ethiopian Rift, the structural features associated are faults. All of the faults in the basin are normal faults. The orientation and the type of faults in the study area is typical of the Main Ethiopian Rift system.

The floor of the basin is also dissected by normal faults having a NNE-SSW orientation. For example the immediate southern boundary of the basin, the Abaya Lake, is also controlled by fault lines having the same orientation to NNE-SSW.

The faults in the escarpment areas which comprises the older undifferentiated rocks of Nazret Group and Dino Formation down faulted towards the rift floor resulted in the development of Boyo plain which is graben.

High density of the faults is observed near North West of Lake Abaya and northern escarpment (figure 3.16). To the eastern escarpments the density decreases significantly indicating that the pre-existing fault systems are covered by the silic volcanics that persisted in Holocene time (AG consult, 2004).

2.8 Hydrogeology

The study area is covered by volcanic rocks, which have extremely variable hydrogeological characteristics because of difference in their mineralogy, texture, and structure. As a result their water bearing capacity varies accordingly. The circulation and storage capacity of these rocks depend on the nature of porosity and permeability of the aquifer. Though porosity may be high, permeability is largely a function of primary and secondary structures in the rock mass (Ayenew T. and Alemayhu T.2001).

To understand the hydrogeology of the study area, the lithologic characteristics of geological units, their mode of occurrence, the depth of ground water table and the flow direction of the ground water, distribution and magnitude of springs discharges ,distribution and fracture setting of the it contains well determined

In general Groundwater leaves the study area aquifer system through pumpage from wells, springs, evapotranspiration, and outflow from the project area to Lake Abaya, even if the groundwater-Lake interaction still require detail investigations.

Many springs in the area discharge ground water onto the land surface from the mainly along the fault and fracture zones of the area at higher elevations within the low lands and/or graven. These have mostly high rates in the escarpments and most are scattered along fault scarps in the west and north of the area.

The shallow groundwater discharge is featured by these springs on the slopes and at the foot of the adjacent escarpments as well as hand dug wells.

The other way of groundwater abstraction in the area is from the existing deep boreholes. As inventory data indicates, there are many boreholes abstracting groundwater for the use of the domestic purposes. In the upper Bilate, the western and northern part of the area is recharging zone and the central and southern part is discharge zone while the area just southeast of Boyo plain is categorized under deep groundwater zone due to the damming effect of Ambericho fault (Legesse S. 2009).

3. Preparation of Thematic maps using GIS and Remote sensing techniques

3.1 General

The groundwater evaluation in the study area involved thematic map generation and their integration through GIS.

Thematic maps were prepared in the scale 1:700,000 with a spatial resolution of 30 meter pixel size from satellite imagery, topographical, and geological mapping and other hydrogeological field data.

The maps were developed in a GIS environment using eight input parameters that indicate groundwater potential as shown in the next section.

3.2 Groundwater movement and occurrence controlling input parameters in the study area

Groundwater potential zonation means identifying and mapping the prospective ground water zones in an area by qualitative assessment of the controlling and indicative parameters.

The main factors responsible for groundwater resource development are rain fall/precipitation, geology/Lithology, geomorphology/land form, land use/land cover, drainage, slope, soil, lineaments etc.

Thematic maps for each parameter prepared as follows:

3.2.1 Hydrometeorology

3.2.1.1 Precipitation

Precipitation and evaporation are the two fundamental phases in the hydrological cycle which involves processes in the atmosphere and at the earth's surface/atmosphere interface.

Precipitation is the primary input of the hydrologic cycle (Warren V, Jr. and Gary L. 20003).It plays an important role in the hydrologic cycle which controls groundwater potential. Knowing the nature and characteristics of precipitation, we can conceptualize and predict its effects in runoff, infiltration, evapotranspiration, and water yield. Therefore, for hydrologic analyses it is important to know the areal

distribution of precipitation. Several areal precipitation estimation techniques are currently used for averaging precipitation depths collected at ground stations. The isohyetal and Thiessen polygon techniques are conventional techniques that are usually applied to estimate the areal precipitation. Since rainfall is not evenly distributed over the area of study due to the topographic variability of the catchment areas, and alternating dry and rainy seasons (Stefan, T., and Gerd, F., 2004), the isohyetal polygon techniques was applied to estimate the areal precipitation over the entire basin.

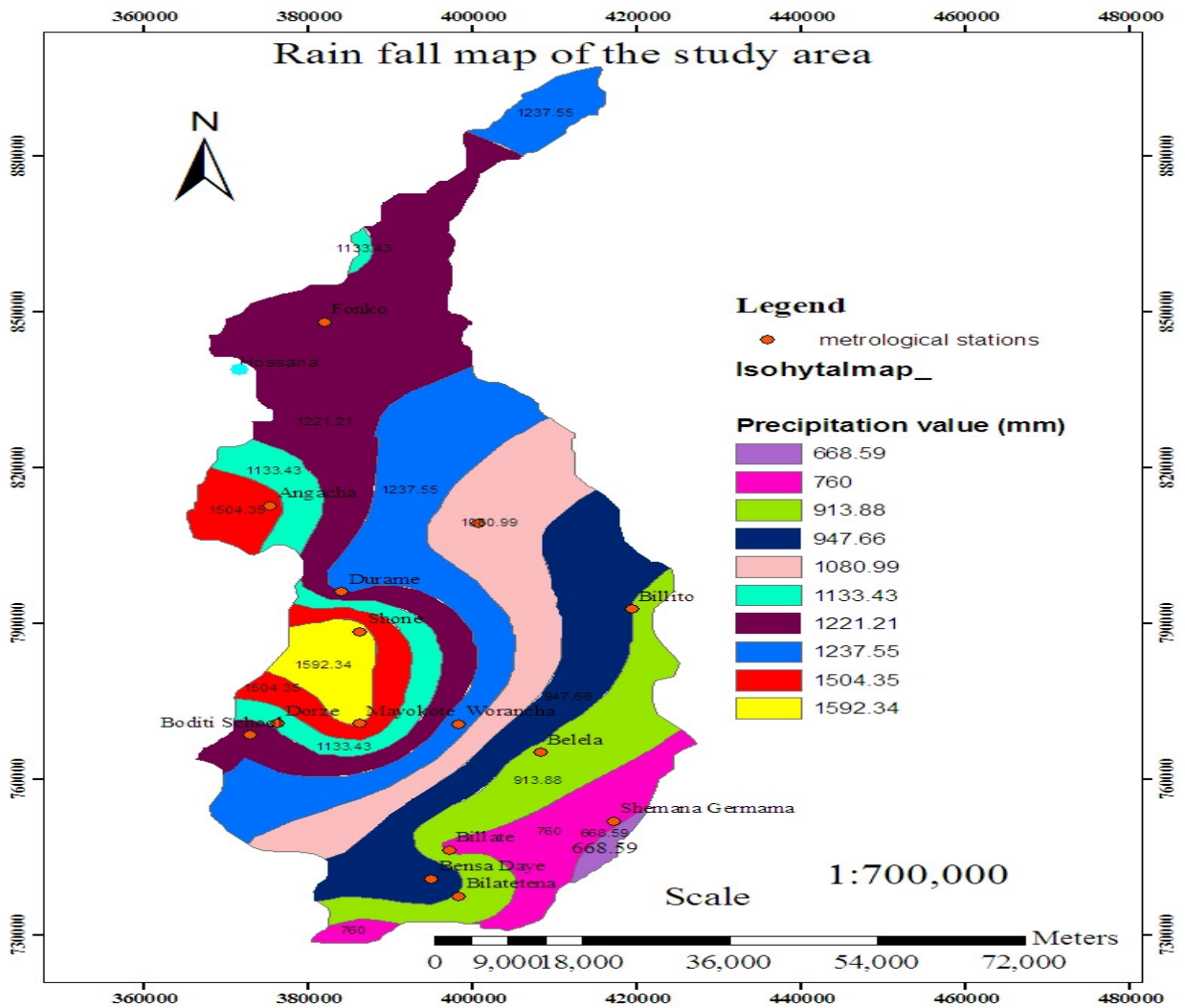


Figure 3-1 Isohytal rainfall map of the study area

Precipitation forms the principal source of direct recharge which occurs in areas with a surplus of rain fall over evapotranspiration (Ayenew, 1998) and it can be governed by the rainfall distribution, topography, land use /land cover, soil and geology etc.

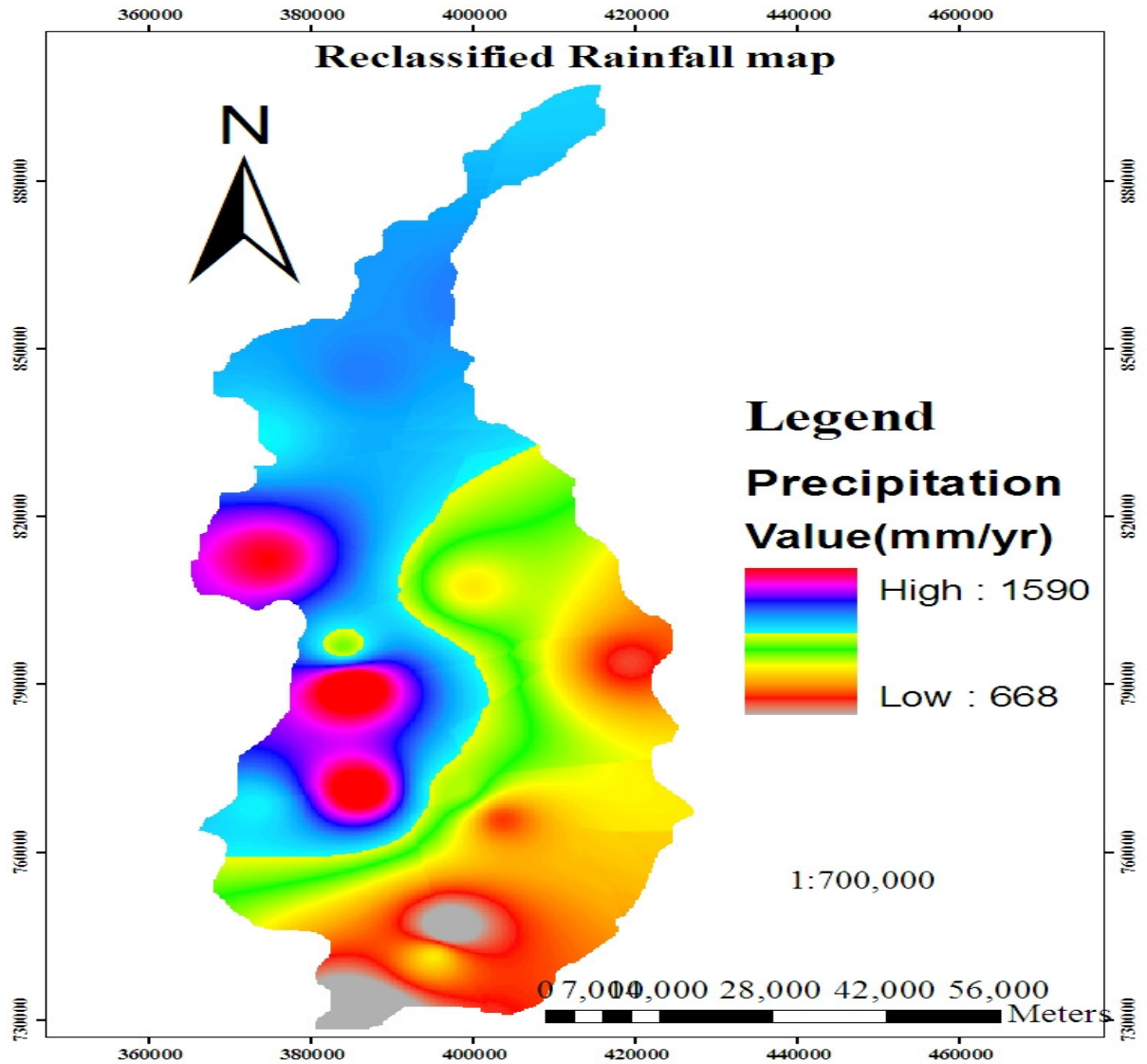


Figure 3-2 Reclassified Rainfall map of the study area

3.2.1.2 Recharge and Discharge

Ground water recharge can be defined as precipitation that infiltrates into soil to saturated zone to a depth below the root zoned of surface vegetation where it cannot be removed by evaporation and becomes ground water. Ground water recharge area is the land area that encompasses this process.

Thus, in groundwater potential evaluation, quantification of groundwater recharge is very important to know the areal distribution of it. There are different models to estimate recharge in a given area depending on actual areal conditions. In this case two methods: Base flow records and water balance approach was used.

Recharge map developed based on annual recharge for each gauging stations and the final below Bilate tena (Dimutu) area recharge amount which was determined on water balance recharge estimation and distributed according to area coverage above gauging stations

In general, groundwater in the region is recharged by precipitation on the mountains and mostly through bedrock beneath these mountains may also receive direct recharge, which feeds the valley fill sediments and alluvial deposits mainly along fault/fracture zones graven.

3.2.1.2.1. Recharge Estimation using water balance approach

Water balance can be determined by calculating the input, output, and storage changes of water at the Earth's surface. The main input of water is from precipitation and output is from evapotranspiration.

In water balance studies , it is usually assumed that the catchment is water tight and that no subsurface movement of water across the defined water shed is occurring and the evaluation of change in storage depends on the time period over which the water balance is being made on annual basis , the time at which the balance is effected is chosen so that the water stored in the ground and in surface storage is approximately the same each year and thus in the equation change in storage $\Delta S = 0$ (Shaw,1982).

Table 3.1 Potential Evapotranspiration Calculated using Penman Combination method

Parameter	Description																		
H _T	The available Heat, calculated from incoming (R _i) & outgoing (R _o) radiation determined from sunshine records, temperature and humidity using the formula: $H_T = R_i(1-r) - R_o; \quad R_i(1-r) = 0.75R_a f_a \left(\frac{n}{N}\right)$																		
	R _a – Solar radiation (fixed by latitude and season and is constant for a given latitude and season, obtained from standard meteorological tables); r – the reflective coefficient for incident radiation or albedo of the vegetation covers of the catchment that depends on the nature of the surface. - $f_a \left(\frac{n}{N}\right)$ takes several forms based on latitude and for the study area latitudes south of 54 ½ °N is taken as $f_a \left(\frac{n}{N}\right) = \left(0.16 + 0.62 \frac{n}{N}\right)$ (Shaw, 1988) n – monthly mean sunshine hrs (from Meteorological record); N – Daylight factor (Fixed by latitude and season and is constant for a given latitude and season) - $R_o = \sigma T^4 (0.47 - 0.075\sqrt{e_d})(0.17 + 0.83n/N)$; σT^4 – the theoretical blackbody radiation at the temperature of the air (T in Kelvin scale); σ (Stefan – Boltzmann constant) = $5.67 \times 10^{-8} \text{ Wm}^{-2}\text{k}^{-4}$, e _d – the saturated mean vapor pressure at dew point(mm of mercury), e _d = e _a (RH/100) e _a – the saturated vapor pressure at air temperature(T _a), RH– Relative Humidity in % - obtained from meteorological record																		
E _{at}	The Energy for evaporation based on the air humidity and air temperature, the subscript t signifies inclusion of transpiration effects. $E_{at} = 0.35 \left(1 + \frac{u_2}{100}\right) (e_a - e_d);$ e _a -e _d is saturation deficit, U ₂ – Mean wind speed (miles/day) at 2m above the surface (from Meteorological record)																		
Δ	The slope of the curve of saturated vapor pressure against temperature corresponding to the air temperature (e _a at T _a against T _a). $\Delta = (e_a - e_d)/(T_a - T_d)$																		
γ	The reflective coefficient for incident radiations or the Albedo of the basin that depends on the nature of the surface. The dominant land cover of the study area are mature forest, bushes and shrubs, grasses and cultivated crops; and therefore albedo of 0.24 is taken for the catchment.																		
Month	Temp(°C)	e _a (mm/d)	RH (%)	e _d (mm/d)	U ₂ (mile/d)	T (Kelvin)	n (hr/d)	N (hr/d)	n/N	Ra (mm/d)	fa (n/N)	RI(1-r) (mm/d)	σT ⁴ (mm/d)	R _o (mm/d)	H _T	E _{at} (mm/d)	Δ/γ	PET (mm/d)	PET (mm/month)
January	19.4	16.78	59.40	9.97	98.27	291.85	8.1	11.6	0.7	12.8	0.59	16.55	14.75	2.89	2.80	4.72	2.42	3.36	100.90
February	20.13	17.87	56.10	10.03	102.56	293.12	8.3	11.8	0.7	13.9	0.60	16.62	14.9	2.91	3.30	5.56	2.56	3.94	118.07
March	20.27	18.08	63.30	11.44	90.21	293.42	7.9	12	0.66	14.8	0.57	16.64	14.9	2.58	3.73	4.42	2.60	3.92	117.62
April	19.8	16.25	70.90	11.51	82.69	292.55	6.7	12.3	0.54	15.2	0.5	16.59	14.81	2.22	3.45	3.83	2.46	3.33	99.85
May	19.21	16.08	75.10	12.13	74.64	292.16	7.5	12.6	0.60	15	0.53	16.57	14.66	2.30	3.65	2.46	2.69	3.33	99.91
Jun	18.62	16.15	78.50	12.62	75.71	291.62	5.9	12.7	0.46	14.8	0.45	16.53	14.54	1.87	3.10	2.13	2.18	2.80	83.90
July	17.73	16.08	81.20	12.31	71.96	290.85	4.4	12.6	0.35	14.9	0.38	16.49	14.38	1.57	2.64	1.72	2.13	2.34	70.34
August	17.84	15.16	79.70	12.56	67.66	290.98	4.8	12.4	0.39	15	0.4	16.50	14.35	1.66	2.84	1.87	2.14	2.54	76.07
Sept	18.47	15.75	77.8	12.43	58.53	291.39	6.1	12.1	0.50	14.8	0.47	16.52	14.55	2.00	3.25	1.97	2.13	2.84	85.18
Oct	18.61	16.24	71.7	11.64	75.18	291.59	7.8	11.8	0.66	14.2	0.57	16.53	14.61	2.54	3.52	2.82	2.18	3.30	99.09
Nov	18.36	16.12	61.4	9.89	95.05	291.28	9.2	11.6	0.79	13.1	0.65	16.52	14.65	3.20	3.20	4.25	2.13	3.54	106.12
Dec	18.97	16.46	58.10	9.56	105.78	291.98	9.1	11.5	0.79	12.5	0.65	16.56	14.68	3.26	2.84	4.97	2.16	3.51	105.44
Annual PET (mm/year) of the study area																			1162.48

After substituting relevant values in the below equation variables obtained from table 2.2 and annex 3), resulted,

$$Ea = 0.35 \left(0.5 + \frac{u_2}{100} \right) (e_a - e_d)$$

$$Ea = 3.33 \text{ mm / yr}$$

From Penman formula for open water evaporation, $E_0 = (\Delta/\gamma H + E_a)/\Delta/\gamma + 1$

Substituting 2.32mm/yr for Δ/γ , 3.19 mm/yr for H and 3.33mm/yr for E_a gives the E_0 value equal to 2.93 mm/yr. Also runoff R_o was averaged from River flow data which is 60.07mm/yr.

Based on the assumptions recharge was estimated using water balance equation representing the catchment: Inflow = Out flow $\pm \Delta S$ where, ΔS is change in storage

$P = AET + E_o + RO + \Delta G + W$, which is the general water balance equation Where, P is Precipitation, E_o is Open water evaporation, RO is runoff, ΔG is groundwater recharge and W is abstraction by groundwater pumping.

The general water balance equation set for the catchment in annual bases is as follows:

$P = AET + E_o + RO + \Delta G$, where the system is under natural condition

From the annex 2 and figure 3.3, P is 1145.82mm, AET is 966.31mm, E_o is 2.93 mm, RO is 60.07mm and substituting all these parameters in the above equation gives ΔG is equal to +116.51mm.

The final result +125.92mm violates the assumption which was given for water balance equation conducted in annual bases that stated the change in storage should be zero.

This result because, in the rift floor aquifers far from large rivers and escarpments bounded by intermountain grabens, the highland recharge may preferentially move to the rift within large regional faults. These large open faults play very important role in the indirect recharge that comes from rivers channel losses and adjacent Omo_Gibe basin (Ayenew, Demlie and Stefan, 2008) and Figure 3.17 confirms these ideas.

Also, the presence of large springs with high yield such as Moshoshe(47l/s), Sheshera(52l/s), Kereso(40l/s), Adiyo(12l/s) flow from Gurage high lands followed by Bonga transverse fault system which indicates the inter aquifer connectivity between adjacent basin(Sintayehu L.,2009).

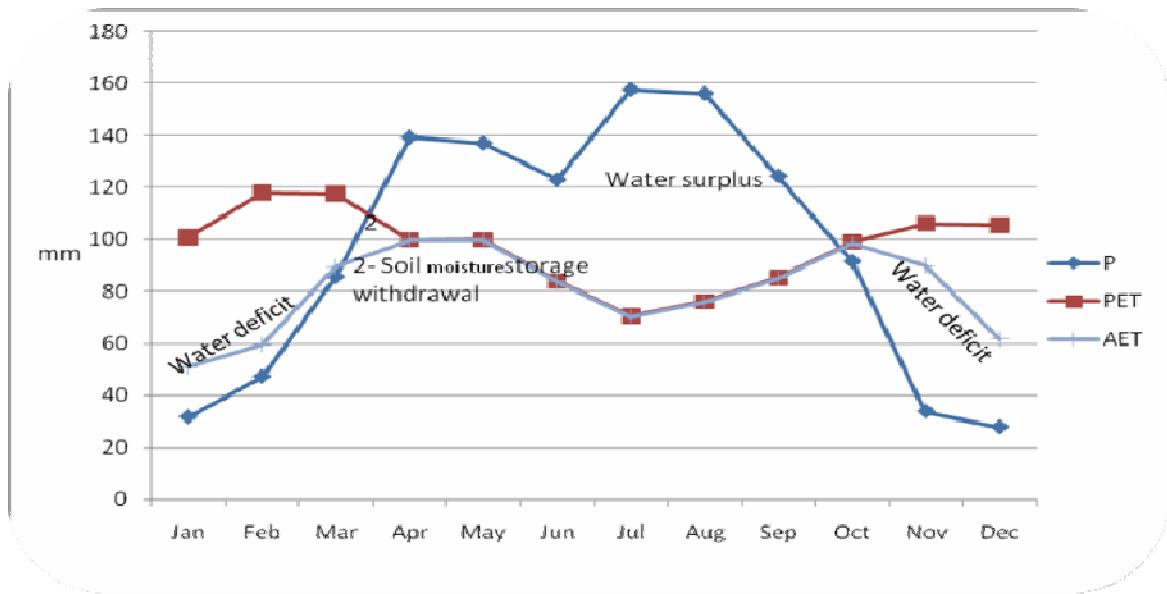


Figure 3-3 Thornthwaite soil water balance of the area
 P – Precipitation PET – Potential Evapotranspiration, AET – Actual Evapotranspiration

3.2.1.2.1 Recharge estimation using Base flow records

Extended periods of river base flow measurements can be used to estimate catchment area groundwater recharge (Shirmohammadi et al, 1987 as cited Ayenew, 1998).

