MINISTRY OF WATER & ENERGY (MoWE)
THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA
SOMALI REGIONAL WATER RESOURCES DEVELOPMENT BUREAU

THE STUDY ON JARAR VALLEY AND SHEBELE SUB-BASIN WATER SUPPLY DEVELOPMENT PLAN, AND EMERGENCY WATER SUPPLY IN THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA

FINAL REPORT (2/7)

VOLUME 1

SURVEY ON THE POTENTIAL OF WATER RESOURCES (GROUNDWATER) UTILIZATION

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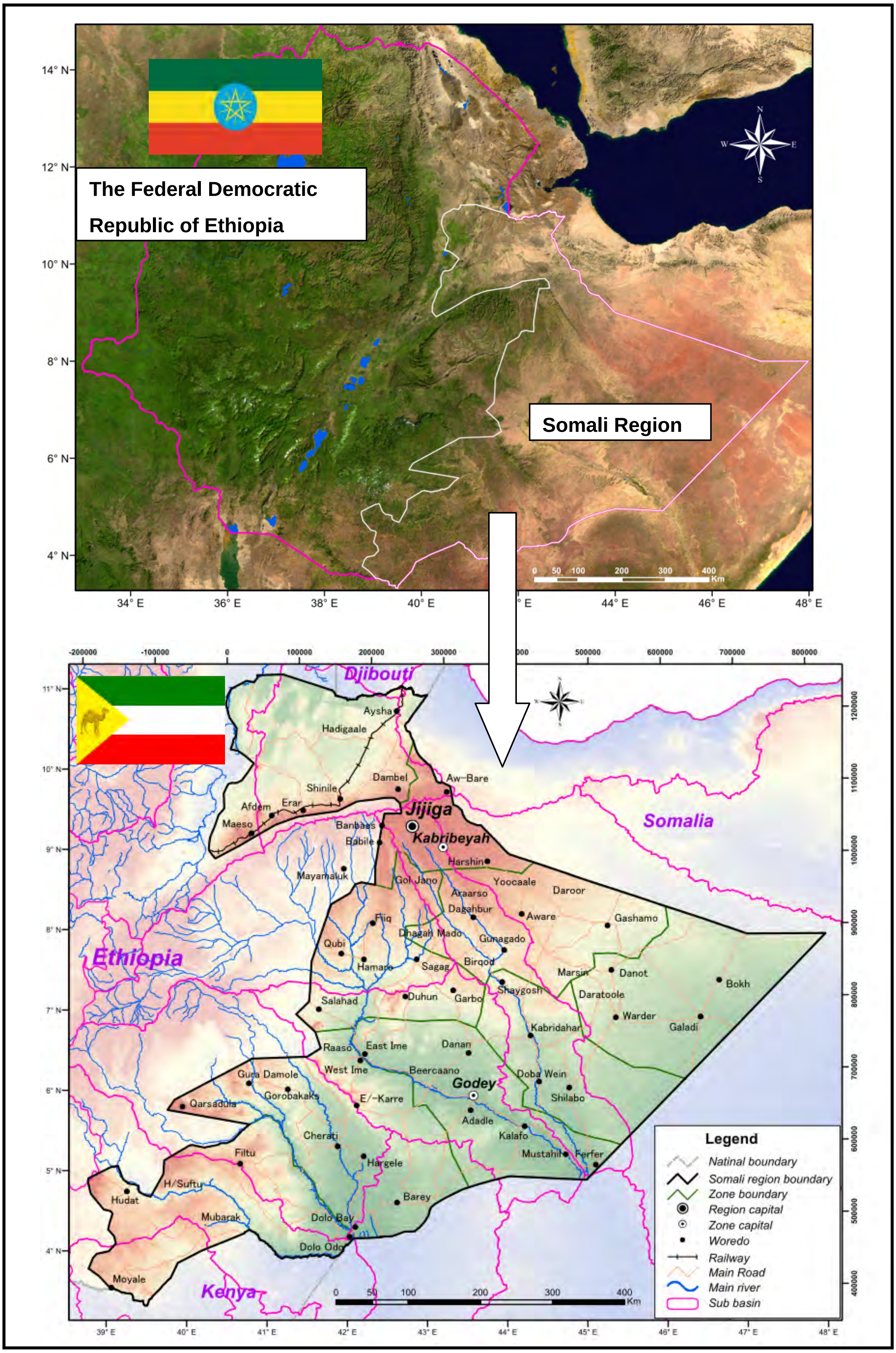

Location Map of Study Area

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Abbreviations

ABE	Alternative Basic Education
ARRA	Administration for Refugee and Returnee Affairs
BoFED	Bureau of Finance and Economic Development
BPR	Business Process Reengineering
CGIAR	Consultative Group on International Agricultural Research
CSA	Central Statistical Agency
CSE	The Conservation Strategy of Ethiopia
COD	Chemical Oxygen Demand
C/P	Counterpart (organization or personnel)
DFID	Department for International Development
DF/R	Draft Final Report
DTH	Down the Hole Hammer
DPPB	Disaster Prevention and Preparedness Bureau
EC	Electric Conductivity
EIA	Environmental Impact Assessment
EPA	The Environmental Protection Authority
EPC	The Environmental Protection Council
ESA	European Space Agency
ESIA	Environmental and Social Impact Assessment Unit
EU	European Union
EU-WATCH	Water and Global Change (WATCH) program funded by the European Union
EWTEC	Ethiopia Water Technology Center
FAO	Food and Agriculture Organization of the United Nations
F/R	Final Report
F/S	Feasibility Study
GEM	Global Environment Monitoring
GIS	Geographical Information System
GLCF	Global Land Cover Facility
GLG	Grass Land GIS
GMT	Greenwich Mean Time
GSE	Geological Survey of Ethiopia
GPS	Global Positioning System
GUPE map	Groundwater Utilization Potential Evaluation map
IC/R	Inception Report
IEE	Initial Environmental Examination
IRC	International Rescue Committee
ISCGM	International Steering Committee for Global Mapping
IT/R	Interim Report
JICA	Japan International Cooperation Agency
JSS	JAXA Supercomputer System
JWSO	Jijiga Water Supply Office
MODIS	MODIS Land Cover Product by using Moderate resolution Imaging Spector radiometer of Earth-Observing-System EOS
MoFED	Ministry of Finance and Economic Development
MoWR	Ministry of Water Resources
MoWE	Ministry of Water and Energy
MrSID	Multi-resolution Seamless Image Database
NFE	Non Formal Education
NGO	Non-Governmental Organization
NMA	(Addis Ababa) National Meteorology Agency
NOAA	National Oceanic and Atmospheric Administration

NRCS	Natural Resources Conservation Service, United States Department of Agriculture
O&M	Operation and Maintenance
OJT	On the Job Training
P/R	Progress Report
PA	Preliminary environmental assessment study
PALSAR	Phased Arrayed L-type Synthetic Aperture Radar
R/D	Record of Discussion
REA	Regional Environmental Agencies
RGSR	Regional Government of Somali Region
RWBs	Regional Water Bureaus
SAGE	Center for Sustainability And the Global Environment at the University of Wisconsin Madison
SEDAC	Socioeconomic Data and Applications Center
SEPMEDA	Somali Regional State Environmental Protection, Mine and Energy Development Agency
SHAAC	Shaac Consulting Engineers
SRTM	Shuttle Radar Topography Mission
SRWDB	Somali Regional Water Resources Development Bureau
SWWCE	Somali Water Works and Construction Enterprise
TDM	Time Domain Method
TEM	Transient（or Time-domain）Electromagnetic Method
TOT	Training of Trainers
TVETC	Technical and Vocational Education and Training College
UAP	Universal Access Program
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNHCR	United Nations High Commissioner for Refugees
UNICEF	United Nations Children’s Fund
USDA	United States Department of Agriculture
USAID	United States Agency for International Development
USGS	United States Geological Survey
UTM	Universal Transversal Mercator
VES	Vertical Electrical Sounding
WASH	Water Supply, Sanitation and Hygiene Programme
WASHCO	Water Supply and Health Committee
WATSANCO	Water, Sanitation & Hygiene Committee
WFP	World Food Programme
WLR	Water Level Recorder
WMO	World Meteorological Organization
WRI	World Resources Institute
WRIM	Water Resources Information Map
WSDP	Water Sector Development Program
WTP	Willingness to Pay

Chapter 1

Introduction

1 Introduction

1.1 The project

This report was prepared to present the results as of the end of July 2013 of the Study of "Jarar Valley and Shebele Sub-basin Water Supply Development Plan, and Emergency Water Supply in the Federal Democratic Republic of Ethiopia (hereafter, the Study)" based on the results of the record of discussions (R/D) agreed and signed by the Federal Democratic Republic of Ethiopia and Japan International Cooperation Agency (JICA) on 23 December 2011. JICA organized a team of consultants (the Study Team) made up of 14 members (one member was added later) to conduct the Study. The Study started in March 2012 and is confirmed to end in August 2013. The work schedule was shown in Figure 1.1 below.

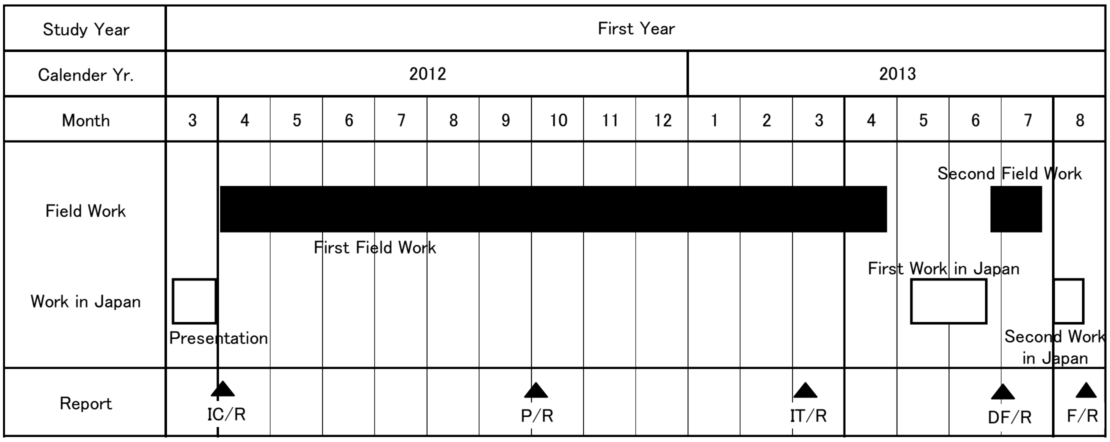


Figure 1.1: Outline of the Study Schedule

The first field work was carried out from April 2012 to April 2013, before starting of the Study, the Study Team submitted the inception report (IC/R) and discussed its contents with the Ethiopian side. After that, Minutes of Meeting (M/M) were exchanged between JICA and MoWE in consideration of the request of modification from the Ethiopian side (April 2012). The results of the Study were reported in the Progress Report (P/R) after seven months and the reporting in the stage of interim results was executed in the Interim Report (IT/R) five months after submitting of the P/R. The contents of both reports were discussed with the Ethiopian side at the steering committee, and M/M of P/R and IT/R was exchanged among JICA, Somali Regional State Water Resources Development Bureau (SRWDB) and Ministry of Water and Energy (MoWE) after reflecting the corrections from the Ethiopian side (M/M of P/R: November 2012, M/N of IT/R: April 2013). After the first work in Japan, Draft Final Report (DF/R) was submitted to Ethiopian side at the end of June 2013 on the second field work, and M/M was exchanged between JICA and Ethiopian side after discussion of contents at the steering committee meeting. After that, Ethiopian side carried out the final modification, and finally JICA will submit the Final Report (F/R) to the Ethiopian side by the middle of September 2013.

The study objectives are mainly to prepare a water supply plan based on the collection and analysis of the existing data, and the information of natural conditions and socio-economic situation data in the Jarar valley and Shebele sub-basin. Other important tasks are: the arrangement of a hydrogeological information system, construction works for emergency water supply focused on Kabribeyah and Godey towns and the rest of Somali region, and training to strengthen the ability of SRWDB and other relevant organizations.

The expected output and the activities of the Study are as follows;

(1) Expected outcome of the implementation of the Study

1) The potential of utilization of water resources in Jarar Valley and Shebele River watersheds will be evaluated.
2) The water supply plan for the Jarar Valley and Shebele River watersheds will be prepared.
3) The technical and organizational capacity of C/P personnel in water supply planning will be improved.
4) Water supply situation in Kabribeyah Town will be improved
5) Feasibility study for the planned water supply facilities (system) will be conducted.
6) Situation of emergency water supply in Somali Region will be improved through the use of the water supply equipment and materials donated.

(2) Activities in the Study

In order to realize the outcomes stated above, the following activities will be conducted in this Study.

1) Confirmation of potential of water resources development though "water resources utilization potential survey,"
2) Proposition of concrete improvement plans for water supply systems by water supply planning, and
3) Improvement of current water supply condition by implementing emergency water supply projects
4) Capacity development of relevant staff through short-term technical training.

To sum up the above, the following Figure 1.2 illustrates the outline of this Study: the activities under (2) above will be first conducted to realize the outcomes under (1) above by the end of the Study. The Ethiopian C/P organizations, then, will be expected to realize the formulated water supply plan making the best of what they will have learnt through short- to long-term training in order to achieve the future long-term goals in the Study that are stated under the outcomes.

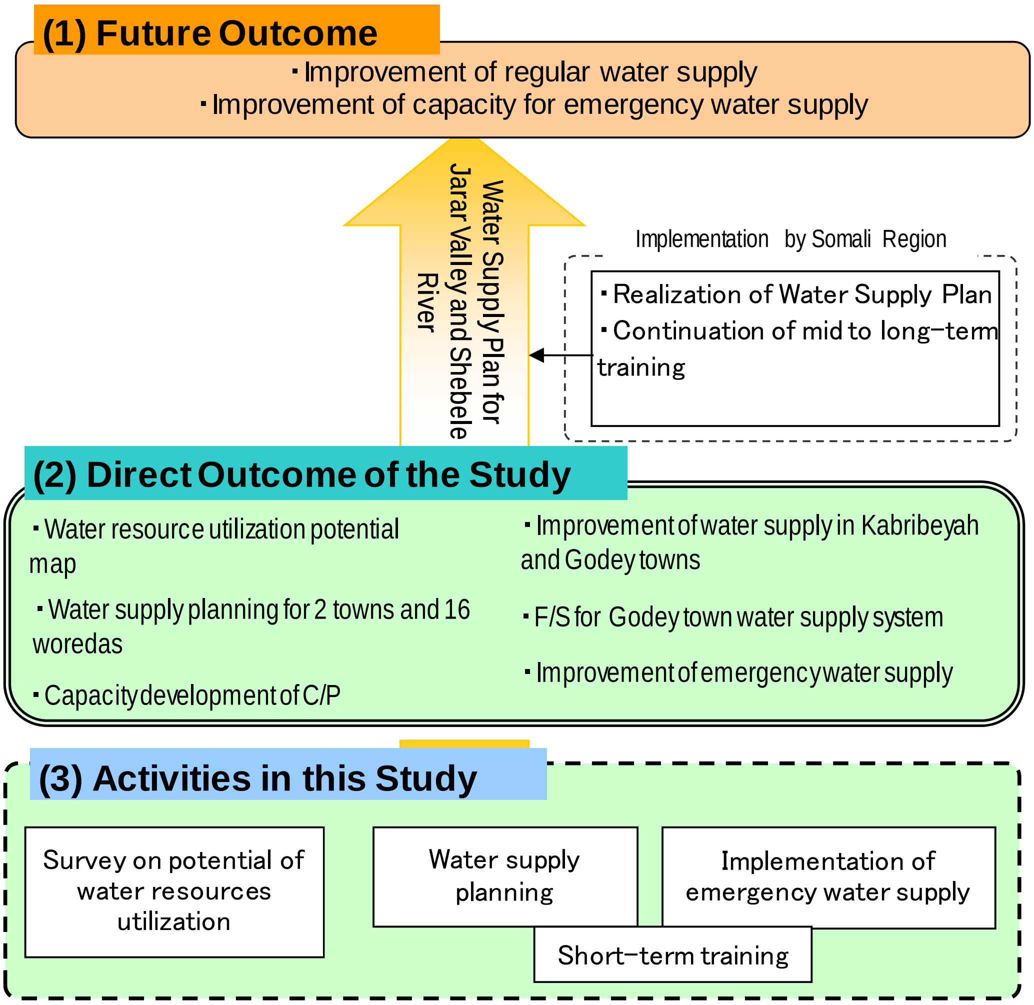


Figure 1.2: Flow of the Study (Project)

The target area differs depending on the work components of the Study: Emergency water supply works covers the whole region, water supply plan and water resources potential study target the sub-basins of Jarar Valley and Shebele River. Also pilot projects were conducted in Kabribeyah and Godey towns. These areas of project components and locations of the towns are indicated in Figure 1.3 below. The sixteen woredas and main two towns (Kabribeyah and Godey towns) have been selected for the final target.

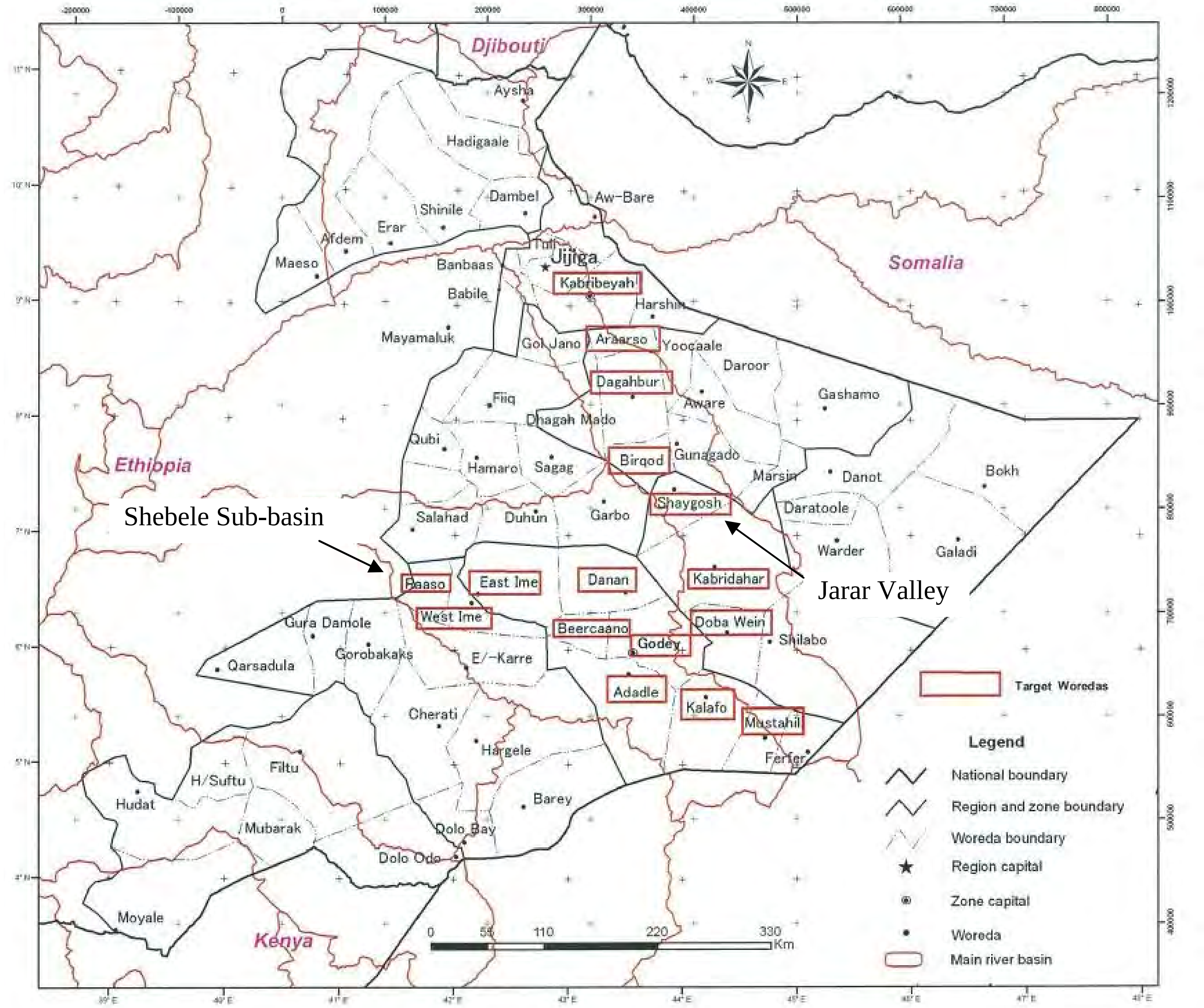


Figure 1.3: Study Area Map

The JICA Study Team was composed of the fifteen (15) experts and each C/P person was assigned to work exclusively with one of the Study Team members in this Study. The Study was to be executed through close collaboration between the Study Team and counterpart personnel (C/P) and others of Ethiopia. According to the R/D, a steering committee was supposed to be established for the Study. There were many organizations concerned with this Study. Therefore, as a measure to assure good communication and information sharing with these organizations, a steering committee needed to be organized. The Study Team will interact with the Steering Committee when there were any important issues to discuss; making important decisions, sharing the progress of the Study, acceptance of various reports to be prepared in the course of the Study etc. in order to realize smooth implementation of the Study. The Steering Committee members were as follows below;

<Chairman>

Director of Water Sector and Capacity Building Directorate, MoWE

<Members>

1) Representative of Ministry of Finance and Economic Development (MoFED)
2) Staff of Water Supply and Capacity Building Directorate, MoWE
3) Representative of ARRA
4) Head of SRWDB
5) Deputy Head of SRWDB in charge of Water Supply Core Process
6) Deputy Head of SRWDB in charge of Water Supply Management Core Process
7) Representative of Kabribeyah town water supply utility office
8) Representative of Godey town water supply utility office
9) Representative of DPPB
10) Representative of Jijiga sub office of UNHCR
11) Representative of Somali Regional State Environmental Protection, Mine and Energy Development Agency (SEPMEDA)
12) Representative of Bureau of Finance and Economic Development (BoFED)
13) Study Team
14) JICA Ethiopia Office

1.2 Report structure

The report structure in this Study has been composed of four activities in principal. However the results of the feasibility study in Godey town have been reported in one volume. The main items are as follows below;

<Main Report>

Chapter 1 Study Summary

Chapter 2 In Relation to the Emergency and Long-Term Water Demand in Somali Region

Chapter 3 Operation and Maintenance of Water Supply Facilities

Chapter 4 Feasibility Study on Water Supply Plan

Chapter 5 Conclusions and Recommendations

<Volume 1 Survey on the Potential of Water Resources (Groundwater) Utilization>

Chapter 1 Introduction

Chapter 2 Meteorology and Hydrology

Chapter 3 Geology

Chapter 4 Hydrogeology

Chapter 5 Water Quality Analysis

Chapter 6 Groundwater Utilization Potential Evaluation Map

Chapter 7 Water Resources Information Map for Somali Region

Chapter 8 Conclusions

<Volume 2 Water Supply Plan>

Chapter 1 Introduction

Chapter 2 Basic date of Water Supply Plan

Chapter 3 Water Resources and Existing Water Supply Facilities

Chapter 4 Water Supply Plan, Cost Estimation and Implementation Plan of Each Woreda

Chapter 5 Water Supply Plan and General Design, Cost Estimation and Implementation Plan of Kabribeyah Town

Chapter 6 Water Supply Plan and General Design, Cost Estimation and Implementation Plan of Godey Town

Chapter 7 Conclusions

<Volume 3 Emergency Water Supply, Operation and Maintenance of Water Supply Facilities>

Chapter 1 Introduction

Chapter 2 Emergency Water Supply

Chapter 3 Operation and Maintenance of Water Supply Facilities

Chapter 4 Conclusions

<Feasibility Study on Water Supply Plan in Godey Town>

Chapter 1 Summary of the Study

Chapter 2 The Project Area

Chapter 3 Socio-Economic Survey

Chapter 4 Water Resources Study

Chapter 5 Population and Water Demand

Chapter 6 Existing Water Supply

Chapter 7 Water Supply Plan

Chapter 8 Cost Estimates

Chapter 9 Operation and Maintenance

Chapter 10 Environmental and Social Consideration

Chapter 11 Financial and Economical Evaluation

Chapter 12 Conclusions

1.3 Summary of Volume 1

The data arrangement and analysis of the meteorology and hydrology, geography and geology, hydrogeology and water quality were executed in relation to the water resources of natural conditions in Somali Region in this volume. Based on the results of analysis, the potential evaluation of water resources including groundwater was conducted and after that, this volume was prepared, describing the water resources (groundwater) utilization potential evaluation map in the Jarar valley and Shebele River sub-basin. Moreover, the water resources information map as a result of the data analysis by the remote sensing technique and the analysis of the existing water quality data in Somali Region was also presented.

The hydro-meteorological survey was carried out so as to estimate groundwater recharge and to calculate the perennial river flow in the study area from the viewpoint of securing river water for water supply. The major data sets collected included precipitation data for calculation of areal differences of precipitation, evapotranspiration data, river discharge data, and areas of major and sub-basins. And also, the correlation with annual amount of runoff and drainage area was examined in the river flow analysis using the river flow and drainage data. Several methods of estimating the groundwater recharge amount were employed, which included mathematical balance method (areal precipitation and potential evaporation were based on Thiessen method), BFI (base flow analysis) method and the tank model method.

The results of the geomorphological & geological analysis, hydrogeological analysis, and the water quality analysis were all integrated into the groundwater utilization potential maps. The regional geology of Somali Region was compiled based on the analysis of existing documents and data and the stratigraphic table with description of major formations have been prepared as an outcome. Then, based on the established stratigraphic sequence, geomorphological and geological analysis results combined with the log data of existing wells were further analyzed. As a result, geomorphological, geological, and hydrogeological (well information) classifications were conducted along with preparation of geological cross sections & well log database for each of the target woredas for the master planning. This made it possible to understand both horizontal and vertical geological and well characteristics of each of the target woredas. The well information covers their locations, depths, and the relation between water level fluctuation and pumping rates. The collected well logs helped identify aquifers and clearly establish stratigraphic sequences through comparison with the geological characteristics of the formations. These formations were used as the type formations in the legend of the groundwater utilization potential map to evaluate development potential.

The water quality analysis was executed for the water from 103 (one hundred three) points such as 30 borehole sites, the 39 hand dug well sites, 14 points from water treatment plants and the river water of 20 points. The results of the water quality analysis were plotted on tri-linear and hexa-diagrams. The water samples were analyzed for 19 items of water quality in a laboratory and the results were compared with the WHO and Ethiopian standards. In turbidity, TDS, Cl ion and total hardness, many samples exceeded the standard values.

The groundwater utilization potential evaluation map shows classification of relative potential evaluation map due to the lack of quantitative aquifer data of wells. A geological map and a potential evaluation map with a scale of 1/250,000 were created as the combined map of Jarar valley area and Shebele River sub-basin area.

The water resources information map (WRIM) (scale: 1/2,000,000) was prepared based on the groundwater utilization potential maps for Jarar Valley and Shebele River sub-basin areas. WRIM used the results of water resources evaluation by remote sensing technique to evaluate these areas. The main factors affecting water resources information are: groundwater recharge (the method of the relative comparison between precipitation and potential evapotranspiration), topography, geological strata and lineament. As their influence over WRIM is not the same, the factors should be weighted accordingly. The final map was created by integrating all the weighted factors and by using the water quality data of UNESCO, 2012.

Chapter 2

Meteorology and Hydrology

2 Meteorology and Hydrology

2.1 Collection and review of meteorological data

In this study, the study team collected the necessary meteorological data from Addis Ababa National Meteorology Agency (here after "NMA") and Jijiga NMA office, which is under the control of Somali Region. However, most of the data collected from Jijiga NMA office were from the last few years, and there is limited data of year-round measurement. Jijiga NMA office staff said that it takes a lot of time to solve equipment problems or repair broken equipment, so it is difficult to continue the measurement. The study team inspected three meteorology stations (Lefiesa, Kebribeya, Hadew near Jijiga and Godey Town) with the aim of grasping and analyzing the current situation. These stations come under the category of class-3 as described later, and NMA commissions it to a person (teacher of school or government official) who lives near the station. The reliability of the data is considered to be low because there is a large variation in observation time and method of recording. In this report, the same spelling of observing stations as in NMA's list is used.

The study team obtained the data of Rainfall, Wind direction/Wind speed, Evaporation, Temperature (Max. and Min.), and Sunshine from Addis Ababa NMA, and except for Gode Met. and Err stations (for which there was daily rainfall data), only monthly rainfall data was obtained from Jijiga NMA office.

In Ethiopia, meteorological observation stations are classified as follows (after NMA Website).

Class 1: It is called synoptic station. The data are transmitted to branch offices daily by telemeter. There are 22 stations in Ethiopia. Following parameters are recorded in Table 2.1.

Table 2.1: Class 1 Measured Parameters at Synoptic Station

	Parameter	Method
1	Daily rainfall	Rainfall gauge (manual, automatic)
2	Daily temperature (Max. and Min.)	Max. and Min. Thermometer (mercury)
3	Relative humidity	Hygrometer
4	Dew point temperature	Calculated
5	Evaporation	Class A pan, Piche evaporimeter
6	Sunshine duration	Campbell-stokes recorder
7	Wind speed/direction	Cup anemometer, Wind mill anemometer
8	Cold cloud duration	Satellite image interpretation, meteo-balloon
9	Air pressure	Air pressure gauge
10	Weather forecast	Computation and assessment
11	Visibility	Visual observation
12	Soil temperature	Mercury thermometer

Class 2: The purpose of these observation stations is climatology. Measurements are taken every three hours (3:00, 6:00, 9:00, 12:00, and 15:00 GMT). There are 150 class 2 observation stations in Ethiopia; and measured parameters are the same as class 1 except air

pressure and visibility.

Class 3: These class observation stations measure only temperature (Max., Min.) and rainfall. Observations are only made twice a day (6:00, 15:00 GMT).

Class 4: The observation of these classes is only made once a day (6:00 GMT).