In estimating recharge for a given catchment from base flow the assumption is that the base flow of a river is equal to the total groundwater recharge of the catchment upstream of the discharge measuring site (Ayenew, 1998).in this case any loss upstream of the gauging station is considered to be negligible.

In the present case four gauging stations were used to estimate recharge over the entire upstream catchment and the area to downstream of the last gauging station recharge estimated based on the assumption 10-20% of the annual rainfall of the region is recharge for volcanic aquifers (Ayenew et al, 2008).

Summary of long-term annual average base flow and surface runoff for each gauging stations described in the following figures:

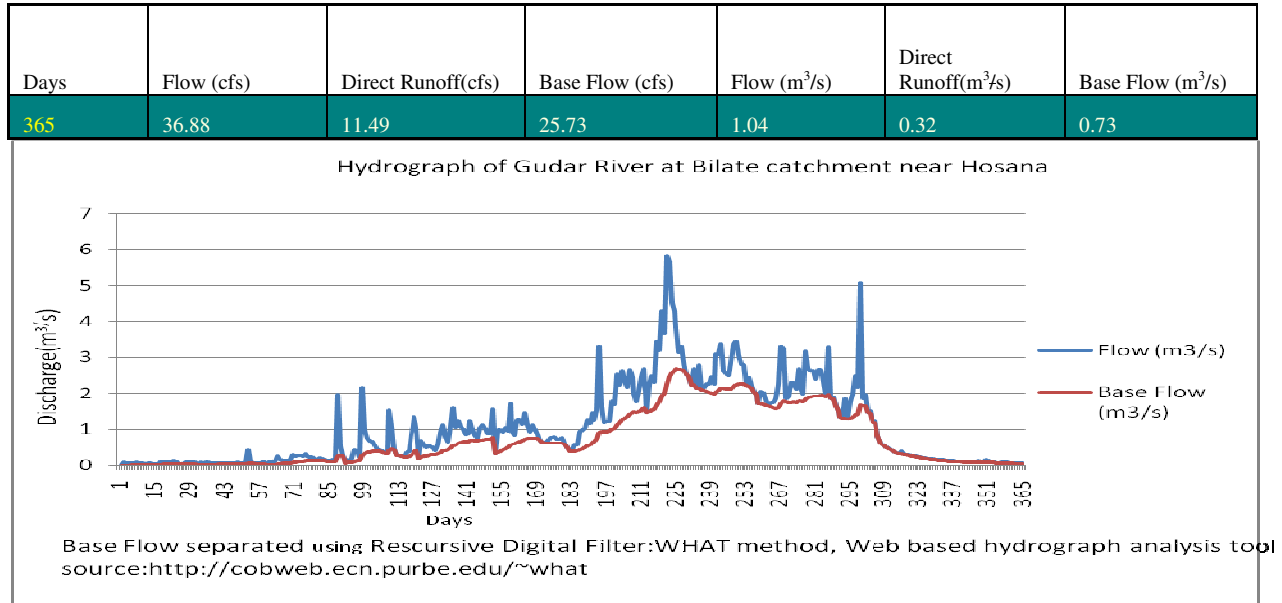


Figure 3-4 Base flow separations for up to 365 days of Gudar River near Hosanna

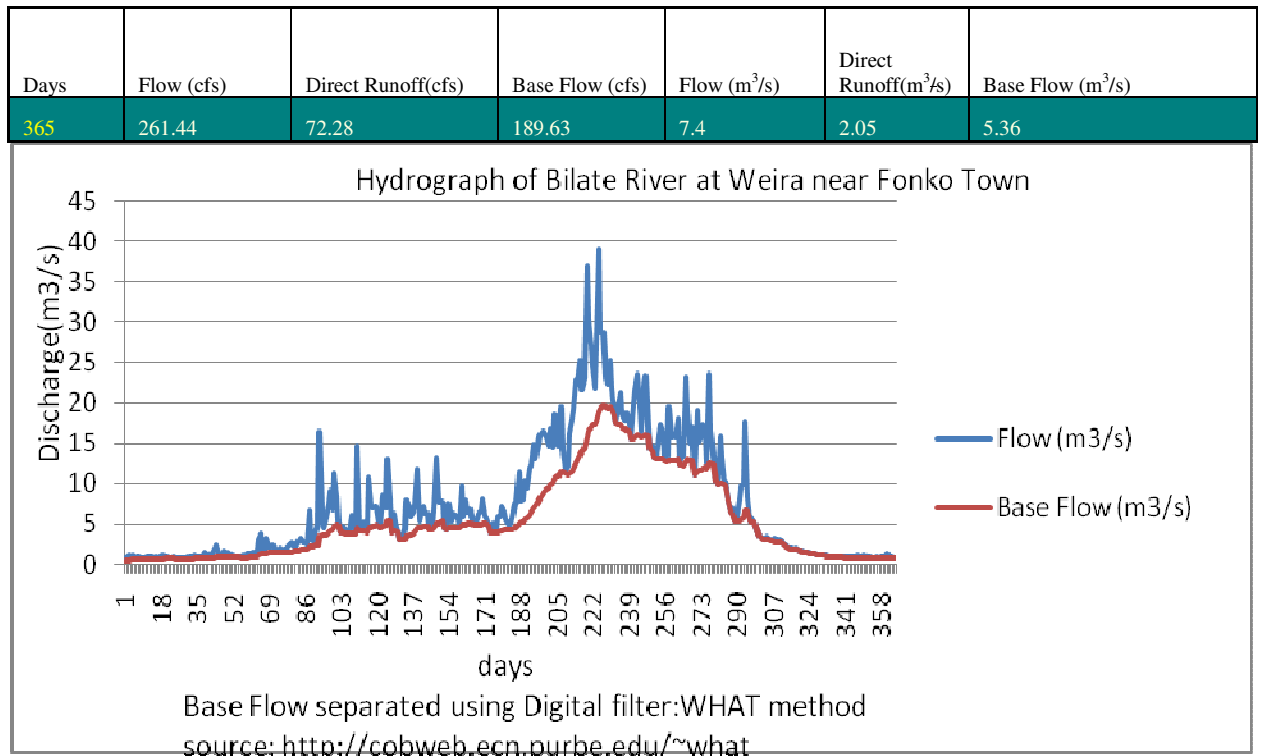


Figure 3-5 Base flow separation for up to 365 days of Bilate River at Weira

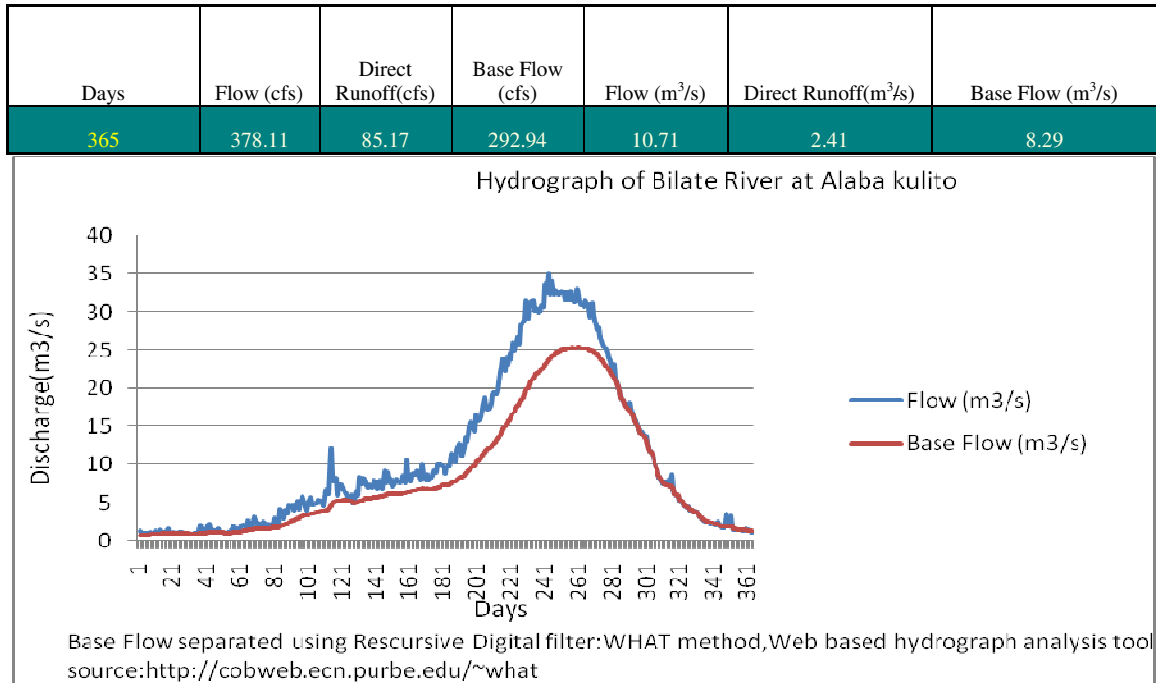


Figure3-6 Base flow separation for up to 365 days of Bilate River at Alaba near Kulito town

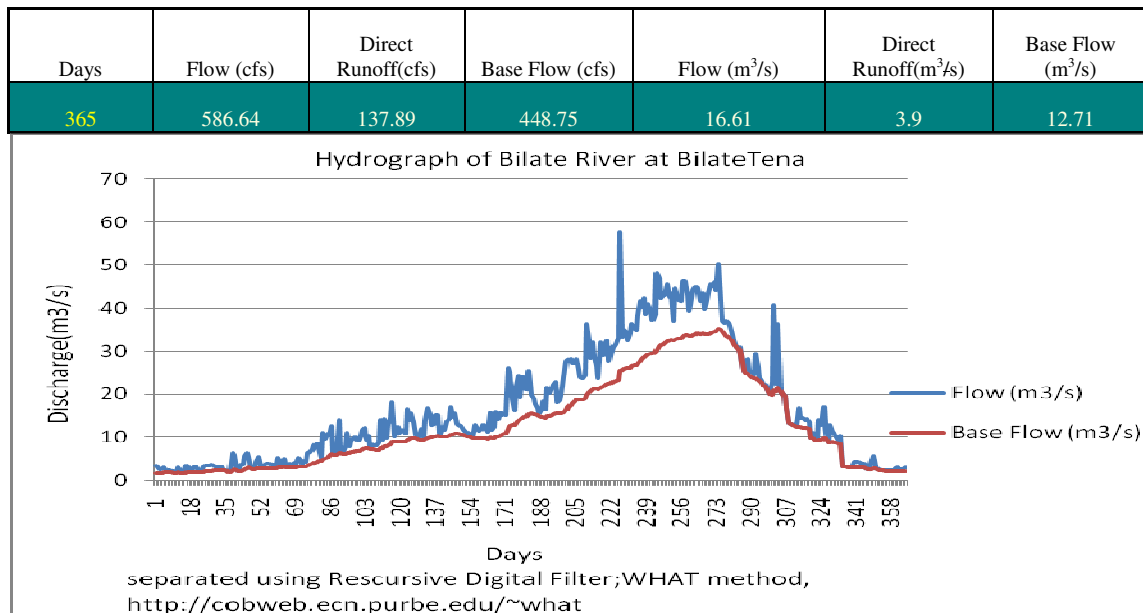


Figure 3-7 Base flow separations for up to 365 days of Bilate River at BilateTena River

Table 3.2 Summary of Computed recharge in the study area

ID	Gauging Station Name	Area enclosed(m ²)	Drainage area(m ²)	Runoff (m ³ /s)	Recharge (m ³ /s)		Recharge (m/y)	Recharge (mm/yr)
0	Bilatetena	1813000000	3773960000	3.9	12.71	3.368E-09	0.11	106.21
1	Abaya	1863000000	5636960000					102.36
2	Gudar	79160000	79160000	0.32	0.73	9.222E-09	0.29	290.82
3	Weira	455800000	455800000	2.05	5.36	1.176E-08	0.37	370.85
4	Alaba kulito	1426000000	1960960000	2.41	8.29	4.228E-09	0.13	133.32

The above table summarizes the area distribution of recharge in the catchment with runoff in computed both water balance approach and base flow separation methods.

In the table for Abaya station there is no defined gauging station set so that recharge was estimated based on the assumption 10-20% of the annual rainfall of the region is recharge for volcanic aquifers (Ayenew, Demlie and Stefan, 2008). The recharge value for Weira is 370.85mm/yr, which is comparable with the value estimated for the southwestern highlands recharge may reach as high as 400 mm (Ayenew, Demlie and Stefan, 2008). And also the average direct recharge in the rift floor of the study area is 113.96 mm/yr or 10% of the mean rainfall 1155.23mm. This value is good estimate for a volcanic area (Lulu S. and G/Hiwot A., 2004).

From the figure 3.6 peak base flow curve indicates relatively high recharge and low runoff, due to damping effect of Boyo graven, the flow gets time recharge the area.

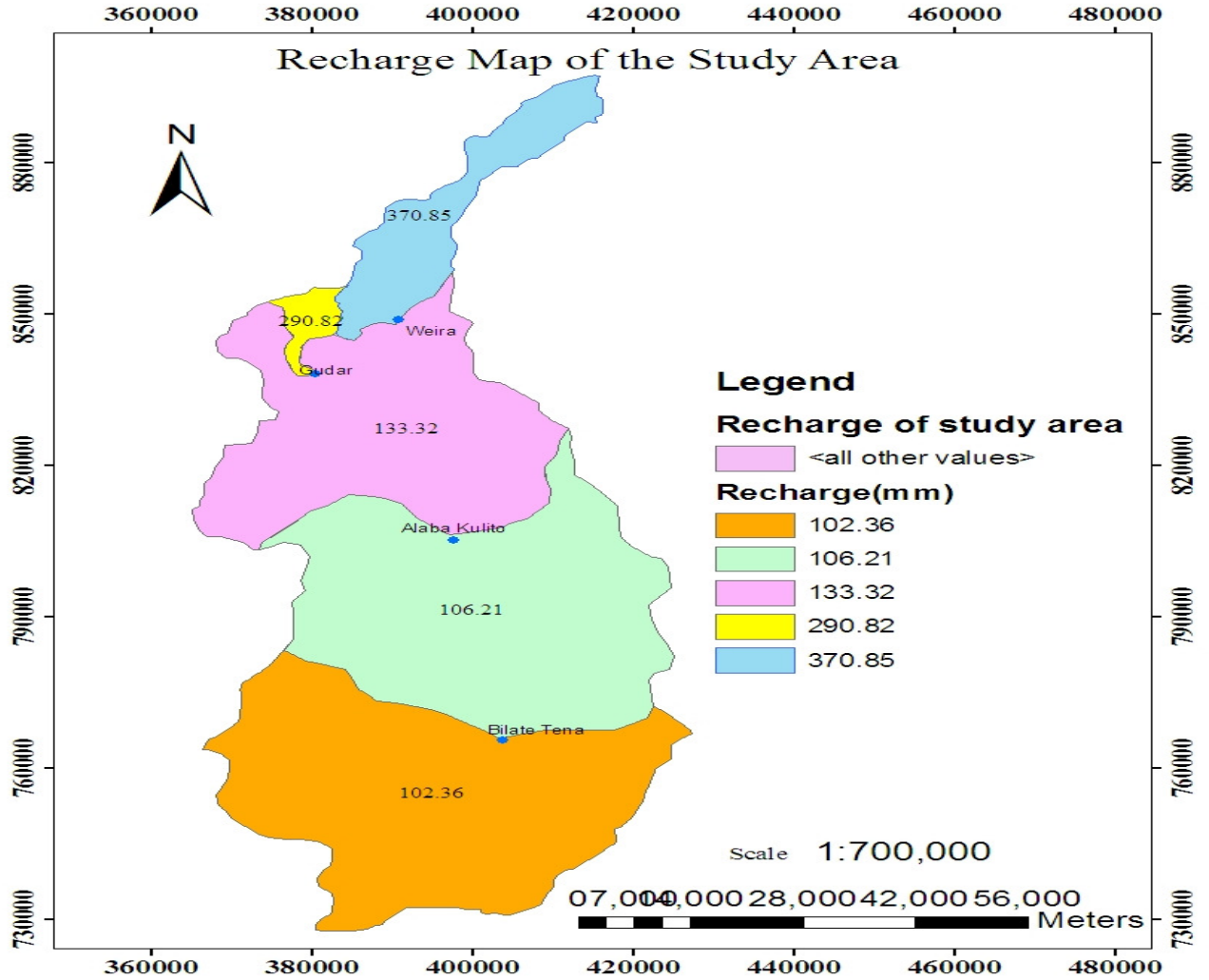


Figure 3-8 Recharge map of the study area

3.2.1.3 Groundwater flow direction

The groundwater level of the area was found by subtracting the static water level from surface ground elevation. Based on this the ground water level map of the area was developed and the flow direction was indicated.

The ground water level map of the study area below shows that the level of groundwater depth getting vary from place to place with mostly, deeper towards east of Bilate River.

The flow direction indicator arrows show that the ground water flows towards Bilate River in the northern and western parts even from the surrounding Basin Omo-Gibe and towards Shalla Lake from the northern part of Alaba special woreda.

From, the conceptual flow system based on topographic setting, in general three flow system is observed, where topographically undulation of the catchment creates local and intermitted flow system in the area and those part with shallower and short flow paths known with local flow system (Fetter, 2001) and where small permant lakes in the upland portions of watersheds are usually discharge areas for local and intermediate systems (Ayenew, 2008).

So that from this logical point of view, the presence of small permanent Boyo Lake indicates the local and intermediate flow systems in the northern part of the area. The groundwater flow system around Alaba and Sankura area are dominated by intermediate flow system (Legesse S, 2009). On the other hand, well depth report of south east of Alaba Kulito, the groundwater comes from deep depth, which in turn indicates deep groundwater flow system.

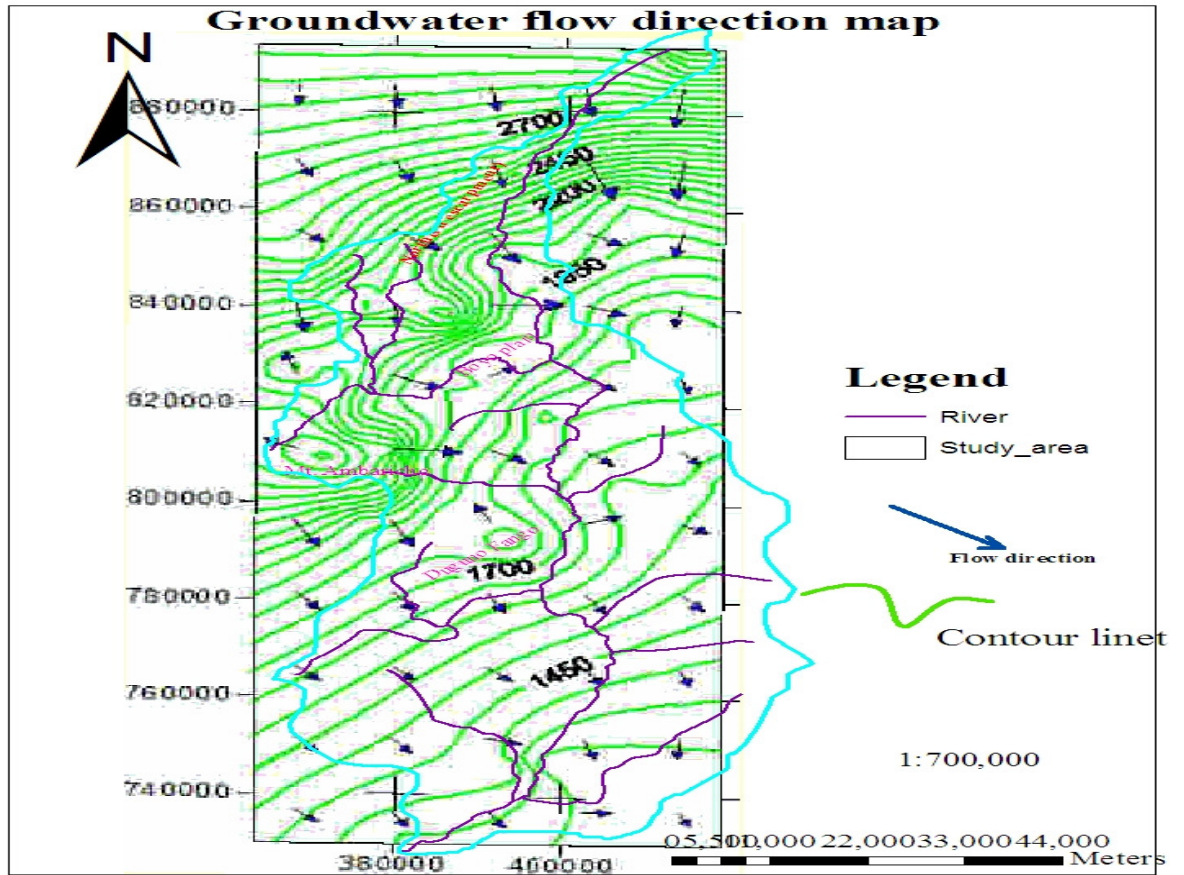


Figure 3-9 Groundwater flow direction map of the study area

3.2 .2 Slope

Topographic setting relates to the local and regional relief situation and gives an idea about the general direction of groundwater flow and its influence on groundwater recharge and discharge.

Steeper the slope, greater will be the runoff and thus lesser is the groundwater recharge. Digital Elevation model (DEM) is derived using contour information from the topographical map for estimation of slope in degree.

The identified slope category varies from 0° to 39° degree in the study area and area classified in to four classes like 0-2° (gentle), 2-7° (moderate), 7-13° (high), and 13-39° (steep).

Gentle slope (0–2°) indicates the presence of high groundwater potential zones where as steep slope (>13°) shows the presence of poor groundwater potential zones as water runs rapidly off the surface and does not have sufficient time to infiltrate the surface, keeping other parameters constant.

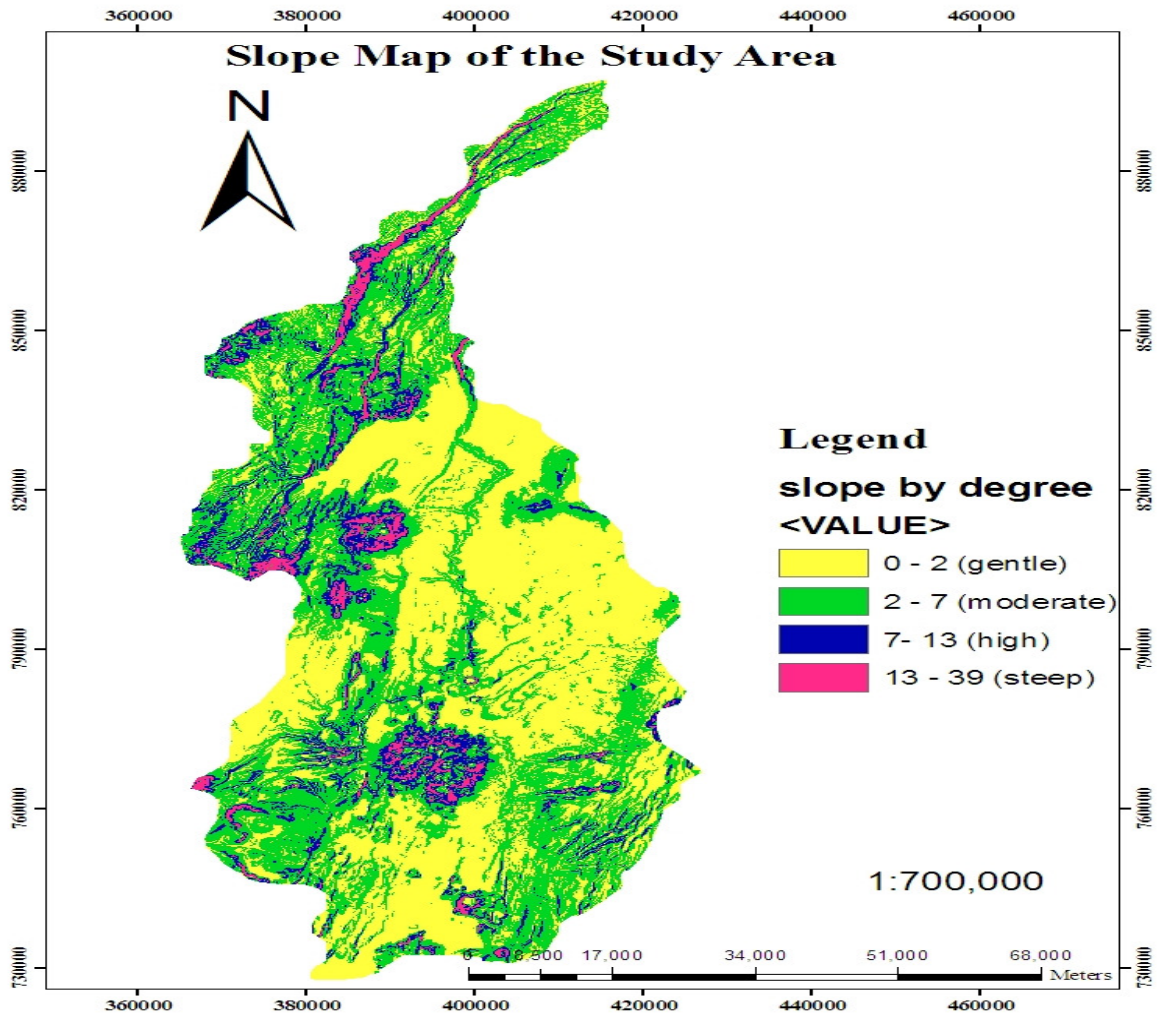


Figure 3-10 Slope map of the study area

3. 2.3 Drainage density map

Drainage density indicates rock permeability and infiltration capacity, and therefore recharges capacity. They are reflection of the rate that precipitation infiltrated compared to surface runoff. Where rocks are highly permeable, infiltration to groundwater is high, and less water is transported in rivers as surface water; but where rocks have low permeability there is little infiltration and more surface water runoff. Low drainage density is therefore related to higher recharge and higher groundwater potential (M. Thangarajan, 2007). The drainage density is high in the plateau and escarpment and very low in the rift floor (Ayenew, 1998)

Drainage density delineated using 3DEM hydroprocessing module of SRTM data of the study area after consecutive processes such as Importing of SRTM data, filled sinks for undefined values ,created Flow Direction, Created Flow Accumulation, created Stream network, generated Stream Order and finally converted Stream Order to drainage density.

The stream order values were regrouped to produce a drainage density map that was reclassified into four categories i.e., 1(high), 1-2 (medium) , 2-4 (low), and 2-6 (very low) density (figure). But some anomalies observed in the order due to the effect of Boyo marshy area.

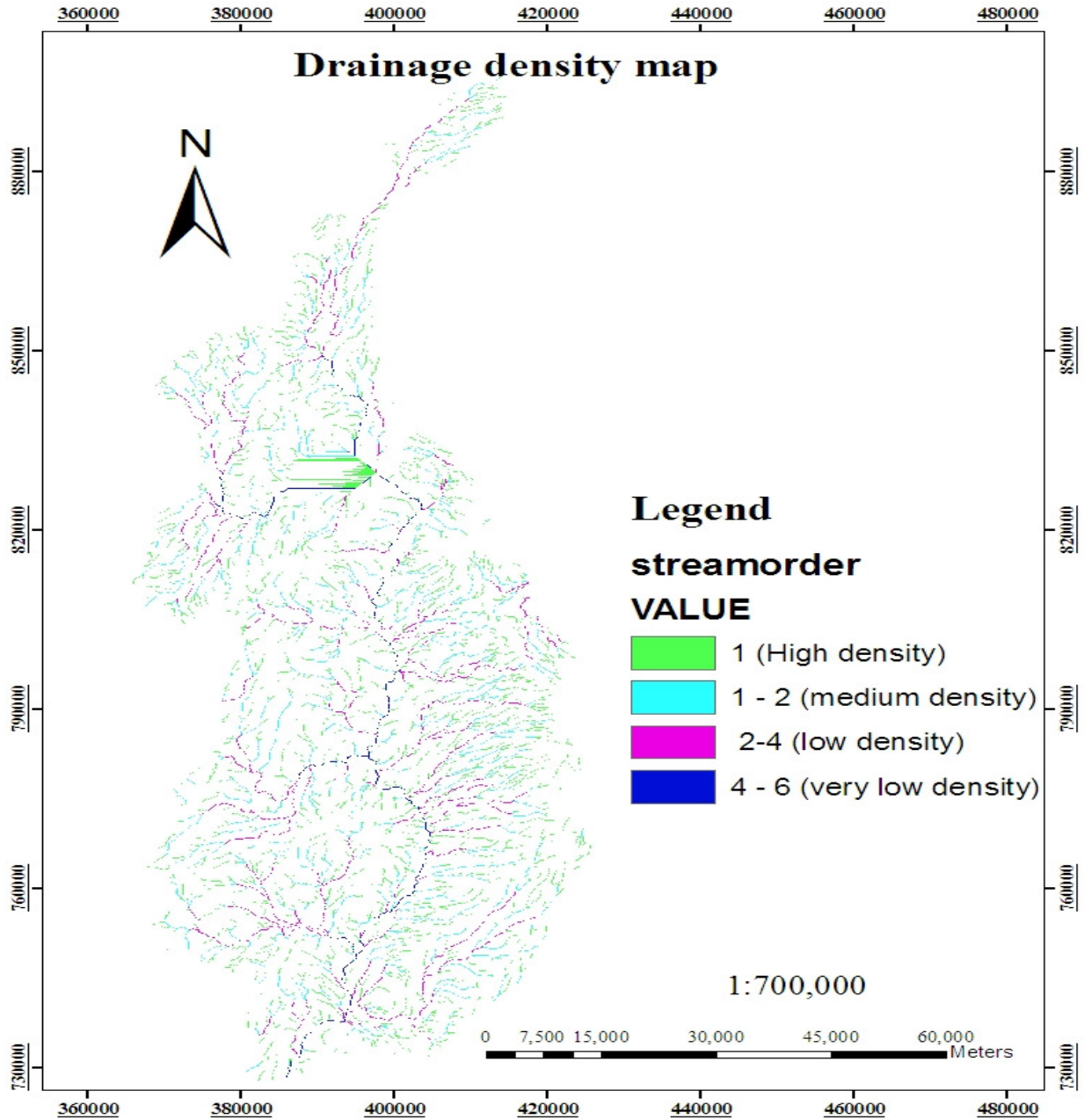


Figure 3-11 Stream order map of the area

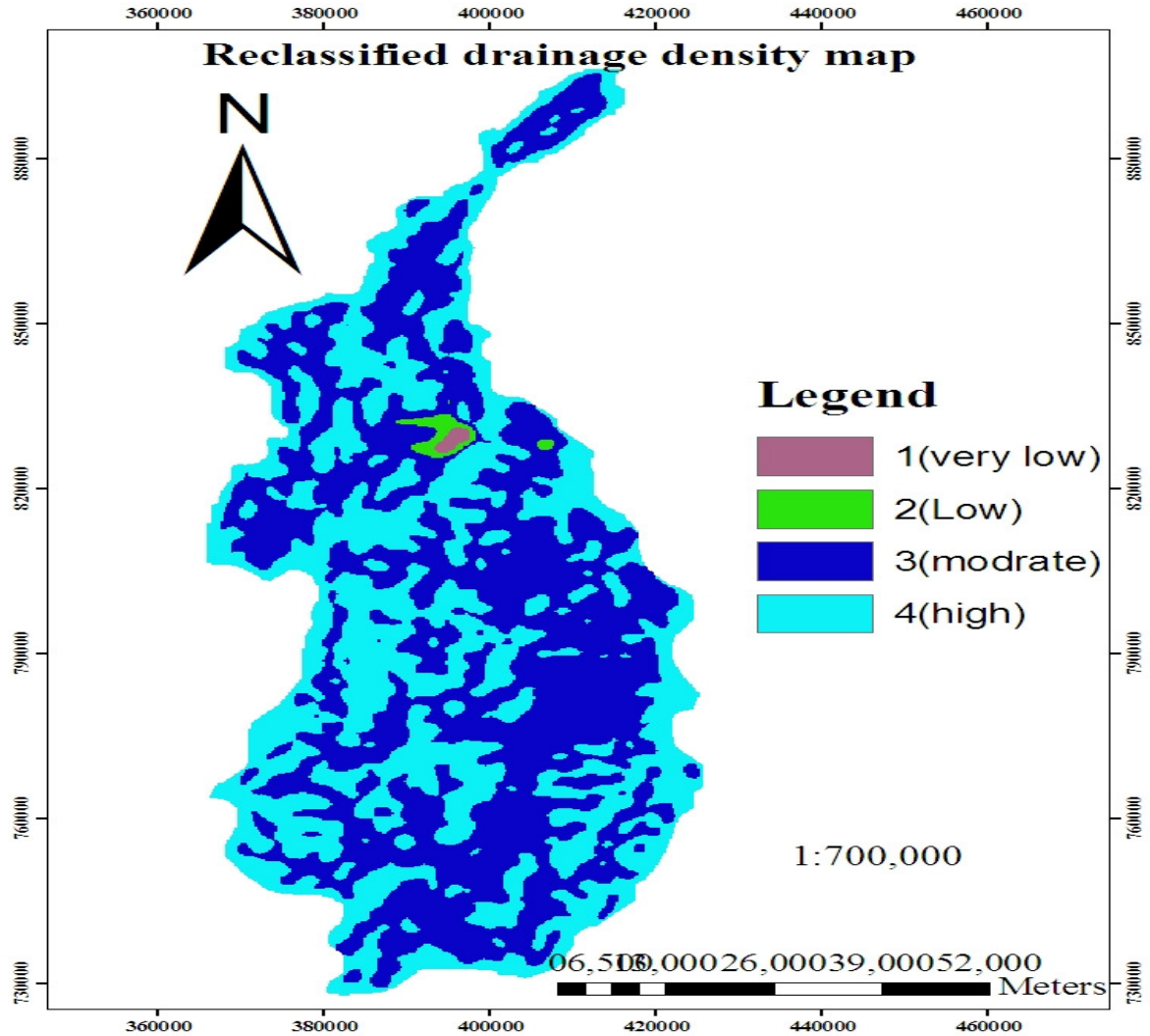


Figure 3-12 Reclassified drainage density map

3.2.4 Land use/ Land Cover

Land use is an important characteristic of the runoff process that affects infiltration, erosion, and evapotranspiration.

The land use/cover map of the area was readily interpreted from Landsat image of the year 2001 by using visual interpretation, supervised classification using ERDAS 9.1 software.

Classification of land use/cover for analysis was done based on their character to infiltrate water in to the ground and to hold water on the ground.

various land use/ land cover classes delineated includes, cultivated land, bare land, grass land, plantation, shrub land, riparian plantation, wood land, exposed surface, marshy land and water body (Figure 3.12), because of high population density in the area most part is covered by cultivation land(Sendabo D. 2007).

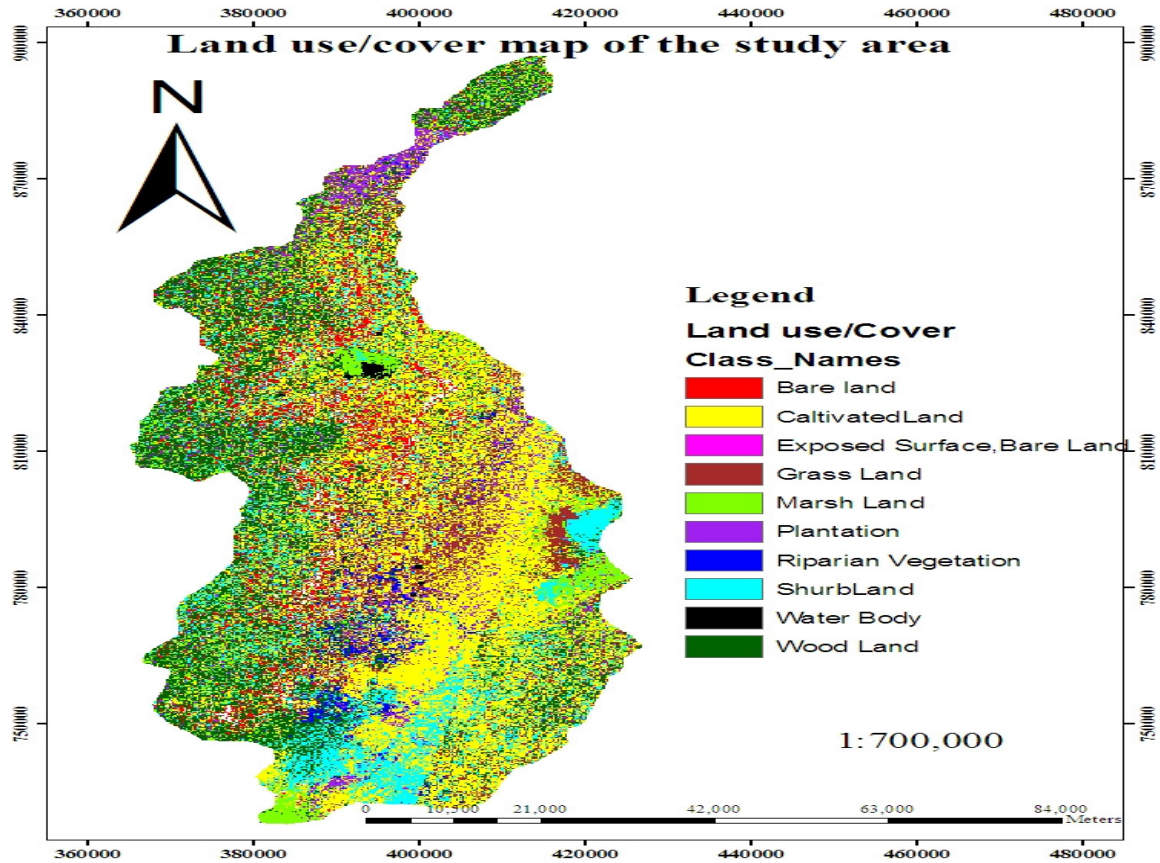


Figure 3-13 Land use/ Land cover map of the area

3.2.5. Soil map

Soil properties influence the relationship between runoff and infiltration rates which in turn control the degree of permeability, the principal factor in hydrogeology that determines the groundwater potential.

Classification of soil types in relation to groundwater potential controlling was done based on FAO soil texture classification (FAO 1997) and the Land use/land cover practice of the area, see figure below.

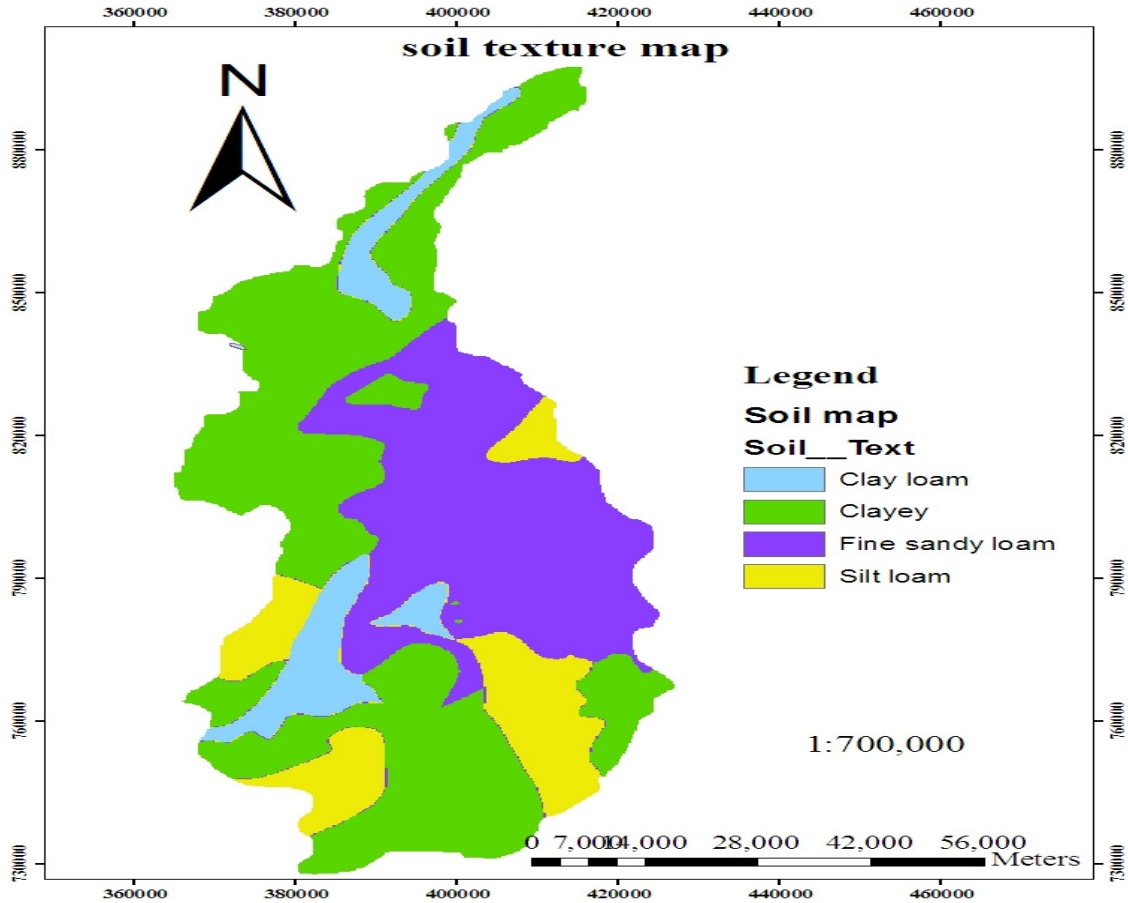


Figure 3-14 Reclassified FAO, 1997 Soil map of the area

3. 2.6. Geomorphology

Geomorphology maps depict landforms relating to groundwater occurrence as well as to groundwater prospects.

Due to rift effect and different land use condition the study area has complex land form features, which is manifested by hills, and undulating surfaces.

Geomorphology units which have been identified and delineated from the study area include hills, valley, flood plain, lake, and mountain; plateaus, and ridge and undulating surfaces. The distribution and extent of these geomorphic zones are varying from place to place.