The necessary data for analysis can be bought from NMA of Addis Ababa and from each branch. Data of local regions are submitted to Addis Ababa NMA head office after being arranged in the local NMA. When obtaining data for this Project, the location and class of stations was confirmed at Addis Ababa NMA to decide on which stations were necessary. The parameters of data obtained are daily rainfall, daily temperature (Max. Min.), evaporation, sunshine, wind direction and wind speed. However, even class 1 or 2 observatories have a great deal of missing data due to mechanical troubles of the equipment or other causes. In the case of classes 3 and 4, a capable person in the neighborhood is employed to make observations. However, many mistakes and missing data are reported, due to an apparent lack of instruction on how to conduct observations properly.

2.1.1 Meteorological stations in Somali Region

List of the Meteorological stations is shown in Table 2.2. (From Addis Ababa NMA Office) and the location of the meteorological stations are as in the following Figure 2.2.

Table 2.2: Meteorological Stations List of all Somali Region

No	Lon	Lat	Alt	Station name	Class	Region		
1	44.27	6.73	537	Kebridehar	1	Somale		
2	43.58	5.9	290	Gode	2	Somale	Gode	Gode
3	42.233333	10.416667	758	Adigala	3	Somale	Shinile	Adigala
4	40.983333	9.45	1056	Afdem	3	Somale	Shinile	Afdem
5	41.87	9.37	1755	Dawe	3	Somale		
6	42.6	9.8	1340	Dembel	3	Somale	Shinile	Shinile
7	44.68	8.22	941	Deror	3	Somale		
8	42.616667	11.033333	807	Dewole	3	Somale	Shinile	Ayisha
9	41.366667	9.55	1088	Erer	3	Somale	Shinile	Erer
10	43.17	9.48	1693	Gobiyere	3	Somale		
11	43.58	5.88	291	Gode Town	3	Somale	Gode	Gode
12	42.866667	10.116667	1097	Gogeti	3	Somale	Jijiga	Awber
13	41.57	9.2	2280	Goromitte	3	Somale		
14	42.666667	9.3666667	1807	Hadew	3	Somale	Jijiga	Jijiga
15	41.5	10.17	2712	Harewacha	3	Somale		
16	43.733333	8.9166667	1441	Harshin	3	Somale	Shinile	Shinile
17	41.83	8.65	1124	Husie	3	Somale		
18	42.1	9.72	1084	Jeldessa	3	Somale		
19	43.166667	9.1	1753	Kebribeya	3	Somale	Jijiga	Kebribeya
20	42.97	9.6	1733	Lefiesa	3	Somale		
21	41.33	9.22	2733	Mekella	3	Somale		
22	45.33	8.12	798	Misraq gashamo	3	Somale		
23	41.833333	9.6833333	1024	Shinile	3	Somale	Shinile	Shinile
24	42.43	9.5	2007	Tuluguled	3	Somale		
25	42.716667	9.9166667	1097	Arabi	4	Somale	Shinile	Denbel
26	42.6	9.5	2007	Chinakson	4	Somale	Jijiga	Jijiga
27	43.35	9.15	1630	Hartisheik	4	Somale	Jijiga	Kebribeya
28	42.966667	9.6	1733	Lefeisa	4	Somale	Jijiga	Jijiga
29	43.216667	9.7833333	1611	Teferi ber	4	Somale	Jijiga	Aware
30	42.3167	10.75		Aysha	1	Somali		
31	42.61	4.6355	318m	Barre	1	Somali		
32	40.2882	6.8237	1234m	Belle	1	Somali		
33	43.55	8.2166667	1070	Degahabour	1	Somali	Degahabur	Degahabur
34	42.05	4.173	179m	Dolooddo	1	Somali		
35	42.1052	5.8355	924m	Elkerre	1	Somali		
36	40.643	5.1063	1225m	Filtu	1	Somali	Liben	Liben
37	42.13	5.26		Harghelle	1	Somali		
38	42.117	6.45		Immi	1	Somali		
39	42.783333	9.3333333	1775	Jijiga	1	Somali	Jijiga	Jijiga
40	41.5333	4.5177	391m	Boqolmayo	3	Somali	Korahiy	Shilabo
41	41.874	5.336	286m	Cheretti	3	Somali	Afder	Cheretti
42	42.5	9.5833		Giraqocher	3	Somali		Geraqocher
43	44.116667	5.6	250	Kelafo	3	Somali	Gode	Kelafo
44	43.5	9.36		Togochale	3	Somali	Jijiga	Jijiga

Source: Ethiopia National Meteorological Agency, Meteorological Data and Climatology Directorate(2012)

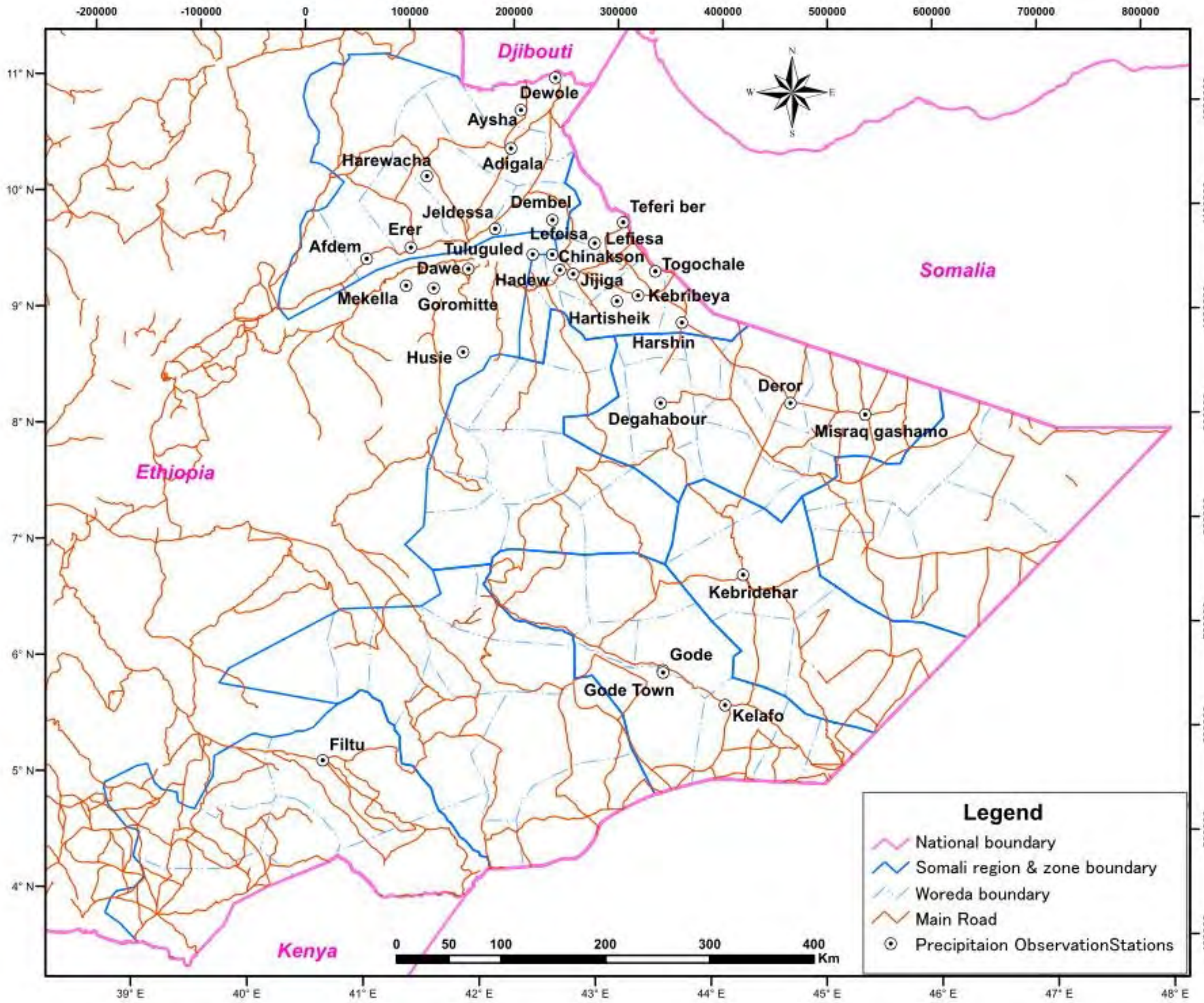


Figure 2.1: Location Map of Meteorological Stations

2.1.2 Rainfall

The following Table 2.3 of daily rainfall data sheets was obtained from Addis Ababa NMA.

Table 2.3: Available Meteorological Station (Addis Ababa NMA)

No.	Station Name	Coordinates		Altitude(m)	Duration	MD-1(%)	MD-2(%)
		LON(E)	LAT(N)				
1	Hadew	9.37	42.67	1807	2001-2010	20.4	20.4
2	Kebri Dehar	6.73	44.27	537	1985-2003	13.0	13.0
3	Gode Met	5.9	43.58	290	1985-2010	41.3	15.2
4	Gode Town	5.88	43.58	291	2004-2009	40.9	60.6
5	Kebribeya	9.1	43.17	1753	2009-2010	36.2	36.2
6	Chinaksen	9.5	42.6	2007	2004-2010	7.3	7.3
7	TeferiBer(Aware)	9.78	43.22	1611	2003-2006	33.7	33.7
8	Degahabur	8.22	43.55	1070	1985-2010	21.4	10.7
9	Jijiga	9.33	42.78	1775	1985-2010	57.9	15.8
10	Filtu	5.11	40.64	1225	1980-1999	19.1	21.5
11	Hartishiek	9.15	43.35	1630	2003-2008	39.5	19.6

MD-1: Percentage of missing data for the whole observation years.
MD-2: Percentage of missing data except those years without any observation data.

Source：Ethiopia National Meteorological Agency, Meteorological Data and Climatology Directorate, Addis Ababa(2012)

The following data sheets of Table 2.4 were obtained from Jijiga NMA.

Table 2.4: Meteorological Station (Jijiga NMA)

Station Name	Class	Altitude (SML-m)	Coordinate		Duration	MD-1	MD-2
			Latitude	Longitude			
Errar	3	1,088	41.37	9.55	1968～2011	28.8	15.9
Kebribeya	1	537	44.27	6.73	2009～2011	16.7	16.7
Gode Town	3	291	43.58	5.88	1979～2011	14.4	5.8
Adigala	3	758	42.23	10.42	2009～2011	66.7	66.7
Afdem	3	1,056	40.98	9.45	2009～2011	52.8	52.8
Dawe	3	1,755	41.87	9.37	2009～2011	27.8	27.8
Dembel	3	1,340	42.6	9.8	2009～2011	30.6	30.6
Deror	3	941	44.68	8.22	2009～2011	47.2	47.2
Dewole	3	807	42.62	11.03	2009～2011	47.2	47.2
Goromuti	3	2,280	41.57	9.2	2009～2011	25.0	25.0
Harawacha	3	2,712	43.73	8.92	2009～2011	41.7	41.7
Harshin	3	1,441	43.73	8.92	2006～2011	6.9	6.9
Husie	3	1,124	41.83	8.65	2009～2011	75.0	75.0
Jeldesa	3	1,084	42.1	9.72	2010～2011	33.3	33.3
Lefiesa	3	1,733	42.97	9.6	2009～2011	50.0	50.0
Mekela	3	2,733	41.33	9.22	2010～2011	8.3	8.3
Misraq Gashamo	3	798	45.33	8.12	2009～2011	61.1	61.1
Tuluguled	3	2,007	42.43	9.5	2009～2011	69.4	69.4
Kocher	–	–	–	–	2009～2011	25.0	25.0
Toguchale	3		43.5	9.36	2009～2011	19.4	19.4
Kelafo	3	250	44.12	5.6	2009～2011	50.0	50.0
Aysha	1		42.32	10.75	2009～2011	13.9	13.9
Hadew	3	1,807	42.67	9.37	2001～2011	9.1	9.1

MD-1: Percentage of missing data for the whole observation years.
MD-2: Percentage of missing data except those years without any observation data.

Source：Ethiopia National Meteorological Agency, Data Management ＆ Dissemination, Jijiga Office(2012)

Generally, it is known that there is a correlation between annual rainfall and altitude, but the following result in Table 2.5 does not show a definite correlation in Somali region. The variation of period of the data collection has an effect on the correlation (refer to Figure 2.2).

Table 2.5: Altitude and Annual Rainfall Data of each Station of Somali Region

Station Name	Altitude(m)	Precipitation (mm/year)	Duration
Hadew	1807	637.8	2001～2011
Kebridahar	1753	220.0	1985～2003
Gode Met	290	272.7	1966～2012
Gode Town	291	236.0	2004～2009
Chinaksen	2007	621.0	2004～2010
Teferiber(Aware)	1611	746.6	2003～2006
Degahabur	1070	335.1	1985～2010
Jijiga	1775	572.1	1985～2010
Filtu	1225	436.3	1980～1999
Hartishiek	1630	246.3	2003～2008
Kebribeya	537	271.1	2009～2010
Dawe	1755	603.0	2009～2011
Dembel	1340	425.0	2009～2011
Harshin	1441	427.1	2006～2011
Mekela	2733	866.0	2010～2011
Errar	1088	525.4	1968～2011

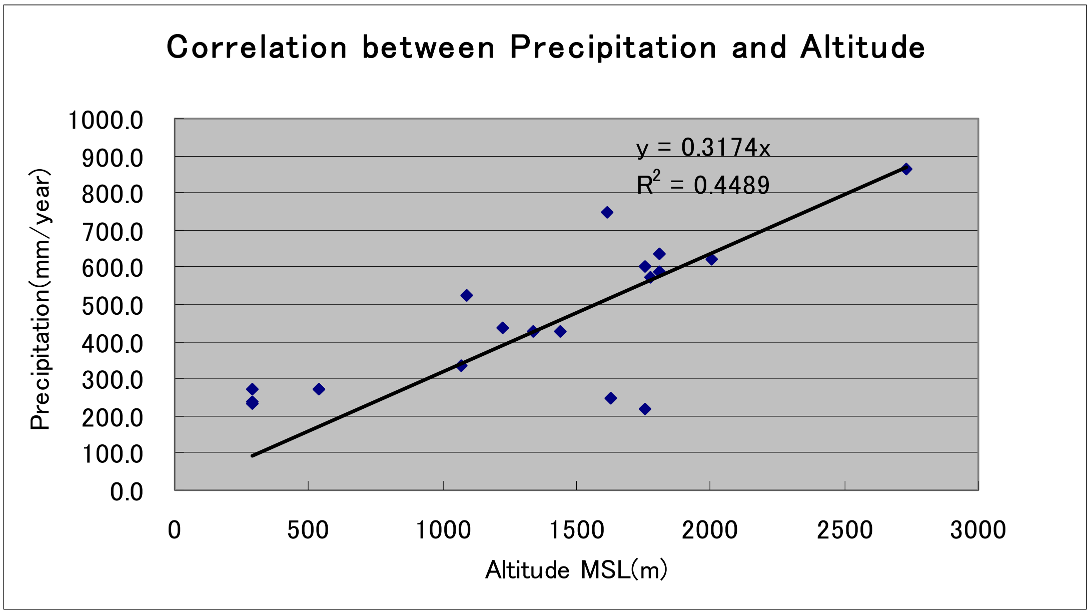


Figure 2.2: Correlation Chart of Annual Rainfall and Altitude

The following Table 2.6 is the result of calculating probability precipitation based on annual rainfall data of major areas. Since the amount of precipitation changes every year, the amount of water resources that are formed by precipitation also changes from year to year (refer to Figure 2.3). Thus, it is necessary to analyze the probability of changes in precipitation amount in addition to the analysis of its tendency in change and cyclic characteristics. There are many probability calculation methods, however, this report uses the graphical method (Hazen plot and Tomas Plot).

Table 2.6: Probability Precipitation

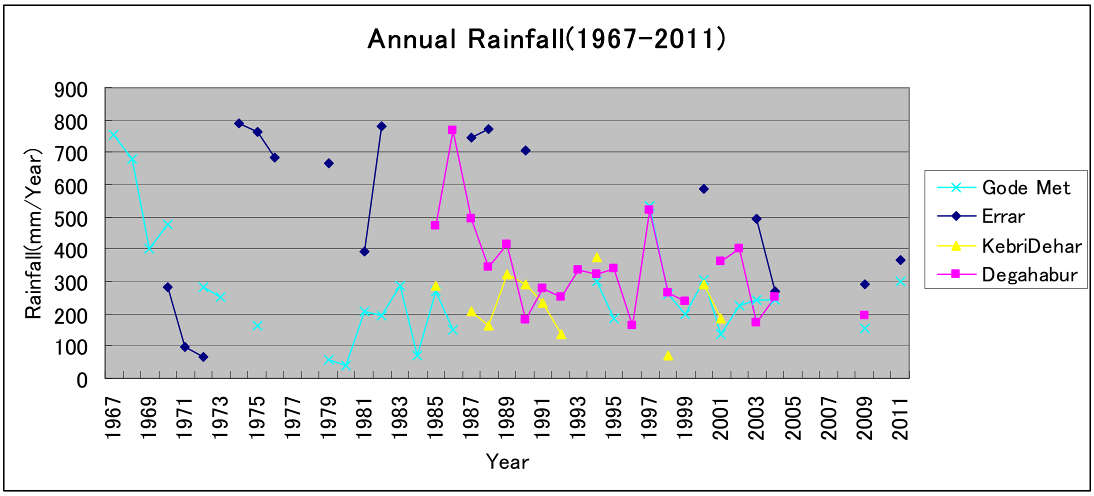
	Kebridahar				
	Non-Ex(%)	Thomas	Hazen	Mean	Return Period
Dry Year	1	61.0	73.3	67.1	100
	2	70.6	83.1	76.8	50
	5	88.0	100.2	94.1	20
	10	107.0	118.4	112.7	10
	25	135.6	144.9	140.2	5
	50	213.2	213.2	213.2	2
Wet Year	75	335.3	313.7	324.5	5
	90	424.9	383.9	404.4	10
	95	516.7	453.6	485.1	20
	98	643.8	547.2	595.5	50
	99	745.5	620.2	682.9	100
			Number of Data	N=11	

	Gode Met.				
	Non-Ex(%)	Thomas	Hazen	Mean	Return Period
Dry Year	1	43.0	49.0	46.0	100
	2	52.2	58.6	55.4	50
	5	69.8	76.6	73.2	20
	10	90.4	97.2	93.8	10
	25	123.6	129.6	126.6	5
	50	224.9	224.9	224.9	2
Wet Year	75	409.2	390.2	399.7	5
	90	559.6	520.5	540.0	10
	95	724.7	660.2	692.4	20
	98	969.3	862.9	916.1	50
	99	1176.7	1031.5	1104.1	100
			Number of Data	N=27	

	Degahabur				
	Non-Ex(%)	Thomas	Hazen	Mean	Return Period
Dry Year	1	108.6	121.2	114.9	100
	2	122.9	135.4	129.2	50
	5	148.0	159.9	153.9	20
	10	174.5	185.3	179.9	10
	25	213.1	221.7	217.4	5
	50	312.1	312.1	312.1	2
Wet Year	75	457.3	439.5	448.4	5
	90	558.3	525.7	542.0	10
	95	658.3	609.4	633.8	20
	98	792.4	719.6	756.0	50
	99	896.8	804.0	850.4	100
			Number Of Data	N=20	

	Errar				
	Non-Ex(%)	Thomas	Hazen	Mean	Return Period
Dry Year	1	73.8	90.2	82.0	100
	2	90.7	108.2	99.4	50
	5	123.4	142.1	132.8	20
	10	162.3	181.2	171.7	10
	25	226.1	243.1	234.6	5
	50	426.6	426.6	426.6	2
Wet Year	75	804.6	748.5	776.5	5
	90	1121.1	1004.2	1062.7	10
	95	1474.4	1280.1	1377.2	20
	98	2006.8	1682.2	1844.5	50
	99	2464.8	2018.3	2241.5	100
			Number Of Data	N=17	

N : Number of the Data



Source: National Meteorological Agency(NMA), Meteorological Data and Climatology Directorate (2012)

Figure 2.3: Fluctuation of the Annual Rainfall

2.1.3 Evaporation

The following Table 2.7 is monthly evaporation data from 5 stations. This data is observed by the use of evaporation pan. Filtu station is located outside of Wabi Shebele river basin.

Table 2.7: Observational evaporation data

													(Unit:mm)	
Staion	Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jly.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual total
Filtu	1989	367.3	347.0	255.2	129.7	88.9	120.2	141.2	168.0	169.1	114.2	121.9	188.1	2210.8
	1990	246.1	221.7	152.3	62.0	109.1	160.8	150.7	165.9	177.7	124.7	181.2	232.2	1984.4
	1991	296.7	333.2	309.8	178.1	170.9	68.2	99.1	92.7	207.7	228.3	234.6	329.0	2548.3
	1992	309.3	266.7	273.7	190.6	156.5	175.5	116.1	174.1					
	1993	228.9	199.6	256.5	186.9	183.4	156.1	192.6	248.6	256.4	212.0	146.8	208.7	2476.5
	1994	273.6	297.6	261.7	130.9	116.8	198.5	242.9	229.2	254.8	157.1	93.0	190.7	2446.8
	1995	271.0	260.0	253.8	188.9	219.7	242.0	301.9	256.6	239.1	157.8	188.4	202.7	2781.9
	1996	205.5	185.9	181.7	146.8	148.6	142.3	172.4	184.4	233.1	146.9	140.5	140.3	2028.4
	1997	201.6	176.1	177.6	140.9	154.3	171.4	142.0	165.1	151.5	122.8	124.2	161.2	1888.7
	Mean	**266.7**	**254.2**	**235.8**	**150.5**	**149.8**	**159.4**	**173.2**	**187.2**	**211.2**	**158.0**	**153.8**	**206.6**	**2306.4**
Kebridehar	2000	171.6	120.3	117.2	140.1	133.0	250.9	252.8	288.3	262.5	112.0	159.3	201.8	2209.8
	2001	241.8	201.9	197.0	97.8									
	Mean	**206.7**	**161.1**	**157.1**	**119.0**	**133.0**	**250.9**	**252.8**	**288.3**	**262.5**	**112.0**	**159.3**	**201.8**	**2304.5**
Jijiga	1987	225.0		116.7	108.9	117.8	103.0	142.7	143.8	130.1	143.6	205.6	211.9	
	1988	215.9	188.6	282.4	180.1	220.2	176.4	182.7	170.3	130.0	172.8	225.1	222.8	2367.3
	2000	121.5	94.5	146.6	127.4	175.8		237.5	182.4	133.9	177.8	154.9	158.1	
	2001	179.1	168.3	182.2	193.2	165.0	203.1	181.4	175.5	173.6	177.6	191.5	212.3	2202.8
	2002	197.2	193.8	189.5	155.4	147.6	215.0	229.1	212.5	156.5	188.3	223.8	166.3	2275.0
	2003	202.9	226.8	235.1	176.6	207.1	177.7	215.6	168.9	153.1	215.3	197.6	208.2	2384.9
	2004	158.5	254.8	230.2	123.8	181.9	152.5	190.4	180.5	137.3	168.7	157.3	173.7	2109.6
	Mean	**185.7**	**187.8**	**197.5**	**152.2**	**173.6**	**171.3**	**197.1**	**176.3**	**144.9**	**177.7**	**193.7**	**193.3**	**2151.2**
Gode	1987	447.9	393.2	399.5		153.9	238.7	354.9	436.0	394.2	262.9	240.7	291.3	
	1988	374.8	432.8	413.7	245.6	273.7								
	2000	475.6	477.4	525.9	373.8	173.3	369.6	429.9	486.4	403.6	134.2	213.2	368.1	4431.0
	2001	449.8	416.8	473.6	325.6	389.2	492.4	504.1	482.5	428.7	312.4	363.5	425.6	5064.2
	2002	512.2	461.8	484.4	273.6	389.5	325.6	485.5	480.8	322.0	201.8	219.8	399.4	4556.4
	2003	443.5	449.6	527.7	337.3	279.8	459.3	512.9	523.1	491.9	382.3	302.4	285.0	4994.8
	2004	404.4	481.1	551.1	236.0	363.2	425.1	493.8	498.6	451.1	301.5	140.6	305.4	4651.9
	Mean	**444.0**	**444.7**	**482.3**	**298.7**	**288.9**	**385.1**	**463.5**	**484.6**	**415.3**	**265.9**	**246.7**	**345.8**	**4565.4**
Degabour	1987	283.5	122.8	245.9	175.6	109.7	110.4	106.9	157.2	171.4	137.2	142.3	114.0	1876.9
	1988	130.2		102.8	82.4	131.9	90.6	157.0	124.3	202.4	87.6	97.9	220.4	
	2000		430.5	501.2	412.4	186.3	307.0	324.5	358.4	315.4	171.7	237.5	265.2	
	2001	202.5	229.1	218.5	145.4	157.7	188.9	155.0	211.2	140.3	140.5	179.6	230.2	2198.9
	2002	252.2	217.5	205.8	190.4	176.0	229.6	277.8	308.5	210.3	116.4	244.9	182.1	2611.5
	2003	218.2	191.8					293.7	297.1	248.3	298.8	340.5	299.4	
	2004	250.0	319.8	345.0	126.0	239.6				339.5	327.7	164.6	316.9	
	Mean	**222.8**	**251.9**	**269.9**	**188.7**	**166.9**	**185.3**	**219.2**	**242.8**	**232.5**	**182.8**	**201.0**	**232.6**	**2596.4**

Source: National Meteorological Agency(NMA), Meteorological Data and Climatology Directorate(2012) (*Blank: missing data)

The following Figure 2.4 presents the monthly evaporation for two stations (Gode Met. and Jijiga Met.). There is not so much annual fluctuation in Jijiga and the values are less than 200 mm each month; evaporation of April, May, October, and November of Godey is less than 300mm but the annual total evaporation is more than 4,500mm.

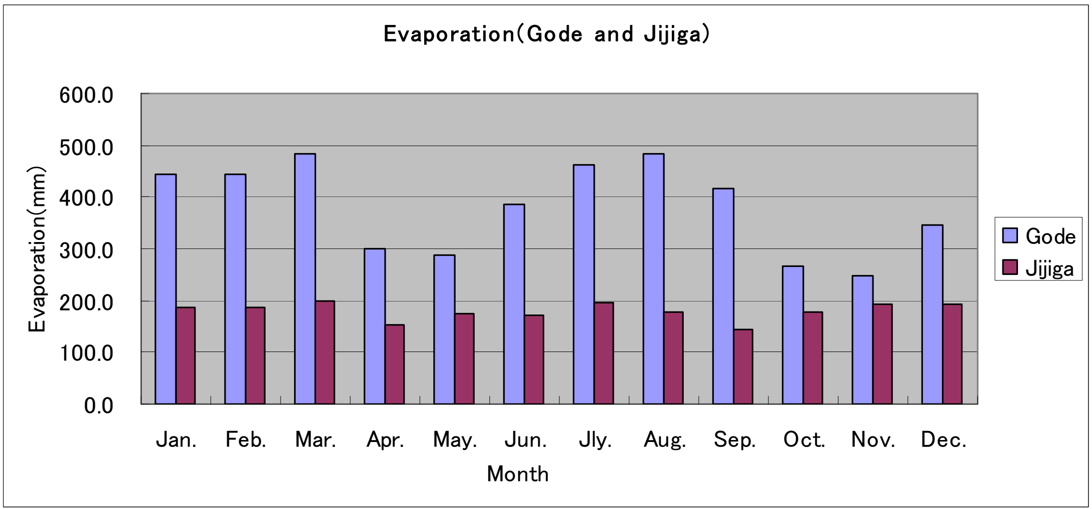


Figure 2.4: Observational Evaporation of Gode and Jijiga

2.1.4 Temperature and other data

a. Temperature

The following Table 2.8 presents the mean maximum and minimum temperatures at various observational stations. This data is the mean of the daily maximum and daily minimum temperature for observed duration. The monthly average temperatures of Gode Met. and Jijiga stations are shown in Figure 2.5 and Figure 2.6. Records of Gode Met. shows flat feature throughout the year (the variation is less than 5^{o}C. The variation of maximum temperature of Gode is also small and minimum temperature of November to December is less than 10^{o}C indicating the feature of highlands.

Table 2.8: Observational Data (Max. and Min.)