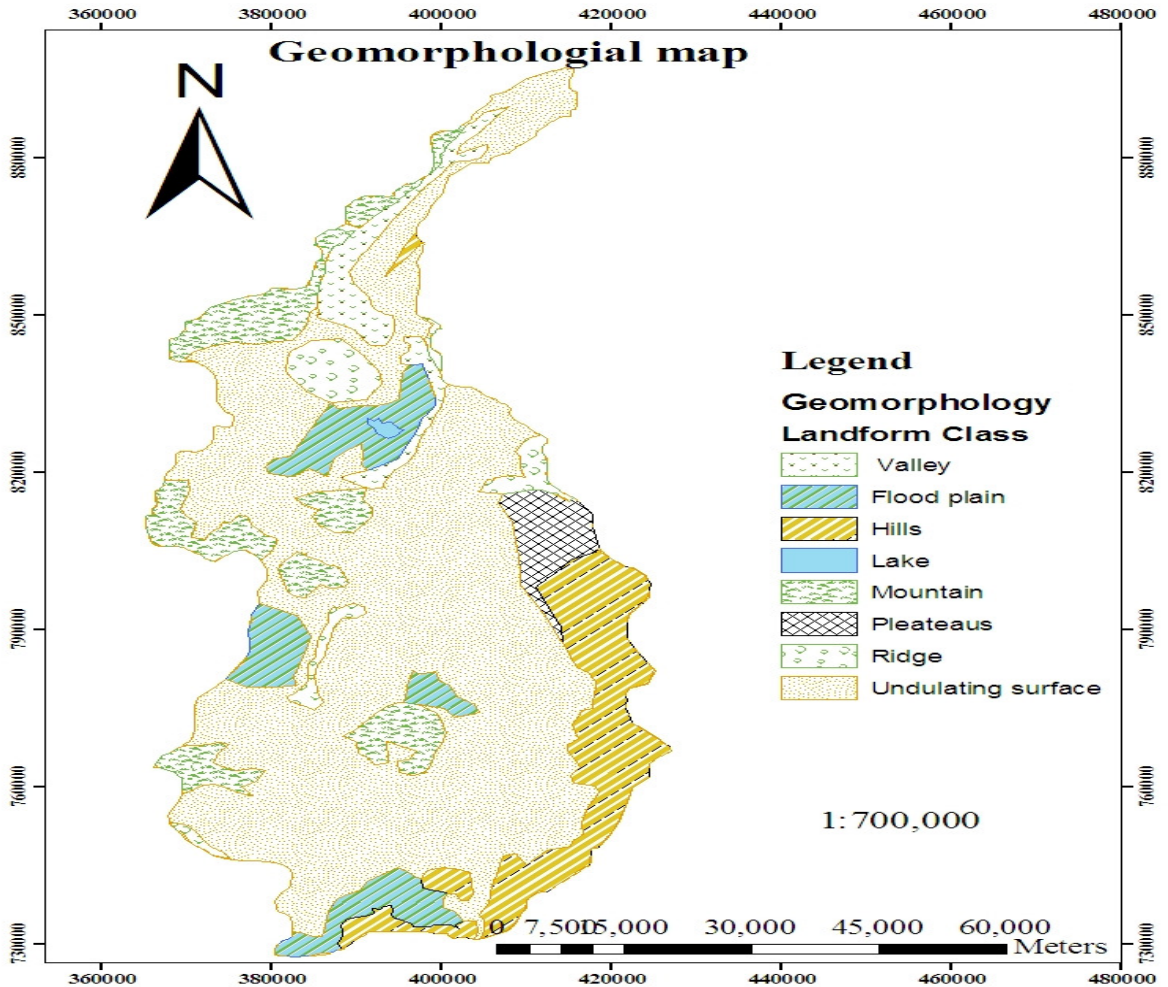


Figure 3-15 Landscape of the Bilate River Basin with prominent topographical features

3.2.7 Lithology

Groundwater inevitably occurs in geological formations that require knowledge of how these earth materials formed and the changes they have gone to understanding the distribution of geologic materials of varying hydraulic conductivity and porosity (Fitter, C.W., 1994).

Higher porosity contributes to higher Groundwater storage and higher permeability contributes to higher groundwater yields.

In the present study geological map was prepared using previous data from different studies, satellite image interpretation as well as field verification.

The study area comprises of variety of volcanic and volcano-sedimentary rocks that exhibit different ages and composition of stratigraphic sequence categorized based on hydrogeological point of view (Figure 3.15).

The alluvial sediment is strictly bound to the stream courses and flood plains. These river channel deposits are composed of mainly sand and gravel possessing good permeability.

The basalts is exposed in north of Lake Abaya and river scarp ridges is often weathered and faulted ,following which hot springs emerges showing the existence recent volcanic actives in the area. The basalt in the escarpment area is highly broken due to the effect of the rift faulting.

Hard highly jointed grey ignimbrite overlies the basalt (Jima volcanic), near Abaya Lake and on other places exists in a complex mixture of other pyroclastic such as tuff, ash and interbedded with lacustrine deposits along the river beds. The quaternary ignimbrite well exposed in the northern peaks of the area especially in mappable unit around Hosanna town.

Recent acidic volcanic rocks mostly characteristics the eastern part of area around Alaba and Ropi. It is comprises of an enormous accumulation pyroclastic products consists of pumice and ash and the flows and domes are more massive pumice or obsidian. Most of mount DugunoFango and plateau in the northern Alaba woreda, for example, is made up of a series of superimposed of flows of pumice and obsidians.

The volcano-sedimentary rocks are pyroclastics ejected from a volcanic center or fissure and laid down in the surrounding lakes and river banks compositionally variable in sizes ranging from reworked rounded and surrounded poorly sorted and angular shapes which cause the lower permeability and transmissivity compared to other sediments.

The lacustrine sediments are located in topographical low places, where the rainfall amount is low, thus recharge comes from high runoff in the escarpments.

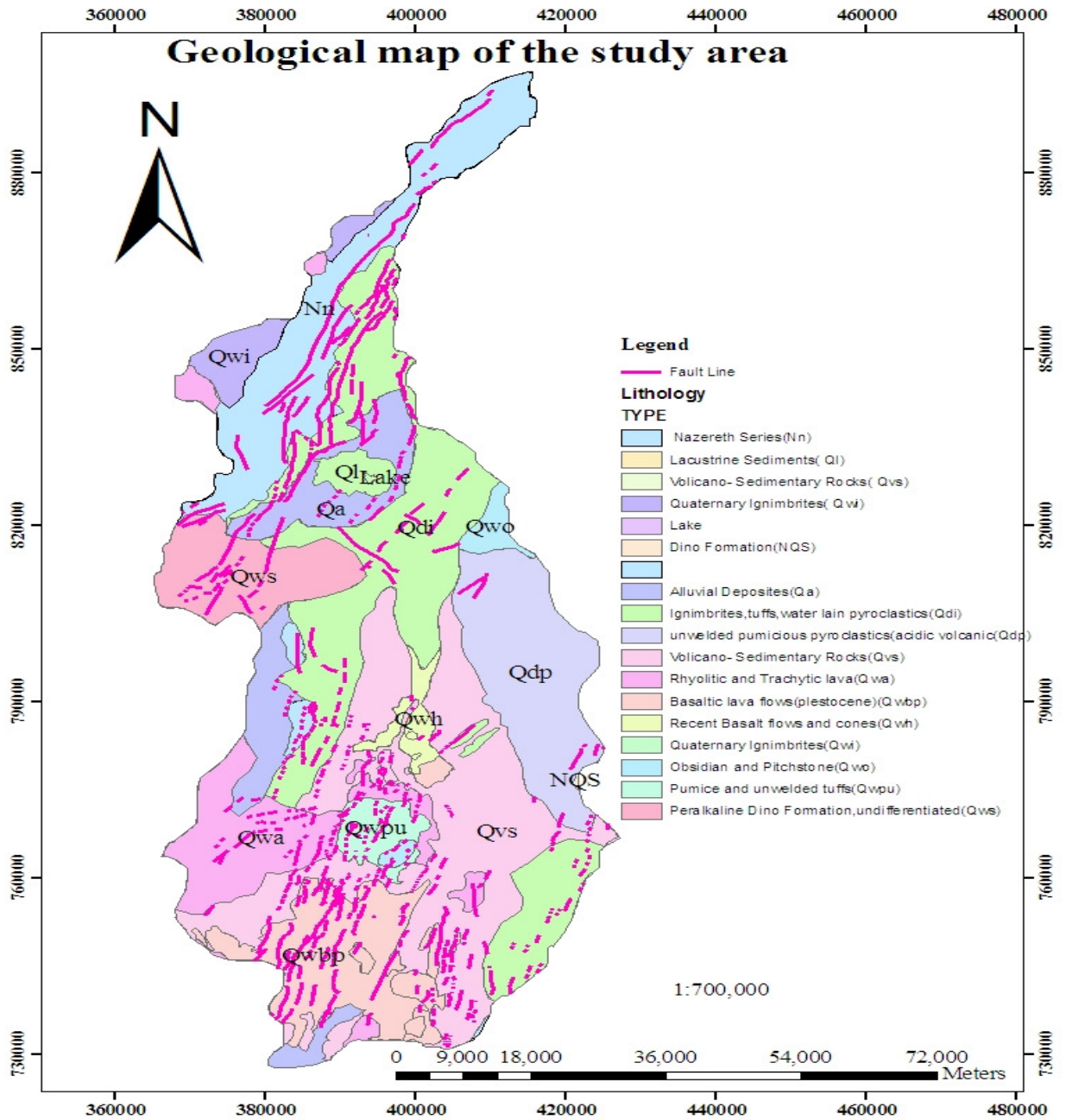


Figure 3-16 Geological map of the area

3.2.8 Lineament density

Lineaments are structural lines such as faults, which often represent zones of fracturing and increased secondary porosity and permeability, and therefore of enhanced groundwater occurrence and movement.

In hard rock terrain the storage and movement of groundwater is controlled by the secondary porosity i.e. presence of lineaments and fractures. Lineaments study of the area from remotely sensed data provides important information on subsurface fractures that may control the movement and storage of the groundwater.

The distribution of the lineaments is observed to be high on the escarpment and rift floor (Figure 3.16). These are normal faults having a NNE-SSW orientation. Faults may act either as pathways for water movement or as flow barriers. At the foot of some of the fault scarps which bound the basin there exist springs indicating that these faults act as conduits.

The faults in the escarpment areas which comprises the older undifferentiated rocks of Nazret Group and Dino Formation down faulted towards the rift floor resulted in the development of Boyo plain which is graben.

High density of the faults is observed near North West of Lake Abaya and northern escarpment. To the eastern escarpments the density decreases significantly indicating that the pre-existing fault systems are covered by the silic volcanic that persisted in Holocene time (AG consult, 2004). Those, faults on the floor may possibly be filled with a weathered glassy volcanic ash. In such cases the faults could act as barriers (Nedaw, 1997).

Most of the lineaments are identified Classified into lineament density map in to four categories, i.e. 0.062 -1.33(high), 0.34 -0.62(medium), 0.12 – 0.34(low), and 0- 0.12 (very low) in the study area (Figure 3.16)

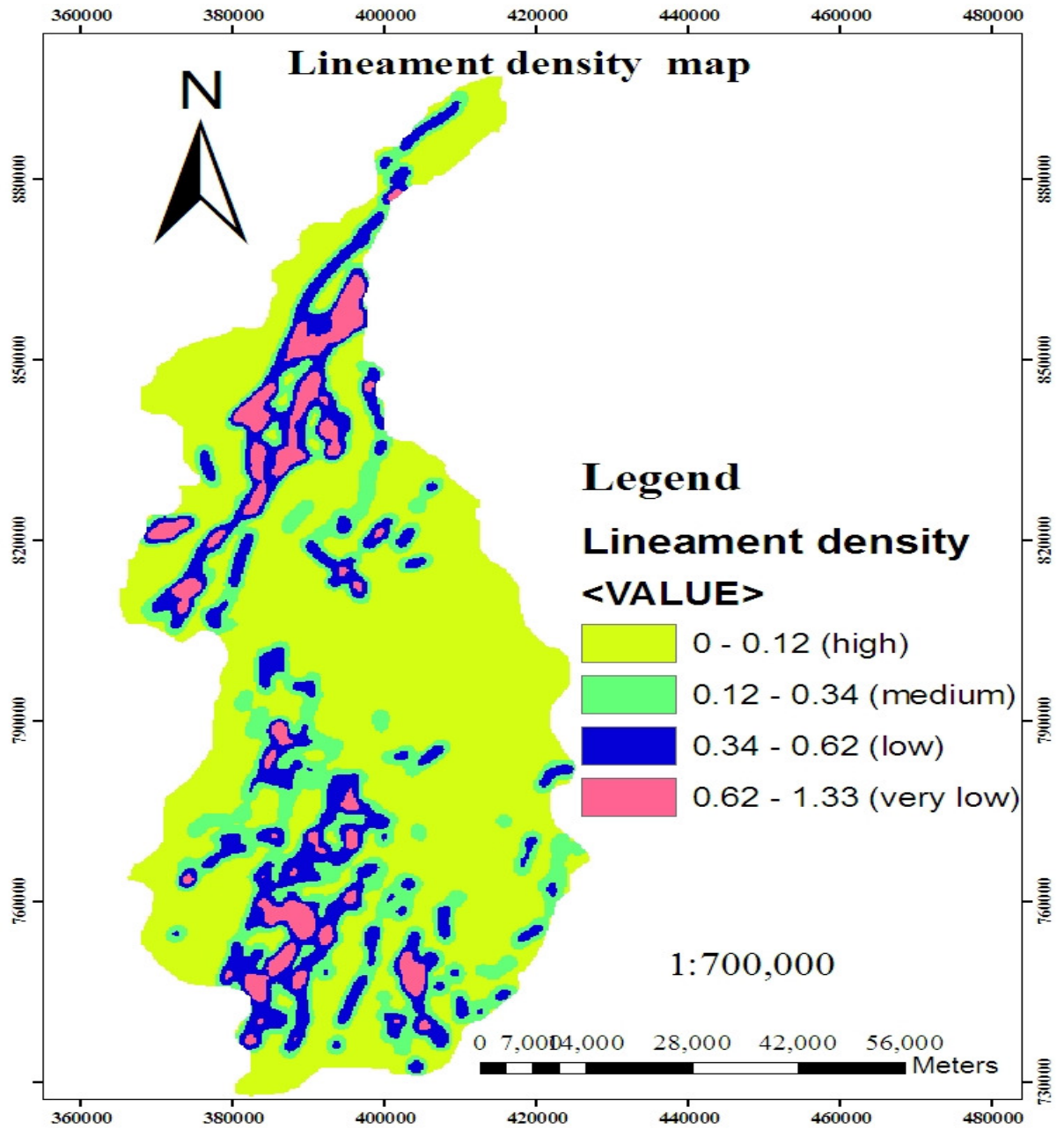


Figure 3-17 Lineament density map of the area

4. Results and Discussions

4.1 Data Integration Analysis in GIS Environment

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

To account for varying geology (Chernet,1982) alluvial deposits, volcano –sedimentary rocks, recent basalts and lacustrine sediments were assigned highest weightage due to their higher porosity and impermeability, Ignimbrites of rift floor, Dino formations of pyroclastic deposits and Pleistocene basalt were assigned moderate value for they mostly well jointed and have moderate permeability and based on where dense Wonji fault belt cuts this rock it increases the degree of jointing of these rocks thereby increasing their permeability(Figure 3.16)(Chernet, 1982) , low value were assigned for peralkaline Dino formations less affected by faulting and fracturing.

Similarly, for hydro-geomorphic units, mountains, ridge and plateaus were assigned lowest values, small valleys and undulating surfaces moderate value and highest weightage was assigned to the flood plains. The ridge type structural hills with low lineament density and higher drainage density were assigned low values.

For lineament density weightage was assigned in increasing manner for the 0.062 -1.33(high), 0.34 -0.62(medium), 0.12 – 0.34(low), and 0- 0.12 (very low) respectively owing to secondary porosity decreasing accordingly.

The slope degree between 0-2° (high value), 2-7° (moderate value), 7-13° (low value), and 13-39° (least value) was assigned on account of increasing run off and decreasing infiltration respectively.

In the contrary to lineament density, higher drainage density value were assigned the lowest and the lowest drainage density values assigned highest values for decreasing runoff in the area.

For clayey Soil least value was assigned because of the presence of clay-horizons in the area considerably restricts percolation where as highest value was assigned for fine sandy loam for their low water holding capacity and high permeability allow fast percolation(Ayenew, 1998). Similarly owing to influence the ground water infiltration and alters the rate of percolation of precipitation out of land use cover/ land cover marsh land and riparian vegetation was assigned highest weightage, degraded forest(exposed surfaces) and shrub land moderate vales and bare land the least weightage.

Finally, high precipitation and recharge values favor groundwater potential and thus, the weightage was assigned in increasing order of precipitation amount mention in the rain fall map (Figure 3.1).

All the weighted thematic maps were integrated and defined criteria weight using the IDRIS software and overlay analysis done using ArcGIS software and potential ground water prospect zones were identified (Figure 4.3).

4.2 Criteria weights and Map Scores

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

The importance matrices and their weights are mentioned as follows:

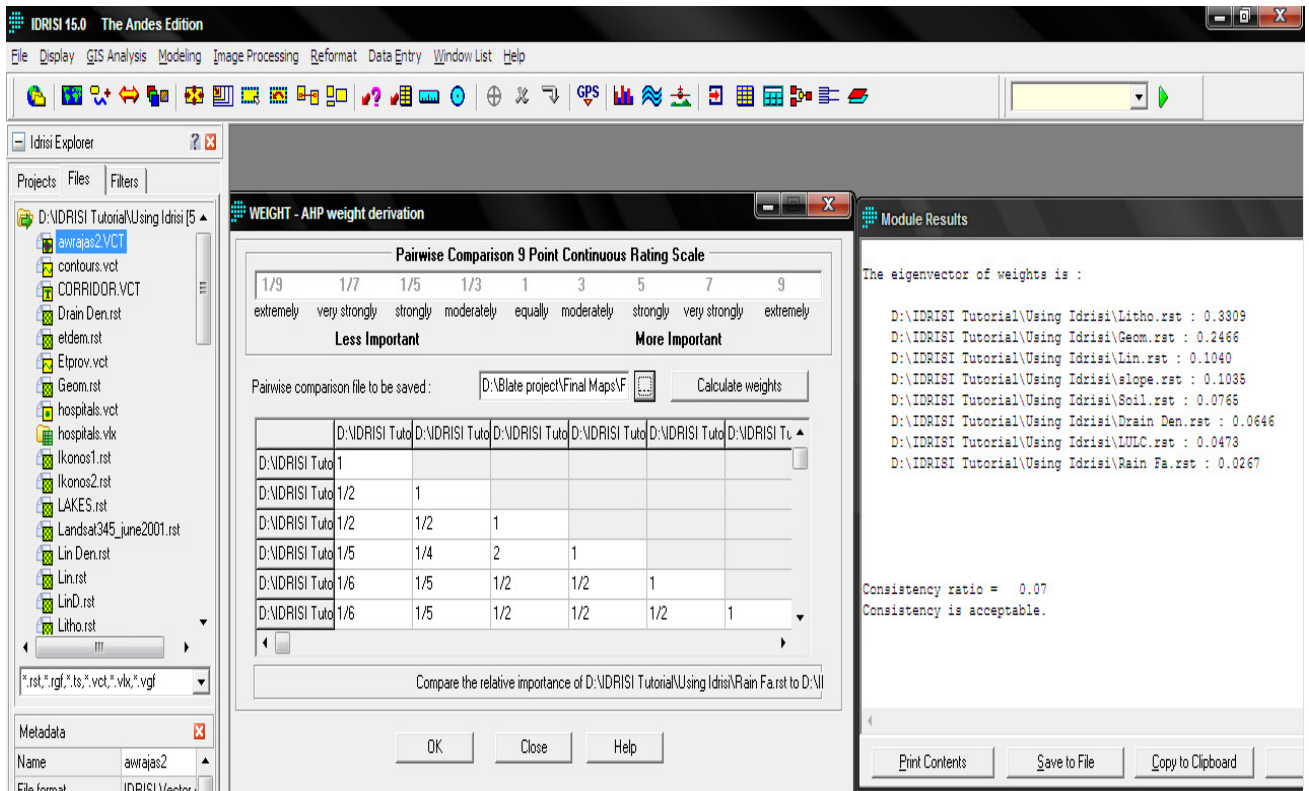


Figure 4-1 Weights of parameters determined using analytical hierarchy principle (AHP) nine point scales

Table 4.1 Paired Comparison matrix

	Litho	Geom.	Lin	Slope	Soil	Drain Den	LULC	Rain Fa	Weight	Weight (%)
Litho	1	2	2	5	6	6	6	7	0.3329	33
Geom.	1/2	1	2	4	5	5	5	6	0.2458	25
Lin	1/2	1/2	1	1/2	2	2	2	3	0.1037	10
Slope	1/5	1/4	2	1	2	2	2	3	0.1031	10
Soil	1/6	1/5	1/2	1/2	1	2	3	4	0.0810	8
Derain d	1/6	1/5	1/2	1/2	1/2	1	3	4	0.0638	6
LULC	1/6	1/5	1/2	1/2	1/3	1/3	1	4	0.0460	5
Rain Fa	1/7	1/6	1/3	1/3	1/4	1/4	1/4	1	0.0265	3

Consistency ratio = **0.07**

Key

Litho = Lithology

Geom. = Geomorphology/Land form

Lin = Lineament density

LULC = Land use/ Land cover

Slope = Slope

Soil = Soil

Drain d = Drainage density

Rain Fa = Rainfall

From the table above lithology and geomorphology hold highest values relative to the other parameters for the complex spatial and temporal distribution of the volcanic rocks, their different intricate stratigraphic and structural relationships, wide compositional variability, and different degree of weathering and topographic position highly control the groundwater potential in the area.

In the opposite, however, it is the main source of recharge; precipitation shows least weightage because of the extreme variability of daily and monthly precipitation amounts all over the catchment area essentially limits the exact assessment or even prediction of water resource availability (Stefan and Gerd, 2004) and Figures 3.1 and 3.2.

After categorization, all the reclassified thematic layers were integrated with one another through GIS using the weighting overlay analysis as follows.

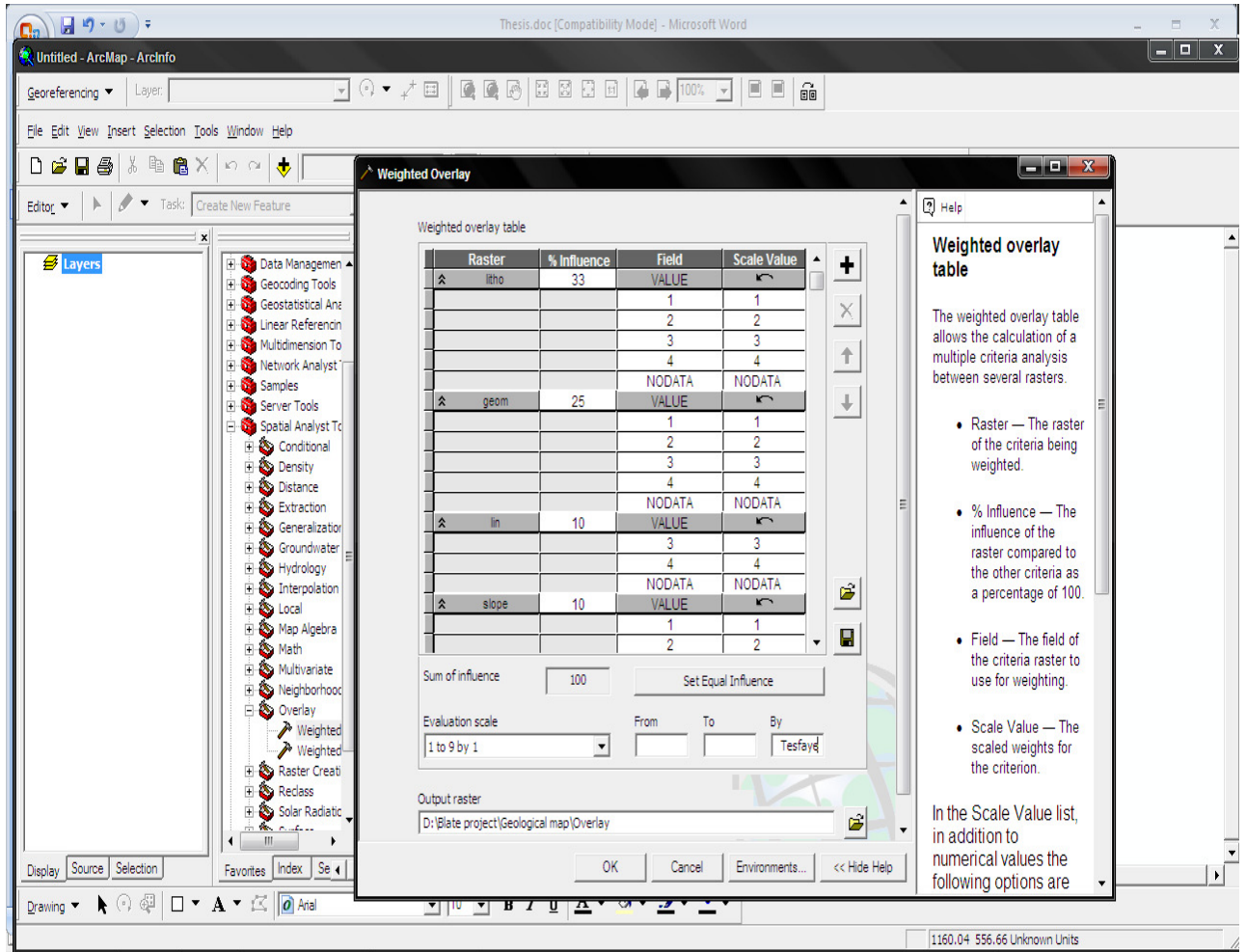


Figure 4-2 weighted Overlay analysis table to produce Groundwater potential zone map

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

$$GPZM = 33 * \text{lithology map} + 25 * \text{geomorphology map} + 10 * \text{lineament density map} + 10 * \text{slope map} + 8 * \text{soil map} + 6 * \text{drainage density map} + 5 * \text{Land use/ Land cover map} + 3 * \text{rainfall map}$$

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

4.3 Output/Groundwater potential zoning map

By integration of all the thematic maps, groundwater potential zones were delineated and classified as: high potential, moderate potential, low potential and poor potential zones (Figure 4.3). The high potential zones correspond to alluvial plains, lacustrine sediments, the fracture valleys, and valley fills, which coincide with the low slope and high lineaments density areas. The low zones mainly comprise structural hills and escarpments which contributes high run-off. Poor groundwater potential zones are present in the mountain peaks, plateaus and escarpments with steep cliff, where low fractured rocks undifferentiated Dino formation exists and comprise an area of 54.31 km².

The area having high groundwater potential is characterized by mountain foote of graven in Boyo plain in northern part, Ambricho mountain downstream drainage through Dura me town at Demote Worada and Mirab Badawacho woredas in the western, at Dendo dame site area near the foot of mountain Duguno Fango and at the vicinity of Lake Anya in the southern part. It covers an area of 158.04 km². The eastern portion and some small patches in the northern and valley escarpment of Bilate River of the study area fall under moderate groundwater potential zone. Moderate groundwater potential zones cover an area of 3175.35km² .To the eastern part of the area, through Alaba woreda low groundwater potential in high depth has been observed due to very thick pyroclastic acidic rocks especially highly permeable pumice layer that don't retain water at shallow depths but simply allow percolation of recharging water to great depth. Low groundwater potential zones cover an area of 2218.82 km² (see Table 4.2).

NE-SW fault system highly control the permeability of the rocks in the basin apart from other parameters, in which most of springs, marsh lands and drainage lines following these weak zones that would favor groundwater flow. But, in some cases this geological structure serve as a barrier for groundwater flow result for dry wells in the vicinity of productive wells in the area.

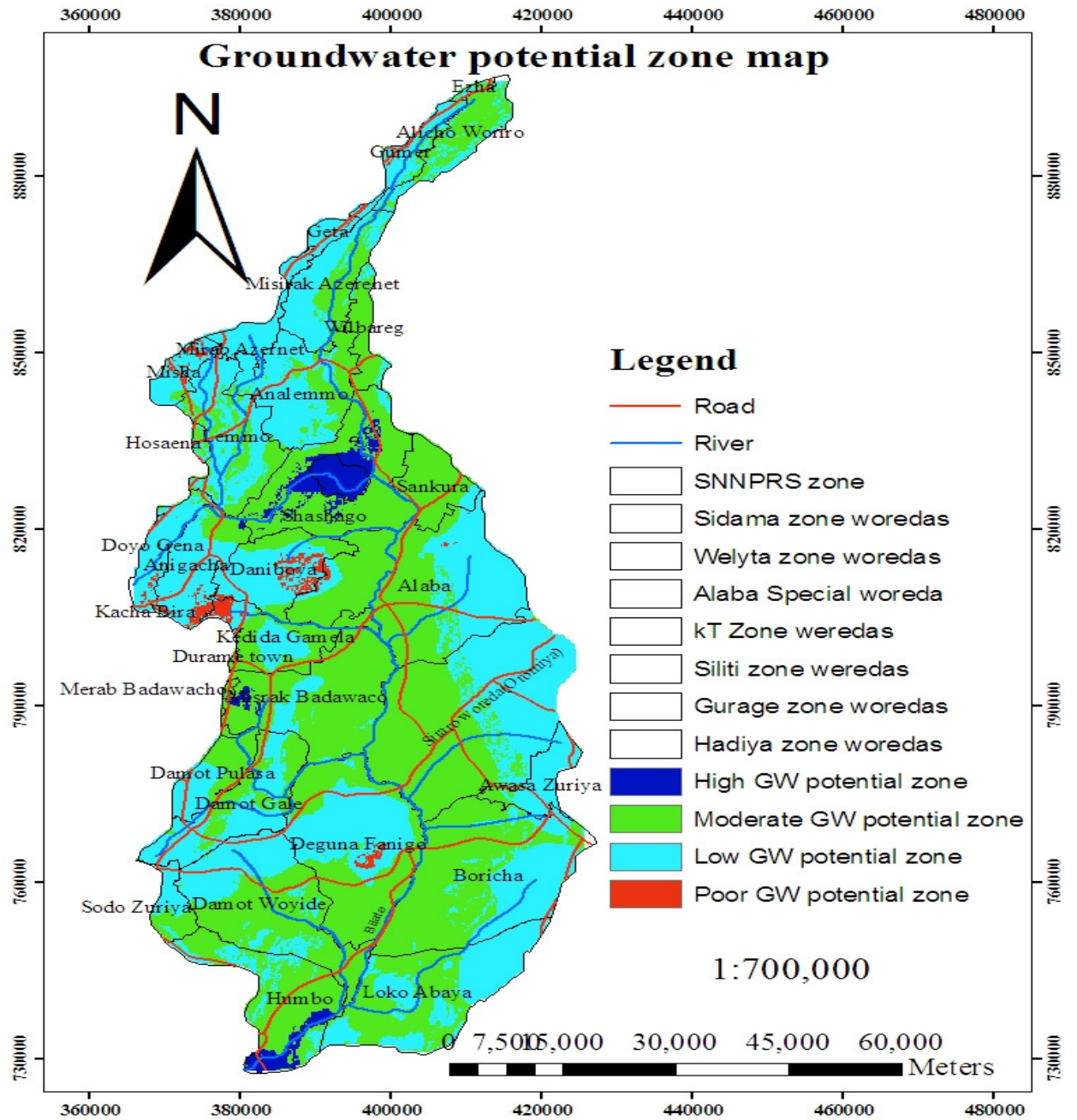


Figure 4-3 Groundwater potential map with Woredas in the study area

Table 4.2 Area coverage of each Groundwater potential zone

No	Groundwater potential zone	Area Coverage(km ²)
1	High	158.04
2	Moderate	3175.35
3	Low	2218.82
4	Poor	54.31

4.4 Results Validation

It was found that the zonation of groundwater potential by integrated GIS and remote sensing techniques was in close agreement with the available point source inventory data (Figure 4.4)

On the other hand, special cases were observed in the Alichu wirer (the northern escarpment) where unexpectedly moderate potential pixels exist. This may be happened when the rift faults in the area have caused variable degrees of displacement on rock formations coming to lateral contact to different rock types which have high permeability and as a result the lacustrine sediments and/or pyroclastic deposits on the rift floor extended to the escarpment (Chernet, 1982). From my fieldwork experience this is also confirmed by the presence of relatively high discharge wells and springs in the area, even though, the result in the specific escarpment is still exaggerated. It is because of the fact that alluvial deposits in the project area occurs mainly along the river channels containing clay and silt to coarse sand and gravel, have high water storing and transmitting capacity. This part of aquifer gets recharge in addition to precipitation is supposed to be the confluence part of seasonal streams and the main Bilate River stream, which is originating in the surrounding mountains, and intersections of fracture systems give rise to have locally moderate to high permeability and productivity. But this violates the previous study, despite the occurrence of permeable rocks and high recharge rates in some highlands adjacent to steep escarpments; the groundwater reserve is low due to the fast release of the recharged water to the rift plains through large open faults (Demile et al., 2008).

The point water sources data with high density and brownish color in Figure 4.4 indicates the shallow wells fitted with hand pumps where shallow groundwater exists. From my field work experience in the area they highly concentrated to high groundwater potential zones especially in the alluvial and lacustrine sediments. On the other hand yellowish color symbols show that deep bore holes with motorized unit. The others are springs and hand dug wells. From the point water sources distribution, in general the groundwater to the west is in shallow depth and to the east depth of groundwater level increasing.

In the figure, those points in the legend with red color are dry wells and in the vicinity of the dry wells, there are productive wells (legend values with discharge) present indicating that geological structure control in the area as has been identified in lineament map (Figure 3.16). No wells are exist in the poor potential zone also suggests good confirmation of the result.

The numbers on the map attributes the discharge amount in liter per second. It can be clearly observed that in the eastern side bore holes found in low potential zones have less discharge (2 to 4 l/sec.) than boreholes in the moderate zones (4 to 10 l/sec). These values coincide with aquifer classification in the hydrogeological map of Ethiopia in, which estimated optimum yield (litre/second) classified as 1.8 -68.4 l/sec. high potential, 0.45 – 9.9 l/sec. moderate potential and 0.045 – 4.5l/sec low potential aquifers.

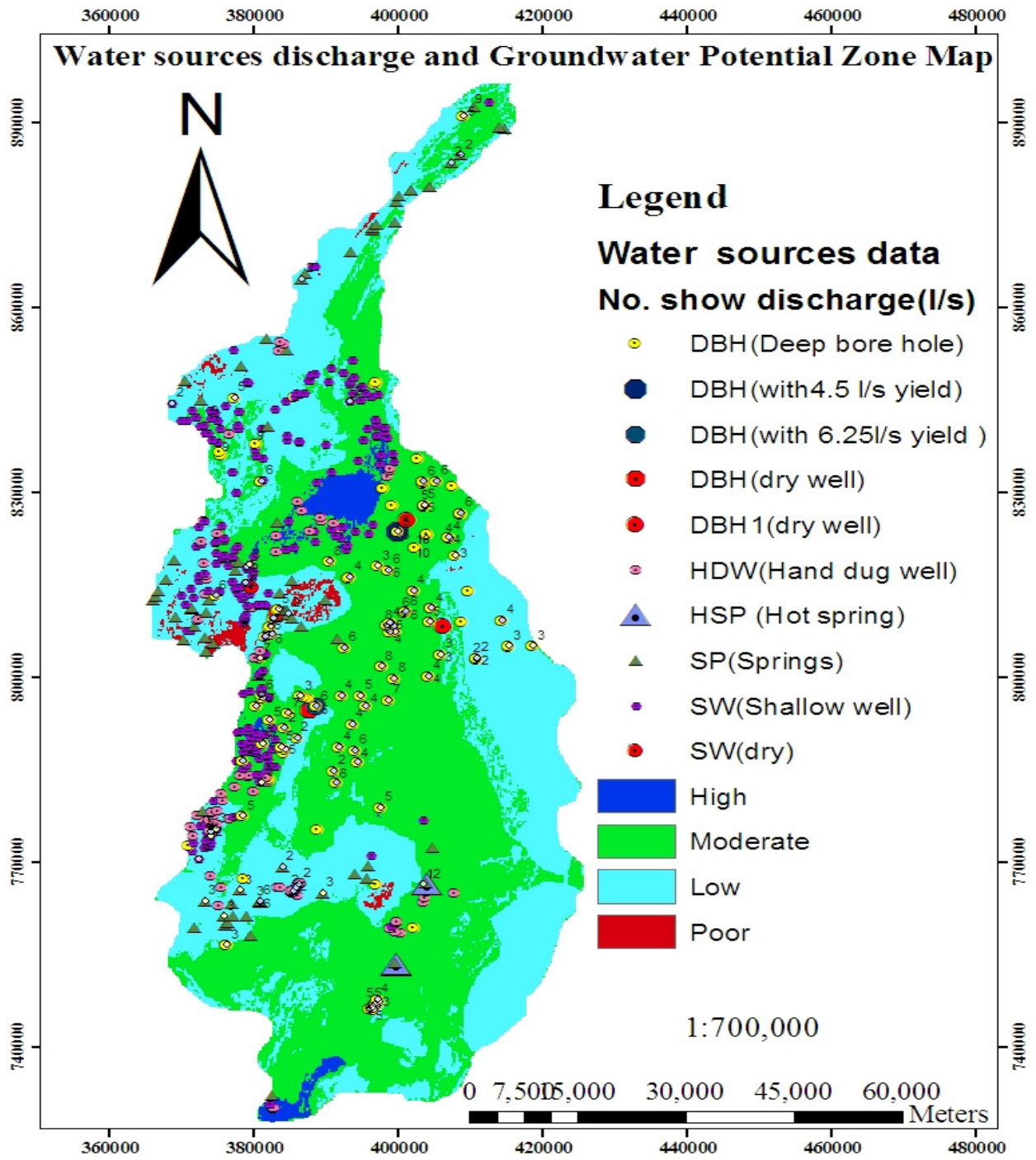


Figure 4--4 Distribution of boreholes and springs with discharge in groundwater potential zone

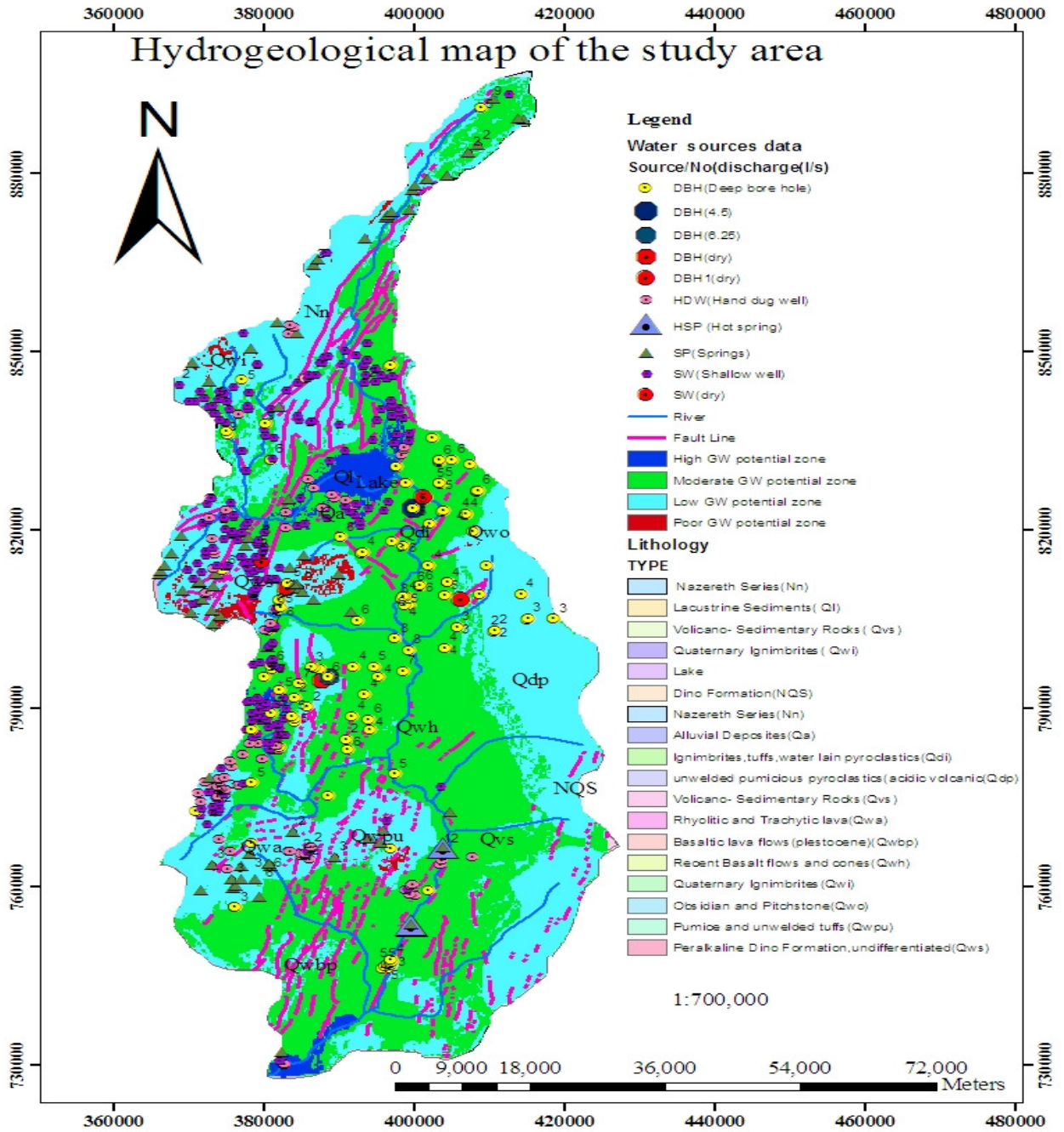


Figure 4-5 Hydrogeological map of the study area

The hydrogeological map compiled using geological map, lineament map and water point source data. Most of the information on the map was mentioned in the previous part.

The aquifer classes are categorized under extensive aquifers with fracture permeability of volcanic rocks such as basalts, ignimbrites, rhyolites, trachytes and alluvial and lacustrine sediments.

In the figure above just to north of Lake Abaya next to alluvial deposits, boreholes in fractured recent basalt in the Bilate military camp falls in the moderate zone in spite of they would be expected to categorize in high potential zone from hydrogeological point of view, may be due to the weathering of basalt with time tends to the formation of secondary minerals that subsequently fill up the primary pores within the rock mass that with time water –transmitting capacity decreases.

The older basalts (Jima volcanic of Pleistocene age), tend to be kindly weathered and have their secondary openings filled by clay minerals that have destroyed their water –transmitting capacities (Zeka[^]I, 1995).

4.5 Limitations

The groundwater potential zone of this study was constructed with available site specific hydrologic data, hydrogeologic and physiographic data of the study area and satellite imagery. The point discharge data would not actually determine the exact potential yield of wells may be due to improper pumping test analysis and under capacity pumps used.

Single step in the process of integrating input parameters may come with uncertainties ranging from data acquisition to model calibration to result visualization, as far as I am concerned, currently lack effective methods to handle and communicate these uncertainties step by step until final results.

The majority of the GIS data sets are currently represented in vector format, which is convenient due to strong efficiency but can be difficult to manipulate analytically. The processes involved in vectorization as well rasterization manifests error in a given GIS system.

5. Conclusion and Recommendation

5.1 Conclusions

- The study has resulted the groundwater potential zone map for the Bilate River catchment which identified and delineated in four categories namely high, moderate, low and poor
- Most of the high potential areas represented by alluvial plains, lacustrine sediments, the fracture valleys, and valley fills, which coincide with the low slope and high lineaments density areas and in contrary zones with poor groundwater potential lie in the mountain ranges where undifferentiated peralkaline Dino formation, obsidian and pitch stone exist.
- It can be concluded that Integrated GIS and remote sensing techniques are very efficient and useful, time and cost effective tool for the identification/delineation of groundwater potential zones.
- Paired Comparison matrix analysis indicates that all parameters are significant but the most effective parameters in the area are: litho logy, geomorphology, lineament density, drainage density and slope.
- Most of area, around 57% zoned under moderate potential and the next high coverage of the area is low potential zone where as only 1% covers the poor potential zone .

5.2 Recommendations

In the light of the findings obtained and conclusions reached the following recommendations are forwarded.

- The present study was based on logical conditions and reasoning, the same method can be used with appropriate modifications where occurrence and distribution of groundwater is more complex.
- The groundwater potential map along with other thematic maps forms serve as resource information database which can be updated from time to time by adding new information.