No.	Station Name	Duration		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1	Hadew	2001～2010	MAX	24.9	26.6	27.5	26.4	29.4	24.5	23.2	23.5	24.7	25.7	25.7	25.1	25.6
			MIN	10.8	11.8	13.5	13.5	13.5	13.0	12.7	12.5	12.2	11.9	11.6	10.9	12.3
			Mean	**17.8**	**19.2**	**20.5**	**19.9**	**21.5**	**18.8**	**17.9**	**18.0**	**18.4**	**18.8**	**18.6**	**18.0**	19.0
2	KebriDehar	1985～2003	MAX	34.4	35.6	36.0	34.6	32.5	31.7	31.0	31.8	33.1	30.6	33.6	34.1	33.3
			MIN	19.1	19.9	21.7	22.7	22.0	21.5	21.6	21.6	20.3	19.6	19.4	19.1	20.7
			Mean	**26.8**	**27.7**	**28.9**	**28.6**	**27.3**	**26.6**	**26.3**	**26.7**	**26.7**	**25.1**	**26.5**	**26.6**	27.0
3	Gode Met	1985～2005	MAX	35.6	36.8	37.3	35.8	34.4	33.8	33.0	33.7	35.4	34.3	34.1	34.8	34.9
			MIN	21.8	22.7	24.5	24.4	24.3	24.0	23.6	23.5	24.2	23.6	22.2	21.8	23.4
			Mean	**28.7**	**29.8**	**30.9**	**30.1**	**29.4**	**28.9**	**28.3**	**28.6**	**29.8**	**28.9**	**28.1**	**28.3**	29.2
4	Gode Town	2004～2009	MAX	30.3	36.7	37.6	35.8	35.2	33.7	34.3	34.9	35.8	33.5	34.5	35.6	34.8
			MIN	21.0	21.2	22.1	21.0	21.7	21.0	22.1	22.3	22.7	20.7	21.0	21.0	21.5
			Mean	**25.6**	**28.9**	**29.8**	**28.4**	**28.4**	**27.4**	**28.2**	**28.6**	**29.2**	**27.1**	**27.7**	**28.3**	28.1
5	Kebribeya	2007～2010	MAX	26.6	27.3	28.0	27.9	28.3	27.0	26.5	26.8	28.5	27.3	27.8	27.2	27.4
			MIN	11.4	13.7	14.4	15.8	15.3	14.4	13.6	14.3	14.9	13.7	13.6	11.5	13.9
			Mean	**19.0**	**20.5**	**21.2**	**21.8**	**21.8**	**20.7**	**20.0**	**20.5**	**21.7**	**20.5**	**20.7**	**19.4**	20.7
6	Degahabur	1985～2010	MAX	31.6	33.2	33.7	32.2	30.9	29.9	28.8	30.1	31.8	31.3	31.9	31.5	31.4
			MIN	16.9	17.2	17.2	18.2	19.6	19.6	19.4	20.0	20.3	19.4	17.6	17.2	18.5
			Mean	**24.3**	**25.2**	**25.5**	**25.2**	**25.3**	**24.7**	**24.1**	**25.0**	**26.1**	**25.4**	**24.8**	**24.3**	25.0
7	Jijiga	1985～2010	MAX	27.2	29.7	29.8	28.9	28.7	27.8	26.9	26.9	27.7	28.6	27.6	27.2	28.1
			MIN	7.7	7.9	10.9	13.7	15.0	16.0	16.0	15.9	15.3	10.7	7.8	7.3	12.0
			Mean	**17.5**	**18.8**	**20.4**	**21.3**	**21.8**	**21.9**	**21.4**	**21.4**	**21.5**	**19.6**	**17.7**	**17.2**	20.0
8	Harishiek	2009～2010	MAX	26.6	28.4	29.6	27.9	29.1	28.9	26.4	25.7	27.4	26.7	27.4	26.1	27.5
			MIN	3.1	4.9	7.0	7.5	8.3	8.6	8.0	7.7	7.7	5.5	1.1	5.5	6.2
			Mean	**14.9**	**16.7**	**18.3**	**17.7**	**18.7**	**18.7**	**17.2**	**16.7**	**17.5**	**16.1**	**14.2**	**15.8**	16.9

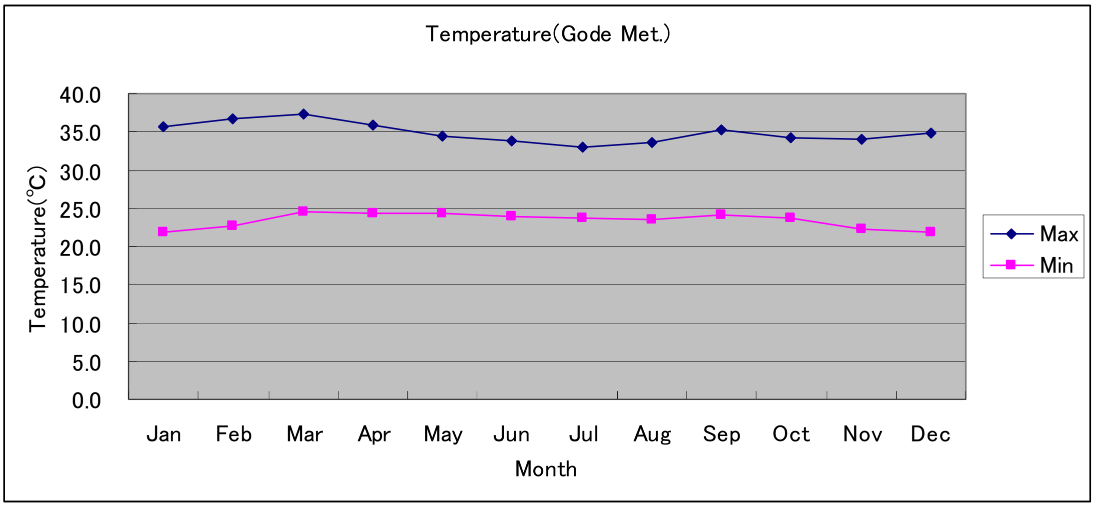


Figure 2.5: Monthly Temperature of Gode Met. (Max, Min)

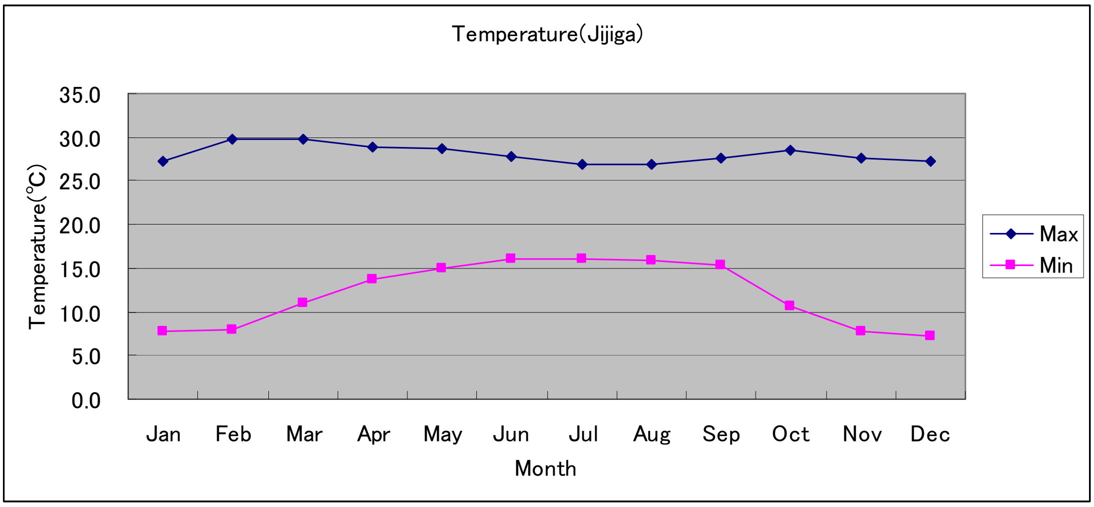


Figure 2.6: Monthly Temperature of Jijiga (Max, Min)

b. Sunshine

Table 2.9 and Table 2.10 are the observed monthly duration of sunshine. The duration of sunshine of Gode Met. is shorter than that of Jijiga by about 50 hours from July to August. But Annual total of the two stations is almost the same.

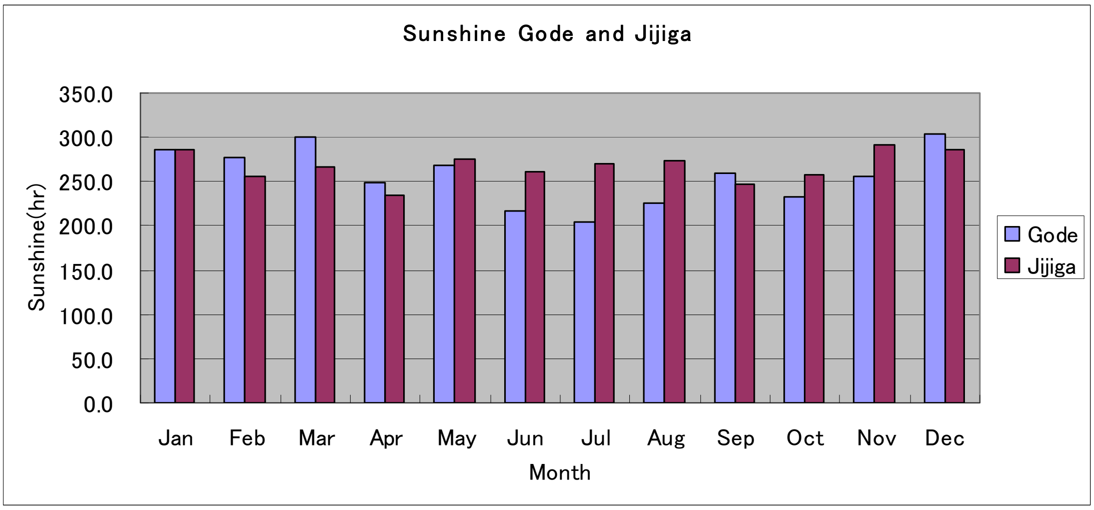


Figure 2.7: Monthly Duration of Sunshine in Gode Met. and Jijiga

Table 2.9: Duration of sunshine in Gode Met.

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean
Jan	250.6	310.1	316.0	206.7		170.1	326.9	332.0		326.4	245.1	326.6		327.5	322.6		313.3	313.4		210.5	286.5
Feb	297.8	292.2	293.6	183.4	271.8	277.2	294.1	291.5		290.4	271.2	288.1		305.6	303.9	299.7	308.3	291.0	131.8	288.9	276.7
Mar	291.9	296.5	281.1	247.4		321.4	328.4	283.2		279.4	319.6		327.0	270.4	318.7	321.6	323.9	308.9	293.4	297.6	300.6
Apr	215.6	258.1	207.2	245.1	264.7	259.1	247.7	193.7		207.5	283.9		273.1	328.4	244.8	268.5	240.3	241.3	235.6	263.2	248.8
May	288.0	247.4			276.8	247.6	243.0	298.2		301.3	251.5		224.4	275.5	299.0		265.4	250.5	271.3	279.9	268.0
Jun		237.7			212.1		216.0	211.0	122.4	235.8	250.4		243.4	237.8	163.4	248.2	226.9	234.0	236.2	170.6	216.4
Jul	196.4	150.3			211.6	126.5	208.7	250.6	113.9	196.0	320.5	171.2	197.6		276.7	233.4	246.9	176.0	150.9	250.9	204.6
Aug	226.9	245.1			178.5	233.0	240.1	193.7	236.1	259.4	192.5		238.1	226.7	228.3	237.8	199.9	212.5	243.3	239.2	225.4
Sep	218.5	221.9			251.2	281.1	258.8		283.0	284.9	285.6		275.7	250.4	250.7	293.6	269.6	285.1	211.0	240.0	260.1
Oct	252.2	226.2			238.5	244.3	221.8	207.0	245.7	196.8	198.6		232.0	245.2	236.7	292.6	233.0	256.6	205.5	229.0	233.0
Nov	290.4	250.4			273.3	305.2	257.6	301.8	262.1	194.1	279.6		274.2	288.2	280.2	247.4	225.2		109.0	244.1	255.2
Dec	316.7	249.7			286.1	304.5	307.8		312.6		332.6		329.4	319.8	300.6	283.3	307.9			308.2	304.6
																				Σ mean	3079.8
Total		2985.6					3150.9				3231.1				3225.6		3160.6			3022.2	3129.3

Table 2.10: Duration of sunshine in Jijiga

	Jijiga Sunshine																
	1983	1984	1985	1986	1987	1988	1989	1990	1991	2000	2002	2003	2004	2005	2006	2007	Mean
Jan			278.9	314.4	309.1	288.4	291.4	282.5	271.5	286.9	281.0	293.6	245.6	277.4	278.7	303.6	285.9
Feb	214.5		273.6	223.2	248.8	252.0		179.3		255.6	295.3	285.9	301.2	287.9	243.3	270.1	256.2
Mar	268.3		262.8	261.2	204.7	301.1	222.7	279.5		300.2	274.8	298.3	254.5	250.6	271.5	286.0	266.9
Apr	238.3		200.7		251.2	211.8	183.2	206.2		266.7	248.7	251.6	246.4	255.6	239.9	256.9	235.2
May	255.4		243.4	302.9	243.3	295.3	288.7	286.0		261.9	288.5	288.0	299.0	243.6	279.7	268.5	274.6
Jun			250.2	261.4		282.4					284.0		268.0	282.4	236.9	229.9	261.9
Jul			275.6	260.0	296.4	238.1	244.9	270.8		286.1	294.5	273.0	282.7	261.0	248.3	273.1	269.6
Aug			298.4	281.7	286.7	264.4	274.6	276.2				242.7	266.9	295.5	254.4	273.1	274.1
Sep		228.9	258.5	252.7	274.6	251.4					245.8	259.8	239.8	244.1	237.6	223.4	247.0
Oct		279.3	266.3		274.2	282.6		114.1			257.5	291.8	265.9	275.3	215.1	307.0	257.2
Nov	290.3	293.4	284.7	295.7		315.0		275.2			308.2	289.0	280.6	298.2	283.2	277.8	290.9
Dec	299.9	272.2	308.5	253.6		299.0		281.9			237.1	278.6	298.2	312.3	266.5	324.6	286.0
																Σ mean	3205.4
Total			3201.6			3281.4							3248.8	3284.0	3055.1	3294.0	3227.5

c. Wind-direction and Wind-speed

Addis Ababa NMA provides the data of 4 stations (Jijiga, Gode Met., Gode Town, Degahabour). NMA already made the graph charts of Jijiga and Gode Met., which are attached in Data 1.1.2 and Data 1.1.3 on Final Report Data Book. Statistical duration and Observation time is described below.

1) Jijiga
   Wind-rose diagram of Jijiga for the month of January to December
   Based on 1980-2003 data at 15:00 GMT
2) Gode Met.
   Wind-rose diagram of Gode Met for the month of January to December
   Based on 1966-2002 data at 12:00 GMT

At Jijiga, there are many days of wind from North or North-East from October to February. And most days the wind speed is over 5m/sec. From March, the wind-direction gradually shifts from east to south, and the wind speed becomes less than 5m/sec. In May, the wind blows from all directions, and from June to September wind from the southwest increases and for most days the wind speed is over 5m/sec.

At Gode Met., there are many days of wind from the east from November to March. And most days the wind speed is over 5m/sec. After that, wind from the southwest increases from May to October, and the wind speed is 6m/sec～8m/sec, which is comparatively strong throughout the year.

The monthly wind speed and the distribution of the frequencies of annual wind speed are shown in Figure 2.8-Figure 2.11. (Source: Ministry of Water and Energy, Hydrology Department office (2012))

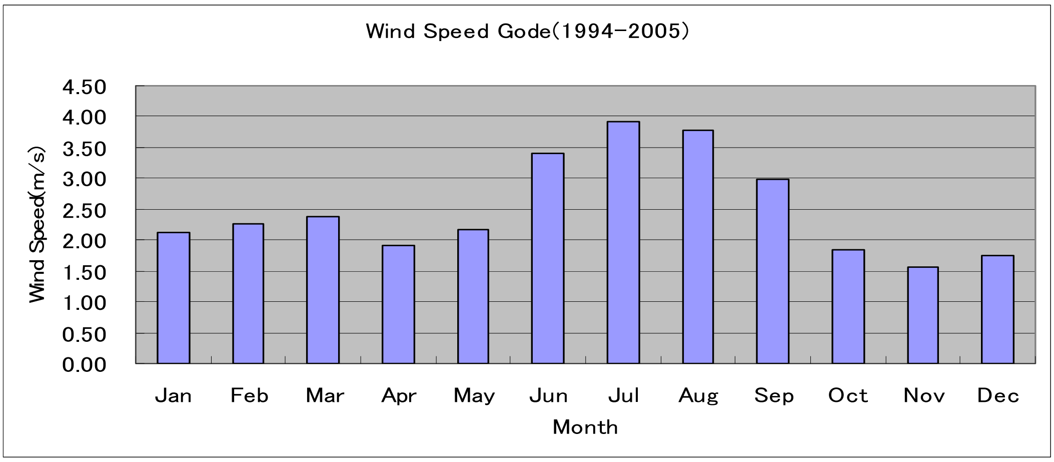


Figure 2.8: Monthly wind speed at Gode Met.

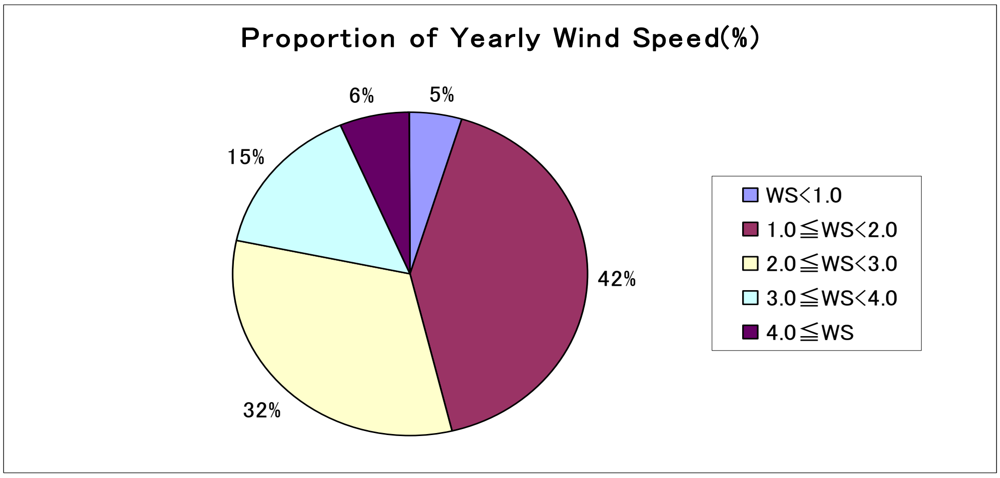


Figure 2.9: Distribution of the frequencies of annual wind speed at Gode Met.

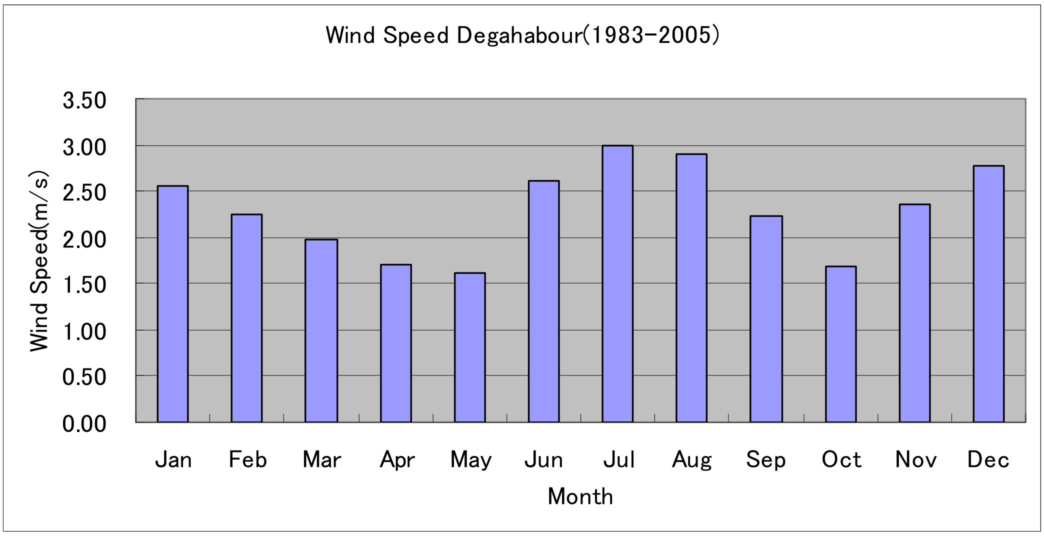


Figure 2.10: Monthly wind speed at Degahabour

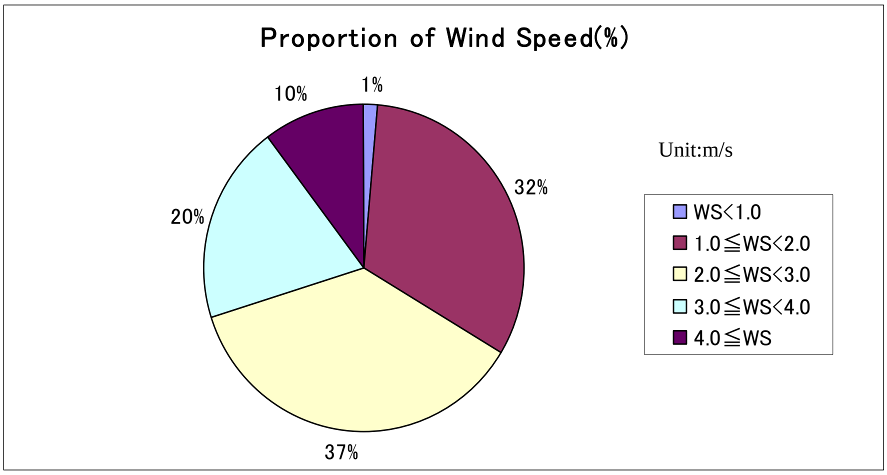


Figure 2.11: Distribution of the frequencies of annual wind speed at Degahabour

2.2 Collection and review of hydrological data

All hydrological stations are operating under the Ministry of Water and Energy (MoWE). The position of hydrological (river discharge) stations in Wabi Shebele River are shown in Figure 2.12. The report of "Wabi Shebele River Basin Integrated Development Master Plan Study Project" MoWR (now MoWE) use the data of Table 2.11.

2.2.1 Hydrological stations in Somali Region

The information of the River Discharge Station and content of the data (existence or nonexistence) are shown in Table 2.11. The study team tried to check the condition of the stations (at Jijiga and Gode), but these had been abolished many years ago. As shown in Data 1.1.1 on Final Report Data Book, there are many discharge stations in Shebele River basin, but Table 2.12 shows the only available data in this project. It is not known when or why the observation stations have been abandoned. This report uses the same spelling of observing stations as those in the list of MoWE. The location map of the observation station and the basins is shown in Figure 2.12.

Table 2.11: Information of Discharge Station (MoWE)

○:No Missing Data △:Missing Data ∗:No Observation

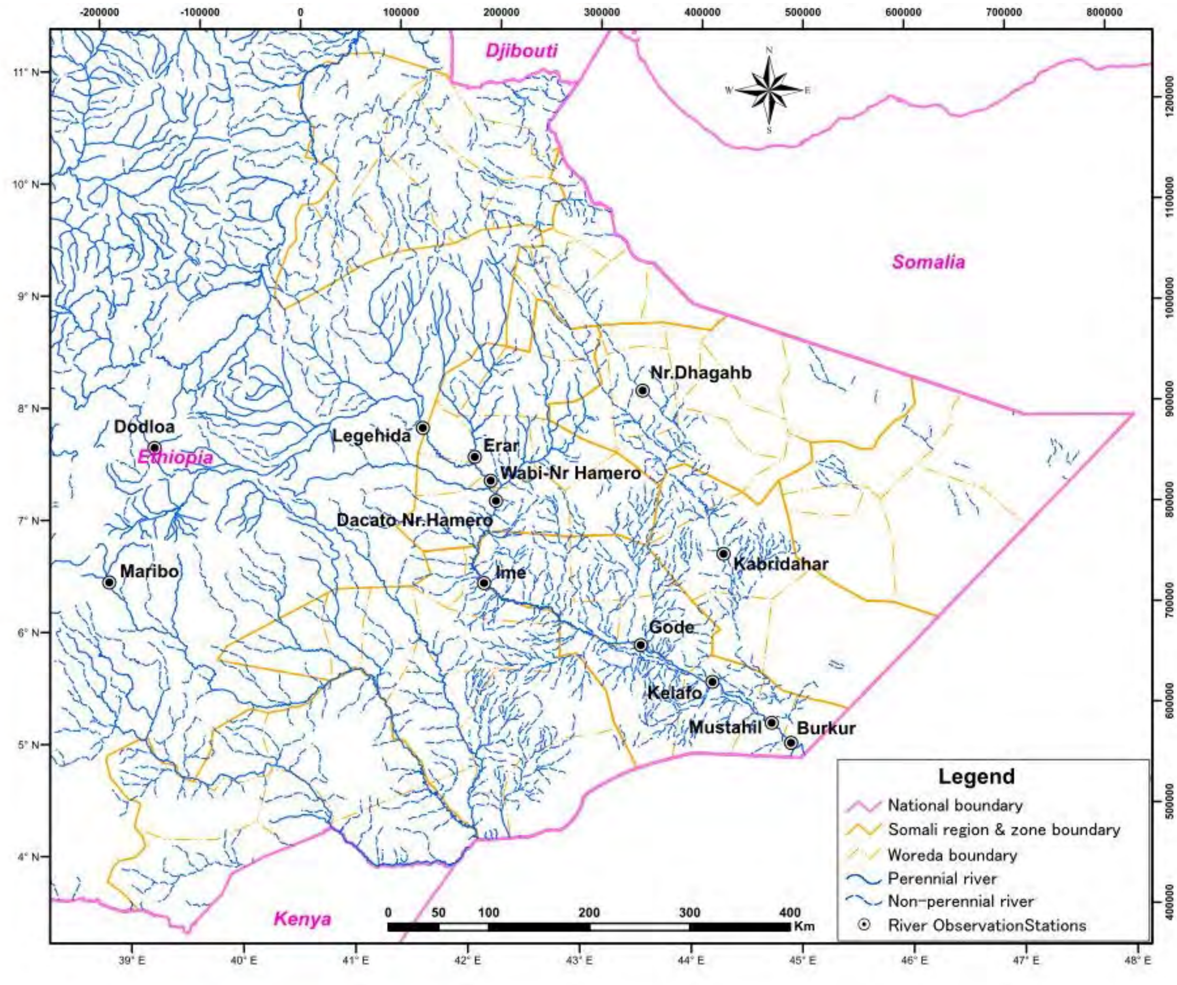
No.	River Name	Station Name	Station No.	Drainage Area(km^2)	Altitude(m)	Coordinate Latitude(N)	Coordinate Longitude(E)	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1	Jijiga	**uper jijiga @ bridge**	62016	910	1,520	9°14'	42°36'	○	△	△	○	○	○	△	△	○	○	△	○	∗	∗	∗	∗	∗	∗
2	Wabi	**wabi gode**	63001	127,300	285	5°56'	43°33'																△	○	△
4	Jawis	**Jawis bedessa**	62015	22	1,800	8°55'	40°47'									○	△				△	○	○	△	△
5		**Errer Jijiga Road**	002	947	1,700	9°21'	42°48'	○	△	△	○	○	○	△	△	○	○	○	○	∗	∗	∗	∗	∗	∗

Table 2.12: Information of Discharge Stations

Station Name	River	Station No.	Coordinate Lat(North)	Coordinate Lon.(East)	Altitude (m)	Watershed area (km²)	year of installation	1967	1968	1969	1970	1971	1972	2000	2001	2002
Daketa Hamaro hedad	Dacata	13281109 62001	7° 20′	42° 17′	500	15,188	1968/2/5		△	△	△	◎				
Erer Hamaro Hedad	Erer	13281412 62003	7° 37′	42° 02′	450	15,132	1968/5/23				◎	◎				
Fafen Kebridahar	Fafen	13281602 63004	6° 45′	44° 17′	525	26,670	1968/6/28			◎	◎	◎				
Jerer Degahabur	Jerer	13284101 63003	8° 13′	43° 33′	1,050	6,338	1967/10/9			△	◎	◎	△			
Maribo Maribo confluence	Maribo	13282202 61010	7° 06′	39° 22′	2,350	1,039	1968/1/1		△	◎	◎					
Maribo Bridge Road of Dodola		13282201	7° 00′	39° 03′	2,450	137	1967/1/25	△	◎	◎	◎					
Wabishebele at Burkur	Wabishebele	13280103 63005	5° 11′	44° 48′	247	144,000	1969/1/6				△	◎				
Wabishebele Bridge Road of Dodola		13280108							△	◎	◎	◎				
Wabishebele At Gode	Wabishebele	13280112 63001	5° 56′	43° 43′	285	127,300	1967/10/4	△	△	◎	◎	◎		△	◎	△
Wabishebele Hamaro Hedad	Wabishebele	13280115 62002	7° 24′	42° 11′	470	63,644	1968/2/11		△	◎	◎	◎				
WabiShebele At Imi	Wabishebele	13280118 63006	6° 29′	42° 8′	405	91,600	1969/3/1			△	◎	△				
WabiShebele At Kelafo	Wabishebele	13281021 63010	5° 36′	44° 8′	249	139,100	1969/1/8			◎	◎	◎				
Wabishebele Lege hida	Wabishebele	13280124 61011	7° 58′	40° 54′	950	20,473	1968/4/4				△	◎				
Wabi Shebele Malka Wakana	Wabishebele	13280127 61009	7° 11′	39° 26′	2,485	4,388	1967/7/22		△	◎	◎	◎				

* ◎ :no missing data, △ :There will be some missing data.