- For further validation field geophysical investigations on the potential well drilling sites are recommended.
- Detail hydrochemistry analysis study in the area requires due attention to determine hydrodynamic conditions of a basin.
- Filed data indicates that water supply in the study area highly dependent on groundwater sources thus groundwater modeling study is recommended to determine the sustainable exploitations of this resource

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Appendix

Annex 1 Arthetically estimated mean monthly rainfall

Mean Monthly Rainfall In the study Area																
Station	Geo.coordinate		Duration	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
	Easting	Northing														
Bilito	419244	793807	1981 -1990	18.18	80.58	64.86	186.3	106.03	52.88	64.88	76.28	94.38	69.22	40.36	45.38	899.33
HumboTebela	364209	740462	1990 -2009	34.57	31.81	60.55	133.76	149.97	122.27	152.38	153.84	95.1	102.15	46.79	41.44	1124.63
BilateTena	403593	765578	1973 - 2009	32.81	34.52	94.03	124.05	106.24	86.5	111.1	101.58	88.23	93.68	34.52	21.16	928.42
Maykote	385923	770924	1991 -2009	35.68	46.81	94.67	187.66	222.81	150.07	231.66	223.99	115.88	131.31	66.7	37.56	1544.8
Worancha	397966	771325	1995 -2009	36.46	42.33	70.15	135.06	146.61	125.12	109.3	116.51	125.17	147.84	61.87	47.61	1164.03
Abaya	385923	728369	1979 - 1989	19.79	33.26	39.48	89.27	103.1	92.97	85.94	67.45	42.97	38.8	28.6	26.96	668.59
Bensa Daye	395023	741091	1998 - 2009	29.12	22.53	38.43	116.85	138.58	103.38	95.29	111.23	111.55	155.56	74.56	40.18	1037.26
Bilate Agri State	384920	730000	1973 - 2004	29.53	32.65	51.26	97.13	86.69	82.07	97.84	73.27	59.89	74.68	32.68	25.7	743.39
Areka	356419	781248	1988 - 2003	42.19	67.02	105.85	216.31	190.6	162.89	217.22	218.77	186.93	126.23	30.99	30.06	1595.06
Bilate	396852	746143	1971 - 2004	28.52	34.88	49.95	104.18	92.46	84.74	99.3	75.39	62.72	78.89	32.4	23.43	766.86
Boditi School	372888	768077	1976 - 2007	32.09	47.98	103.37	164.33	158.33	125.16	149.69	139.95	109.79	83.92	43.42	38.06	1196.09
Durame	383915	796617	1978 - 2007	26.54	55.23	95.47	146.8	146.8	102.63	132.97	155.24	132.39	93.97	29.43	25.76	1143.23
Fonko	386038	844026	1986 - 2007	31.57	52.08	129.44	162.22	135.07	124.44	164.05	188.2	152	98.26	12.16	26.38	1275.87
Hosana	373677	834025	1978 - 2007	32.47	53.8	104.74	141.84	136.56	121.41	151.25	181.38	145.46	77.91	18.45	26.4	1191.67
Angacha	374532	812196	1987 - 2005	42.5	59.2	119.2	191.5	159.8	133.1	183.6	195.7	187.5	110.9	51.7	29.2	1463.9
Aje	429170	806475	1972 - 1991	23.6	42.2	74.1	86.9	137.4	88.5	131.5	119.7	116.8	62.4	12.3	11	906.4
Shone	384986	789446	1978 - 2007	58.28	81.71	136.64	196.1	182.96	138.63	184.65	212.31	191.59	116.56	46.99	43.19	1589.61
Alaba Kulito	399846	807264	1985 - 2007	35.3	56.21	98.36	152.16	120.17	89.17	112.73	135	114.61	77.96	22.37	23.3	1037.34
Imdiber	382484	899111	1980 - 2007	25.01	27.53	71.99	89.16	96.22	167.79	230.23	214.5	118.98	71.87	12.28	7.87	1133.43
Gunchire	371439	889928	1988 - 2007	29.52	38.14	95.06	101.93	124.78	194.38	258.84	236.62	172.52	78.07	14.89	18.11	1362.86
Wulberg	403587	857638	1978 - 2007	30.35	53.82	104.89	133.52	149.93	154.39	212.32	187.81	163.05	74.56	12.02	12.8	1289.46
Mean Precipitation(mm)				31.68	47.21	85.6	139.29	137.07	122.93	157.7	156.21	124.4	91.55	33.82	27.82	1155.23

Annex 2 Thornthwaite soil water balance of the area

**AET for cultivated land, Moderately deep rooted crops (corn and cereals) and fine sandy loam texture,
Water capacity root zone of 150mm**

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	31.68	47.21	85.6	139.3	137.07	122.9	157.7	156.21	124.4	91.55	33.82	27.82	1155.23
PET	100.90	118.07	117.62	99.85	99.91	83.90	70.34	76.07	85.18	99.09	106.12	105.44	1162.48
P – PET	-69.22	-70.86	-32.02	39.44	37.16	39.03	87.31	80.14	39.22	-7.54	-72.30	-77.62	-7.25
AP WL	-226.7	-297.53	-330.54	0	0	0	0	0	0	-7.54	-79.83	-157.5	-1099.56
S _m	33.11	20.63	16.62	56.06	93.22	132.3	150	150	150	142.72	86.51	52.54	1083.66
ΔS _M	-26.27	-12.48	-4.01	39.44	37.16	39.03	17.75	0	0	-7.28	-56.21	-33.97	-6.84
AET	51.11	59.69	89.61	99.85	99.91	83.9	70.34	76.07	85.18	98.83	90.03	61.79	966.31
SM D	49.79	58.38	28.01	0	0	0	0	0	0	0.26	16.09	43.65	196.18
S	0	0	0	0	0	0	69.56	80.14	39.22	0	0	0	188.92
TAR O	6.04	3.02	1.5	0.75	0.38	0	69.56	114.92	96.68	48.34	24.17	12.01	377.37
RO	3	1.5	0.75	0.38	0.19	0	34.78	57.46	48.34	24.17	12.09	6	188.66
D	3	1.5	0.75	0.38	0.19	0	34.78	57.46	48.34	24.17	12.09	6	188.66

Mean monthly flow of Bilate River @ Bilate Tena (MCM)													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1970	-	-	-	23.91	-	8.73	77.924	95.143	110.276	70.529	-	-	386.512
1971	2.766	2.149	3.162	6.585	11.034	115.539	54.086	44.803	119.884	30.975	22.562	5.781	419.326
1973	3.15	1.558	1.3	3.243	17.816	14.686	32.712	67.311	136.581	74.411	16.809	4.462	374.04
1974	2.136	1.747	9.594	5.846	8.426	8.277	27.638	58.452	75.633	34.729	9.279	2.18	243.94
1975	1.443	1.668	5.615	17.31	12.773	14.508	71.077	98.314	142.342	51.203	0.28	0	416.53
1976	0	0	0.281	0.54	5.186	0.534	7.999	41.048	48.827	6.664	10.578	2.434	124.09
1977	8.343	13.643	7.942	18.826	27.286	42.032	139.022	205.324	247.507	197.676	136.981	19.429	1064.01
1978	3.708	5.792	21.236	10.642	14.453	20.371	97.276	250.168	262.516	184.012	19.414	10.943	900.53
1979	14.126	42.921	28.45	28.874	39.054	36.376	46.551	102.032	113.879	72.467	20.239	4.313	549.28
1980	2.497	3.406	6.028	17.665	62.461	114.587	47.594	-	-	-	-	2.064	256.30
1981	1.47	2.031	79.442	74.916	21.431	13.667	40.437	36.522	166.29	76.775	3.794	1.463	518.24
1983	3.026	6.335	29.169	82.116	111.409	116.848	55.623	206.556	297.184	191.144	39.213	4.49	1143.11
1984	2.563	1.634	1.613	1.688	15.714	18.667	42.572	98.559	125.948	23.523	4.948	3.858	341.29
1985	4.202	1.385	2.79	42.885	88.767	-	-	86.684	63.32	-	-	-	290.03
1986	2.673	9.304	29.114	56.796	104.206	150.77	354.381	366.254	374.715	255.203	203.771	18.43	1925.62
1987	5.418	2.781	7.077	41.15	55.61	127.315	122.413	50.911	42.437	99.286	36.272	3.582	594.25
1989	2.195	24.136	6.921	48.546	31.485	20.055	27.455	42.671	107.609	-	-	-	311.07
1990	-	-	-	-	-	-	-	-	44.983	40.417	17.598	14.198	117.20
1991	8.145	12.637	38.132	16.194	43.732	50.023	44.176	50.295	49.877	16.668	18.865	17.648	366.39
1992	49.857	32.407	31.457	27.105	27.149	50.701	45.175	85.427	148.549	148.648	-	-	646.48
1998	-	-	-	-	26.175	18.271	29.629	122.226	62.672	58.777	17.766	8.183	343.70
1999	6.325	4.054	10.648	7.431	10.742	16.226	38.191	39.738	57.404	122.484	25.221	8.043	346.51
2000	5.558	4.113	3.774	13.531	35.894	14.592	20.953	40.306	35.852	55.596	19.702	12.938	262.81
2001	9.325	6.804	23.529	14.155	26.421	26.29	35.972	33.135	47.117	33.313	12.776	7.986	276.82
2002	6.982	10.012	27.195	18.408	14.977	14.268	15.774	32.557	26.091	14.282	9.769	14.251	204.57
2003	17.046	11.961	12.63	25.704	15.128	19.223	20.658	28.662	36.947	-	-	-	187.96
2004	-	-	9.286	27.112	19.097	20.365	61.608	67.505	46.952	50.191	9.795	8.002	319.91
2005	9.488	7.67	14.307	38.613	67.889	21.484	50.831	64.462	50.436	33.722	18.216	8.765	385.88

Mean monthly flow (MCM)	7.19	8.76	16.43	25.76	35.17	41.32	61.84	92.89	112.66	80.95	30.63	7.98	521.58
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Annex 3 Mean monthly flow of Bilate River at Bilate Tena

Annex 4 Water Point Inventory data

No	Woreda	Kebele	Source	Easting(m)	Northing(m)	Elev.(m)	Depth (m)	SWL (m.a.s.l)	Yield(m/s)	Water elev(m)
1	Alaba	U/Tuqa	DBH	407942	819799	1935	286.5	254.7	2.5	1680.3
2	Alaba	Kulufo	DBH	407117	822518	1912	220	177.13	4	1734.87
3	Alaba	Besheno	DBH	414866	824656	1999	300	266.65	1.83	1732.35
4	Alaba	Eleloqa	DBH	397150	818125	1812	195	139	3	1673
5	Alaba	1st Choroqo	DBH	400933	810493	1793	183.5	104.15	6	1688.85
6	Alaba	Qulito	DBH	399055	808866	1772	154	85.1	5.1	1686.9
7	Alaba	Qulito	DBH	398725	808936	1786	147	81.95	4.1	1704.05
8	Alaba	Qulito	DBH	398840	807421	1759	144	94	4.1	1665
9	Alaba	Alaba town, health cent	DBH	399403	808431		154		5.6	
10	Alaba	Alaba town, kera	DBH	398453	808456		141	94	8.3	1678
11	Alaba	Alaba town, water off	DBH	399542	807414		144	86	7	1692
12	Alaba	Choroko	DBH	401016	810693		183.5	104	6	1689
13	Alaba	Alem tena	DBH	402079	814106		230		3.5	
14	Alaba	Kerenso	DBH	397653	801799		180	105	8	1665
15	Alaba	Elo- luka	DBH	398696	817387		195	139	6	1706
16	Alaba	Kulifo shedger	DBH	406989	822810		220	177.1	3.5	1712
17	Alaba	Bercho kulifo	DBH	408578	826654		270	182.6		1751
18	Alaba	Bonesha kore	DBH	403600	828065		236	155.6	4.5	1749
19	Alaba	Alem gebeya , bonesha	DBH	410022	836292		152	105		1695
20	Alaba	Gendela, damboya	DBH	393153	816091		193	127		1813
21	Alaba	Second mekala, alaba	DBH	405856	803711		262	196.5	3	1596
22	Alaba	Ashoka	DBH	404229	800161		217	158.4	4	1602
23	Alaba	Guba felka	DBH	410860	803207		362	268	2	1597
24	Alaba	Gutancho	DBH	403500	831782		220	177	6.25	1778
25	Alaba	Lower linda	DBH	404591	811234		219	167	3.8	1662
26	Alaba	Hamata	DBH	404600	811234		220		0.5	
27	Alaba	Debeso	DBH	415328	805148		324	294	3	1599
28	Alaba	Yaye shuwako	DBH	418721	805131		360	273	2.8	1530
29	Alaba	Upper Linda well#2	DBH	404282	809022		253	192.25	5.2	1610
30	Alaba	Besheno	DBH	415292	824381		320	267	4.5	1722
31	Alaba	Gofessa	DBH	414388	809236		328	242.7	4	1622
32	Alaba	Ajo huliko	DBH	426056	837671		180	65.5	7.3	
33	Alaba	Bedene	DBH	402302	821036		220	124.3	9.8	1692
34	Dalocha	Simbita	DBH	414417	835857		117	28.8	7.3	1909.6
35	Dalocha	Upper tuka not true data	DBH	409800	814100		285			2011.6
36	Dalocha	Teffo	DBH	418064	812454		317			2049.2
37	Dalocha	Ambericho Gimba	DBH	396810	847700		150	98.75		1966.25
38	Sankura	Getem Gurbaye	DBH	405258	840627		186	128		1815
39	Sankura	Bercho Kulfo	DBH	408565	826559		270	182.6		1727.4
40	Sankura	Gutancho	DBH	403494	831512		210	152.12		1779.88
41	Sankura	Kore (Bonesha Kore)	DBH	403664	827808		236	155		1753
42	Sankura	Hergedina Mazoria	DBH	403963	823095		180	110.75		1730.25

Annex 5 Water Point Inventory data

43	Shashego	Alage	DBH	399094	827908		119	83		1816
44	Shashego	Bonesha Wanchikota	DBH	397867	830788		86	17		1883
45	Shashego	Doisha Hule	DBH	402651	835554		158	118.2		1850.8
46	Demboya	Damboya 01	DBH	383279	810877		300	228.4		1940.6
47	Demboya	Hego	DBH	382198	808182		284	181.65		1927.35
48	Sankura	Gumbi Feten	DBH	410487	833037		204	142.52		1742.48
49	Doyo Gena	Doyo Gena Town	DBH	363355	811819		200	35.2		2263.8
50	Lemo	Hosaina town	DBH	375262	836761		200	132.5		2129.5
51	Lemo	Kalisha	DBH	375410	831143		189	130.8		2129.2
52	Lemo	Lisana	DBH	381012	831847		157	89.21		2076.79
53	Lemo	Fonko	DBH	385674	845578		139	74		2176
54	Lemo	Fonko	SW	386196	845921		149	111		2122
55	Shashego	Hirko Fofo	SW	384391	820769		57	12.3		1917.7
56	Shashego	Hirko Fofo	SW	385457	821190		48	4.2		1902.8
57	Shashego	Afto Uterancho	SW	388219	823653		54	4.5		1903.5
58	Shashego	Golicho Boyo(well#4)	SW	390701	824093		50	7		1898
59	Shashego	Doisha Ambericho	SW	396945	840676		46	21		1911
60	Shashego	Doisha Ambericho	SW	396955	841151		46	18		1909
61	Shashego	Doisha Amberich	SW	396864	841786		46	18		1929
62	Shashego	Doisha town	SW	396971	839360		39	10		1915
63	Shashego	Doisha town	SW	396970	839035		40	11		1907
64	Shashego	Doisha Ambericho	SW	398048	840493		42	14		1909
65	Shashego	Beche Gola	SW	397275	834657		35	8		1905
66	Shashego	Beche Gola	SW	397509	836214		33	9		1907
67	Demboya	Hamancho	SW	380496	811701		53	10.8		2156.2
68	Demboya	Hamancho	SW	381496	811675		79	67		2092
69	Angecha	1st Angecha & Ke'lama	SW	375034	813821		81	45		2145
70	Angecha	Hobicho Miliso	SW	375819	819808		51	21		2062
71	Angecha	1st Angecha & Ke'lama	SW	376894	819378		75	57		1991
72	Angecha	Hobicho Miliso	SW	375639	819314		65	49		2041
73	Doyo Gena	Wunjela	SW	373029	825466		63	19		2188
74	Angecha	Bucha	SW	377705	814550		70	42		2118
75	Lemo	Bobicho	SW	372170	837610		63	39		2231
76	Lemo	Bobicho	SW	373265	839600		62	33		2276
77	Lemo	Ana Limu	SW	386220	838319		60	30		2351
78	Lemo	Hankgela Senfe	SW	386916	846061		56	32.5		2120.5
79	Lemo	Kidigisa	SW	374864	838210		81	34		2256
80	Lemo	Kidigisa	SW	374955	841764		58	32		2287
81	Lemo	Kidigisa	SW	374588	842898		75	52		2295
82	Lemo	Kidigisa	SW	374048	843353		62	43		2290
83	Lemo	Kidigisa	SW	373555	839631		69	34		2272
84	Lemo	Lefto Lenka	SW	387776	848148		78	52.15		2058.85
85	Lemo	Lembuda	SW	372018	842250		52.2	19		2313
86	Lemo	Lembuda	SW	370709	841682		63	30		2352

Annex 6 Water Point Inventory data

87	Lemo	Lembuda	SW	369964	841754		79	59.8		2358.2
88	Lemo	Lisana Sena	SW	380237	836029		51	22.5		2129.5
89		Dulacha Belela	SW	395542	846076		78.5		1	
90	Lemo	Mento Akebela	SW	396229	845563		33	7		1974
91	Lemo	Mento Akebela	SW	393338	844757		72.5		2	
92	Lemo	Mento Akebela	SW	394759	845030		62	40		1953
93	Lemo	Sheshe Gimba	SW	393674	851433		70	45.8		2004.2
94	Lemo	Mesena Bako	SW	367819	826806		80	60.8		2078.2
95	Lemo	Tachignaw Ambicho	SW	377016	833345		84	69		2148
96	Lemo	Tachignaw Ambicho	SW	377604	829973		74	52.5		2082.5
97	Misha	Was Gebeta	SW	366318	843654		96	62		2400
98	Lemo	Sheshe Gimba	SW	390733	850293		70	1.35		1998.65
99	Lemo	Denfa	SW	393752	848772		80	58.06		1981.94
100	Lemo	Hongolame	SW	374090	838472		51	24.2		2272.8
101	Lemo	Harbucho	SW	377863	843078		63	42.08		2308.92
102	Lemo	Guder fofate	SW	377908	840303		70	34.25		2269.75
103	Lemo	Dakaye	SW	376000	844016		81	58.8		2286.2
104	Lemo	Belela	SW	392282	849451		63	19.19		1990.81
105	Lemo	Site 2	SW	393752	848772		87	47.6		2080.4
106	Lemo	Duna	SW	393198	847668		72	45.7		1997.3
107	Misha	Santo	SW	368628	844459	2510	80	47.6	1.5	2462.4
108	Misha	Moristo	SW	369702	850791	2615	70	37.7	1.5	2577.3
109	Misha	Moristo/Keleda	SW	369899	849837	2581	57	16.65	2	2564.35
110	Shashego	Shemo Boyo	SW	388671	831746		40	3		1897
111	Shashego	Ajacho Boyo	SW	390717	833370		45	19		1893
112	Shashego	Biramora Kemo	SW	394420	835135		43	16		1907
113	Shashego	Biramora Kemo	SW	395080	838470		43	14.5		1910.5
114	Shashego	Doisha Belaye	SW	395080	838486		43	18		1906
115	Shashego	Doisha Belaye	SW	395640	840360		40	17.4		1912.6
116	Shashego	Mololicho	SW	384741	825452		7.5	3		1907
117	Shashego	Suta	HDW	386645	827094		7	0.95		1908.05
118	Shashego	Golocho Boyo	HDW	389402	825311		6	1		1899
119	Shashego	Golocho Boyo	HDW	389143	825973		6	1		1900
120	Shashego	Urbecha	HDW	383047	823021		7	4		1900
121	Shashego	Afto Uterancho	HDW	387722	823762		9	3.5		1903.5
122	Shashego	Golocho Boyo	HDW	390993	825079		11	5		1895
123	Shashego	Golocho Boyo	HDW	391993	824075		11	5		1896
124	Shashego	Sheyembe Wanchikota	HDW	398360	832630		14	12		1887
125	Shashego	Sheyembe Wanchikota	HDW	398731	833527		16	13		1895
126	Shashego	Sheyembe Wanchikota	HDW	398731	833827		16	14		1894
127	Demboya	Geremba	HDW	379751	811243		7	5.45		2226.55
128	Kedida Gemila	Kerchicho	HDW	380878	804315		22	17		2088
129	Kedida Gemila	Durame 08	HDW	380093	803146		24	8		2089
130	Angecha	Bondena	HDW	372223	809187		18	9		2375

Annex 7 Water Point Inventory data

131	Angecha	Bondena	HDW	372310	809436		15.5	13		2367
132	Angecha	Kerekicho	HDW	373319	813523		10	5		2252
133	Angecha	Gede Genet	HDW	374897	823305		13	9		2125
134	Angecha	Shino Funomura	HDW	373156	818544		24	14		2165
135	Angecha	Shino Funomura	HDW	373271	816411		14	10		2168
136	Angecha	Shino Funomura	HDW	373478	815926		13	7		2171
137	Doyo Gena	Wunjela	HDW	373029	825466		16	8		2199
138	Doyo Gena	Dinika	HDW	372753	821990		13.5	7		2171
139	Doyo Gena	Murasa Woiram	HDW	367437	818615		23	13		2260
140	Shashego	Mololicho	HDW	386013	828572		8	4		1891
141	Lemo	Dubanco	HDW	376580	839387		8	4		2320
142	Shashego	Jello Adancho	HDW	383037	820444		8	4		1915
143	Shashego	AlageGimbichu1	DBH(dry)	40008	823627		158		dry	
144	Shashego	alageGimbichu2	DBH(4.5)	400009	823627		220	121.5	4.5	
145		Hossana #5	DBH	380313	837958			132.5	8.8	
146		Lisana	DBH	381014	831845			89.21	6	
147		Kalisha	DBH	375411	836136			130.8	8.8	
148		Bedene	SW	420171	828642			124.3	9.8	
149		Lemo Belela	SW	392282	849451			19.19	1.01	
150		L/Hongolam	SW	374090	838472			24.2	0.81	
151		Alaba Feleka	DBH	410787	802987			267.9	2.2	
152		Lemo Duna	SW	393198	847668			45.7	0.861	
153		Alaba	DBH	405856	863711			196.5	3	
154		Shurmo	DBH	377288	845381			110	5	
155		Lera T/W/S	DBH	379554	854853			26.1	5	
156		Hule Gutancho	DBH	405281	831914			118.2	6.25	
157		Bonosha Kore	DBH	403664	827808			155.7	4.5	
158	Lemo	Kidigisa	SW	373907	842115			41.1	6	
159		Harbucho	SW	377863	843078			42.08	0.56	
160	Bilate Military caump	8A	DBH	396010	746208	1480	89	50	3.3	1430
161	Bilate Military caump	6D	DBH	396682	746187	1289	120	39.45	3	1249.55
162	Bilate Military caump	3G	DBH	397000	747120	1288	105	36.1	4.5	1251.9
163	Bilate Military caump	2F	DBH	397254	747404	1291	56	31.1	3	1259.9
164	Bilate Military caump	10J	DBH	396709	747013	1292	120	63.83	5	1228.17
165	Bilate Military caump	4H	DBH	396970	746838	1287	108	41.67	4	1245.33
166	Bilate Military caump	7B	DBH	396327	746522	1288	118	56.53	5	1231.47
167	Bilate Military caump	1I	DBH	397113	747744	1303	71		3.5	
168	Dugna Fango	Dimtu	Hot Spring	403731	766422					
169	Dugna Fango	Dimtu	Hote spring	403731	766422					
170	Dugna Fango	Tobacco Monopol	Hot Spring	399510	753493					
171	Dugna Fango	Tobacco Monopol	Hot Spring	399550	753353					
172	Humbo	Chokare	Hot spring	379351	733461					