Source: Ministry of Water and Energy, Hydrology Department office (2012)



Source: Ministry of Water and Energy, Hydrology Department office (2012)

Figure 2.12: Map of the Basin and Observatory Location

2.2.2 River flow

The entire research zone (area) of this study is the Shebele River Basin. Shebele river starts from Bale highlands and has as large as a 200,000 km^2 drainage area. In Godey town, there is surface water throughout the year and it is classified as a perennial river. However, in Jarar valley, a tributary of Shebele river, the water flows across comparatively high land area and flows into Shebele river around the border of Somalia. These rivers (valleys) don't have streams except in the rainy season or in the case of intensive temporary precipitation. These are classified Wadi (intermittent streams) (refer to Figure 2.13). The discharge-duration curve and monthly discharge of the Jarar river (Degehabur discharge station, drainage area A=5,184 km^2) and Shebele river (Gode discharge station, drainage area A=127,300 km^2) are shown in Figure 2.13,Figure 2.14 and Figure 2.15, Figure 2.16. (Source: Ministry of Water Resources, Hydrology Department office (2004))

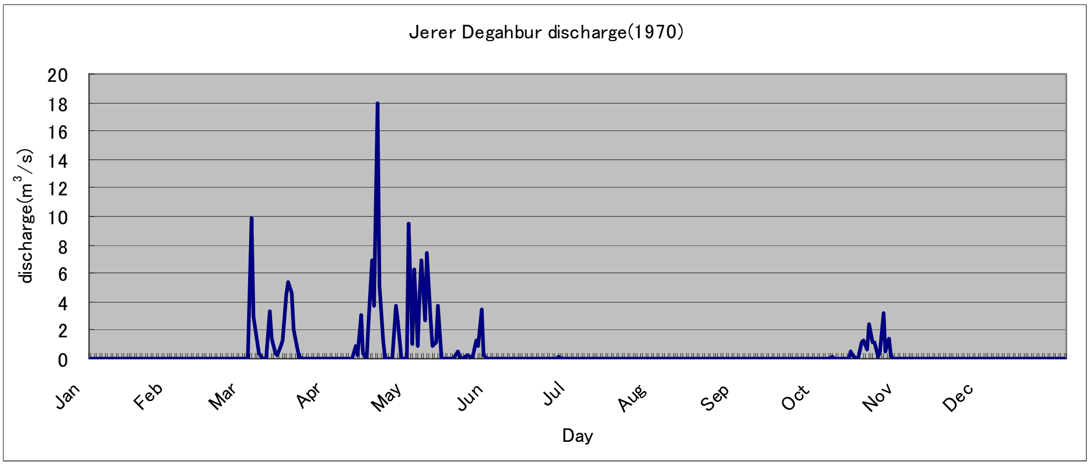


Figure 2.13: Hydrograph (Jarar Degahabur)

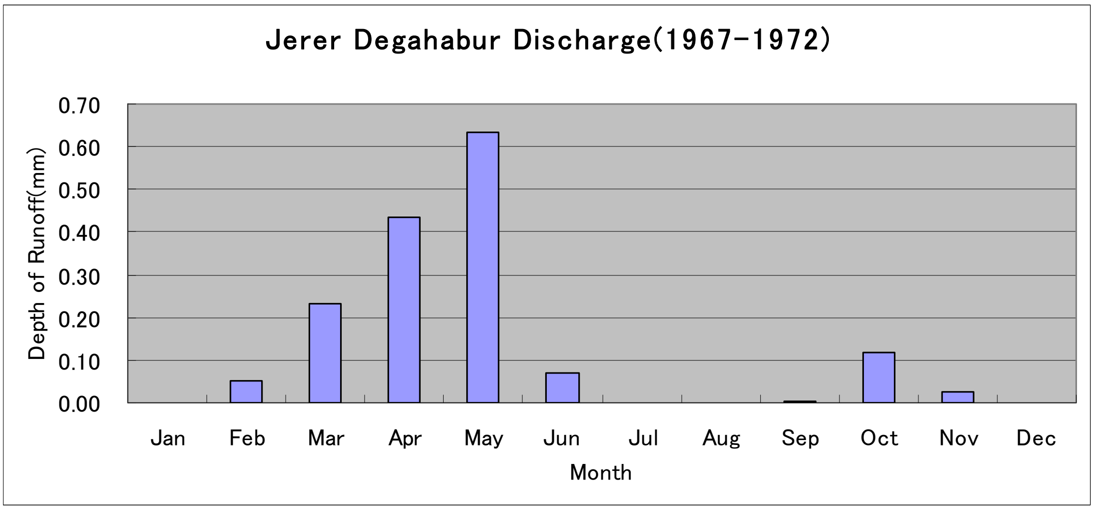


Figure 2.14: Monthly Depth of Runoff (Jarar Degahabur)

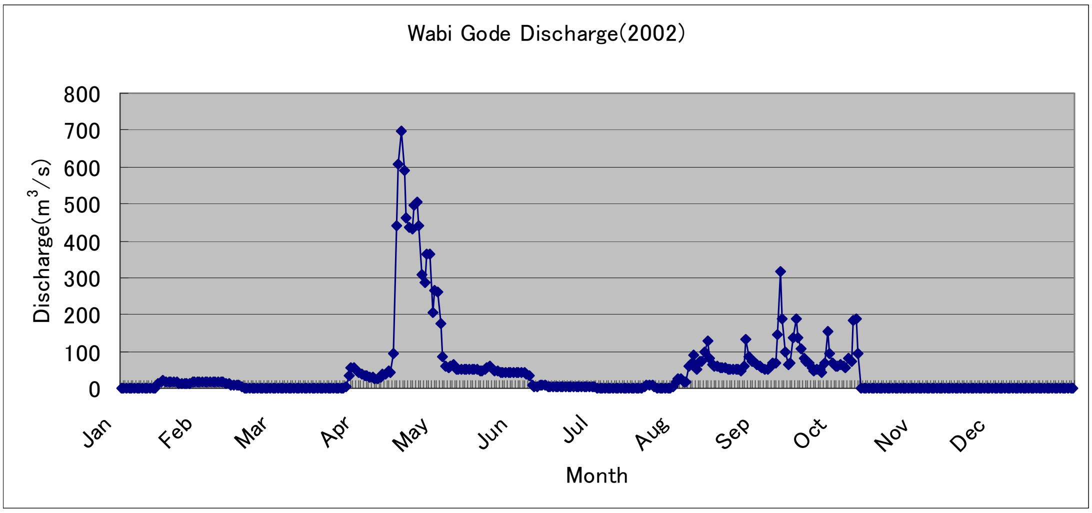


Figure 2.15: Hydrograph (Wabi Gode)

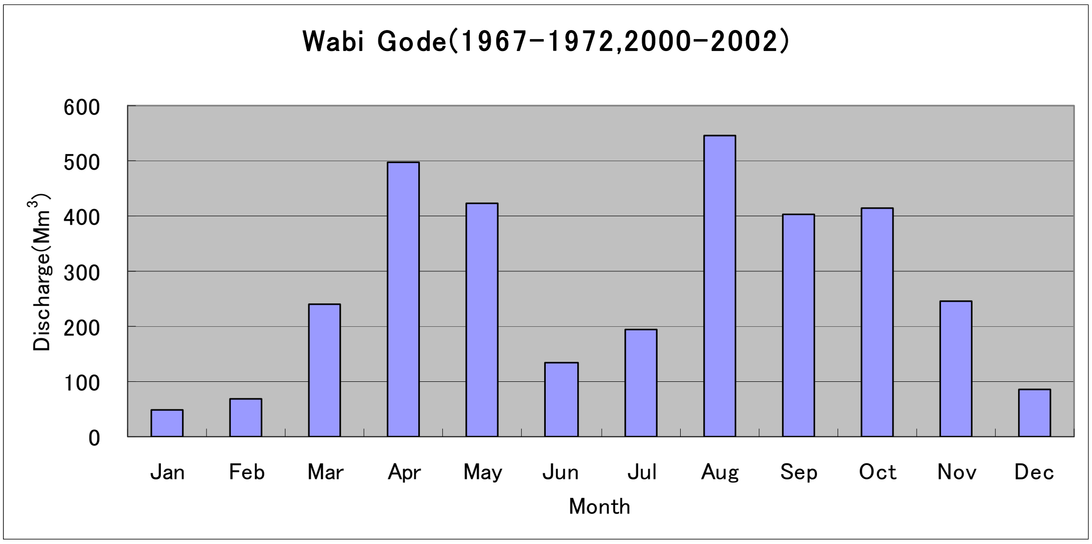


Figure 2.16: Monthly Depth of Runoff (Wabi Gode)

The following Table 2.13 shows the monthly river discharge of each station. It is easy to understand that there is hardly any discharge from the Jarar Valley from December to January and July to September.

Table 2.13: Monthly River Regime (Depth of runoff)

	Propotion of Monthly Discharge			(Jarar)						Unit:(mm)		
Station Name	Watershed(Km^2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jerer Degahbur	6,338	0.00	0.05	0.23	0.43	0.64	0.07	0.00	0.00	0.00	0.12	0.02	0.00
Fafen Kebridahr	26,670	0.00	0.00	0.07	0.21	0.47	0.02	0.00	0.00	0.01	0.11	0.04	0.00
Mean	(mm)	0.00	0.03	0.15	0.32	0.55	0.05	0.00	0.00	0.01	0.11	0.03	0.00
	Propotion(%)	0.0	2.1	11.9	25.8	44.3	3.6	0.0	0.0	0.7	9.0	2.6	0.0

	Propotion of Monthly Discharge			(wabishebele)						Unit:(mm)		
Station Name	Watershed(Km^2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wabi MelkaWakena	4,388	3.96	6.14	13.45	20.71	13.81	8.41	25.94	49.94	31.02	15.65	5.57	3.36
Wabi Legehida	20,473	1.11	0.82	13.13	8.91	7.23	4.72	12.89	29.20	16.84	11.27	5.17	1.52
Wabi Hamaro	63,644	0.92	1.78	4.94	6.84	6.28	2.83	4.75	10.54	7.19	3.98	2.26	0.99
Wabi Imi	91,600	0.55	3.01	3.65	3.19	3.59	1.26	3.04	7.38	5.28	3.19	1.49	0.43
Wabi Gode	127,300	0.39	0.54	1.89	3.90	3.33	1.05	1.52	4.28	3.16	3.25	1.93	0.67
Wabi Burker	144,000	0.20	0.32	1.33	1.72	2.57	0.76	1.17	2.56	3.31	2.28	1.26	0.39
Mean	(mm)	1.19	2.10	6.40	7.54	6.14	3.17	8.22	17.32	11.13	6.60	2.94	1.22
	Propotion(%)	1.6	2.8	8.6	10.2	8.3	4.3	11.1	23.4	15.0	8.9	4.0	1.7

Source: Ministry of Water Resources, Hydrology Department (2004)

2.3 Data analysis

2.3.1 River flow analysis

First of all, the correlation with annual depth of runoff and drainage area is shown below on a logarithmic graph. (Table 2.14, Figure 2.17) There is a strong correlation between annual depth of runoff and drainage areas. So it is easy to calculate the annual discharge at a given point based on this relation. And the monthly discharge can be estimated using the correlation chart. As shown in the information of discharge stations of Table 2.14, these calculations used the data from 1968 to 1971.

Table 2.14: Drainage Area and Depth of Runoff

	Wabi MelkaWakana	Wabi Legehida	Wabi Kelafo	Wabi Imi	Wabi Hamaro	Wabi Gode	Wabi Dodola	Wabi Burker	Maribo Dodola	Maribo confluence
Depth of Runoff(mm)	197.96	112.82	20.87	36.04	53.31	25.92	1893.07	17.84	1062.87	361.15
Watershed Area(km^2)	4,388	20,473	139,100	91,600	63,644	127,300	137	144,000	137	1,039

Source: data collected in 1968 to 1971 from Ministry of Water Resources, Hydrology Department (2004) *intermittent missing data from the year 1972 to 2012

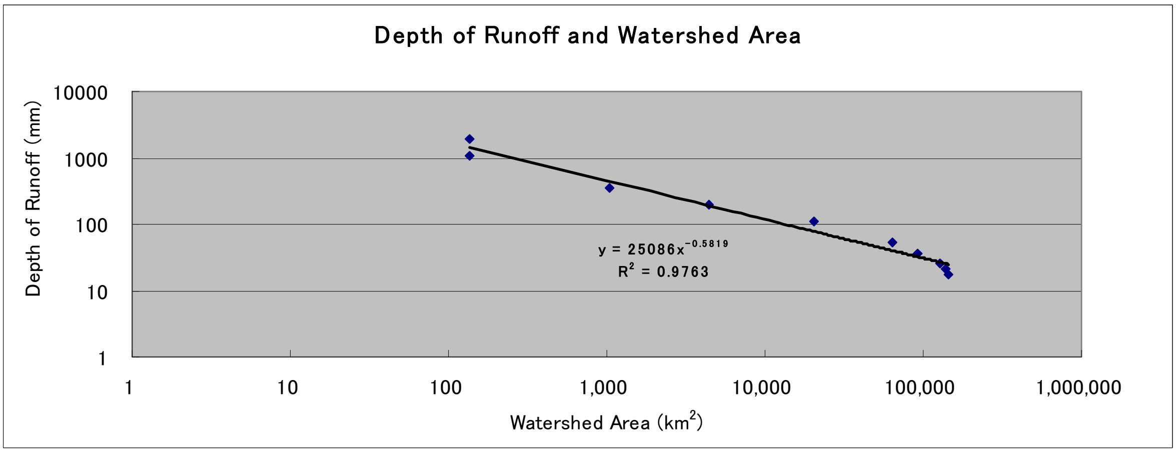


Figure 2.17: Correlation Chart

2.3.2 Water balance analysis

The results of water balance analysis in Somali region are used as reference for the groundwater development by the estimation of groundwater recharge in the study sub-basin. It is important for the groundwater development to make analysis and research not only on quantity of groundwater, but also the water quality, however in this chapter, the relative comparison will be executed by the discussion in regard to quantity of groundwater recharge.

a. Arithmetical computation

Generally speaking, water balance of a drainage basin is described by the following formula.

P=D+E+R+⊿W（R=P-D-E-⊿W）

Where

P: Precipitation, D: River Discharge, E: evapotranspiration, R: Groundwater Recharge,
ΔW: Others for water resources consumption

There is no data on which to base calculations of water resource consumption (agricultural water, daily life water etc.), so it is neglected in this report. In this computation, the data analysis of Jarar valley watershed was executed because the meteorological and river flow stations which the data were observed located in the Jarar valley.

a.1 Precipitation data (P)

There are 2 catchments in Jarar valley. Kebridehar (A=25,405 km^2) is in the catchment of the Fafen River, a branch of the Shebelle River. And Degehabur (A=5,184 km^2) is located in the upstream of Kebridehar. The precipitation values for these catchments are shown in Table 2.15, which are calculated as the arithmetical mean of the annual precipitation data from the observatory stations in each watershed. The duration of data was scattered as mentioned above (refer to Table 2.15).

Table 2.15: Annual Rainfall Data Used for the Area Rainfall Depth

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Hadew	16.3	1.9	43.7	128.7	99.9	46.2	85.6	101.6	82.0	47.4	10.8	5.2	**669.2**
KebriDehar	2.6	0.0	5.5	83.7	53.2	0.7	0.5	0.6	8.9	80.7	31.1	4.0	**271.5**
Kebribeya	0.0	47.2	38.4	45.7	71.7	27.7	21.2	33.0	45.5	62.6	0.0	8.6	**401.6**
Degahabur	5.2	1.5	21.6	100.7	92.8	10.0	1.0	2.6	47.9	52.5	10.2	3.2	**349.2**
Jijiga	12.4	9.9	35.9	113.7	79.0	35.6	66.7	80.7	72.6	40.2	19.9	22.6	**589.3**
Harishiek	6.4	4.4	22.0	95.3	31.4	41.2	31.4	48.1	44.1	6.9	0.0	0.8	**331.8**
Mean	**7.1**	**10.8**	**27.8**	**94.6**	**71.3**	**26.9**	**34.4**	**44.4**	**50.2**	**48.4**	**12.0**	**7.4**	**435.4**

Source: data collected in 1969 to 1971 from Ministry of Water Resources, Hydrology Department (2004)

a.2 Depth of Runoff (D)

The flow rate is derived by selecting from the records of the annual precipitation of the two stations along the Jarar valley for which the data are considered valid, calculating the annual flow rate, and converting it to runoff depth (discharge divided by area). The calculation results are shown Table 2.16.

Table 2.16: Annual Depth of Runoff at Control Point

Fafen Kebridahr
Watershed area(MoWR) 25,405 Km^2 Unit:cm^3/s

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1969		0.00	0.00	0.10	0.00	5.47	0.00	0.00	0.00	0.00	0.19	1.44	0.00	7.20
1970		0.00	0.00	1.85	5.47	4.30	0.04	0.00	0.00	0.30	1.75	0.04	0.00	13.75
1971		0.00	0.00	0.00	1.05	4.32	0.59	0.03	0.00	0.26	1.98	0.12	0.00	8.35
Mean		0.00	0.00	0.65	2.17	4.70	0.21	0.01	0.00	0.19	1.31	0.53	0.00	9.76
Monthly Total	(Mm^3)	0.00	0.00	1.74	5.63	12.58	0.55	0.03	0.00	0.48	3.50	1.38	0.00	25.88
	(mm)	0.00	0.00	0.07	0.22	0.50	0.02	0.00	0.00	0.02	0.14	0.05	0.00	**1.02**

Jerer Degahbur
Watershed area(MoWR) 5,184 Km^2 Unit:cm^3/s

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1969			0.40	0.37	0.00	0.12	0.00	0.00	0.00	0.00	0.23	0.18	0.00	1.29
1970		0.00	0.00	1.27	1.94	1.48	0.01	0.00	0.00	0.00	0.47	0.00	0.00	5.17
1971		0.00	0.00	0.00	1.24	2.92	0.51	0.00	0.00	0.04	0.14	0.00	0.00	4.84
Mean		0.00	0.13	0.55	1.06	1.50	0.17	0.00	0.00	0.01	0.28	0.06	0.00	3.77
Monthly Total	(Mm^3)	0.00	0.33	1.47	2.75	4.03	0.45	0.00	0.00	0.03	0.75	0.15	0.00	9.94
	(mm)	0.00	0.06	0.28	0.53	0.78	0.09	0.00	0.00	0.01	0.14	0.03	0.00	**1.92**

Source: data collected in 1969 to 1971 from Ministry of Water Resources, Hydrology Department (2004)

a.3 Evapotranspiration (E)

Monthly potential evapotranspiration (refer to Table 2.17) which is calculated by Thornthwaite Method was compared with the monthly rainfall (refer to Table 2.15) for the same observatory (but period of each data is different). Then the smaller values were used for analysis. (Table 2.18)

Table 2.17: Potential Evapotranspiration of Each Place by Thornthwaite Method

No.	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	Hadew	63.7	73.9	84.1	79.3	92.1	70.4	64.4	64.9	68.0	70.7	69.5	65.0	**865.9**
2	KebriDehar	142.2	163.4	191.6	185.2	152.9	138.7	133.2	140.9	140.6	111.1	136.4	139.6	**1775.8**
3	Gode Met	153.6	160.6	167.5	162.6	157.9	154.5	150.3	152.6	160.6	154.5	148.9	150.3	**1873.9**
4	Gode Town	114.2	154.9	161.1	153.4	153.4	142.6	149.3	152.8	156.9	140.4	145.7	150.3	**1774.9**
5	Kebribeya	66.1	78.4	84.8	90.5	90.0	80.4	74.5	78.8	89.1	78.7	80.0	69.2	**960.5**
6	Degahabur	105.3	119.3	123.5	118.6	120.3	111.9	103.2	116.7	132.8	121.4	112.4	106.5	**1392.1**
7	Jijiga	56.9	66.6	79.4	87.2	92.1	92.6	88.5	88.2	89.1	73.2	58.9	55.3	**928.1**
8	Harishiek	52.1	63.2	74.1	70.2	77.1	77.2	66.5	63.7	69.0	59.7	48.4	57.9	**779.1**

Table 2.18: Evapotranspiration Values

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Hadew	16.3	1.9	43.7	79.3	92.1	46.2	64.4	64.9	68.0	47.4	10.8	5.2	**540.1**
KebriDehar	2.6	0.0	5.5	83.7	53.2	0.7	0.5	0.6	8.9	80.7	31.1	4.0	**271.5**
Kebribeya	0.0	47.2	38.4	45.7	71.7	27.7	21.2	33.0	45.5	62.6	0.0	8.6	**401.6**
Degahabur	5.2	1.5	21.6	100.7	92.8	10.0	1.0	2.6	47.9	52.5	10.2	3.2	**349.2**
Jijiga	12.4	9.9	35.9	87.2	79.0	35.6	66.7	80.7	72.6	40.2	19.9	22.6	**562.8**
Harishiek	6.4	4.4	22.0	70.2	31.4	41.2	31.4	48.1	44.1	6.9	0.0	0.8	**306.7**
Mean	**7.1**	**10.8**	**27.8**	**77.8**	**70.0**	**26.9**	**30.9**	**38.3**	**47.8**	**48.4**	**12.0**	**7.4**	**405.3**

a.4 Calculation by Thiessen polygon method

Arithmetic mean method, Thiessen polygon method, Isohyetal method and Rainfall-altitude method are the main methodology for the areal precipitation calculation in some watersheds. The criteria of these methods needs uniformly distributed and high density distributed stations or a good correlation between altitude and precipitation of observed station. The Thiessen polygon method will be selected in case of non-uniformly distributed stations, and has been used in such cases since long ago. In this case, the methodological stations in Somali Region are located non-uniformly and unequally, and there is no correlation between the altitude and precipitation (refer to Figure 2.2). Therefore the calculation was executed using the Thiessen polygon method. The weighted average efficiency will be calculated depending on the area ratio which the meteorological stations relevant to precipitation, in the watersheds of the two river flow stations in the Jarar valley, are located. The area distribution map in each watershed using the Thiessen polygon method is according to the following Figure 2.18. The result of arithmetical computation using annual precipitation, evapotranspiration and runoff depth of two watersheds was shown in Table 2.19. As the result of computation, the annual groundwater recharge value of upstream is larger than that of downstream in Jarar valley.

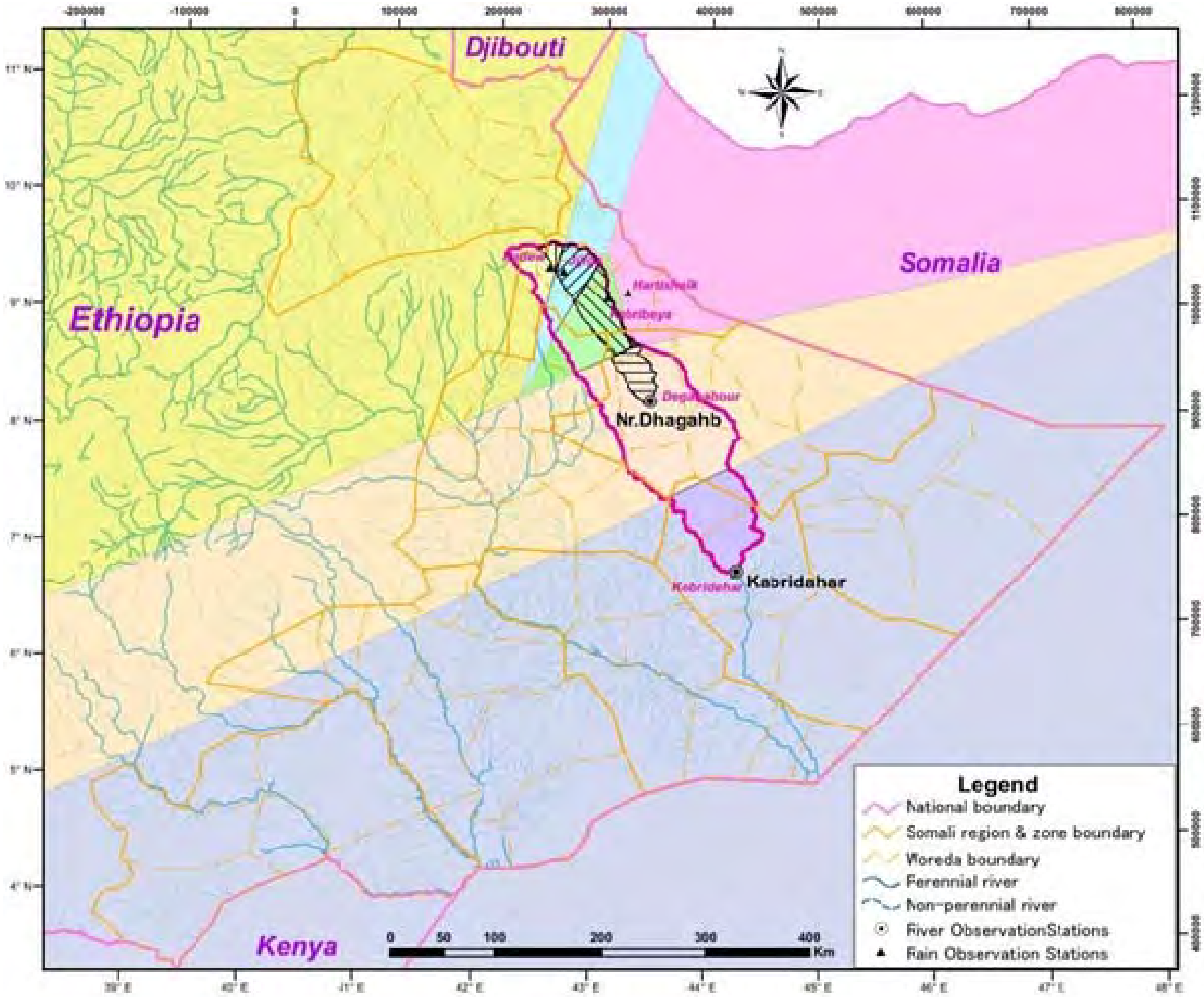


Figure 2.18: Area Distribution Map by Thiessen Polygon Method in Each Watershed

Table 2.19: The Result of Arithmetical Computation

		(A)	(B)	(A)*(B)	(C)	(A)*(C)		
		(km^2)	Annual average rainfall (mm)	(mm)	Annual Evapo-transpiration (mm)	(mm)	Runoff Depth (mm)	Groundwater recharge (mm)
Kabridahar	Degahabour	12817	349.2	4,475,696.4	349.2	4,475,696.4		
	Hadew	1568	669.2	1,049,305.6	540.1	846,876.8		
	Hartisheik	48	331.8	15,926.4	306.7	14,721.6		
	Jijiga	2169	589.3	1,278,191.7	562.8	1,220,713.2		
	Kebribeya	3958	401.6	1,589,532.8	401.6	1,589,532.8		
	Kebridehar	4845	271.5	1,315,417.5	271.5	1,315,417.5		
Total		25,405		382.8		372.5	1.02	9.3
		(A)	(B)	(A)*(B)	(C)	(A)*(C)		
		(km^2)	Annual average rainfall (mm)	(mm)	Annual Evapo-transpiration (mm)	(mm)	Runoff Depth (mm)	Groundwater recharge (mm)
Dhagahb	Degahabour	1329	349.2	464,086.8	349.2	464,086.8		
	Hadew	308	669.2	206,113.6	540.1	166,350.8		
	Hartisheik	48	331.8	15,926.4	306.7	14,721.6		
	Jijiga	1307	589.3	770,215.1	562.8	735,579.6		
	Kebribeya	2192	401.6	880,307.2	401.6	880,307.2		
Total		5,184		450.7		436.2	1.92	12.7

b. Calculation of BFI

The ratio of the groundwater component in a river flow is defined as BFI (Base Flow Index). Many methods have been developed and used to separate the groundwater (base flow) component and direct runoff component from daily river flow data. In this study the following method (program) is selected since it is considered to be reliable.

The computer program is RAP (River Analysis Package; 2005, from CRC (Cooperative Research Center for Catchment Hydrology, Monash University Melbourne, Australia). The method of calculating the base flow component of the hydrograph is through the use of a 3-way digital filter as described below.

In this time, the calculation results of BFI were obtained as Table 2.20 in each observed point from upstream to downstream of Wabi Shebele river.

Table 2.20: The Result of BFI Calculation

Station name	Watershed Area (km^2)	Observed term	BFI
Wabi Legehida	20,473	1970/4/1～1972/1/30	0.425
Wabi Hamaro	63,644	1968/3/1～1971/10/26	0.477
Wabi Imi	91,600	1969/3/1～1971/11/30	0.464
Wabi Gode	127,300	1968/1/1～1971/12/14 2000/12/5～2002/10/9	0.454 0.326

The groundwater recharge was calculated using the BFI values and runoff depth of river flow stations (refer to Table 2.14) and the results of calculation are shown in Table 2.21. The observed stations were located from upstream to downstream, the base flow values of upstream is larger than that of downstream.

Table 2.21: Base Flow Values in Each Station (Groundwater Recharge)

Station	BFI Value	Depth of Runoff unit (mm/year)	Base flow (GW recharge) unit (mm/year)
Wabi Legehida	0.425	112.82	47.95
Wabi Hamaro	0.477	53.31	25.43
Wabi Ime	0.464	36.04	16.72
Wabi Gode	0.454	25.92	11.77

c. Discussion of tank model

Figure 2.19 shows the shape of the tank model used for the water balance analysis of the study area.

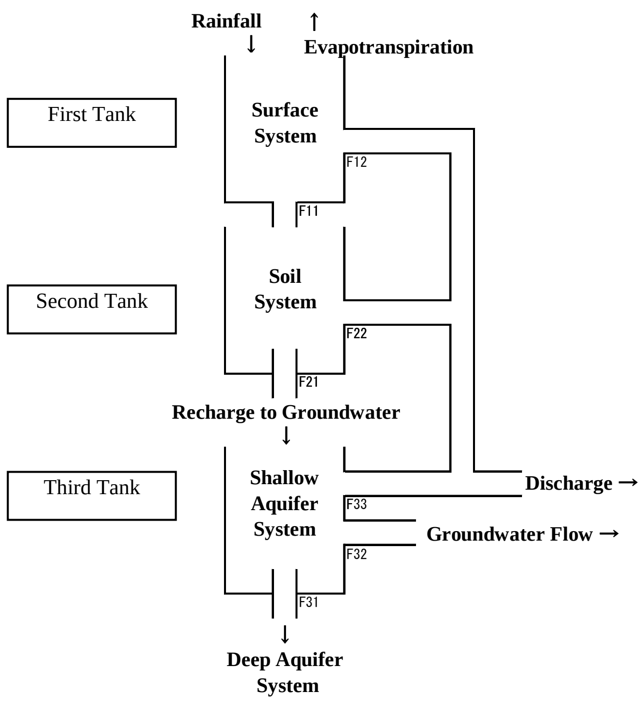


Figure 2.19: Structure of Tank Model

The input data required for calculation consists of catchment area precipitation, evapotranspiration. Calculation was performed on a daily basis, and all the results were converted into millimeters to unify the units of measurement. The data used was from the Gode Met. which had a complete set of data for daily precipitation and evapotranspiration of data for 1968-1971. The daily data of evapotranspiration used was calculated using the monthly results of Thornthwaite method. Wabi Gode main river flow rate observatory station, which had flow rates over the same period.

The above conditions and data were put into the tank model, and then the parameters of the tank model were adjusted on a trial basis until the calculated flow rates were approximately equal to the observed flow rates. Figure 2.20 below shows the results of the calculation using the tank model.

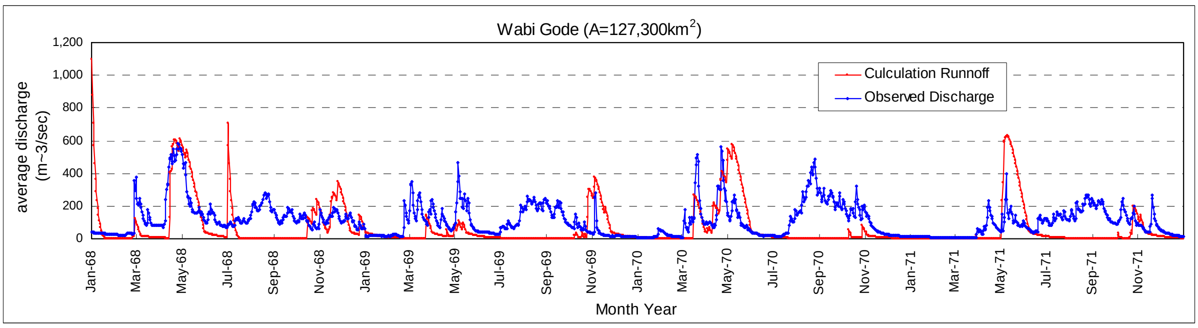


Figure 2.20: Hydrograph

In addition, the calculation result can be expressed as water balance as follows.

Table 2.22: The Results of Water Balance by Tank Model

Year	P: Precipitation (mm)	D: Depth of Runoff (mm)	E: Evapotranspiration (mm)	R: Groundwater Recharge (mm)
1968	681.4	28.0	642.9	12.8
1969	402.4	8.7	397.5	3.2
1970	475.9	15.5	452.3	9.1
1971	357.2	12.9	337.7	7.4

2.3.3 Comparison of groundwater recharge

The values of groundwater recharge were estimated as follows in two sub-basins, such as Wabi Shebele and Jarar valley sub basins divided from Wabi Shebele basin.

- The groundwater recharge value of upstream is larger than that of downstream in Jarar valley sub-basin according to the groundwater recharge values, which were calculated using the areal precipitation, evapotranspiration and runoff depth of river (upstream: Degahabur station; 12.7mm/year, downstream: Kebridahar station; 9.3mm/year).

- The BFI values were calculated for four river flow stations from Wabi Legehida upstream to Wabi Gode, which is downstream Wabi Shebele River. After that the groundwater recharge values were also calculated using the observed runoff data in each station and BFI values. As the results, the groundwater recharge value of upstream is larger than that of downstream (for example, 47.95 mm/year of Wabi Legehida and 11.77mm/year of Wabi Gode).

- As for the reference, the groundwater recharge values in Gode station calculated using Tank Model was shown as similar values in Gode station calculated using BFI except the result of 1969.

In general, the precipitation is larger and the evapotranspiration is lower than those of downstream in each river area, therefore the above results are appropriate values. The average annual values of groundwater recharge was estimated range from 9.3mm to 47.95 mm in the area of average annual precipitation of from 220mm to 570mm. It is difficult to make absolute evaluation for the results of groundwater recharge values in Somali Region. As the sample of Africa area, the groundwater recharge values were estimated using the chloride mass balance (CMB) technique range from 15mm to 54mm in the area of average annual precipitation of 434mm (Bridget R Scanlon, et al, 2006).

Chapter 3

Geology

3 Geology

3.1 Overview of the geology of Somali Region

3.1.1 Location, access and physiography

a. Landform

The Federal Democratic Republic of Ethiopia is a land-locked country with a land area of 1,127,000km^2. It is divided into three physiographic regions: i) northwestern plateau, ii) southeastern plateau and iii) the Rift Valley that separates them[20]. The surface elevation varies between -125 m amsl (above mean sea level) in the Denakil Depression (northern section of the Afar Depression) to 4620 m amsl at the Ras Dashen Terara (Figure 3.1).

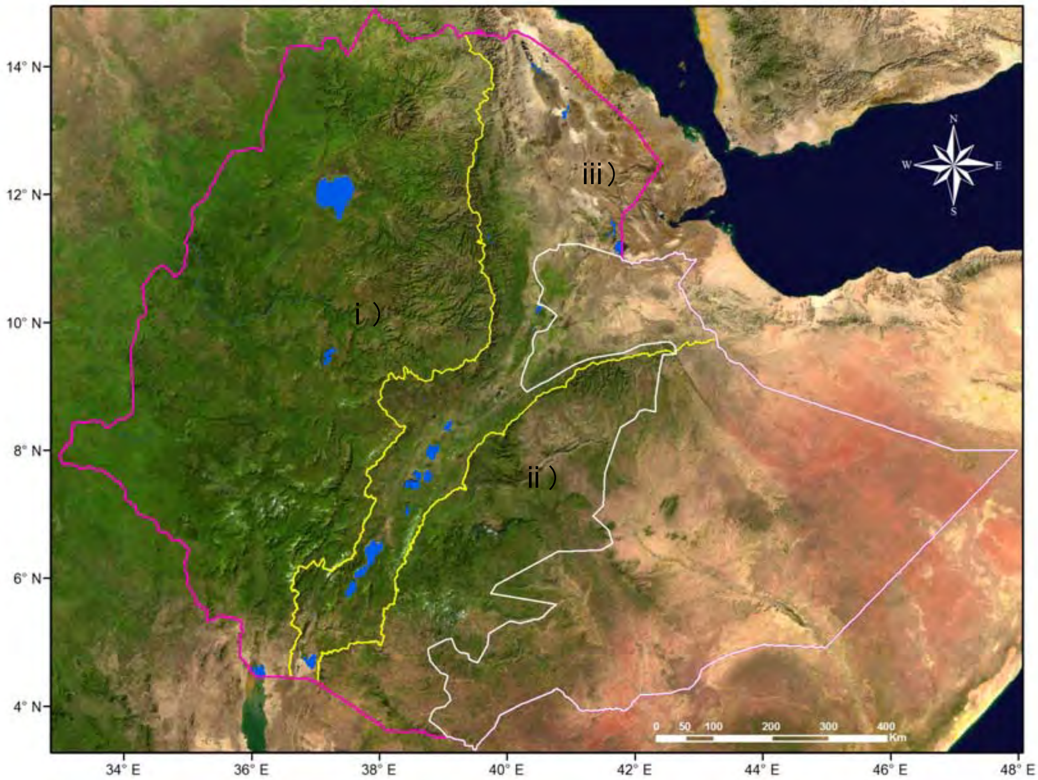
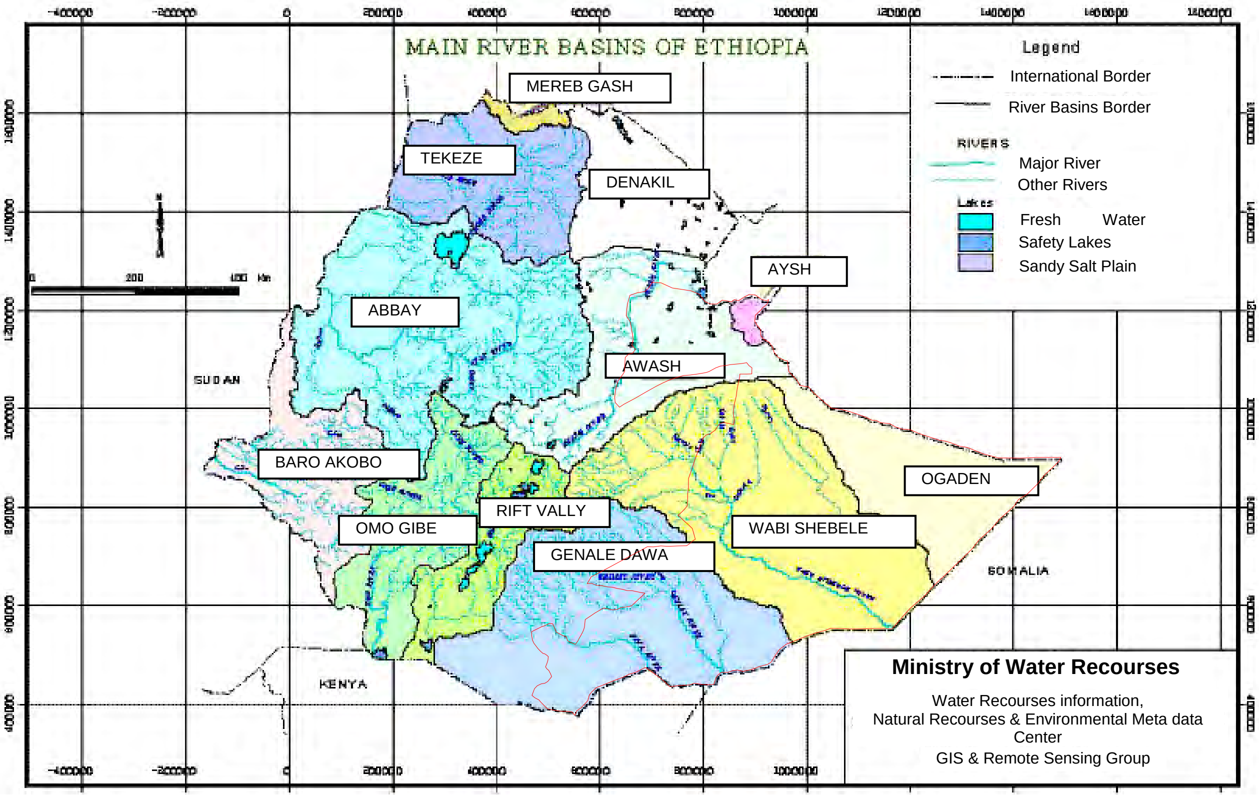


Figure 3.1: Ethiopia with Major Physiographic Zones[20]

Somali Regional State is one of nine regional states and two city administrations in Ethiopia and is located in the southeastern part of the country. In the east, north and south it shares international boundaries with Djibouti, Somalia Republic and Kenya respectively. In the northwest and west it shares boundaries with Afar and Oromia regions respectively. Somali Region has the largest area in regions of Ethiopia and covers an area of 363,300 km^2. The region is bounded between the geographical coordinates of 38.758884° East - 47.986780° East Longitude and 3.393054° North - 11.226088° North Latitude and the elevation varies between 210 m amsl – 2000 m amsl.

b. Watershed classification

In Ethiopia, there are 12 major basins and each is subdivided into minor sub-basins (divided by MoWE refer to Figure 3.2). Somali Region lies southeast of the rift system and it is tilted toward southeast, hence the present physiography is closely reflected by the dipping of the strata. Based on the relief and the drainage system, Somali Region lies within five Major Basins.



Source: Ministry of Water and Energy

Figure 3.2: Major Basins in Ethiopia

There are five major basins in Somali Region and follows:

a) Wabi Shebele drainage basin
b) Ogaden drainage basin
c) Genale – Dawa drainage basin
d) Awash basin
e) Aysha basin

- Wabi Shebele drainage basin comprises several small drainage basins such as Fafem - Jarar sub-basin (Jarar valley). This basin is the largest and the area is sloping toward the Shebele River. The elevation varies from 200 - 2000 m amsl[18)]. Wabi Shebele drainage basin covers an area of about 193,670 km^2 and 70% (136,050 km^2) of the entire basin area is located in Somali Region[18)].

- The second drainage basin is Ogaden drainage basin and this area comprises part of Jijiga zone, part of Dagahbur zone and most of Warder zone[18)]. This basin is characterized as flat plains with low slopes. Basically the drainage is toward Somalia and all the way to the Indian Ocean[18)].

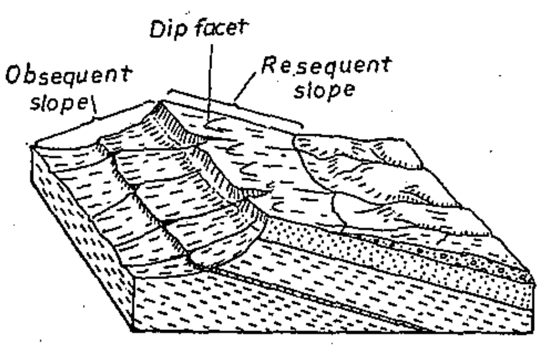
- The third drainage basin is Genale-Dawa drainage basin and this comprises three major river drainage systems and the area is sloping toward south. The elevation varies between 150 to 1600 m amsl[18].

- Awash Basin is in an area where Awash River flows from southwest to northeast, and Somali Region is located in northeast of Awash Basin. Awash Basin is basically area west of Amhara Highland including the entire Shinile zone in Somali Region[18].

- Aysha Basin (2,223km^2) is considered to be dry in most cases with seasonal river flows[2].

c. Morphostructure

Landform of the target area (Jarar valley and Shebele sub-basin in Shebele River basin) is complex; one is the landform controlled by dip direction of layer shown in Figure 3.3, the other is gradual anticline structure shown in Figure 3.4.



<u>Dip facet</u>: Plan of dipping sedimentary bed.
<u>Resequent slope</u>: Slop that is formed consistent with the geological structure (e.g, the direction of dipping sedimentary bed) by the result of erosion etc.
(The gradient of slope is similar to the dip of sedimentary bed and relatively flat appearance is shown.)
<u>Obsequent slope</u>: Slop opposite to the direction of dipping bed.
(Generally, the gradient of slope is steep and the microrelief is often shown.)

Figure 3.3: Relation between Strike and Dip of Layer, and Landform[15]

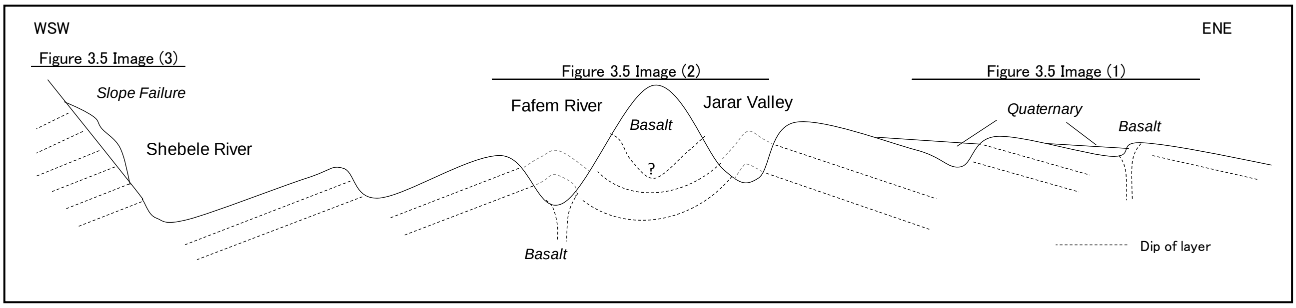


Figure 3.4: Schematic Morphostructure in Jarar Valley and Shebele Sub-basin

The topography of target area generally dips toward the southeast. Meanwhile, the anticline structure and the anticlinal axis of NNW-SSE direction are located around Fafem – Jarar area. In the left bank (east side), the topographic profile slightly dips toward the east (referred to the landform and geological profile in 3.3 Section). However, this slope is not uniform and inclines stepwise as shown in Figure 3.4. An individual unit consists of west-facing steep slopes and east-facing gentle slopes (tilt block). On the other hand, the direction of the right bank's slope is opposite that of the left bank and inclines west. Though the right bank's slope shows stepwise as well as the left bank, the angle of inclination is different and one unit consists of east-facing steep slopes and west-facing gentle slopes.

Due to such a structure, collapses and talus develop at the foot of west-facing slopes on the left bank (east side) of the Jarar valley basin. On the other hand, they occur at the foot of east-facing slopes on the right bank (west side) (Figure 3.5 image (1)). The Shebele River's right bank slope has many slope failures (Figure 3.5 image (3)) that are one of cases of the bad water quality (concentrated turbidity) of Shebele River water.

Though the macroscopic slope direction of the left bank in Jarar valley dips toward east, the unconsolidated sediments move in the direction of Jarar valley that is low-ground, because the eastward down-slope angle is very gentle. On the other hand, the moving direction of the unconsolidated sediments of the Fafem - Shebele area is the same direction as inclination of the surface level and they are moving in a westward direction (in the direction of Shebele River).

Moreover, In Fafem – Jarar area (Figure 3.5 image (2)) where the anticline structure has developed and around flexure scarp in left bank (Figure 3.5 image (1)), the basalt with NNW-SSE direction is distributed along these anticlinal axises.

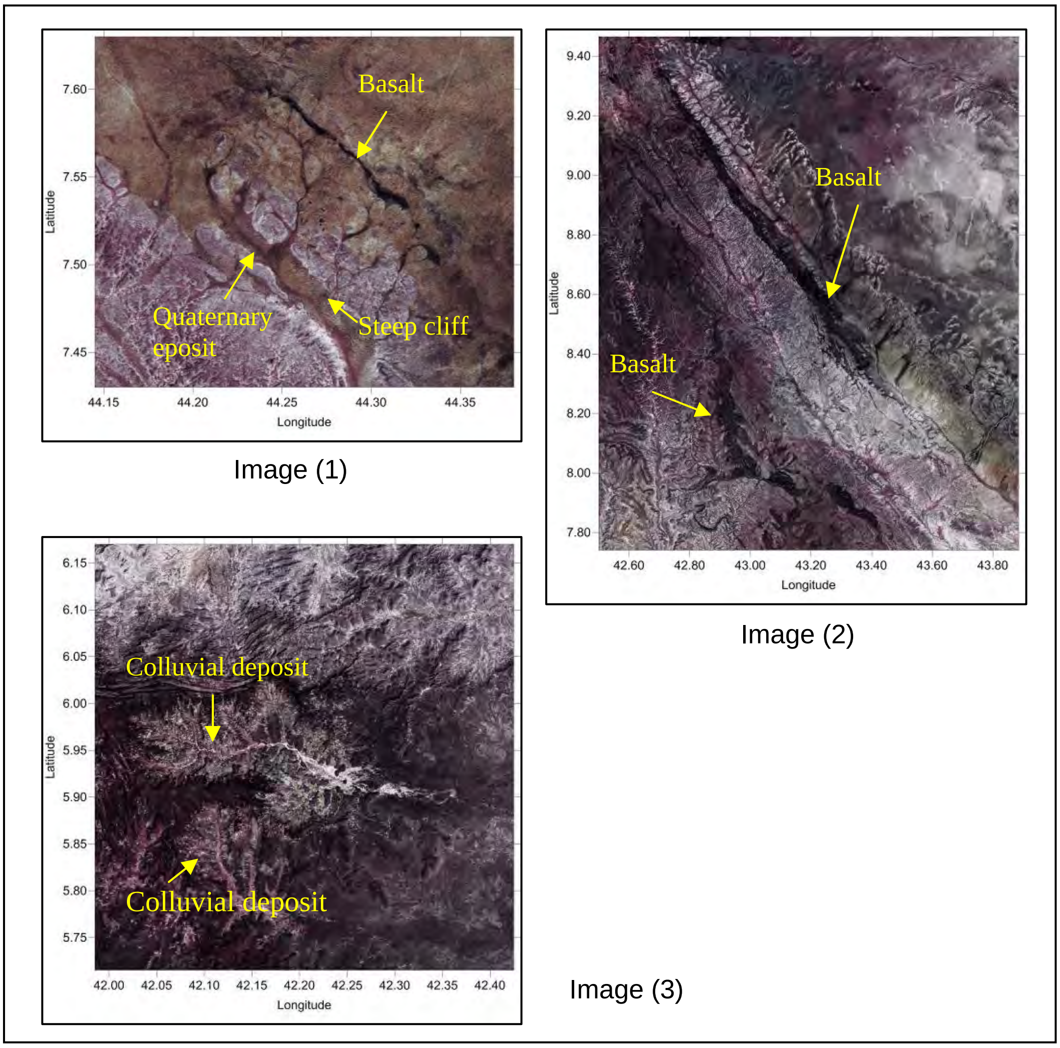


Figure 3.5: Landsat Images Showing Typical Topographic Features

The morphostructure inferred to be controlled by the geological structure running in the direction of ENE – WSW as shown in Figure 3.6 was found besides the above-mentioned structure.

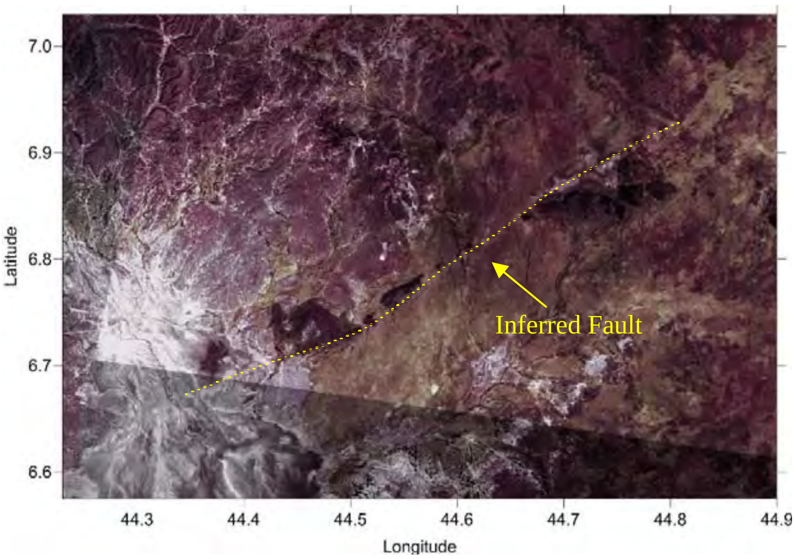


Figure 3.6: Geological Structures inferring a Fault in the Direction ENE - WSW

3.1.2 Regional geological and tectonic setting

The geology of Ethiopia comprises a crystalline rocks (basement rock) that make up the basement of Africa, volcanic rocks associated with the East African Rift system and sediments of various ages[5)] (Figure 3.7).

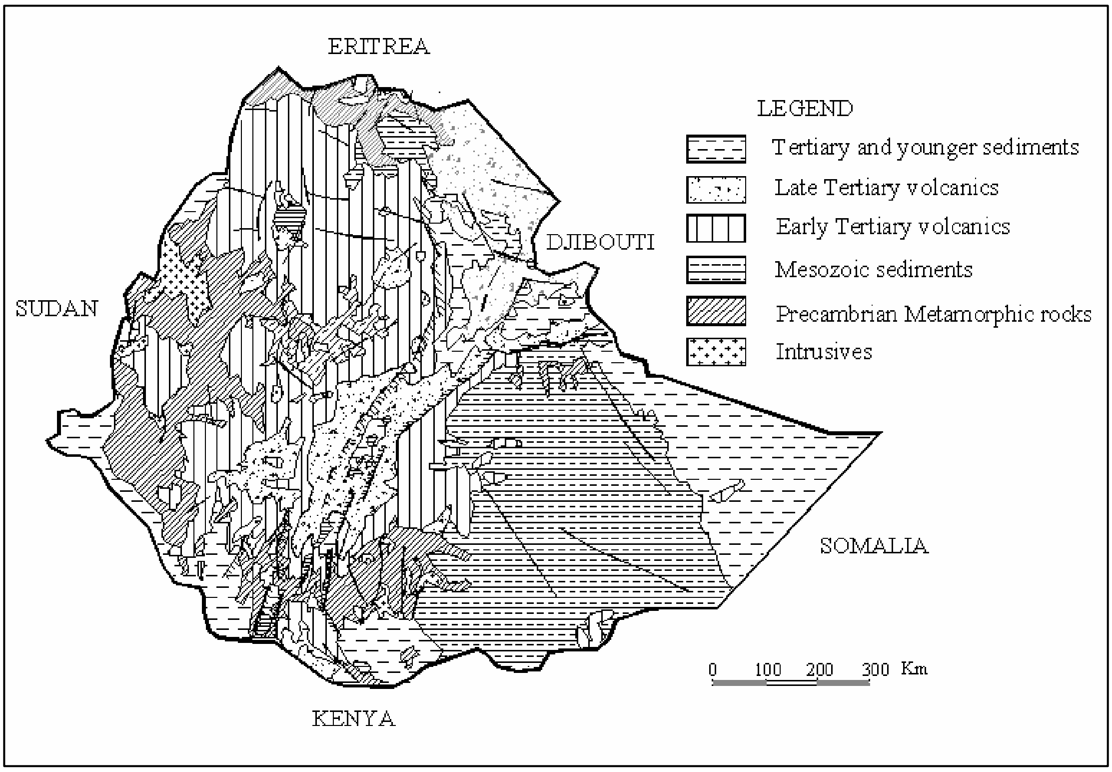


Figure 3.7: Simplified Geological Map of Ethiopia[20)]

Basement rocks are distributed in four main regions: i) Tigray in the north, ii) along the Sudanese border, iii) Oromia region in the south iv) Somali Region in the east[5)]. These rocks consist of granites, granodiorite, porphyrite, gneiss, migmatite, granulite, amphibolite, schist, phyllite and so on[20)].

The Rift Valley and its surrounding areas are dominantly composed of volcanic rocks (lavas and ashes, mainly of Tertiary and younger age), associated with the evolution of the Rift system[5)]. In the southern part of the Rift, the volcanic rocks are dominantly acidic (silica-rich), including much ash and pumice[5)]. In the Afar section of the Rift and much of the flanking plateau areas, the rocks are dominantly basaltic (iron- and magnesium-rich)[5)]. The volcanic rocks in these areas are often interbedded with sediments[5)]. During the period of rifting and volcanism, downfaulting in the north produced the low-lying Afar Depression (Tefera et al., 1996)[21) in 5)].

The lowlands of south-eastern Ethiopia as well as parts of the north are composed of sedimentary rocks of various ages[5)]. Many occupy low-lying depressions (e.g. the Danakil Depression) which are the result of the many tectonic movements associated with rifting[5)]. The sediments are largely mixed deposits of sandstone, limestone and silt, but contain frequent occurrences of evaporite minerals, including halite (rock salt), gypsum (a calcium-sulphate mineral), and potassium- and magnesium-salts[5)].

3.2 Local geology

3.2.1 Previous geological studies and mapping

The main existing geological maps in the Study area and its surrounding areas are as follows;

① Geological Map of Ethiopia, 1:2,000,000 (Kazmin, 1972; Tefera et al., 1996)[8), 21)]

② Geological Map of the Wabi Shebelle basin, 1:1,000,000 and Geological Map of Ogaden, 1:250,000 (Ethiopia-France cooperation Program, Wabi Shebelle Survey, 1972)[14)]

③ Geological Map of Ethiopia and Somalia, 1:2,000,000 (Merla et al., 1973)[11), 12)]

④ Geological Map of the Ogaden and surrounding Area 1:1,000,000 (BEICIP, 1985)[3)]

⑤ Geological Map of Harar Area (NC38-9) (Yihune and Haro, 2010) and Geology of Harar Area (Haro, 2010)[26), 10)]

⑥ Geological Map, 1:250,000, Project: Improving Water Resources Management and Information in Somali Region (UNESCO, 2012)[22)]

The descriptions of geology in this report take into consideration the geological maps above and the reports below. The descriptions are discussed and evaluated in relation to the geological maps of ① to ⑤ above.

- Wabi Shebele River Basin Integrated Development Master Plan Study Project, Phase II – Data Collection, Site Investigation, Survey & Analysis, Section II Sectoral Studies, Volume I – Natural Resources, Part 1- Geology, Final Report (WWDSE, 2004)

- Hydrogeological Mapping Project Report (SHAAC, 2009)

- Fafem - Jerer Sub Basins and the Adjacent Eastern Areas Groundwater Potential

Assessment and Supervision of Test and Pilot Production Well Drilling Project Inception Report (Ministry of Agriculture, 2012)

The outline of existing geological map (①,④and⑤) is described by the re-presentation of the above report's examination and evaluation of them.

a. Geological Map of Ethiopia (Kazmin, 1972; Tefera et al. 1996) [8), 21)]

- The geological map of Ethiopia (scale 1:2,000,000), first compiled by Kazmin (1972) and then revised by Tefera et al. (1996), constitutes an excellent reference material to have general lithological distributions and structural setup of the country. As large parts of the map were covered by interpretations of aerial photographs and satellite imageries, modifications and updates based on recent geological mapping being carried out by the Geological Surveys of Ethiopia (hereafter referred to as "GSE") and research findings are very essential. The map broadly categorizes the geology of the country into Precambrian basement rocks and Phanerozoic cover rocks, which include Late Palaeozoic and Mesozoic sedimentary successions and Cenozoic volcanic and sedimentary rocks[23)].

- Hence, according to Kazmin (1972, 1975) and Tefera et.al (1996) the south-eastern part of Ethiopia is mainly underlain by Mesozoic and Tertiary sedimentary rock successions with sporadic occurrences of Tertiary volcanic rocks and Precambrian basement rocks at the north-eastern and south-western margins of the Ogaden Basin[23)].

- According to the generalized geological map, the Fafem, Jarar and adjacent eastern areas are underlain mainly by Mesozoic – Tertiary sedimentary rocks and minor metamorphic basement rocks, Tertiary volcanic rocks and alluvial deposits. The project area (Ministry of Agriculture (2012) project (FAJE[1]) is mainly covered by Mesozoic sedimentary rocks, namely the Adigrat sandstone, Hamanlei limestone and shale, Urandab marl and shaly limestone, Tertiary volcanics (Ashange basalts) and Quaternary alluvial deposits. Moreover, the Precambrian basement rocks grouped as Archean Alghe Group consisting of biotite and hornblende gneisses, granulite and migmatites with para-gneisses are restricted to north-western part of the project area in the upper Fafem valley. The Jarar area is almost entirely underlain by Jessoma sandstone and minor Auradu limestone, which have Late Paleocene to Early Eocene ages[23)].

b. Geological Map of the Ogaden and surrounding Area (BEICIP, 1985)

- The geological map of the Ogaden and surrounding area (1:1,000,000) conducted by BEICIP (1985) covers the south-eastern corner of Ethiopia, i.e. south of 8° N and east of 40° E, which covers southern Ogaden Sedimentary Basin, north-eastern tip of Kenya and north-central Somalia. As such only the southern portion of the FJAE[1)] project falls within this map, which exposes upper Hamanlei bioclastic limestone, Urandab marl and shaly limestone, lower Gabredarre (Kabridahar) limestone and shaly limestone, and Jessoma sandstone. The extents of some of these units are inferred and require further investigation and updating with new findings[23)].

[1] FJAE: Fefem – Jerer Sub Basins and the Adjacent Eastern Areas Groundwater Potential Assessment and Supervision of Test and Pilot Wells Drilling Project

c. Geological Map of Harar Area (Yihune and Haro, 2010) and Geology of Harar Area (Haro, 2010)

- The north-western part of the FJAE project is located in the Harar Map sheet (NC38-9), which is bounded between latitudes 42° 00' to 43° 30' and longitudes 9° 00' to 10° 00'. The geology (Haro, 2010) and geological map (Yihune and Haro, 2010) of the Harar sheet at a scale of 1:250,000 are completed recently. A wide range of lithologies comprising high- and low-grade Precambrian basement rocks, Mesozoic sedimentary rocks, Tertiary volcanic rocks, and Quaternary sediments are mapped in the map sheet. All these rocks are also found to occur in Fafem and Jarar valleys and areas to the east[23)].

- The Precambrian basement rocks are exposed in upper Fafem valley, north of Jijiga as pockets in the Phanerozoic rocks; Daketa, Tinishu Erer, Erer and Hamaressa valleys as well. The basement rocks are reported to be Archean to Proterozoic rocks, which include gabbro/granulite complex, amphibole gneisses, amphibole-biotite or biotite-amphibole gneisses, biotite gneisses, quartzo-feldspathic gneisses, marbles, calc-silicates, amphibolites and granitoid ortho-gneisses (Haro, 2010).