Annex 8 Water Point Inventory data

173	Humbo	Chokare	Hot Spring	380409	734555					
174	Humbo	Chokare	Cold Spring	382492	732186					
175	Dugna Fango	Dimtu	HDW	403892	766001					
176	Dugna Fango	Fango Bijo	HDW	399676	760140					
177	Dugna Fango	Fango Bijo	HDW	398894	759329					
178	Humbo	Abaya gurucho	HDW	382735	730116					
179	Humbo	Abaya gurucho	HDW	382772	729903					
180	Humbo	Abaya gurucho	SW	382063	730688					
181	Dugna Fango	Bilate camp	DBH	397117	747746					
182	Dugna Fango	Bilate camp	DBH	397106	747116					
183	Dugna Fango	Bilate camp	DBH	396327	746534					
184	Dugna Fango	Bilate camp	DBH	396710	747017					
185	Dugna Fango	Chokare	Swamp area	379351	733461					
186	shashego	AlageGimbichu	DBH1(dry)	401266	825552		158			dry
187	Shashego	AlageGimbichu	DBH	400009	823627		220	121.5	4.5	
188	Alaba	Lenda1	DBH1(dry)	406258	808275		300(dry)			dry
189	Alaba	Andegna Ansha	DBH	408839	809169		280?			
190	Boricha	Konsore Warke	DBH	6,53'51"	3821'39"		203	94.7	4.4	
191	Boricha	Konsore Arke	DBH	430042	763598		105			
192	Boricha	Konsore Arke	DBH	429410	762471					
193	Boricha	Buko	DBH				192	73.44	5	
194	Boricha	Konsore Fulassa	DBH(dry)	426996	764411		300(dry)			dry
195	Boricha	Karbo	DBH	653000	382319		126	47.5	5	
196	Loke Abaya	Desse	DBH	424178	742349		141	0.5	6.5	
197	MisrakBedawacho	TikareAnbase	DBH	393594	792394	1995	208	144.7	3.5	1850.3
198	MisrakBedawacho	Langano	DBH	394073	788126	1697	216		6	
199	MisrakBedawacho	Lenda	DBH	394730	797026	1708	198		4.76	
200	MisrakBedawacho	1 st Chefa	DBH	392085	797026		223		3.8	
201	MisrakBedawacho	Mehal Korga	DBH	391020	784849	1748			2.05	
202	MisrakBedawacho	Kenchera	DBH	385956	790273	1950	216(pp)		2.1	
203	MisrakBedawacho	Edo	DBH	395463	795334	1749	225	219(pp)	3.7	
204	MisrakBedawacho	Bentawosen1	DBH(dry)	387786	794584	1945				dry
205	MisrakBedawacho	bentawosen2	DBH(6.25)	388614	795312	1900	241	134.2	6.25	
206	MisrakBedawacho	2nd Keranso	DBH	399425	799873		180		8	
207	MisrakBedawacho	Buligita	SW	380634	786789		36		0.3	
208	MisrakBedawacho	Buligita	SW	381961	786716		52			
209	MisrakBedawacho	Buligita	SW	381764	787391		36			
210	MisrakBedawacho	Buligita	SW	381565	787237		90			
211	MisrakBedawacho	Buligita	SW	382586	788368		45			
212	MisrakBedawacho	GereBuligita	SW	380306	788159		42			
213	MisrakBedawacho	Mehal Jariso	SW	379041	788734		25			
214	MisrakBedawacho	Mehal Jariso	SW	378371	787874		24			
215	MisrakBedawacho	Mehal Jariso	SW	379031	785739		32			
216	MisrakBedawacho	Mehal Jariso	SW	376764	788278		58			

Annex 9 Water Point Inventory data

217	MisrakBedawacho	Mehal Jariso	SW	380069	787867		55			
218	MisrakBedawacho	wera Gere	SW	382973	790060		94			
219	MisrakBedawacho	wera Gere	SW	381660	790659		60			
220	MisrakBedawacho	wera Gere	SW	382506	791771		40			
221	MisrakBedawacho	Jarso Kutube	SW	379315	789657		26			
222	MisrakBedawacho	Jarso Kutube	SW	380234	790115		32			
223	MisrakBedawacho	Jarso Kutube	SW	380214	790977		40			
224	MisrakBedawacho	Jarso Kutube	SW	378120	791278		45			
225	MisrakBedawacho	Jarso Kutube	SW	378300	789270		33			
226	MisrakBedawacho	Jarso Kutube	SW	379757	788731		42			
227	MisrakBedawacho	Jarso Kutube	SW	379491	790456		43			
228	MisrakBedawacho	Jarso Kutube	SW	379252	791380		40			
229	MisrakBedawacho	Jarso Hadena	SW	377564	786493		40			
230	MisrakBedawacho	Jarso Hadena	SW	375703	786101		26			
231	MisrakBedawacho	Ajeba Elala	SW	379133	791833		28			
232	MisrakBedawacho	Mehal Jariso	SW	379363	788029		33			
233	MisrakBedawacho	WeramoBonkoya	DBH	397539	778956		48		4.9	
234	MisrakBedawacho	Woldiya	DBH	394325	786370		181		3.8	
235	MisrakBedawacho	Bentwosan	DBH	388614	795312		241	134.5	6.41	
236	MisrakBedawacho	shone02	DBH	383897	788723		182		5	
237	MisrakBedawacho	Shone Mazoira	DBH	384779	794200	2011	244		6.5	
238	MisrakBedawacho	Weyra Lalo	DBH	384162	791779		138		1.5	
239	MisrakBedawacho	GereBulgita	DBH	381190	789256		101		3.17	
240	MisrakBedawacho	Weyra Boshera	DBH	382199	793158		235		5	
241	MisrakBedawacho	Gegera	DBH	398664	796357		214	169	7	
242	MisrakBedawacho	LaloGarbe	DBH	384252	787785		145			
243	MisrakBedawacho	Shone01	DBH	384319	788244		178		5	
244	MisrakBedawacho	Abuka	DBH	391860	788696				4	
245	MisrakBedawacho	Jerso Hadena	DBH	378471	786550		108		2	
246	MisrakBedawacho	Ajba Borara	DBH	380260	795426		199		3.5	
247	MisrakBedawacho	Adilo town(1)	DBH	387565	796586	249	174.3	6.4		
248	MisrakBedawacho	KorgaBashilo	DBH	391348	783053	1745	248	100.37	6.2	1644.63
249	Kedida Gemila	Bezena Benara	DBH	376110	796780	1950	206	59.36	10	1890.64
250	Kedida Gemila	Geshgola	DBH	386453	796989	1930	236	181.4	3.3	1748.6
251	Kedida Gemila	Jore	DBH	381095	797145	2021	296	164.75	6.45	1856.25
252	Kedida Gemila	Tezaagera	DBH	380757	803110	2097	194	88.4	7	2008.6
253	Kedida Gemila	Holegaba	DBH	392567	804863		135	64.4	6	-64.4
254	Kedida Gemila	Durame town 01	DBH	377591	799521	2024	240		3	2024
255	Kedida Gemila	Abonsa	DBH	381286	796728	2014	260	159.02	6.67	1854.98
256	Kedida Gemila	Bezena Benara	SW	376551	799047		80			
257	Kedida Gemila	Bezena Benara	SW	376146	798074		61			
258	Kedida Gemila	Bezena Benara	SW	374439	797989		67			
259	Kedida Gemila	Bezena Benara	SW	375682	795895		76			
260	Kedida Gemila	Bezena Benara	SW	375255	798792		60			
261	Kedida Gemila	Bezena Benara	SW	376146	798074		61			

Annex 10 Water Point Inventory data

262	Kedida Gemila	Bezena Benara	SW	375949	796876		93		
263	Kedida Gemila	Zeto shodora	SW	378486	797440		36		
264	Kedida Gemila	Zeto shodora	SW	376769	799938		29		
265	Kedida Gemila	Zeto shodora	SW	376435	800282		39		
266	Kedida Gemila	Zeto shodora	SW	376712	799723		45		
267	Kedida Gemila	Jore	SW	382027	796902		70		
268	Kedida Gemila	Jore	SW	381051	798320		87		
269	Kedida Gemila	Jore	SW	381148	797496		69		
270	Kedida Gemila	Jore	SW	381052	798184		67		
271	Kedida Gemila	Teza Agara	SW	380782	803447		87		
272	Kedida Gemila	Teza Agara	SW	381193	801058		62		
273	Kedida Gemila	Teza Agara	SW	380675	800579		27		
274	Kedida Gemila	Abonsa	SW	381255	797016		75		
275	Kedida Gemila	Abonsa	SW	381207	797250		75		
276	Kedida Gemila	Kerchicho	SW	380782	803447		87		
277	Kedida Gemila	Kerchicho	SW	381357	803718		75		
278	Kedida Gemila	Kerchicho	SW	381504	803861		60		
279	Kedida Gemila	Azedobo	SW	374384	800016		85		
280	Kedida Gemila	Azedobo	SW	374119	797760		23		
281	Kedida Gemila	Azedobo	SW	373437	799290		52		
282	Kedida Gemila	Azedobo	SW	373979	800309		32		
283	Kedida Gemila	Azedobo	SW	374224	799364		58		
284	Kedida Gemila	Azedobo	SW	373955	798669		58		
285	Kedida Gemila	Azedobo	SP	374912	800887				0.46
286	Damboya	Yebu	DBH	382467	807036		251	134(pp)	5.8
287	Damboya	Hego	DBH	382300	808390		330		5.2
288	Damboya	Gendela	DBH	393248	816298		162		4.16
289	Damboya	Geyota Gerba	DBH	382734	809716		223		2.2
290	Damboya	Geyota Gerba	DBH(dry)	383176	810121		321(dry)		dry
291	Damboya	Damboya 01	DBH	383373	811086		300		4.5
292	Damboya	Hamancho	SW	379075	811684		93		
293	Damboya	Hamancho	SW	380524	811854		52		
294	Damboya	Hamancho	SW	380588	811909		51		
295	Damboya	Hamancho	SW(dry)	379761	814615		80(dry)		dry
296	Damboya	Kotatombola	SW	377693	813633		74		
297	Damboya	Kotatombola	SW	378183	812833		84		
298	Damboya	Kotatombola	SW	378654	813128		93		
299	Damboya	Kotatombola	SW	379737	816570		82		
300	Damboya	Kotatombola	SW	379901	817191		82		
301	Damboya	Geyota Ambarcho	SW	378541	809842		48		
302	Damboya	Geyota Ambarcho	SW	378588	809173		57		
303	Damboya	Geyota Ambarcho	SW	378798	810180		47		
304	Damboya	Geyota Ambarcho	SW	378671	809598		42		
305	Damboya	Bonga	SW	381565	806666		75		
306	Damboya	Bonga	DBH	381658	806656		260		6

Annex 11 Water Point Inventory data

307	Damboya	Kazala	SP	384801	810392			2	
308		Megere	DBH	390455	818850		154	69.5	8.15
309	Damboya	Wondo	SP	389913	812661				0.45
310	Damboya	Hego	SP	384497	810257				1
311	Damboya	Geyota Gerba	SP	383563	813743				0.15
312	Angecha	Boldana	SW	371130	807684		56		
313	Angecha	JebaDodoba	SW	372261	816489		58		
314	Angecha	JebaDodoba	SW	371151	814431		43		
315	Angecha	JebaDodoba	SW	372300	815712		40		
316	Angecha	Kelama	SW	377334	820786		48		
317	Angecha	Kelama	SW	376429	818246		40.6		
318	Angecha	Kelama	SW	376988	819581		75		
319	Angecha	Kelama	SW	375127	814029		82		
320	Angecha	Hobicho Miliso	SW	375732	819521		65		
321	Angecha	Hobicho Miliso	SW	377751	821246		52.2		
322	Angecha	GerbaFanideda	SW	370568	807579		29		
323	Angecha	Bucha	SW	378525	814573		82		
324	Angecha	Bucha	SW	379278	818279		55		2.5
325	Angecha	Bucha	SW	378986	817908		69.6		2
326	Angecha	Bucha	SW	377308	814434		52		
327	Angecha	Bucha	SW	378877	815464		58		1.5
328	Angecha	Bucha	SW	379070	817634		87		
329	Angecha	Gubana Hambricho	SW	376890	815537		57		
330	Angecha	Gubana Hambricho	SW	376974	815574		70		
331	Angecha	Mesena	SW	370474	811916		49		
332	Angecha	mesena	SW	371564	812878		40.6		
333	Angecha	Gede Genet	SW	374651	822101		74.6		
334	Angecha	Gede Genet	SW	375495	824560		52.2		
335	Angecha	Gede Genet	SW	375928	822518		65		
336	Angecha	GedeloGawada	SW	369876	813318		37		
337	Angecha	Angecha town 01	DBH	374655	813261		176	114.8	6
338	Angecha	Adanicho	SW	379975	819616		40		
339	Angecha	GedeloGawada	SP	369227	809856				0.15
340	Angecha	Mesena	SP	371389	811380				0.5
341	MirabBedawacho	Denenma 01	SW	372572	786931				
342	MirabBedawacho	SIBEYA	SW	376506	791344		10		0.5
343	MirabBedawacho	WOBERA	SW	374230	790000		80		0.5
344	MirabBedawacho	Wobera	SW	375075	791106		36		0.29
345	MirabBedawacho	Wobera	SW	375189	790297		42		0.37
346	MirabBedawacho	Wobera	SW	734188	791175		36		0.2
347	MirabBedawacho	J/mezoria	SW	377115	789454				0.28
348	MirabBedawacho	J/mezoria	SW	376030	790172		32		0.3
349	MirabBedawacho	J/mezoria	SW	377708	791178		62		0.34
350	MirabBedawacho	Deda	SW	373553	787508				0.2
351	MirabBedawacho	Deda	SW	373145	786946				0.33

Annex 12 Water Point Inventory data

352	MirabBedawacho	DANEMA	SW	373770	791107				0.4	
353	MirabBedawacho	Danema	SW	373671	791006				0.33	
354	MirabBedawacho	Danema	SW	373637	791019				0.31	
355	MirabBedawacho	Danema	SW	372476	390930				0.39	
356	MirabBedawacho	Danema p..A	SW	372576	786935		36			
357	MirabBedawacho	Yabukuna	SW	378422	785167					
358	MirabBedawacho	Wada 0.1	SW	367304	789720		85			
359	MirabBedawacho	SIBEYA	SW	377533	792770		63.7	32		
360	MirabBedawacho	Denema 01	SW	7922310	373451					
361	MirabBedawacho	Haworra	SW	787963	361577		87.78	30		
362	MirabBedawacho	Elfata	SW	796072	374812		77.42	43.28		
363	MirabBedawacho	Deda	SW	786209	372671		88.39	43.28		
364	MirabBedawacho	Wobera	SW	790396	374812		39	10		
365	MirabBedawacho	J/onjojo	SW	787461	375601		34.75	11.6		
366	Damote Woyde	J/Mazoria	SW	789300	375864					
367	Damote Woyde	Degaga Lenda # 1	SW	385499	765347		58		1.5	
368	Damote Woyde	. Degaga Lenda # 2	SW	386234	766466		84		1.5	
369	Humbo	Degaga Lenda # 3	SW	385763	765970		48.3		2	
370	Humbo	Bosa Wancha # 1	SW	366523	749235		52		4	
371	Silte	Sochora Osa # 1	SW	360257	747272		86		1.5	
372	Arekit	Bilalo	SW	377124	853173		62			
373	Alicho	Abzana 1	SP	404565	876288				0.2	
374	Alicho	Abzana 2	SP	403938	875818				0.08	
375	Alicho	Adazer Shebel	SP	398782	870084				0.2	
376	Alicho	Adazr Abecho	SP	396392	872666					
377	Alicho	Adazr Abecho	SP	396490	872948					
378	Alicho	Adazr Abecho	SP	396978	873520				0.2	
379	Alicho	Adazr Abecho	SP	387231	873699				0.2	
380	Alicho	Adazr Abecho	SP	399491	873888					
381	Alicho	Adyo	SP	410512	892705				8.5	
382	Alicho	Adyo	SW	412614	893420		85			
383	Alicho	Adyo	SW	415439	893524					
384	Alicho	Adyo	SP	416932	893830				0.24	
385	Alicho	Edo	SP	413607	885208				0.9	
386	Alicho	Edo	SP	415063	885946				0.1	
387	Alicho	Enfigne	SP	413936	889327				0.3	
388	Alicho	Enfigne	SP	414680	889115				0.02	
389	Alicho	Ficharie	SP	413911	887138				0.01	
390	Alicho	Gedrat	SP	404365	879600				0.08	
391	Alicho	Gedrat	SP	404370	879622					
392	Alicho	Gedrat	SP	413096	884896				0.23	
393	Alicho	Gugso	SP	416712	897332				0.5	
394	Alicho	Gugso	SP	415619	896057				0.7	
395	Alicho	Gugso	SP	416098	896637				0.03	
396	Alicho	Kereso	SP	416310	891997					

Groundwater Potential Evaluation Based on Integrated GIS and Remote sensing Techniques, in Bilate River Catchment,

397	Alich	Ketucha	SP	404823	772485				1.5	
398	Alich	Lemlem 1	SP	403572	870737				0.08	
399	Alich	Lemlem 3	DBH	400527	871244		205			
400	Alich	Shomo	SP							
401	Alich	Shomo	SP	399797	877333				0.3	
402	Alich	Shomo	SP	400116	878092					
403	Alich	Shomo	SP	400850	875056					
404	Alich	Shomo	SP	401689	879096				0.08	
405	Alich	Shomo	SP	401841	879186				0.15	
406	Alich	Tanzhie	SP	407286	883579				1.5	
407	Alich	Tanzhie	SP	408619	884800				1.5	
408	Alich	Shelemat & Kechamo	SP	410126	882068				4	
409	Azernet Berbere	AMB GIMBA	SP	410126	882068		62			
410	Azernet Berbere	AMB GIMBA	SW	397083	845948		62			
411	Azernet Berbere	AMB GIMBA	SW	394760	845028		33			
412	Azernet Berbere	AMB GIMBA	SW	396231	845566		151			
413	Azernet Berbere	ANFAR	DBH	396954	847896					
414	Azernet Berbere	BILALO	SP	380911	860490					
415	Azernet Berbere	DEBELA	SP	384872	860458				0.2	
416	Azernet Berbere	DUNA	SP	378234	850665				0.02	
417	Azernet Berbere	JERAMosenBOYE	SP	381765	855095					
418	Azernet Berbere	JIRO	SP	380787	857805				0.04	
419	Azernet Berbere	JIRO	HDW	383374	852924					
420	Azernet Berbere	JIRO	HDW	383585	854385					
421	Azernet Berbere	JIRO	HDW	384107	854058					
422	Azernet Berbere	KECHA CHUMETA	SP	384494	853175				0.64	
423	Azernet Berbere	KECHA CHUMETA	SP	375492	856381					
424	Azernet Berbere	MEHALMUGO	DBH	376060	855761					
425	Azernet Berbere	MEHALMUGO	SP	383913	867417				0.05	
426	Azernet Berbere	MEHALMUGO	SP	383899	866296				0.5	
427	Azernet Berbere	MEHALMUGO	SP	384603	867659		18		0.22	
428	Azernet Berbere	MUGO	HDW	384396	867050		30			
429	Azernet Berbere	MUGO	SW	388145	866706		30			
430	Azernet Berbere	MUGOTERARA	SW	388421	866629					
431	Azernet Berbere	MUGOTERARA	SP	386575	864700				2.24	
432	Azernet Berbere	MUGOTERARA	SP	386828	866628				1.14	
433	Azernet Berbere	WESTMUGO	SP	387134	865523				0.42	
434	Azernet Berbere	Dulancho	SP	381678	867980				0.7	
435	Azernet Berbere	School/Lera	SW	393308	847913				0.2	
436	Azernet Berbere	Shebel	DBH	379627	855979				3.3	
437	Azernet Berbere	Lera town	SW	377942	856306				0.2	
438	Dalocha	Berchet	SP	413015	871489				0.12	
439	Dalocha	Burka	SP	414532	863503				16	
440	Dalocha	Chanche & Magor	SP	402668	856377				2	

Annex 13 Water Point Inventory data

441	Dalocha	Dalocha Bédget	DBH	418241	860616		150		3	
442	Dalocha	Enkate Agame	DBH	417916	849306		90		4	
443	Dalocha	Fuce Achray	PSS	412044	872036					
444	Dalocha	Fuge & Acheraye	DBH	406964	863386				4.16	
445	Dalocha	Germama Gale	SW	414303	866934		90			
446	Dalocha	Gole Chebe	DBH	436155	862997		140			
447	Dalocha	Hulbarag	DBH	402994	855506		70		2.42	
448	Dalocha	Hulbarag	PSP	403414	855821				0.2	
449	Dalocha	Kure Kolessa	DBH	411926	869329		177		3	
450	Dalocha	Nadugne Lola	DBH	415507	853618		150		3	
451	Dalocha	Obiso Wacho	SW	400558	865973				1	
452	Dalocha	Obiso Wacho	SW	401079	853126				1	
453	Dalocha	Obiso Wacho	SW	402593	855078		79			
454	Dalocha	Wana Dange	DBH	405941	836341					
455	Dalocha	Dalocha	DBH	408661	826762				6	
456	Sankura	Bercho Kulufo	DBH	405353	840834					
457	Sankura	Getem Gurbade	DBH	408148	837902				4	
458	Sankura	Getem Gurbe	DBH	403591	831718		180			
459	Sankura	Gutancho	DBH	409718	843082		280			
460	Sankura	Gutencho	DBH	411822	840735					
461	Sankura	Jabicho lemlem	DBH	407573	831161		175			
462	Sankura	Kemo	DBH	403750	828026		177			
463	Sankura	Kore	DBH	410567	833247		250			
464	Sankura	Kulufo Shadger	DBH	404057	823306					
465	Sankura	Menzo Gumbe	DBH	409686	836778		265			
466	Sankura	Regdina	DBH	610457	773866		130			
467	Sankura	Zeko Dololo	DBH	610457	773866		150			
468	Sankura		DBH	610457	773866				2.66	
469	Sankura		DBH	610457	773866				3	
470	Ezha	Weyra Ber	DBH	408996	891141		142	20.3	5.4	
471	Merab Bedawacho	Wada 0.1	SW	367304	789720					
472	Merab Bedawacho	SIBEYA	SW	377533	792770					
473	Merab Bedawacho	Denema 01	SW	7922310	373451					
474	Merab Bedawacho	Haworra	SW	787963	361577					
475	Merab Bedawacho	Elfata	SW	796072	374812					
476	Merab Bedawacho	Deda	SW	786209	372671					
477	Merab Bedawacho	Wobera	SW	790396	374812					
478	Merab Bedawacho	J/onjojo	SW	787461	375601					
479	Merab Bedawacho	J/Mazorria	SW	789300	375864					
480	Merab Bedawacho	SIBEYA	HDW	376506	791344		10		0.5	
481	Merab Bedawacho	WOBERA	SW	374230	790000		80		0.5	
482	Merab Bedawacho	Wobera	SW	375075	791106		36		0.29	

Groundwater Potential Evaluation Based on Integrated GIS and Remote sensing Techniques, in Bilate River Catchment,

483	Merab Bedawacho	Wobera	SW	375189	790297		42		0.37
484	Merab Bedawacho	Wobera	SW	734188	791175		36		0.2
485	Merab Bedawacho	J/mezoria	SW	377115	789454				0.28
486	Merab Bedawacho	J/mezoria	SW	376030	790172		32		0.3
487	Merab Bedawacho	J/mezoria	SW	377708	791178		62		0.34
488	Merab Bedawacho	Deda	SW	373553	787508		0.212		
489	Merab Bedawacho	Deda	SW	373145	786946				
490	Merab Bedawacho	DANEMA	SW	373770	791107		0.27		
491	Merab Bedawacho	Danema	SW	373671	791006				
492	Merab Bedawacho	Danema	SW	373637	791019		0.2		
493	Merab Bedawacho	Danema	SW	372476	390930		0.33		
494	Merab Bedawacho	Danema p..A	SW	372576	786935		0.4		
495	Merab Bedawacho	Yabukuna	SW	378422	785167		0.33		
496	Duguno Fango	Duguna damot shinka	SW	396250	771096	1992			
497	Duguno Fango	Fango damot	HDW	407766	765014	1471			
498	Duguno Fango	Fango damot	HDW	403628	764314	1477			
499	Duguno Fango	Fango damot	HDW	403450	763577	1466			
500	Duguno Fango	Fango damot	HDW	403850	765094	1468			
501	Duguno Fango	Fango damot	HDW	403850	765468	1477			
502	Duguno Fango	Fango damot	DBH	396972	766432	1858			
503	Duguno Fango	Dugna waraga lasha	SP	394018	768181	1774			
504	Duguno Fango	Edo boloso	DBH	388759	775373	1684			1.11
505	Duguno Fango	Fango bijo	SW	398988	759542	1404			
506	Duguno Fango	Fango bijo	HDW	399504	758649	1039			
507	Duguno Fango	Fango bijo	HDW	399774	760348	1415			
508	Duguno Fango	Anka	SP	389500	765044	1540			2.6
509	Duguno Fango	Dimtu	SW	403371	766398	1498			12
510	Duguno Fango	Dimtu	SP	403833	766632	1483			
511	Duguno Fango	Dimtu	SW	403489	776796	1496			15
512	Duguno Fango	Dimtu	SW	403426	966286	1495			18.75
513	Duguno Fango	Dimtu	SW	403407	766283	1496			
514	Duguno Fango	Bilate Eta	HDW	400277	758499	1396			
515	Duguno Fango	Bilate Eta	DBH	402115	759468	1417			
516	Duguno Fango	Fango wumno	SP	395935	769447	1943			
517	Duguno Fango	Fango offa	SP	395626	767318	1808			0.5
518	Duguno Fango	Bizate charicho	SP	399596	753706	1344			
519	Alaba	Adilo town	DBH	386918	796877	1715			
520	Alaba	Alaba town, health cent	DBH	399403	808431	1786			
521	Alaba	Alaba town, kera	DBH	398453	808456	1772	94		
522	Alaba	Alaba town, water off	DBH	399542	807414	1778	86		
523	Alaba	Choroko	DBH	401016	810693	1793	104		6

Groundwater Potential Evaluation Based on Integrated GIS and Remote sensing Techniqies, in Bilate River Catchment,

524	Alaba	Alem tena	DBH	402079	814106	1792			3.5
525	Alaba	Kerenso	DBH	397653	801799	1770	105		
526	Alaba	Elo- luka	DBH	398696	817387	1845	139		6
527	Alaba	Kulifo shedger	DBH	406989	822810	1889	177.1		3.5
528	Alaba	Bercho kulifo	DBH	408578	826654	1934	182.6		
529	Alaba	Bonesha kore	DBH	403600	828065	1905	155.6		4.5
530	Alaba	Alem gebeya , bonesha	DBH	410022	836292	1800	105		
531	Alaba	Gendela, damboya	DBH	393153	816091	1940	127		
532	Alaba	Second mekala,alaba	DBH	405856	803711	1793	196.5		3
533	Alaba	Ashoka	DBH	404229	800161	1760	158.4		4
534	Alaba	Guba felka	DBH	410860	803207	1865	268		2
535	Alaba	Gutancho	DBH	403500	831782	1955	177		
536	Alaba	Lower linda	DBH	404591	811234	1829	167		0.5
537	Alaba	Hamata	DBH	404600	811234	1823			
538	Alaba	Debeso	DBH	415228	804936	1893	294		
539	Alaba	Yaye shuwako	DBH	418721	805131	1890	273		
540	Alaba	Upper Linda well#2	DBH	404282	809022	1802	192.3		
541	Alaba	Besheno	DBH	415292	824381	1989	267		
542	Alaba	Gofessa	DBH	414388	809236	1865	243		
543	Alaba	Ajo huliko	DBH	426056	837671		65.5		7.3
544	Alaba	Bedene	DBH	402302	821036		124.3		9.8
545	Alaba	Simbita	DBH	414417	835857		28.8		7.3
546	Alaba	Upper tuka not true data	DBH	409800	814100	1960			
547	Alaba	Teffo	DBH	418064	812454	1836			
548	DamoteGale	Ketena 2	HDW	375130	654001	2104			
549	DamoteGale	Ketena 2	HDW	3750242	656010	2106			
550	DamoteGale	Ketena 3	HDW	3756290	704502	1886			0.75
551	DamoteGale	Ketena 3	HDW	3755953	704170	1861			0.5
552	DamoteGale	Ketena 4	SW	375647	704853	1887			
553	DamoteGale	Ketena 3	HDW	3756035	704358	1869			
554	DamoteGale	Ketena 3	HDW	3756641	704361	1881			
555	DamoteGale	Ketena 3	HDW	3754938	700834	1877			0.4
556	DamoteGale	Ketena 2	HDW	3754887	700846	1880			
557	DamoteGale	Ketena 2	HDW	3754868	700847	1884			0.4
558	DamoteGale	Shamuwa Bilbawe	SSP	37525688	658957	1952			0.17
559	DamoteGale	Shibbo	SSP	3754010	700032	1825			1
560	DamoteGale	Ketena 2	HDW	3755364	702078	1879			
561	DamoteGale	Ketena 3	HDW	3755399	702095	1872			
562	DamoteGale	Ketena 3	DBH	3755388	702112	1875			1.4
563	DamoteGale	Ketena 4	HDW	3749704	6580308	1997			0.75
564	DamoteGale	Ketena 4	SW	3756870	703865	1871			
565	DamoteGale	Ketena 4	SW	3756547	702181	1865			
566	DamoteGale	Ketena 5	DBH	3756950	704459	1882			7
567	DamoteGale	Ketena 2	HDW	3750475	658066	1981			0.15

Groundwater Potential Evaluation Based on Integrated GIS and Remote sensing Techniques, in Bilate River Catchment,

568	DamoteGale		DBH	3753863	657752	1907			
569	DamoteGale	Huletgana Wacho	SP	3754097	6574721	1844			0.375
570	DamoteGale	Billbbuwa	SP	3752318	7005901	2005			
571	DamoteGale		DBH	3756073	700062	1878			0.7
572	DamoteGale	Billbbuwa	SP	3757202	700500	1703			5
573	DamoteGale	Woshesha	SP	3743405	654609	2280			1
574	DamoteGale	Wanche	DBH	3754182	65933	1905			1.25
575	DamoteGale	Gata Kayo	SW	3753390	658955	1921			0.5
576	DamoteGale	Ade Shakisho	SW	3753665	659402	1908			
577	DamoteGale		SW	3754089	651842	1923			
578	DamoteGale	Woch chano	SP	3785099	6589582	2005			0.3
579	DamoteGale	Zamoca	SP	3754830	659630	1808			0.18
580	DamoteGale	Sasa Naa	SP	3752695	656500	1879			0.8
581	DamoteGale	Cheroo Minche	SP	3752308	656465	1898			0.3
582	DamoteGale	Washa	SP	3750459	656260	2069			0.04
583	DamoteGale	Endale	SP	3750940	655227	1988			1
584	DamoteGale	Bolo 2	SP	3751743	656234	1920			
585	DamoteGale	Mazoriya	HDW	3750596	655959	2096			
586	DamoteGale	Bolo	SP	3751743	656234	1920			
587	DamoteGale	Plultuwa	SP	3756332	657304	1740			40
588	DamoteGale	Burguto	SP	3758473	706301	1876			
589	DamoteGale	Obe jage	SP	3747895	658175	1957			2.5
590	DamoteGale	Alatta	SP	3746760	658414	2047			0.13
591	DamoteGale	Koyesha	SP	3747009	657895	2064			0.27
592	DamoteGale	Grossa shida	SP	3745793	658295	1962			0.125
593	DamoteGale	Ganga	SP	370122	664374	2065			1
594	DamoteGale	Oge Sade	SP	3750112	654664	2650			0.16
595	DamoteGale	Magadiya	SP	3747475	656710	2104			0.21
596	DamoteGale	Atta	SP	3747141	656578	2230			0.005
597	DamoteGale		HDW	3751490	655138	2006			0.14
598	DamoteGale	Guya	SP	3750447	654845	2028			0.08
599	DamoteGale	Guya	SP	3700447	654845	2028			0.08
600	DamoteGale		SP	3750834	654834	2038			
601	DamoteGale		SP	3750834	654834	2038			0.7
602	DamoteGale	Bolla Wancharo	SP	3745915	656179	2195			0.33
603	DamoteGale	Tukaya Shafa	SP	37403814	656150	2001			2.6
604	DamoteGale	Gido konassa	SP	3746585	656713	2146			0.33
605	DamoteGale		SP	3744065	656324	2229			
606	DamoteGale		HDW	3754181	659129	1904			
607	DamoteGale	Mocho	SP	3754074	659977	1842			0.3
608	DamoteGale	Bilbo	SP	3754020	600033	1826			1
609	DamoteGale		HDW	3753346	659435	1917			0.5
610	DamoteGale	Yelayagenaw offa	SW	3753041	658844	1932			
611	DamoteGale	Zagere	SP	3748123	658945	1937			0.2
612	DamoteGale	Wafiga	SP	37455781	658477	1913			4

Groundwater Potential Evaluation Based on Integrated GIS and Remote sensing Techniqies, in Bilate River Catchment,

613	DamoteGale	Ullulo	SP	3745351	653219	1950			0.125
614	DamoteGale		SP	3746018	656019	2002			0.7
615	DamoteGale	Hanselo	SP	3748545	657463	1992			1.25
616	DamoteGale	Babelle	SP	3749628	657462	1992			1.25
617	DamoteGale	Chunechuge	SP	374998	658180	1977			0.5
618	DamoteGale	Hgaza	SP	3748574	657453	1997			1.25
619	DamoteGale	Amchena	SP	3747933	657178	2114			0.5
620	DamoteGale	Bugge	SP	374998	658290	1978			0.33
621	DamoteGale	Woshareshe	SP	3749300	655566	2098			1
622	DamoteGale	Godda	SP	3749566	656631	2031			0.5
623	DamoteGale	Wokkle	SP	3748937	6500594	2122			0.12
624	DamoteGale	Uppha	SP	3749792	3749792	2009			2
625	DamoteGale		SW	3749129	657116	2030			0.4
626	Damote Fulassa	Santo town	HDW	374211	776534	1946			0.20
627	Damote Fulassa	Santo town	HDW	374128	776672	1950			0.20
628	Damote Fulassa	Santo town	SW	373715	776295	1948			0.2
629	Damote Fulassa	Santo town	HDW	374967	776180	1947			0.2
630	Damote Fulassa	Santo town	HDW	374135	776316	1944			0.3
631	Damote Fulassa	Santo town	HDW	374323	777587	1941			0.03
632	Damote Fulassa	Santo town	HDW	374166	776117	1941			0.2
633	Damote Fulassa	Santo town	HDW	373819	776855	1946			0.2
634	Damote Fulassa	Adeshanto	HDW	374871	778279	1946			0.3
635	Damote Fulassa	Adeshanto	HDW	374007	777914	1943			0.2
636	Damote Fulassa	Adeshanto	HDW	374095	778081	1940			1.5
637	Damote Fulassa	Gamekebicho	HDW	372024	781665	1920			1.5
638	Damote Fulassa	Gamekebicho	HDW	371833	784200	1909			0.2
639	Damote Fulassa	Gamekebicho	HDW	372053	783494	1904			
640	Damote Fulassa	Lera	SW	375364	782810	1925			0.3
641	Damote Fulassa	Lera	HDW	375223	783965	1934			0.5
642	Damote Fulassa	Lera	HDW	375337	784394	1916			0.1
643	Damote Fulassa	Lera	HDW	375422	783979	1919			
644	Damote Fulassa	Lera	HDW	375354	783120	1931			1
645	Damote Fulassa	Waribiru	SW	373193	773482	1967			
646	Damote Fulassa	Waribiru	SW	371655	773185	1965			0.3
647	Damote Fulassa	Waribiru	SW	373128	772479	1966			
648	Damote Fulassa	Waritebalaka	SW	575820	774310	1934			3
649	Damote Fulassa	Tontomementa	SW	373546	782304	1924			0.4
650	Damote Fulassa	Tontomementa	HDW	372006	781159	1985			2
651	Damote Fulassa	Tontomementa	SW	374326	780043	1928			0.2
652	Damote Fulassa	Tontomementa	SW	372026	781152	1906			
653	Damote Fulassa	Tontomementa	SW	374233	781443	1934			0.3
654	Damote Fulassa	Tontomementa	SW	373645	782303	1909			3
655	Damote Fulassa	Tontomementa	SW	373491	784816	1916			3
656	Damote Fulassa	Tontomementa	SW	374332	782434	1923			2
657	Damote Fulassa	Tontomementa	SW	372683	781791	1901			3

Groundwater Potential Evaluation Based on Integrated GIS and Remote sensing Techniques, in Bilate River Catchment,

658	Damote Fulassa	Tontomementa	SW	373692	780483	1920			
659	Damote Fulassa	Golo shanfo	SW	372587	775961	1944			0.5
660	Damote Fulassa	Golo shanfo	HDW	373159	776660	1944			0.1
661	Damote Fulassa	Golo shanfo	SW	373503	774882	1951			0.3
662	Damote Fulassa	Golo shanfo	HDW	373877	775206	1954			1
663	Damote Fulassa	Ollola	HDW	367308	774285	1935			0.3
664	Damote Fulassa	Ollola	HDW	367686	773805	1936			0.5
665	Damote Fulassa	Zamine Welisho	SW	372323	770566	1945			4
666	Damote Fulassa	Zamine Welisho	SW	372088	778161	1925			
667	Damote Fulassa	Zamine Welisho	HDW	372227	777566	1925			1
668	Damote Fulassa	Zamine Welisho	SP	372801	778388	1934			0.2
669	Damote Fulassa	Zamine Welisho	SP	372300	779498	1910			0.3
670	Damote Fulassa	Zamine Welisho	SP	370595	778376	1900			
671	Damote Fulassa	Lamarada	SW	381025	783006	1860			3
672	Damote Fulassa	Lamarada	HDW	379865	781401	1888			1
673	Damote Fulassa	Lamarada	HDW	379874	781406	1891			1
674	Damote Fulassa	Lamarada	HDW	377253	782275	1912			0.32
675	Damote Fulassa	Hilenakorke	HDW	375640	780082	1956			1
676	Damote Fulassa	Hilenakorke	HDW	375815	784033	1934			0.2
677	Damote Fulassa	Hilenakorke	HDW	375542	781080	1950			0.5
678	Damote Fulassa	Siyara mahe	SW	374015	773060	1962			1
679	Damote Fulassa	Siyara mahe	SW	374659	775438	1959			3
680	Damote Fulassa	Siyara mahe	SW	373855	772637	1952			0.02
681	Damote Fulassa	Siyara mahe	HDW	374080	774944	1930			2
682	Damote Fulassa	Siyara mahe	SW	374053	774219	1963			3
683	Damote Fulassa	Bibiso	HDW	367920	773207	1933			0.1
684	Damote Fulassa	Bibiso	HDW	369352	773402	1987			
685	Damote Fulassa	Bibiso	DBH	371061	772739	1963			
686	Damote Fulassa	Bibiso	SW	371464	771936	1985			0.2
687	Damote Fulassa	Abeta ulto	DBH	378485	777498	1906			5
688	Damote Fulassa	Abota ulto	HDW	376628	776947	1939			1
689	Damote Fulassa	Abota ulto	SW	377153	777348	1924			
690	Damote Fulassa	Galachashuke	HDW	369640	778560	1948			0.5
691	Damote Fulassa	Busha	HDW	379281	783988	1915			0.5
692	Damote Fulassa	Busha	HDW	379268	783974	1910			0.54
693	Damote Fulassa	Busha	HDW	378137	783997	1906			0.2
694	Damote Fulassa	Gudicho	HDW	368064	782436	1858			1
695	Damote Fulassa	Gudicho	HDW	369748	781581	1890			3
696	Damote Fulassa	Gudicho	HDW	367323	781937	1870			2
697	Damote Fulassa	Wasedo	HDW	373846	783705	1910			2
698	Damote Fulassa	Wasedo	HDW	373519	787315	1911			2
699	Damote Fulassa	Galebuse	DBH	382169	783513	1886			
700	Damote Fulassa	Galebuse	HDW	382016	783009	1880			0.3
701	Damote Fulassa	Galebuse	SW	382810	785570	1905			0.5
702	Damote Fulassa	Galebuse	SW	382812	785575	1902			

Annex 14 Water Point Inventory data

703	Damote Fulassa	Galebuse	SW	381685	784985	1896			0.3
704	Damote Fulassa	Galebuse	HDW	381653	783650	1888			0.001
705	Damote Fulassa	Galebuse	SW	381662	783650	1885			
706	Damote Fulassa	Galebuse	SW	381875	785809	1903			0.5
707	Damote Fulassa	Galebuse	SW	380707	783136	1902			0.5
708	Damote Fulassa	Galebuse	SW	380707	784238	1881			0.3
709	Damote Fulassa	Galebuse	HDW	381653	783708	1888			0.3
710	Damote Fulassa	Galebuse	SW	380282	784238	1870			
711	Damote Fulassa	Waribiru suke	SW	370553	776670	1928			0.3
712	Damote Fulassa	Waribiru suke	HDW	371304	775684	1954			0.2
713	Damote Fulassa	Waribiru suke	HDW	370723	774365	1935			0.2
714	Damote Fulassa	Waribiru suke	HDW	370757	775209	1939			0.1
715	Damote Fulassa	Waribiru suke	HDW	371630	774269	1956			0.2
716	Damote Fulassa	Waribiru suke	HDW	370907	774639	1954			5
717	Damotewoyde	Tebella	SP	380817	763788	1689			6
718	Damotewoyde	Deep well	DBH	376303	756589	1766			2.78
719	Damotewoyde	Offe spring	SP	379498	758219	2035			1
720	Damotewoyde	Chalia'a spring	SP	378114	765505	1826			2.5
721	Damotewoyde	Bilbo	SP	380813	763788	1689			-
722	Damotewoyde	Meka Spring	SP	380883	763566	1686			2.5
723	Damotewoyde	Tebella	SP	380813	763788	1689			6
724	Damotewoyde	Gagado Tera	HDW	375100	763007	1706			-
725	Damotewoyde	Talas Spring	SP	377068	761284	1889			0.8
726	Damotewoyde	Kindo	SP	375803	761257	1952			2.5
727	Damotewoyde	Ambe - Bedessa	SP	378919	761287	1756			0.086
728	Damotewoyde	Guppale	SP	373199	763715	2001			2.5
729	Damotewoyde	Daza Dawana	HDW	374034	767839	2012			-
730	Damotewoyde	Badalla Godda	SP	376950	763394	1910			0.11
731	Damotewoyde	Bila hanjalo	HDW	383271	765926	1769			-
732	Damotewoyde	Eyob Tega	HDW	383,605	765,948	1759			-
733	Damotewoyde	Deep well	DBH	378589	767377	1893			-
734	Damotewoyde	Adamo Spring	SP	383941	769294	1767			2
735	Damotewoyde	Deep well	DBH	376303	756589	1766			-
736	Damotewoyde	Wofeshe	SP	371710	759397	1801			30
737	Damotewoyde	Deep well	DBH	376303	756589	1766			-
738	Damotewoyde	Ashe	SP	376376	760154	1887			0.8
739	Damotewoyde	Fuche	SP	375981	759757	1910			1.03
740	Damotewoyde	hand pump	SW	385857	766179	1702			-
741	Damotewoyde	hand pump	SW	386324	766674	1737			-
742	Damotewoyde	hand pump	SW	385592	765549	1699			-
743	Damotewoyde	Angino Anjulo	HDW	385303	765059	1719			-
744	Damotewoyde	Tantu Moroce	HDW	385081	765186	1639			-
745	Damotewoyde	Barana alito	HDW	386028	764672	1713			-
746	Damotewoyde	tomas Turo	HDW	375549	765870	1702			-
747	Damotewoyde	Morka Godato	HDW	385543	765575	1696			-

DECLARATION

I, the undersigned, declare that this thesis entitled "Groundwater potential evaluation based on GIS and remote sensing techniques in Bilate River catchment" is my original work, has not been presented for a degree in any other university and that all source of material used for the thesis have been duly acknowledged

Tesfaye Tessema Gintamo

SCHOOL OF GRADUATE STUDIES, Addis Ababa University

June, 2010

CERTIFICATE

This is certified that the thesis entitled "Groundwater potential evaluation based on GIS and remote sensing techniques in Bilate River catchment" is a bonafied work carried out by Tesfaye Tessema under my guidance and supervision. This is the actual work done by Tesfaye Tessema for the partial fulfillment of the award of the Degree of Master of Science in Hydrogology

The Thesis has been submitted for the examination with my approval as University advisor.

Tenalem Ayenew (Prof.)
Addis Ababa University

June, 2010