- Phanerozoic (upper Palaeozoic and Mesozoic) sedimentary rocks, which include the Lower (Adigrat) sandstone, lower limestone, upper limestone, upper sandstone and limestone-sandstone inter-beds, were laid down unconformably on the Precambrian basement rocks. The largely Mesozoic sedimentary rocks are exposed along the mountain range separating Awash River basin from north-eastern Wabi-Shebele and north-western Ogaden River basins, and along ridges between Hamaressa, Erer, Daketa, Fafem and Jarar river valleys. Sporadic Tertiary – quaternary volcanic rocks are exposed along Karamara mountain range and its northwest extension, Aybera Mountain near Ejersa Goro, Mt. Kundudo, Mt. Serita, and rift margin in the Awash River basin. The south-eastern part of the Harar map sheet, which forms a considerable portion of the FJAE project area, was mapped as Quaternary eluvium developed on limestone and Quaternary calcrete, which are considered as hardened secondary limestone or secondary conglomerates. However, unlike the previous workers [e.g.,8), 11), 12), 21)] the geological map of Harar sheet didn't indicate the occurrence of Jessoma sandstone to the east of Jarar river valley[23)].

3.2.2 Outline of Geology in Somali Region

The classification of different geological formations that exist in the Study area follows the above-mentioned existing reports and maps. According to these existing studies, the geological formations of Somali Region range in age from Precambrian to Quaternary deposit (Figure 3.8). The oldest geological formations are undifferentiated Precambrian crystalline rocks, which include granite, granitic gneiss, amphibolite and diorite. The basement rocks are overlain by Mesozoic sediment, which are in turn overlain by Tertiary to Recent volcanic and alluvial deposits.

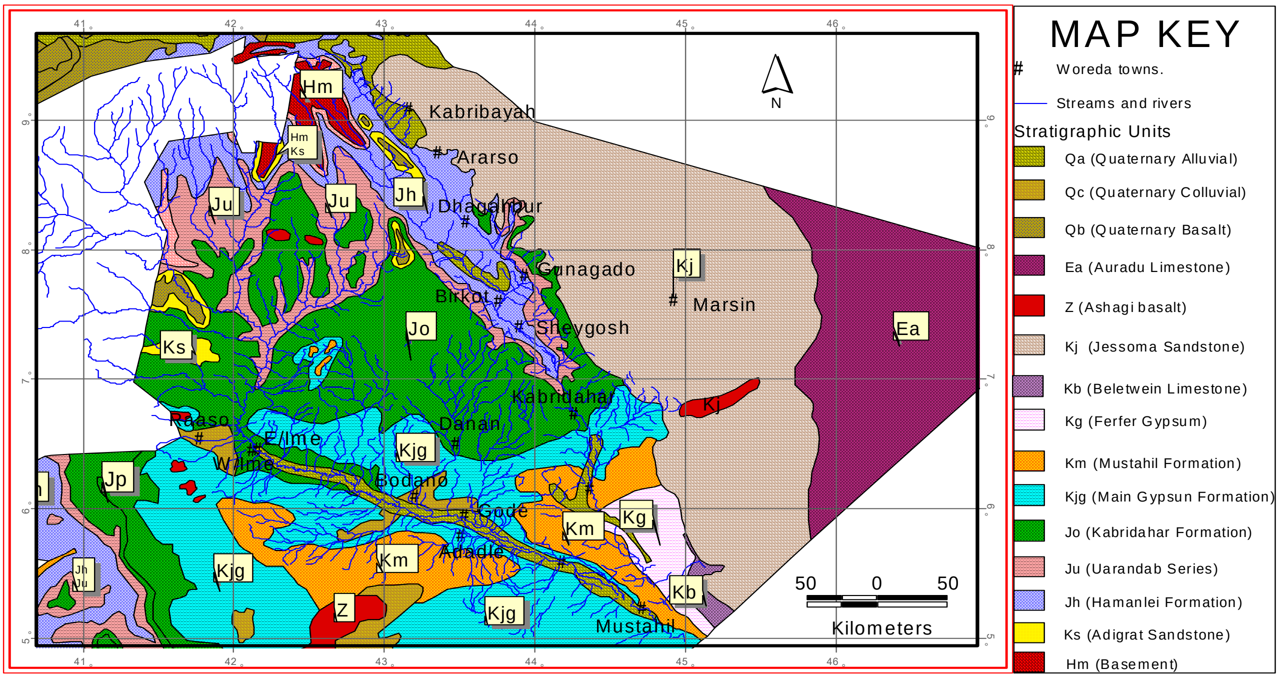


Figure 3.8: Simplified Geological map of Somali Region (SHAAC, 2012) [18)]

3.2.3 Satellite image analysis

a. Landform classification in sub-basin

The Study area consists of a part of Wabi Shebele Basin. The Wabi Shebele basin is relatively subdivided into small basins such as Jarar valley and Shebele sub-basin (see Figure 3.9).

In this study, the landform classification analysis (image analysis by visual inspection) was conducted using the following data.

- SRTM3 and SRTM30 data (SRTM：Shuttle Radar Topography Mission)
- Landsat ETM+ images (Shooting date: refer to Figure 3.10)
- PALSAR data (Shooting date: 15/06/2010 – 26/07/2010)

In the analysis, landform and geological classification maps were created by comparing with the existing geological map after the landform interpretation based on i) tone, ii) texture, iii) shape of object, iv) size of object, v) pattern due to drainage, erosion, soil, vegetation and land-use, etc. of the satellite images as shown in Figure 3.11 and Figure 3.12.

The geological units were identified using the existing geological maps and the landform classification map was created by the interpretation of satellite image. Then, the landform and geological classification map was created by the correlation of the geological units with the landform classification map.

The geological cross-sections were created using the existing well data; in particular, the geological divisions of formation units and the analysis of geological structures were executed using the geological cross-sections in correlation with the lineament interpretation.

Consequently, the geological map was completed by the reanalysis of the landform and geological classifications.

Moreover, there is a limitation[1] to the effectiveness of satellite image interpretation in regard to 1) areas where geological units with similar landform types are adjoining and 2) areas for which the landform cannot be ascertained at a scale of 1:250,000 due to the complexity of landform distribution. In such cases, the two geological units were expressed as one geological unit.

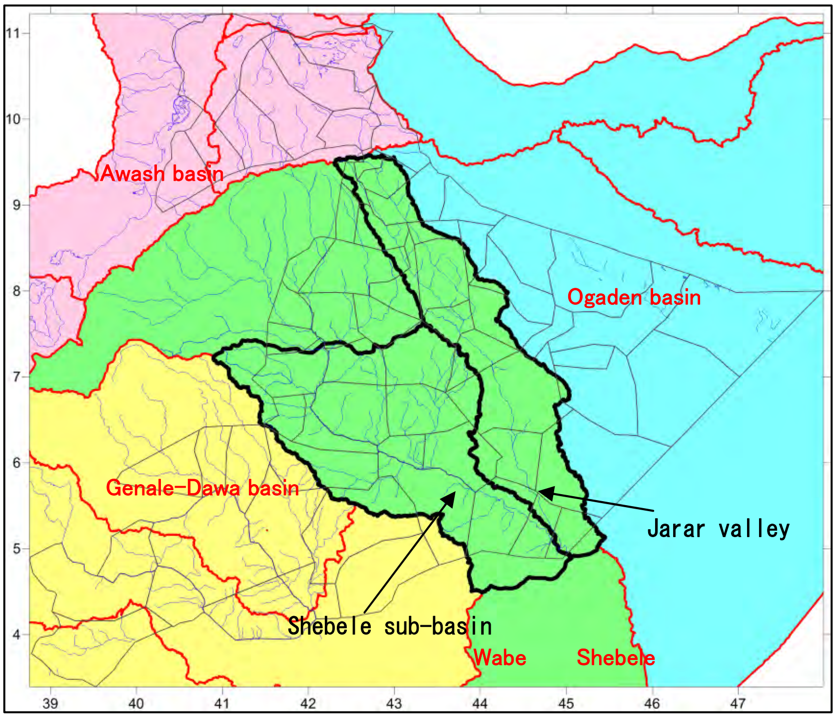


Figure 3.9: Target Area of Landform Classification (Jarar Valley and Shebele Sub-basin)

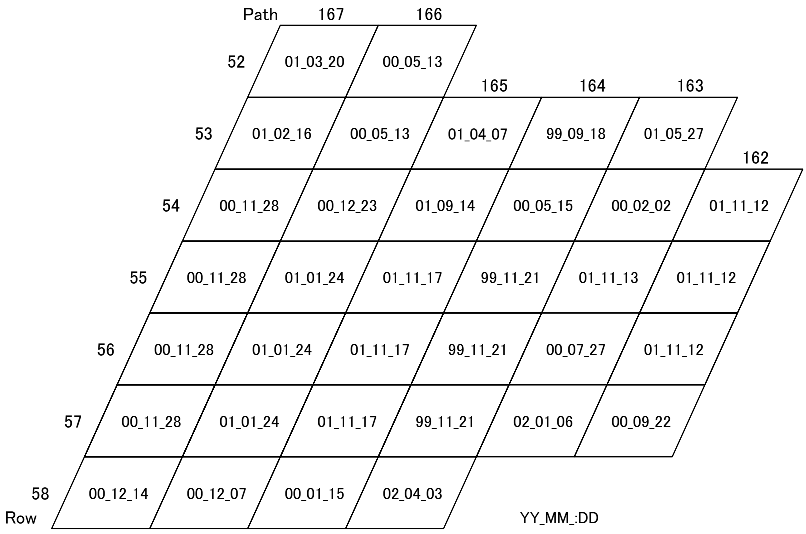


Figure 3.10: Shooting Date of Utilized Landsat Images

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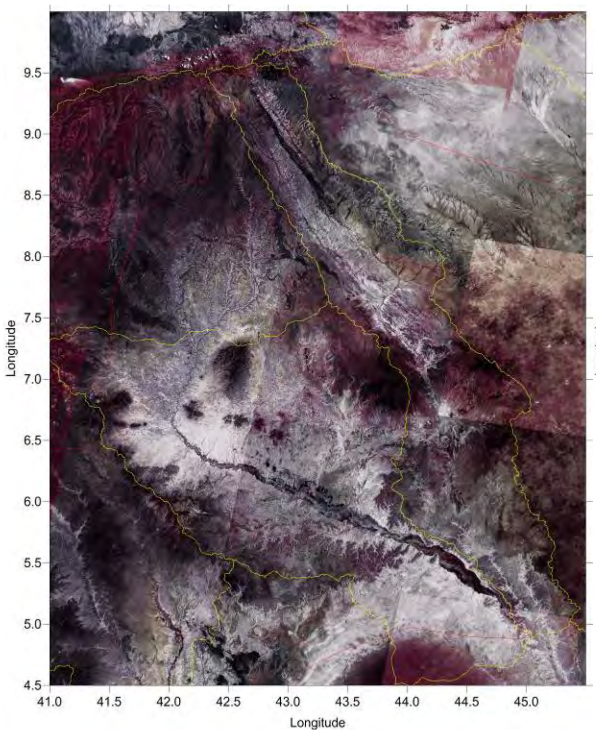
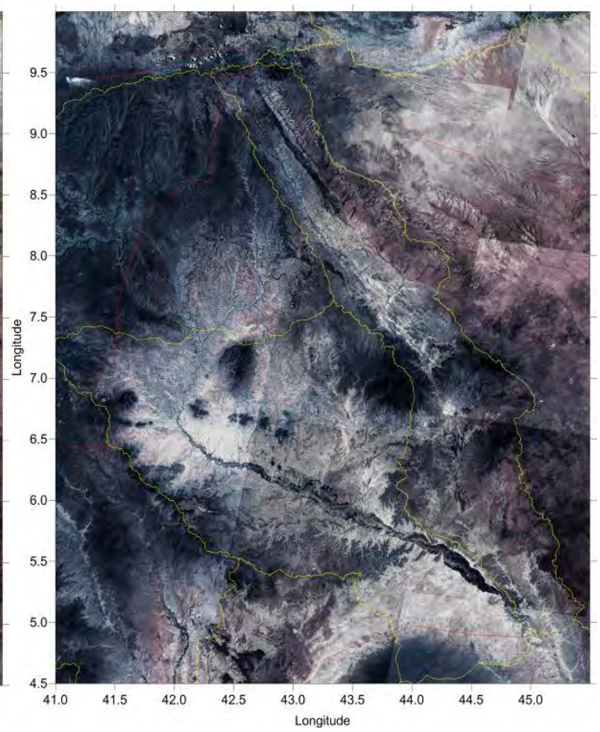
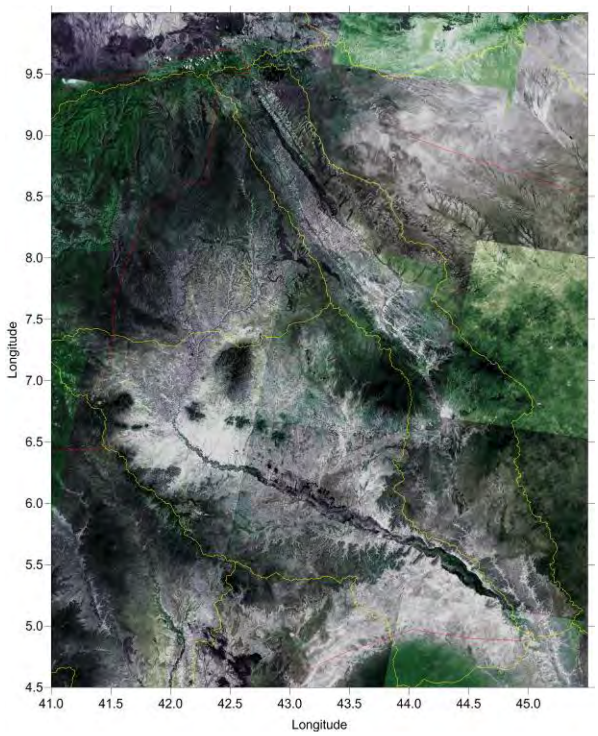
1 This is the limitation of the satellite image interpretation without the field survey.



False Color



True Color



Natural Color

Figure 3.11: Landsat Images Analyzed

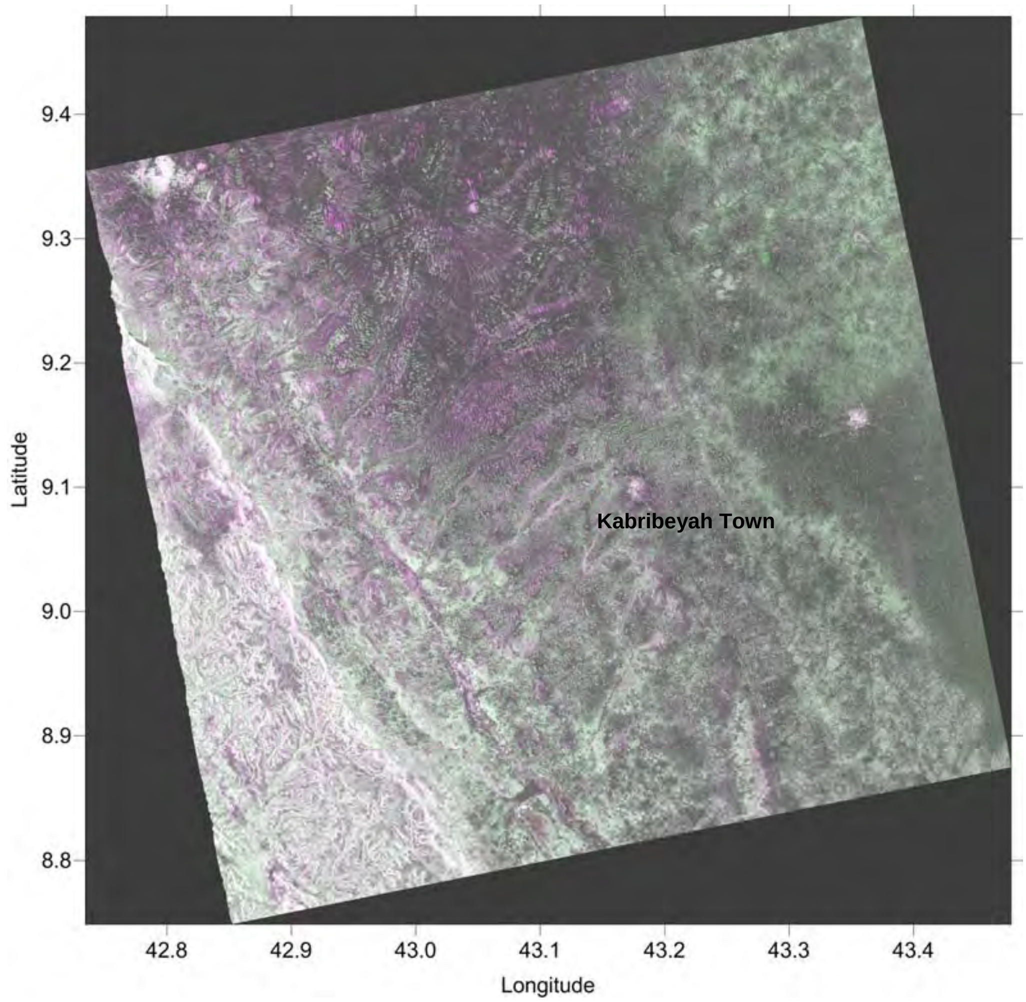


Figure 3.12: Example of PALSAR Image Analyzed

(Central Longitude: 43.0969, Central Latitude: 9.1201)

b. Lineament analysis

Lineament analysis was executed as part of the image analysis involving visual inspection using the abovementioned satellite images. The lineament analysis identified several topographical aspects such as straight valleys, straight cliffs, bending valleys distributed on straight lines, bending ridges, cols, isolated hills, step landforms, type of soil and vegetation, and straight boundaries of landform colors/shades. The lineament analysis involved interpretation of general straight line structures and straight line structures which the inferred fault was expressed in reference to the landform classification analysis and the existing geological maps (refer to Figure 3.13 and Figure 3.14).

The result of lineament analysis by digital method is mentioned in chapter 7 on this report.

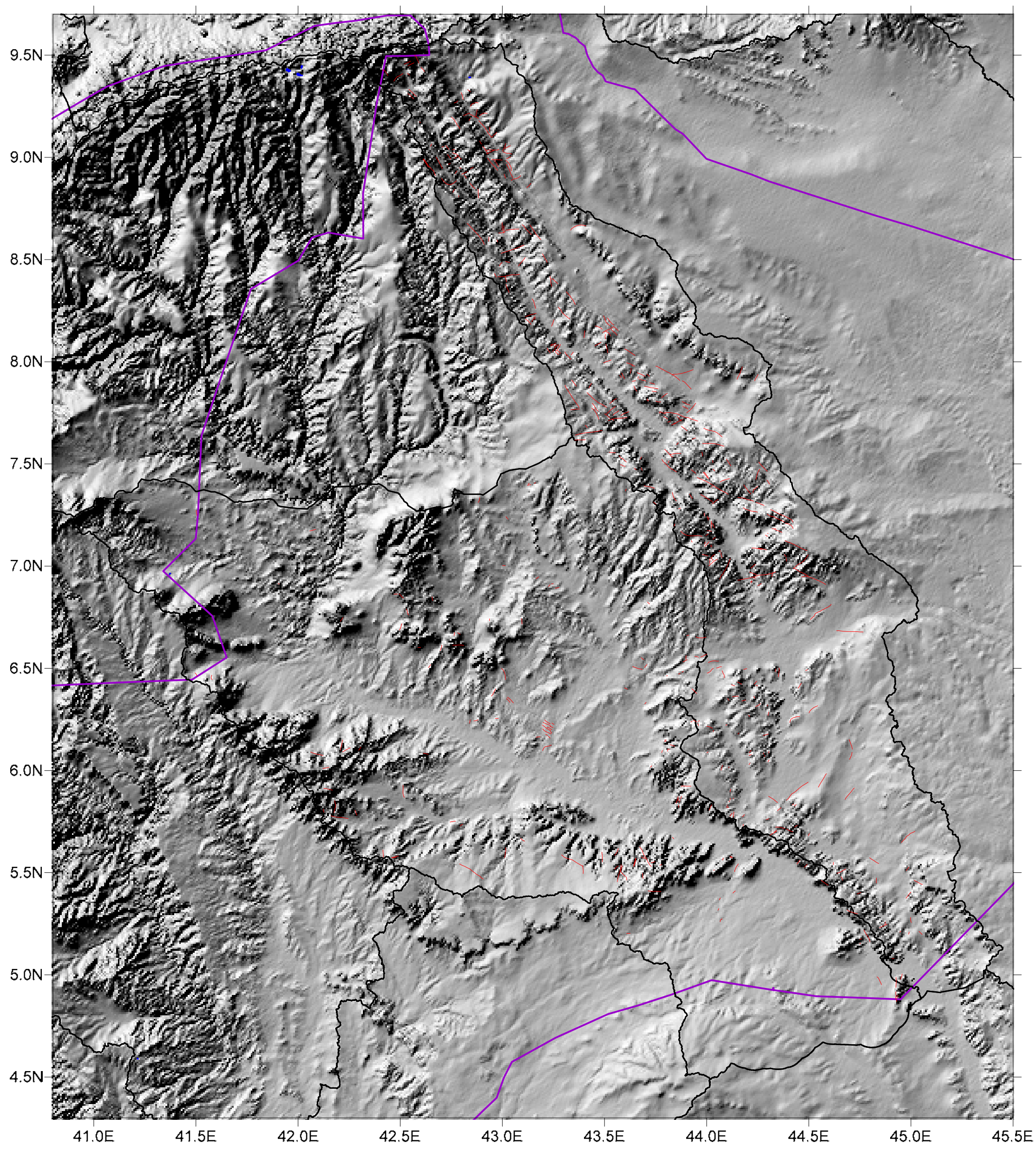


Figure 3.13: Interpretation Map of Lineament (Inferred Faults)

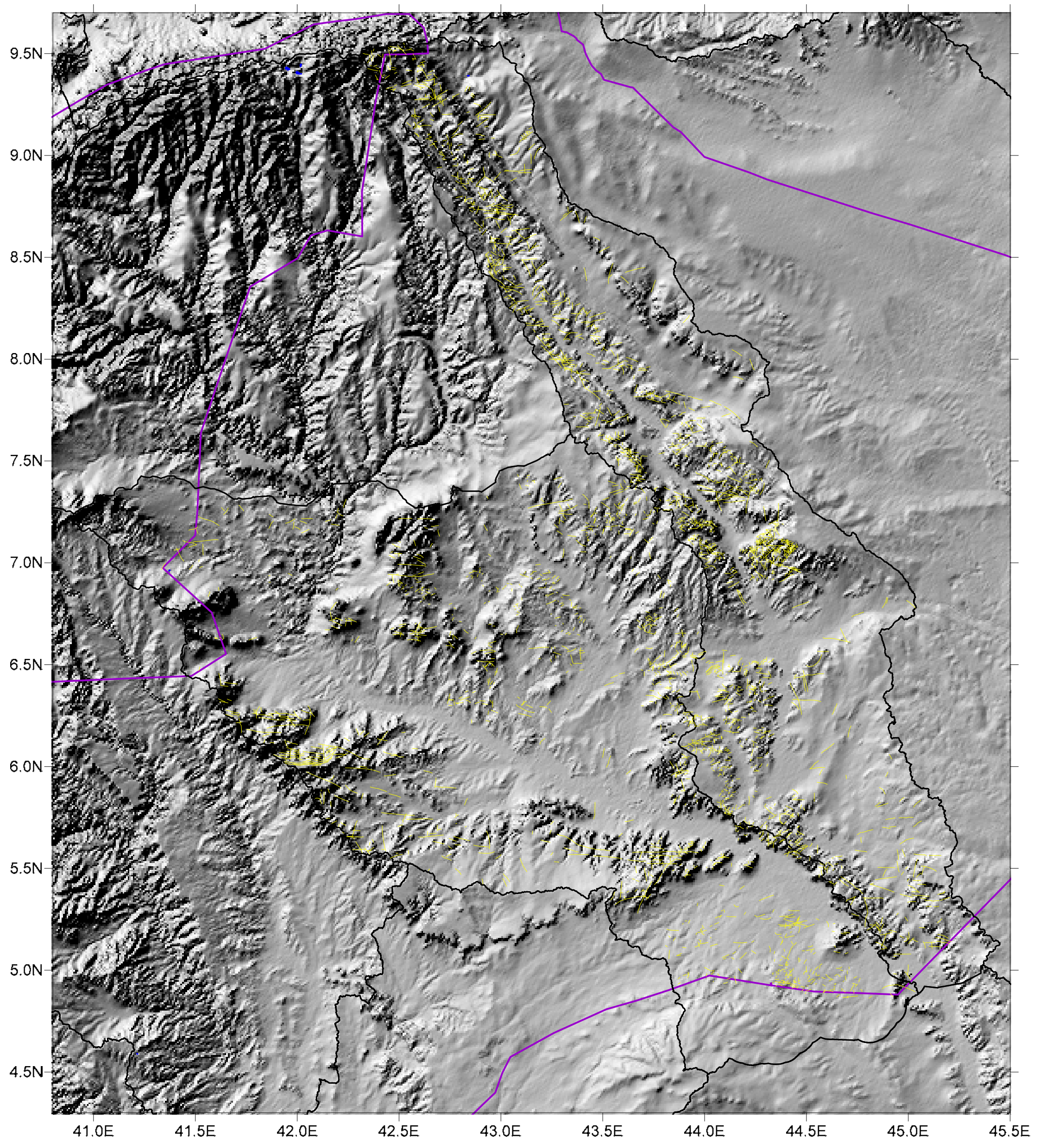


Figure 3.14: Interpretation Map of Lineament (General Straight Line Structure)

3.2.4 Stratigraphy and chronology

The main lithological units outcropping in Jarar valley and Shebele sub-basin from the bottom to top are mainly Basement rock of Precombrian, Adigrat Sandstone of Trassic (?) –Middle Jurassic[24], Hammanlei Formation and Urandab Formation of Jurassic[16) and 25)] outcropping along the Fafem-Jarar area, and also Kabridahar Limestone of Jurassic[1] outcropping in Korahe Zone, Korahe Gypsum (Main Gypsum Formation) of Late Jurassic-Early Cretaceous[16] outcropping in Godey Zone, Jessoma Sandstone of Late Cretaceous- Early Eocene[25) and 9)] distributing in the east side of Jarar Valley, and Alluvial deposits cover the valley (Table 3.1).

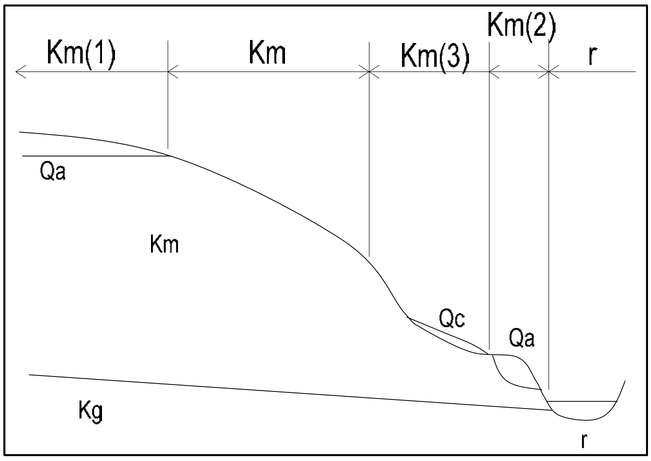
Table 3.1: Stratigraphy around Somali Region

Era	Period/Epoch	Stratigraphic Name	Symbol		Max. Thickness [16] (m)	Lithological Characteristics
Cenozoic	Quaternary	Alluvial Sediment	Qa		150	Terrace deposit mainly, river bed deposit was divided as [r]
		Eluvial & Colluvial	Qc		50	Eluvial & colluvial deposit
	Quaternary – Late Pliocene	Undifferentiated Basalt	Qb		600	Recent volcanic undifferentiated
	Middle – Late Eocene	Karkar Formation	Ek		–	Exfoliative brown shele and banded fibroid gypsum intercalated in white porous chalk limestone, deep sea sediments[9]
	Early – Middle Eocene	Talah Evaporates	Et		150	Banded massive anhydrite with altenative charty limestone irrregularly[9]
	–	Undifferentiated Basalt	Qv		200	Undifferentiated old basalt unknown age was dotted with area
Mesozoic	Early Eocene – Late Cretaceous	Auradu Limestone	Ea		150	Light pinkish biogenic massive limestone with iron color chart and sea floor basalt lava in the base[9]
		Jessoma Sandstone	Pj		400	Continentality to shallow sea deposits, consist of variegated quartz sandstone and silt stone[25]
	Late Cretaceous	Beletwein Limestone	Kb		200	Shallow sea sediments, shaly limestone with some shale and sandstone[25]
		Ferfer Gypsum	Kf		200	Lagoon and shallow area deposits, consist of dolomite, limeston, marlstone, shale, anhydrite, gypsum with sand and marl intercalations[25]
	Early – Late Cretaceous	Mustahil Limestone	Km		300	Continental shelf deposits, consist of biogenic limestone with normal limestone, shale and marlstone[25]
	Early Cretaceous – Late Jurassic	Korahe Gypsum	Kg	Kg2 (Upper) Kg1 (Lower)	500	Lagoon deposits, consist of gypsum, anhydrite, marlstone, shale, iron carbonate (chalybite)[25]
		Amba Aradam Sandstone	Ka		150	Quartz sandstone mainly alternative with siltstone, shale, and marlstone[25]
	Late Jurassic	Kabridahar Limestone	Jg	Jg2 (Upper) Jg1 (Lower)	500	Shallow sea deposits, consist of oolitic limestone, marl and gypsum mainly with gypsum and shale[25]
		Urandab Formation	Ju		120	Deep sea sediments, consist of darkgray black shale mainly[25]
	Middle – Late Jurassic	Hammanlei Formation	Jh	Jh2 (Upper) Jh1 (Lower)	1600	Lagoon and sea deposits, limestone, shale, anhydrite, sandstone alternative with dolomaote, limestone, anhydrite, gypsum, and micritice limestone with fossil[25]
	Middle Jurassic – Triassic (?)	Adigrat Sandstone	Ja		253	Red and brown sandstone mainly, fine to coarse sandstone with banded shale and laterite[25]
Proterozoic	Precambrian	Basement Rocks	PC			Consist of granite, granodiorite, gneiss, anphibolite, schist, and quartzite, crystalline rock[16]

3.2.5 Geological units classification of geology

The results of geological units classification is shown in Table 3.2;

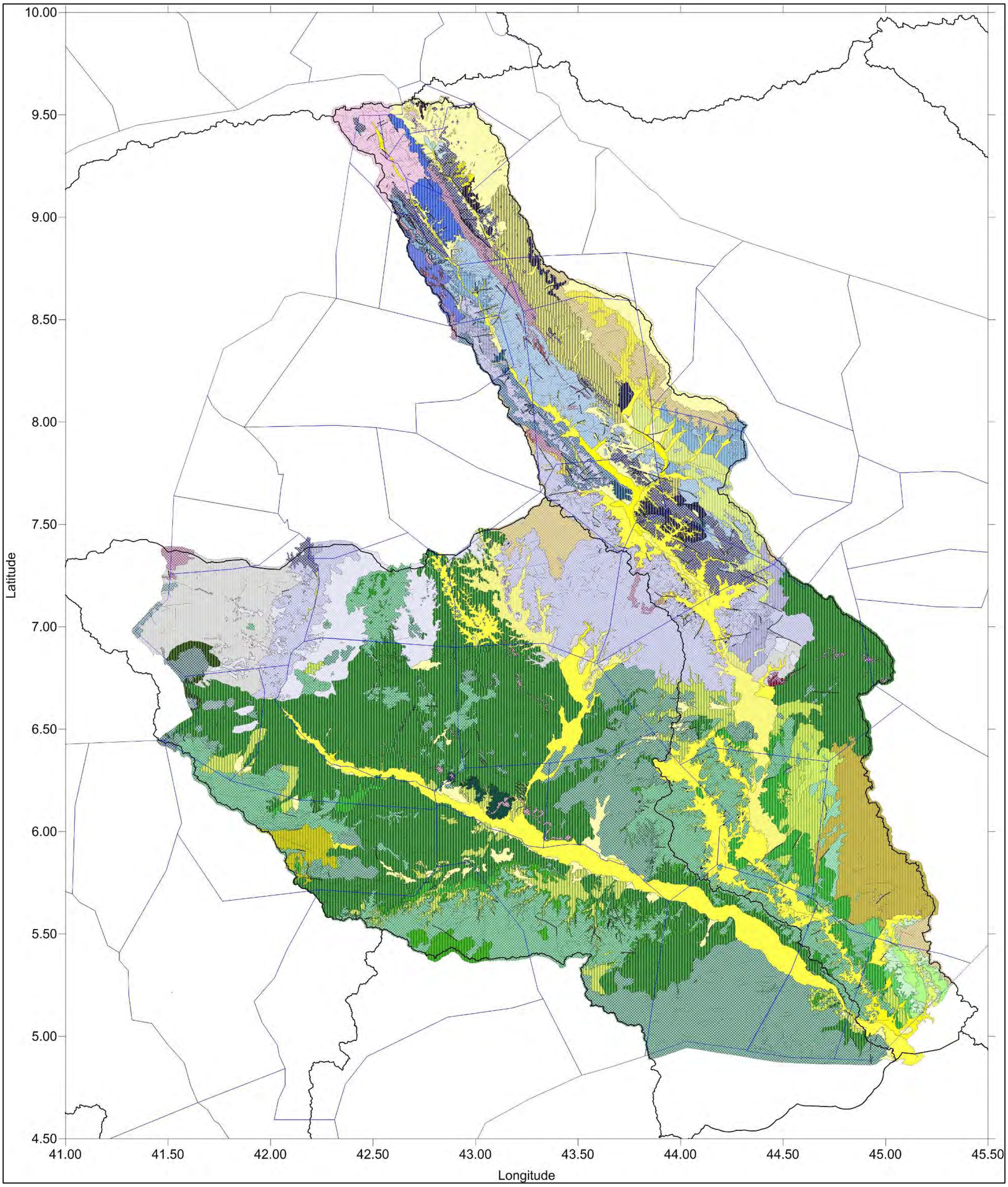
There is a limitation to the effectiveness of satellite image interpretation in regard to 1) areas where geological units with similar landform types are adjoining (for example, areas where it is difficult to recognize in detail between Ju and Jh), and 2) areas for which the landform cannot be ascertained at a scale of 1:250,000 due to the complexity of landform distribution (for example, area covered by Quaternary deposits as shown in Figure 3.15, or areas where it is difficult to recognize the small cone of basalt). In cases, the two geological units were expressed as one geological unit.



- Km (1): Mustahil limestone (Km) is covered thinly by Quaternary deposits (Qa)*.
- Km: Qa* hardly covers Km. Km crops out.
- Km (3): Km is covered thinly by colluvial deposits (Qc).
- Km (4): Km is covered by Qa*, however Qa* has not sufficient thickness for aquifer, or Km is dotted with Qa*.

*: Qa does not include the colluvial deposits.

Figure 3.15: One Sample Idea of Geological Units Classification



(The color of classification of geological units refer to Table 3.2)

Figure 3.16: Geological Map

Table 3.2: Geological Units Classification of Geological Map

Quaternary		
River Deposit: Gravel and sand		
r		Present River Deposit
	r(1)	Presnt River Deposit and terrace deposit (mainly present river deposit)
Alluvial Deposit: Gravel, sand, silt and clay		
Qa		Terrave Deposit
	Qa(1)	Terrace Deposit with present river deposit (mainly terrace deposit)
Colluvial Deposit: Sand, silt, clay and gravel		
Qc		Colluvial Deposit
	Qc(1)	Colluvial Deposit is scattered in areas of Quaternary deposit.
Late Pliocene – Quaternary		
Quaternary Basalt: Basalt lava flow		
Qb		Quaternary Basalt (Recent basalt)
	Qb(1)	Quaternary Basalt is overlain by thin Quaternary deposit
	Qb(2)	Quaternary Basalt is overlain by Quaternary deposit that does not have a sufficient thickness as aquifer. Or Quaternary Basalt is scattered in areas of Quaternary deposit.
Cenozoic (Unknown Period)		
Old basalt: Basalt lava flow		
Qv		Old Basalt
	Qv(1)	Old basalt is scattered in areas of Qc.
Late Cretaceous – Early Eocene		
Jessoma Sandstone: Variegated quartz sandstone		
Pj		Jessoma Sandstone
	Pj(1)	Jessoma Sandstone is overlain by Quaternary deposit that does not have a sufficient thickness as aquifer. Or Jessoma Sandstone is scattered in areas of Quaternary deposit.
Late Cretaceous		
Beletwein Limestone: Shaly limestone with some sandstone		
Kb		Beletwein Limestone
	Kb(1)	Beletwein Limestone is overlain by thin Quaternary deposit.
	Kb(2)	Beletwein Limestone is overlain by Quaternary deposit that does not have a sufficient thickness as aquifer. Or Beletwein Limestone is scattered in areas of Quaternary deposit.
	Kb(3)	Beletwein Limestone is overlain by thin Pj.
Ferfer Gypsum Formation: Gypsum with sand and marl intercalations		
Kf		Ferfer Gypsum Formation
	Kf(1)	Ferfer Gypsum Formation is overlain by thin Quaternary deposit.
	Kf(2)	Ferfer Gypsum Formation is overlain by Quaternary deposit that does not have a sufficient thickness as aquifer. Or Ferfer Gypsum Formation is scattered in areas of Quaternary deposit.
Early to Late Cretaceous		
Mustahil Limestone: Biogenic limestone and marlstone		
Km		Mustahil Limestone
	Km(1)	Mustahil Limestone with flat ground surface
	Km(2)	Mustahil Limestone is overlain by thin Quaternary deposit.
	Km(3)	Mustahil Limestone is overlain by Quaternary deposit that does not have a sufficient thickness as aquifer. Or Mustahil Limestone is scattered in areas of Quaternary deposit.
	Km(4)	Mustahil Limestone is overlain by thin Qc.
	Km(5)	Mustahil Limestone is overlain by Qc that does not have a sufficient thickness as aquifer. Or Mustahil Limestone is scattered in areas of Qc.

Late Jurassic – Early Cretaceous			
Korahe Gypsum Formation (Main Gypsum Formation): Gypsum evaporates with limestone			
	Kg2		Korahe Gypsum Formation (Upper unit)
		Kg2(1)	Korahe Gypsum Formation (Upper unit) is overlain by thin Quaternary deposit.
		Kg2(2)	Korahe Gypsum Formation (Upper unit) is overlain by Quaternary deposit that does not have a sufficient thickness as aquifer. Or Korahe Gypsum Formation (Upper unit) is scattered in areas of
		Kg2(3)	Qv is scattered in areas of Korahe Gypsum Formation (Upper unit).
	Kg1		Korahe Gypsum Formation (Lower unit)
		Kg1(1)	Korahe Gypsum Formation (Lower unit) is overlain by thin Qc.
Amba Aradam Sandstone: Variegated quartz sandstone			
	Ka		Amba Aradam Sandstone
Late Jurassic			
Kabridahar Formation: Oolitic limestone, marl and gypsum			
	Jg2		Kabridahar Formation (Upper unit)
		Jg2(1)	Kabridahar Formation (Upper unit) is overlain by thin Quaternary deposit.
		Jg2(2)	Kabridahar Formation (Upper unit) is overlain by Quaternary deposit that does not have a sufficient thickness as aquifer. Or Kabridahar Formation (Upper unit) is scattered in areas of Quaternary deposit.
	Jg1		Kabridahar Formation (Lower unit)
		Jg1(1)	Kabridahar Formation (Lower unit) is overlain by thin Quaternary deposit.
		Jg1(2)	Kabridahar Formation (Lower unit) is overlain by Quaternary deposit that does not have a sufficient thickness as aquifer. Or Kabridahar Formation (Lower unit) is scattered in areas of Quaternary deposit.
Urandab Formation: Shale and marl with limestone and gypsum			
	Ju		Urandab Formation
		Ju(1)	Urandab Formation is overlain by thin Quaternary deposit.
		Ju(2)	Urandab Formation is overlain by Quaternary deposit that does not have a sufficient thickness as aquifer. Or Urandab Formation is scattered in areas of Quaternary deposit.
		Ju(3)	Qb is scattered in areas of Urandab Formation.
Middle to Late Jurassic			
	Ju+Jh		The boundary between Urandab Formation and Hammanlei Formation is indefinite by image analysis involving visual inspection.
Hammanlei Formation: Organogenic and oolitic limestone with shale and sandstone intercalations			
	Jh2		Hammanlei Formation (Upper unit)
		Jh2(1)	Hammanlei Formation (Upper unit) is overlain by thin Quaternary deposit.
		Jh2(2)	Hammanlei Formation (Upper unit) is overlain by Quaternary deposit that does not have a sufficient thickness as aquifer. Or Hammanlei Formation (Upper unit) is scattered in areas of Quaternary deposit.
	Jh1		Hammanlei Formation (Lower unit)
		Jh1(1)	Hammanlei Formation (Lower unit) is overlain by thin Quaternary deposit.
		Jh1(2)	Hammanlei Formation (Lower unit) is overlain by Quaternary deposit that does not have a sufficient thickness as aquifer. Or Hammanlei Formation (Lower unit) is scattered in areas of Quaternary deposit.
		Jh1(3)	Hammanlei Formation (Lower unit) is overlain by thin Qc.
Triassic(?) – Middle Jurassic			
Adigrat Sandstone: Fine to coarse sandstone			
	Ja		Adigrat Sandstone
		Ja(1)	Adigrat Sandstone is overlain by thin Quaternary deposit. (Quaternary deposit does not have a sufficient thickness as aquifer.)
Precambrian			
Basement rocks: granite, granite-gneiss, migmatite, amphibolite, diorite			
	PC		Basement rocks

3.2.6 Lithology

In this project, the geological outcrop observation was hardly carried out because field reconnaissance was limited due to safety problems. As a result, the outline of each geological unit's lithology was mentioned from the bottom to top based on the result of existing studies.

a. Basement Complex (PC)

These geological formations sum up the Precambrian rocks that make up part of basement rocks in Africa, which include granite, granitic gneiss, amphibolites and diorite. The basement rocks are overlain by Mesozoic sediment, which are in turn overlain by Tertiary to Recent volcanics and alluvial deposits (refer to Figure 3.17).

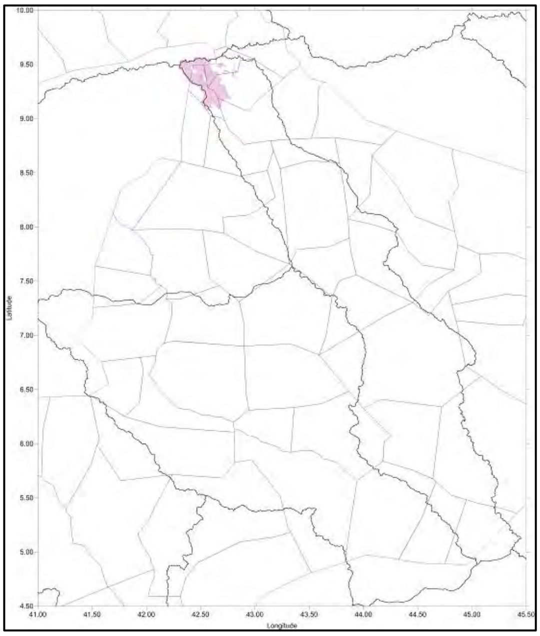


Figure 3.17: Distribution Area of Basement Rocks on and Near the Surface

b. Paleozoic

Paleozoic sedimentary rocks are not outcropping in Somali Region[16)], however, Paleozoic formations (ex. Bokh Formation, Gumburo Formation etc. Bokh Petroleum well-1 (E46° 56′ 35″, N7° 29′ 47″)) are confirmed by the oil well drillings. And tillites and glacial sandstone of Ordovician in age are mapped in Oromia Region[16)].

c. Adigrat Sandstone (Ja)

Adigrat Sandstone (named by W. T. Blanford in 1870)[4)], which type locality is located in Adigrat Town of the north Tigray Region is the basal sandstone in Somali Region and the equivalent formations are present widely throughout East Africa[16).] In southern Somalia it is composed of varicoloured quartz sands with intercalations of gypsum and dark-red shale with a maximum thickness of 130 m. In northern Somalia, this formation consists of fine to coarse-grained, varicolored quartzitic, micaceous, cross-bedded, un-fossiliferous sandstones, locally grading upward into sandy limestone[16)].

In Ethiopia, the Adigrat sandstone is described as a fine to medium-grained sandstone, as much as 60 m thick, commonly poorly cemented, but locally quartzitic, unfossiliferous[16)]. Drilling data in Ethiopia, the Sinclair XEF-1 drilled 24 m of Adigrat sandstone composed of 12 m of sandstone, 9 m of shale, and 3 m of basal conglomerate. In an oil well drilled in Bodle Afder zone, the largest thickness of 253 m of Adigrat sandstone was encountered[16)].

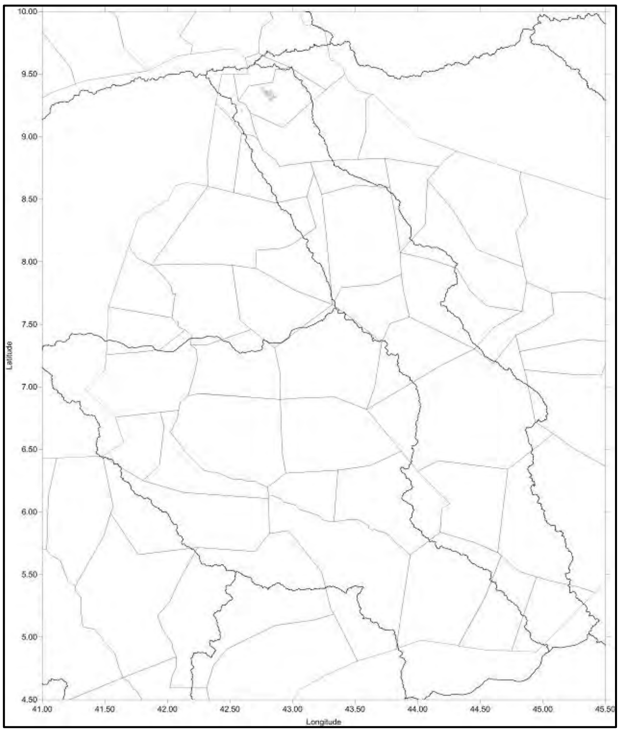
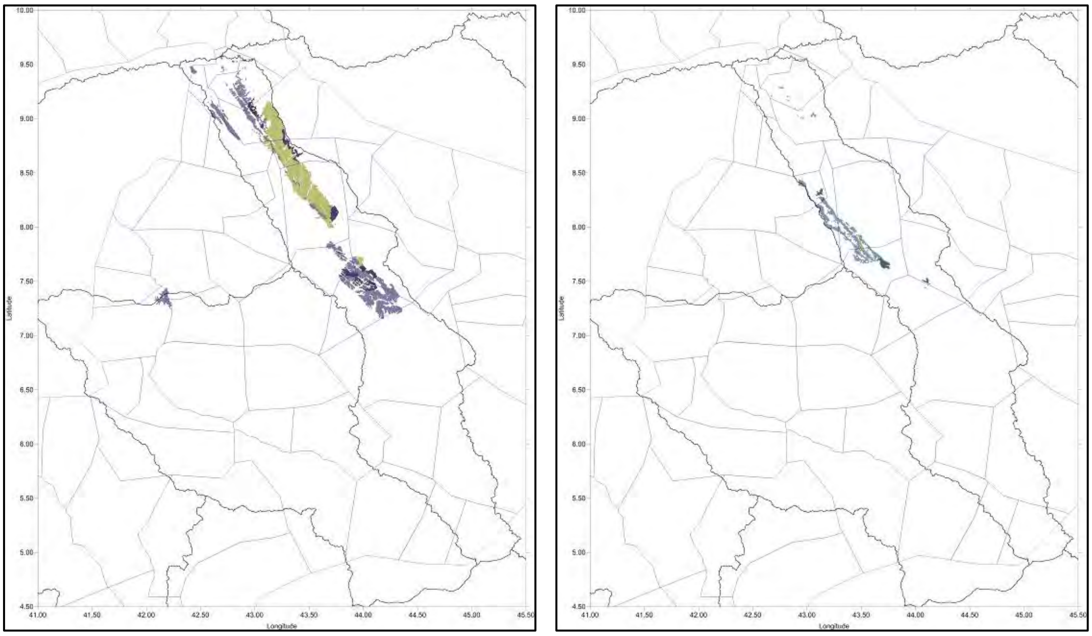


Figure 3.18: Distribution of Adigrat Sandstone on and Near the Surface

d. Hamanlei Formation (Jh)

In regard to the name and type locality of Hamanlei formation, WWDSE (2004)[25)] describes that "the outcrop section of type locality is in the Hammanlei village of Ogaden area, the outcrop section of type locality is described by Migliorini et al. (1956)". And also Merla et al. (1973) [12)] cites in the Chapter of Mesozoic in Somalia that the Hamanlei formation correlates with "Serie di Hammnlei" of Azzaroli & Merla (1959) and "Iscia Baidoa formation" of Barbieri (1968).

Hamanlei Formation is predominantly limestone and dolomite which has a gradational contact with the Adigrat sandstone and with the overlying Urandab formation[16)]. According to Ministry of Agriculture (2012)[23)] and UNESCO (2012)[22)], it rests unconformably with the underlying basement complex, and it is divided into 2 units (upper formation: Jh2, lower formation: Jh1). This formation outcrops in the Amhara mountain ranges and along the Fafem - Jarar valley[18)] (refer to Figure 3.19).



(Jh1) (Jh2)

Figure 3.19: Distribution of Hamanlei Formation on and Near the Surface

e. Urandab Formation (Ju)

In regard to the name and type locality of Urandab formation, WWDSE (2004)[25)] describes that "this formation is named in connection with the Urandab village of north Ogaden area near the type locality of this formation (Migliorini (1948) and Clift (1956)". And also Merla et al. (1973) [12)] cites in the Chapter of Mesozoic in Somalia that the Urandab formation correlates with "Serie di Urandab" of Agip Mission et al. (1936-38) and "Anole formation" of Barbieri (1968).

It is exposed in the southern slopes of the lower Fafem - Jarar valley and in the area of Kabridahar[18)] (refer to Figure 3.20). It is composed of well bedded, fine grained limestone alternating with gradually increasing proportions of marl, gypsiferous clays and massive gypsum as the base of the formation is approached[18)]. It has a consistent thickness of 70 - 120 m. Depth to groundwater is generally shallow (less than 30 m) in most deep valleys[18)]. It is also shallow (20 - 50 m) in the area between Kabridahar and Shaygosh as well as in the north - south valleys between Danan and Kabridahar[18)]. The middle part of the formation contains mineralized water barely potable in most places[18)].

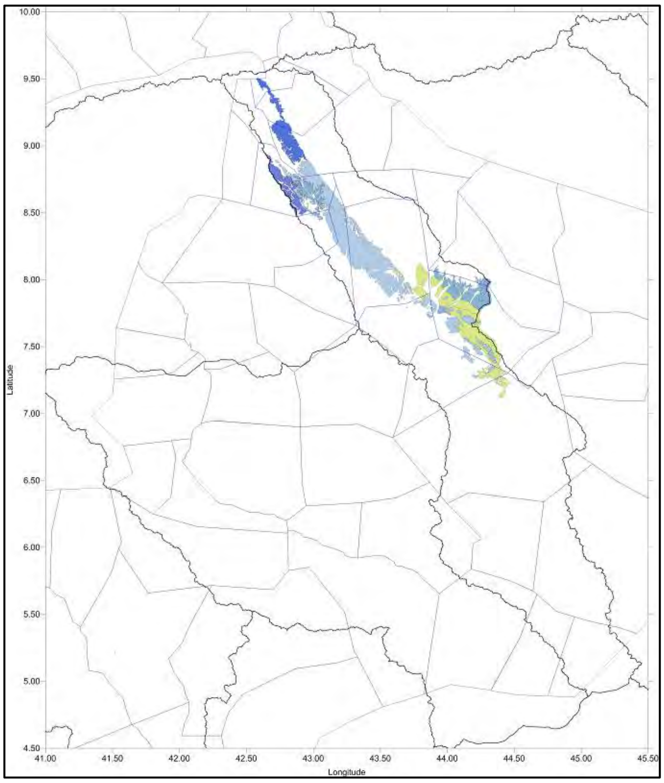
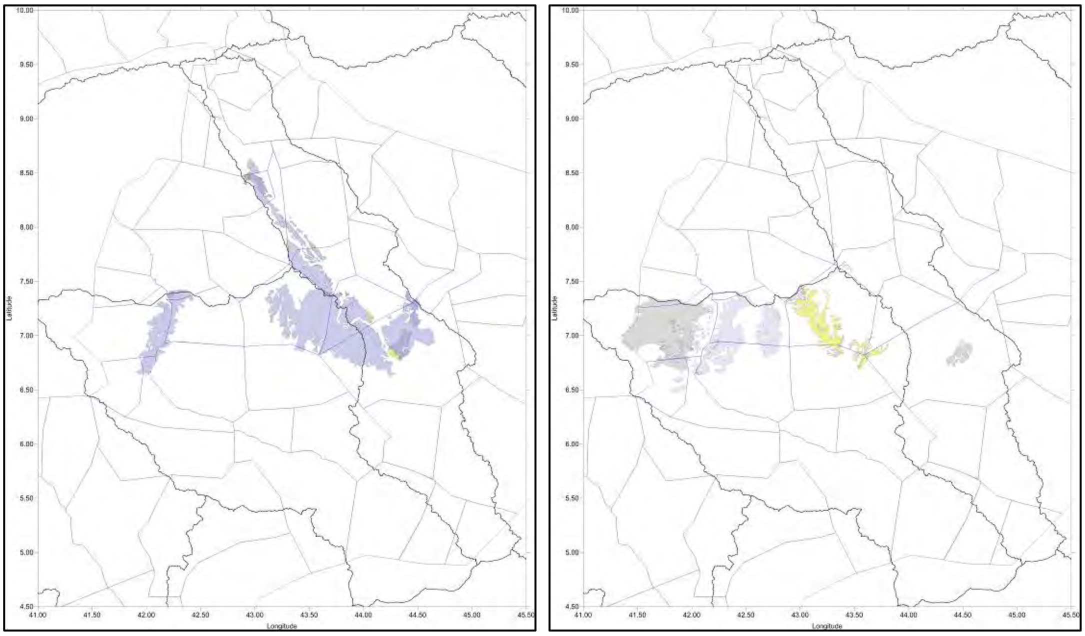


Figure 3.20: Distribution of Urandab Formation on and Near the Surface

f. Kabridahar Limestone (Jg)

In regard to the name and type locality of Kabridahar limestone, WWDSE (2004)[25)] describes that "the outcrop section of type locality is in the Gabredarre (Kabridahar) village of north Ogaden area (Migliorini (1948) and Clift (1956)". And also Merla et al. (1973) [22)] cites in the Chapter of Mesozoic in Somalia that the Kabridahar formation correlates with "Serie di Gabredarre" of Agip Mission et.al. (1936-38) and "Uegit formation" of Barbieri (1968).

Kabridahar limestone consists of a basal shale level covered by a sequence of skeletal limestone and detrital limestone with marly limestone and clay intercalation in the upper part[25)]. Thin beds of gypsum are widespread throughout the formation[25)]. According to Ministry of Agriculture (2012)[23)] and UNESCO (2012)[22)], it is divided into 2 units (upper formation: Jg2, lower formation: Jg1).The formation occupies a vast area in the middle parts of Wabi Shebele and Weyb River valleys[18)] (refer to Figure 3.21).



(Jg1) (Jg2)

Figure 3.21: Distribution of Kabridahar Formation on and Near the Surface

g. Amba Aradam Sandstone (Ka)

In regard to the name and type locality of Amba Aradam sandstone, WWDSE (2004)[25)] describes that “Amba Aradam formation is named in connection with the Amba Aradam village of north Tigray Region near the type locality of this formation”. And also Merla et al. (1973) [12)] cites in the Chapter of Mesozoic in Somalia that this formation correlates with “Merehan Sandstone” of Weir (1929) and “Ambar Sandstone” of Barbieri (1968).

Amba Aradam sandstone is considered to be Early Cretaceous age and represents regressive facies of the Cretaceous sea (Dainelli, 1943[6)] and others) [25)].

The unit mainly consists of medium to coarse grained continental quartzos sandstone beds 1 to 30 m thick with frequent cross laminations[25)]. It is lithologically similar to Adigrat Sandstone. Siltstone, shale and marl beds are often interbedded with the arenaceous layers[25)]. They occur as alternating layers of fine and medium grained, white and yellowish-brown color[25)] (refer to Figure 3.22).

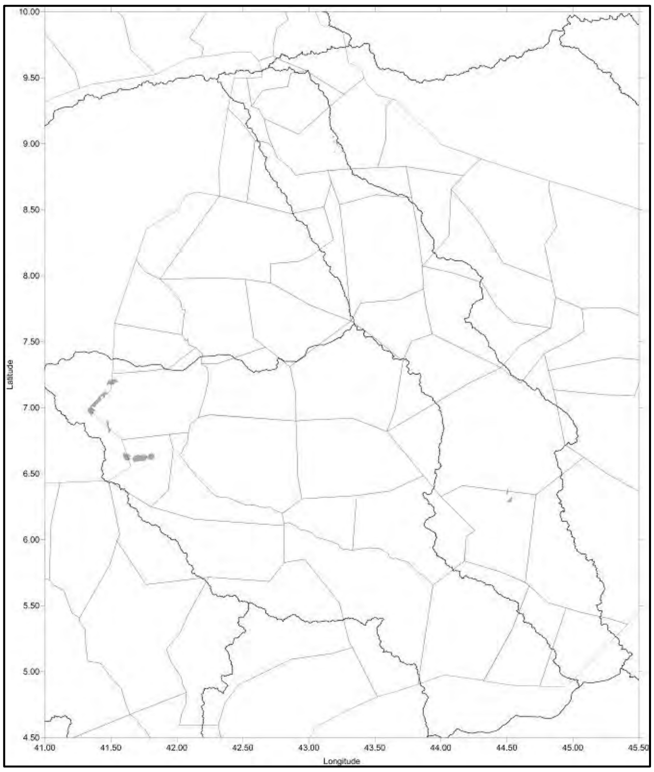


Figure 3.22: Distribution of Amba Aradam Formation on and Near the Surface

h. Korahe Gypsum Formation (Main Gypsum Formation) (Kg)

WWDSE (2004)[25] describes that "Korahe Gypsum formation has been dealt with as "Main Gypsum" units in the past (Migliorini (1948) and Clift (1956)". And also Merla et al. (1973)[12] cites in the Chapter of Mesozoic in Somalia that this formation correlates with "Formazione Selenitosa Principale" of Tavani (1949) (The outcrop section of type locality: Gabredarre (kabridahar).

The outcrop area of the Korahe Gypsum Formation is from east of Kabridahar town to Wabi Shebele and Genale River valleys (refer to Figure 3.23). The general topography represented by the formation is undulating plains dissected by a dense network of small, shallow dry stream channels[18]. According to Ministry of Agriculture (2012)[34] and UNESCO (2012)[22], it is divided into 2 units (upper formation: Kg2, lower formation: Kg1). The upper part is dominantly massive anhydride with some beds of dolomite[18]. The lower part is represented by alternation of dolomitic limestone, marl, shale and anhydride[2]. The total thickness varies from 100 to 150 m but could reach up to 500 m[18]. Owing to the impervious nature of the anhydride, the upper section of the formation can be considered as the largest aquiclude in the Ogaden basin. Nevertheless, where the lower section is exposed to precipitation directly, which does not exceed 150 to 500 mm/yr, brackish ground water could be extracted from the limestone at shallow depth[18].

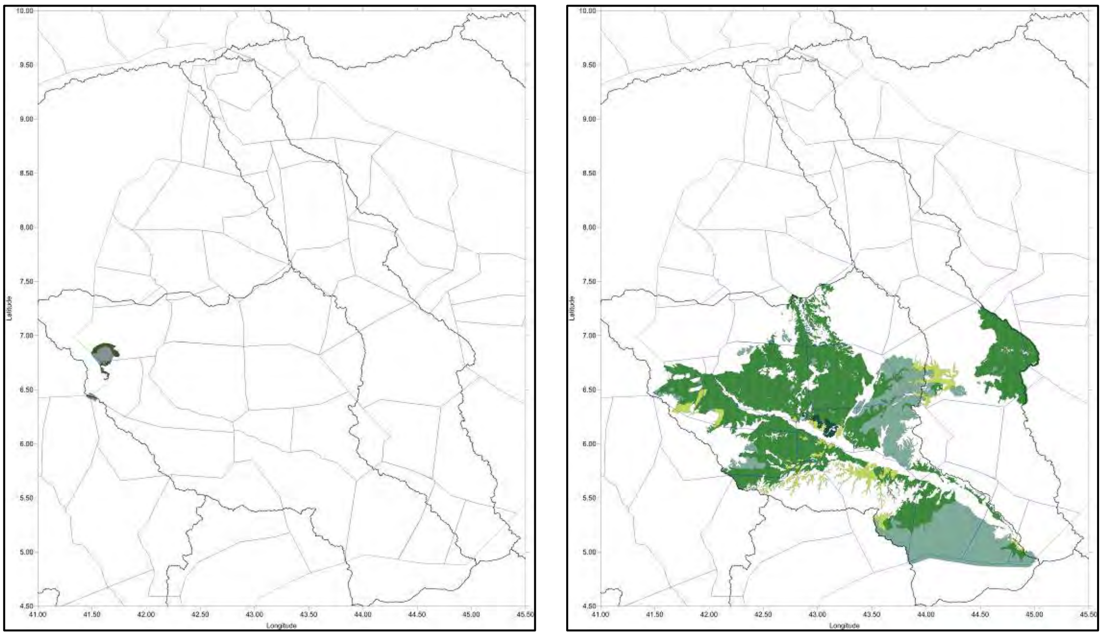


Figure 3.23: Distribution of Korahe Gypsum Formation on and Near the Surface

i. Mustahil Limestone (Km)

In regard to the name and type locality of Mustahil limestone, WWDSE (2004)[25] describes that "this formation is named in connection with the Mustahil village near the type locality of this formation (Taylor (1947), Migliorini (1948,1956) and Clift (1956)". And also Merla et al. (1973) [12] cites in the Chapter of Mesozoic in Somalia that the Urandab formation correlates with "Serie di Mustahil" of Tavani (1949).

Mustahil limestone outcrops in the lower Wabi Shebele and the type locality is near the Mustahil village and covers part of Doba wein woreda[18] (refer to Figure 3.24). The topography is characterized by very extensive undulating plateau with edges highly dissected by short, broad shallow valleys[18]. Mustahil limestone consists of two units. Limestone inter-bedded with shale and marl is characteristic for the lower part, whereas in the upper part reef limestone predominates[18]. Many dug wells are known to exploit perched aquifers, especially around Kalafo and within the Fafan valley towards Kabridahar[18].

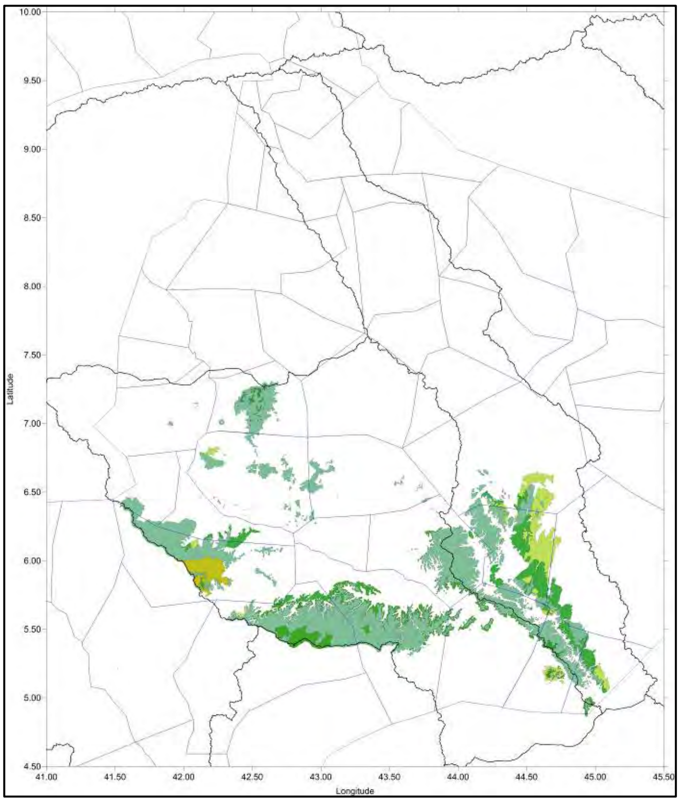


Figure 3.24: Distribution of Mustahil Formation on and Near the Surface

j. Ferfer Gypsum Formation (Kf)

In regard to the name and type locality of Fefer formation, WWDSE (2004)[25] describes that "this formation is named in connection with the Ferfer village near the border of Somalia (Migliorini (1948) and Clift (1956)". And also Merla et al. (1973) [12] cites in the Chapter of Mesozoic in Somalia that the Ferfer formation correlates with "Gessi di Ferfer" of Tavani (1949).

The Ferfer Gypsum Formation outcrops in lower Wabi Shebele[18] (refer to Figure 3.25). The formation is made up of alternation of dolomite, marl, shale and anhydride[18]. The lithology is very similar to the Korahe Gypsum Formation. Its thickness varies from 100 to 200 m[18]. Karstic features are common in places such as south of Shilabo town[25]. Shallow dug wells here exploit groundwater in the alluvium[18]. Otherwise, the Ferfer gypsum acts as an aquiclude or as a saline aquifer at its best condition[18]. In the large outcrop area of this formation, therefore, the only possibility of groundwater abstraction would be by drilling 100 to 150 m to reach and exploit the underlying limestone of the Mustahil formation[18].

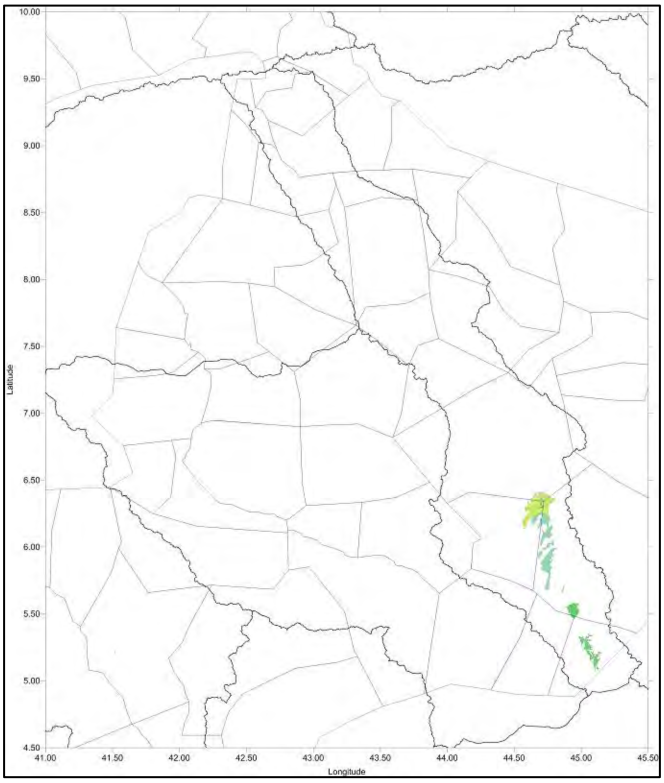


Figure 3.25: Distribution of Ferfer Gypsum Formation on and Near the Surface

k. Beletwein Limestone (Kb)

In regard to the name and type locality of Beletwein limestone, WWDSE (2004)[25] describes that "this limestone is named in connection with the type outcrop section of Belt Uen (Beltwein) village of the south Somalia near the border of Somalia (Migliorini (1948), Taylor (1948) and Clift (1956)". And also Merla et al. (1973) [12] cites in the Chapter of Mesozoic in Somalia that the Beletwein limestone correlates with "Serie di Belt Uen" (Type locality: Belt Uen) of Tavani (1949).

The formation is composed of massive limestone with intercalation of shale and brown sandstone clearly observable on the steep escarpment along the Ferfer - Shilabo road[18] (refer to Figure 3.26). Maximum thickness is about 230 m[18]. Boreholes sunk into this formation have met water of relatively fresh quality in the lower part of the succession but deteriorates in the upward sections[18].

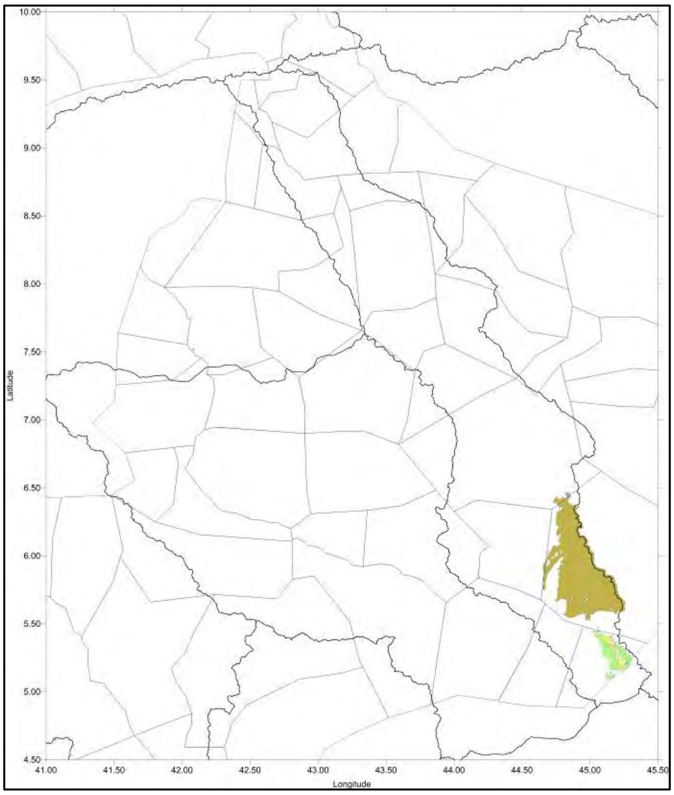


Figure 3.26: Distribution of Beletwein Formation on and Near the Surface

l. Jessoma Sandstone (Pj)

In regard to the name and type locality of Jessoma sandstone, WWDSE (2004)[25] describes that "this sandstone is named in connection with the type locality of Jessoma village of the south Somalia (Migliorini (1948) and Clift (1956)". And also Merla et al. (1973) [12] cites in the Chapter of Mesozoic in Somalia that the Beletwein limestone correlates with "Arenarie di Yesomma" (Type locality: Yessoma) of Stefanini (1925).

The Jessoma Sandstone is widespread in the eastern part of the Ogaden basin resting un-conformably over the upper Cretaceous sediments[18] (refer to Figure 3.27). It represents sandy clays and poorly-sorted quartzitic sandstones[18]. The maximum thickness is estimated to be about 500 m[18]. Grain size and thickness of the deposit progressively increases from west to east[18]. The sandstones are more massive in the west and become more friable eastward[18]. The lithological properties of the formation tend to suggest that water-bearing characteristic of the sandstone could vary considerably in space both vertically and laterally[18]. In the eastern part, due to the absence of a retaining aquiclude at shallow depths, whatever recharge available for the formation tends to percolate to great depths until retained by the underlying impermeable solid limestone and clay horizons of the Upper Cretaceous formations[18]. As a result the groundwater table in this area is expected to be very deep. Drilling in the Jessoma sandstones could be fraught with technical difficulties[18]. Tremendous circulation loss in the west and caving or collapse in the eastern part should be expected during drilling[18]. Frequent siltation of pumps is another problem to envisage after development[18].

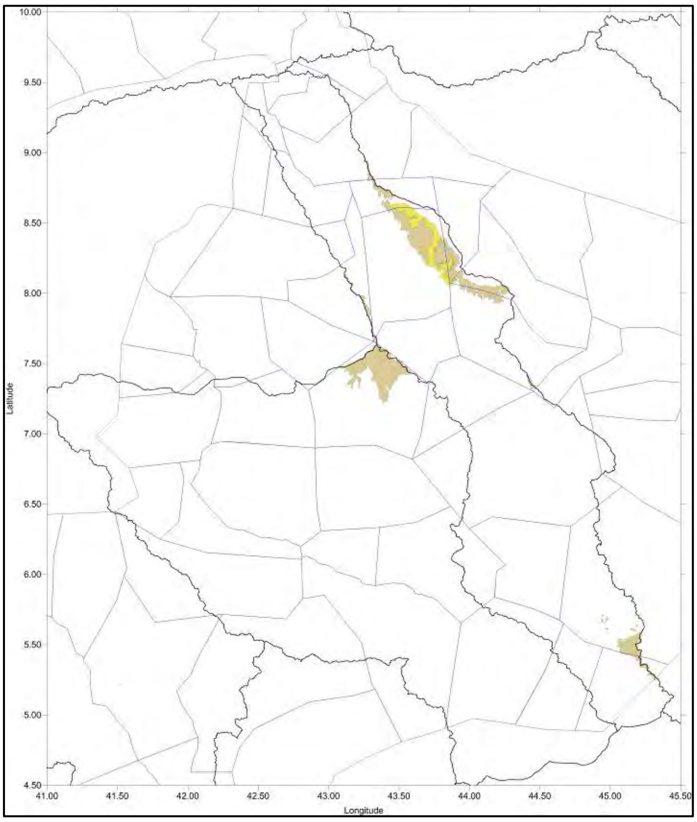


Figure 3.27: Distribution of Jessoma Sandstone on and Near the Surface

m. Auradu Limestone (Ea)

In outcrop the Paleocene is represented by the Auradu limestone[16)].

Merla et al. (1973) [12)] cites that the Auradu limestone correlates with [Uradu limestone] of Gregoy (1900) and "Auradu Series" of Macfadyen (1933). The type area is in Berbera town of north Somalia. SHAAC (2009) [16)] cites that [the type section is in northern Somalia in the Nogal Valley where the Auradu attains a thickness of up to 550 m. It is a fine crystalline, compact, hard, usually tan to light-brown limestone with local thin gray shales. It contains shallow-water Foraminifera such as Lockhartias, Sakesarias, Alveolinas, and Nummulites].

The age of the Auradu limestone in outcrop includes the Paleocene and the Ypresian and part of the Cuisian Stage of lower Eocene as indicated by the presence of Lockhartia tipperi, Nummulites somaliensis, and Daviesina danieli[16)].

In Somali Region, the Auradu limestone outcrops un the eastern part of Warder zone and the Sinclair wells in Warder zone, and a maximum thickness of 399 m of Auradu limestone was found in the XE-3A well located close to Bokh town[16)].

n. Basalt of unknown age (Qv)

Basalt of unknown age is outcropped mostly in isolated areas such as Walwal – Warder – Yucub area, Fik town area, and area surrounding Barey town of Afder zone (refer to Figure 3.28).

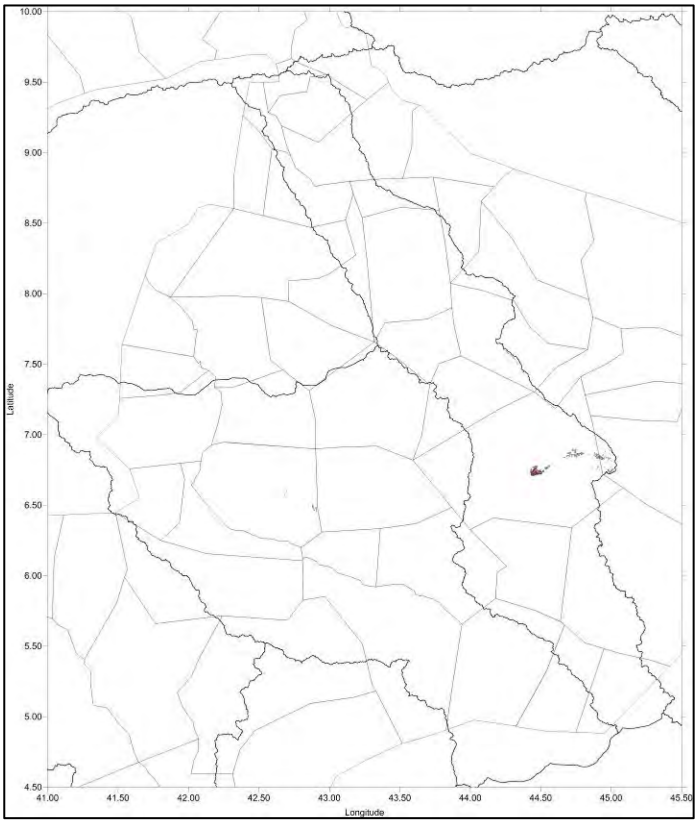


Figure 3.28: Distribution of Basalt (Qv) on and Near the Surface

o. Talah (Et) and Karkar Formations (Ek)

The upper part of the Tertiary sedimentary rocks is categorized into two formations: the Taleh formation and the Karkar formation. Both formations occur in eastern Ogaden. The Taleh Formation is mainly comprised of interbeds of anhydrite and fossilierous limestone[10)].

Merla et al. (1973) [12)] cites that the Talah formation correlates with "Serie di Taleh" of Stefanini (1925) and "Anhydrite Series" of Macfadyen (1933). The type locality is in Nogal valley of north Somalia.

On the other hand, the Karkar Formation which makes up the youngest Tertiary sedimentary formation is comprised of intercalations of cavernous limestone, shale and gypsum[10)].

Merla et al. (1973) [12)] cites that the Karkar formation correlates with "Serie di Carcar" of Stefanini (1925) and the Karkar formation is named in connection with Karkar Hills which composes the south edge of Darror depression in the north Somalia.

p. Quaternary Basalt (Qb)

This litho-stratigraphic sequence that is characterized by outcropping in the region is of Upper Oligocene-Quaternary[16)]. Undifferentiated volcanic rocks are outcropping in Shinile zone [16)] (refer to Figure 3.29). The basalt flows have been dated as Oligocene to Miocene (Mohr, 1963) [19) in16)], although basalt flows in the great rift valleys have been dated as Late Cretaceous into Oligocene (Swartz and Arden, 1960) [13) in 16)]. According to the previous study[16)], the thickness of the volcanic flows in Shinile zone is 50-200 m.

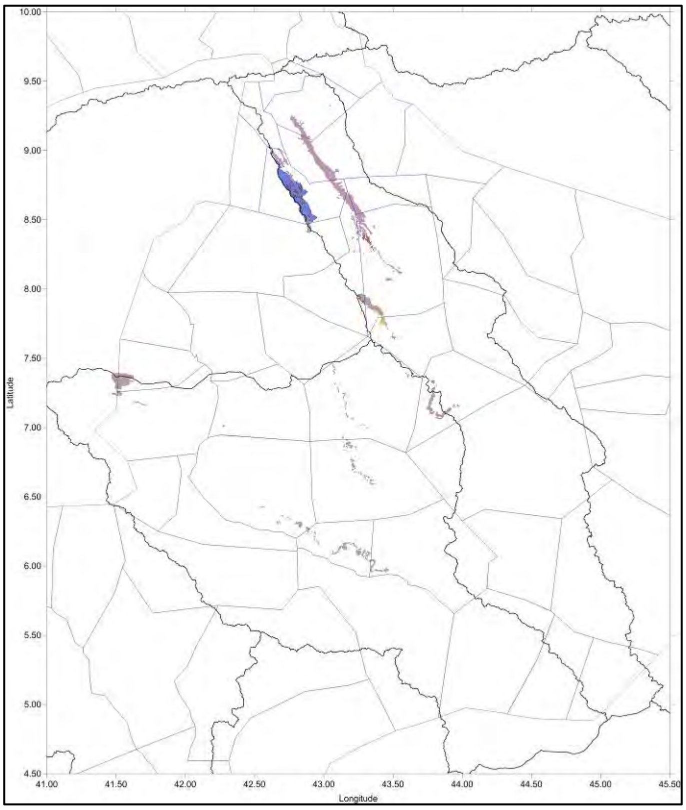


Figure 3.29: Distribution of basalt (Qb) on and Near the Surface

q. Alluvial (Qa) and Colluvial (Qc) Deposit

Alluvial and colluvial deposits are found along the structural valleys and in the dry stream beds. And the terrace deposits of Pleistocene distribute along the Shebele River. Alluvium deposits contain the river bed deposit.

3.3 Analysis of landform and geology

3.3.1 Jarar Valley

Landform and geological classification map and profile are shown for the target woredas of the water supply M/P. The geological unit of this landform and geological classification map is shown in Table 3.2 and the index of this map is shown in Table 3.3. Also Table 3.4 contains the information of the landform and geological profiles.

Table 3.3: Index of Landform and Geological Classification Map

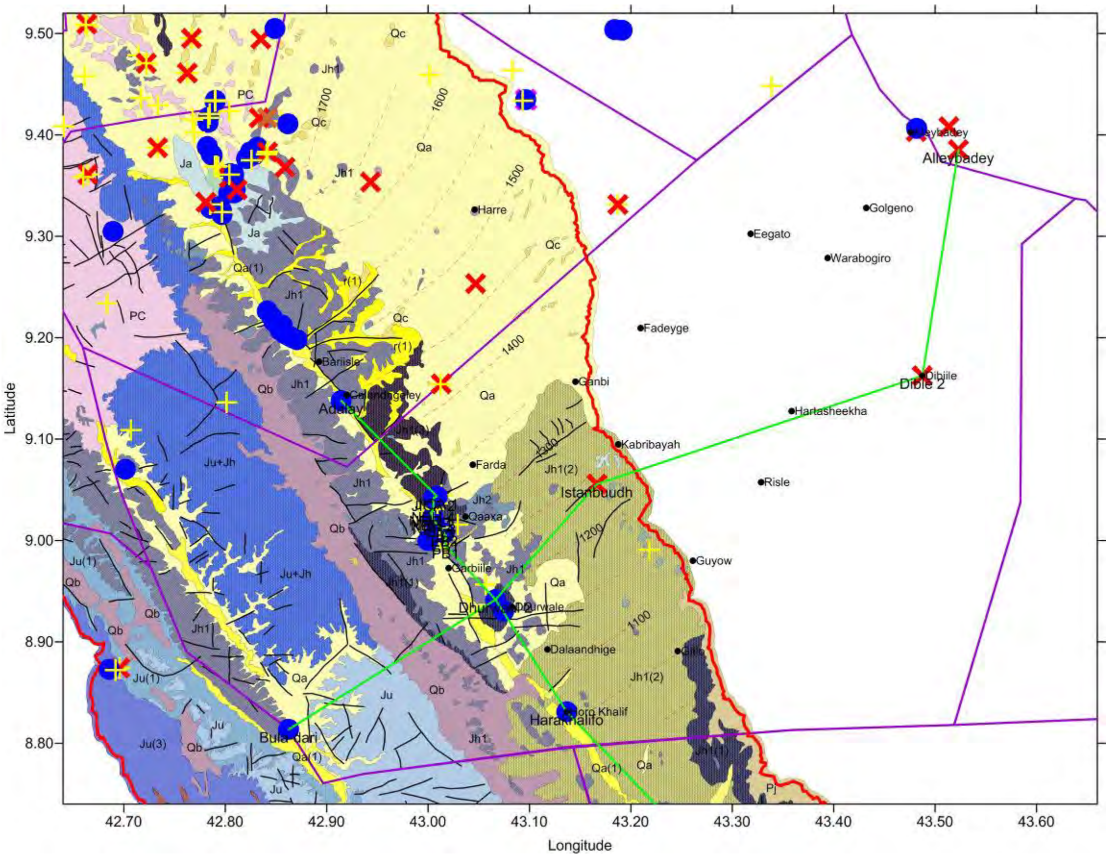
INDEX	
Basin Boundary	Successful Well
Woreda Boundary	Abandoned Well (Dry and Low Yield)
Town/Village	Abandoned Well (Bad Water Quality)
Landform & Geological Boundary	Abandoned Well (Failure of Construction)
Lineament	Abandoned Well (Unknown Reasons)
Profile line	Oil Well
	Insufficient Information Well

Table 3.4: Index of Landform and Geological Classification Profile

INDEX		
Topographic Profile		Geological Columnar Section
Geological Boundary	L.Y.	Low Yield
Probable Fault	B.W.Q.	Bad Water Quality

a. Kabribeyah woreda

As landform and geological information of Kabribeyah woreda, landform and geological classification map is shown in Figure 3.30 and landform and geological profile is shown in Figure 3.31 and Figure 3.32.



（··· : Distribution of upper depth of Adigrat sandstone, unit : m(amsl)）

Figure 3.30: Landform and Geological Classification Map of Kabribeyah Woreda

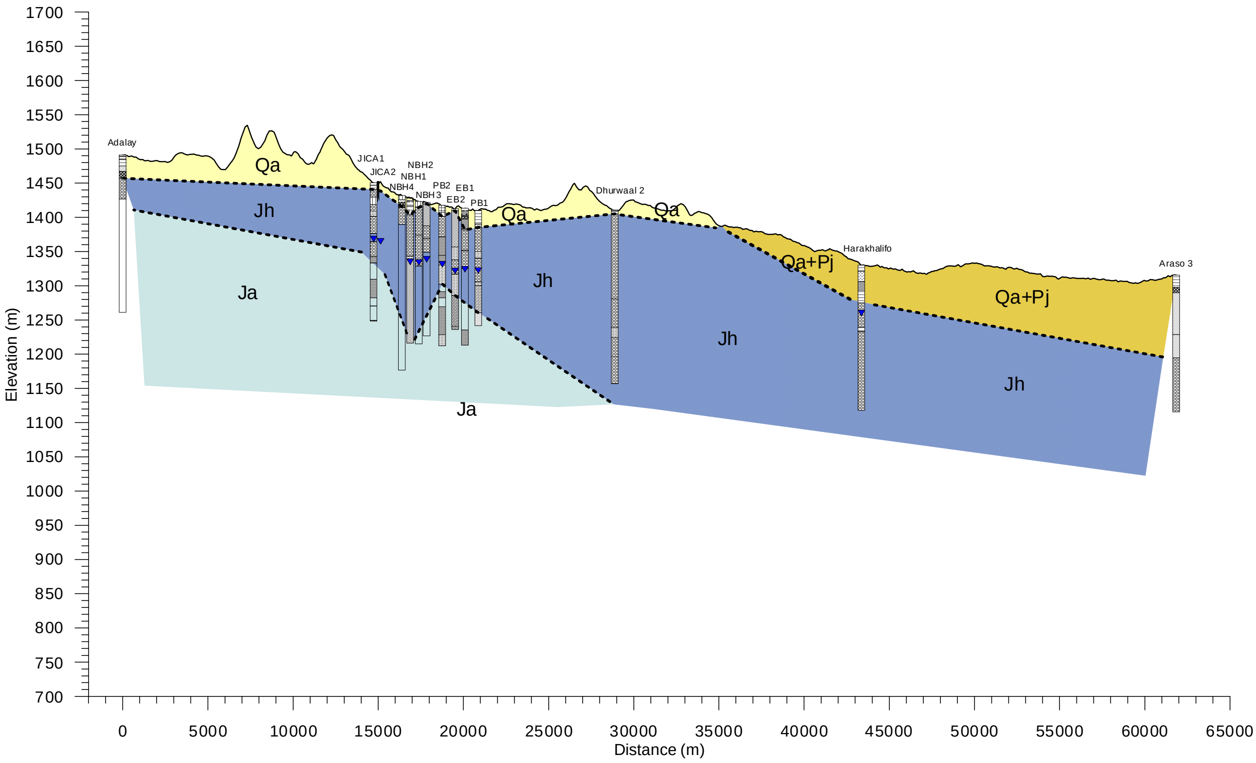


Figure 3.31: Landform and Schematic Geological Profile of Kabribeyah Woreda (parallel to the river)

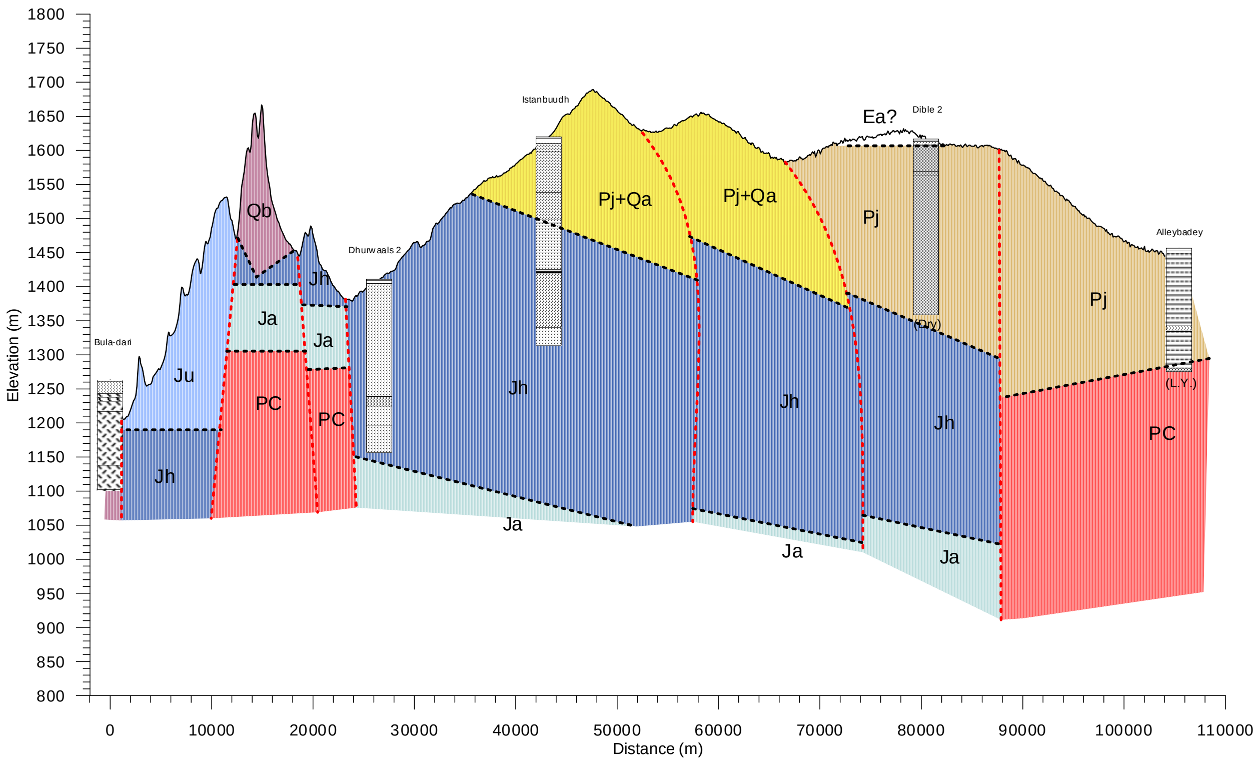
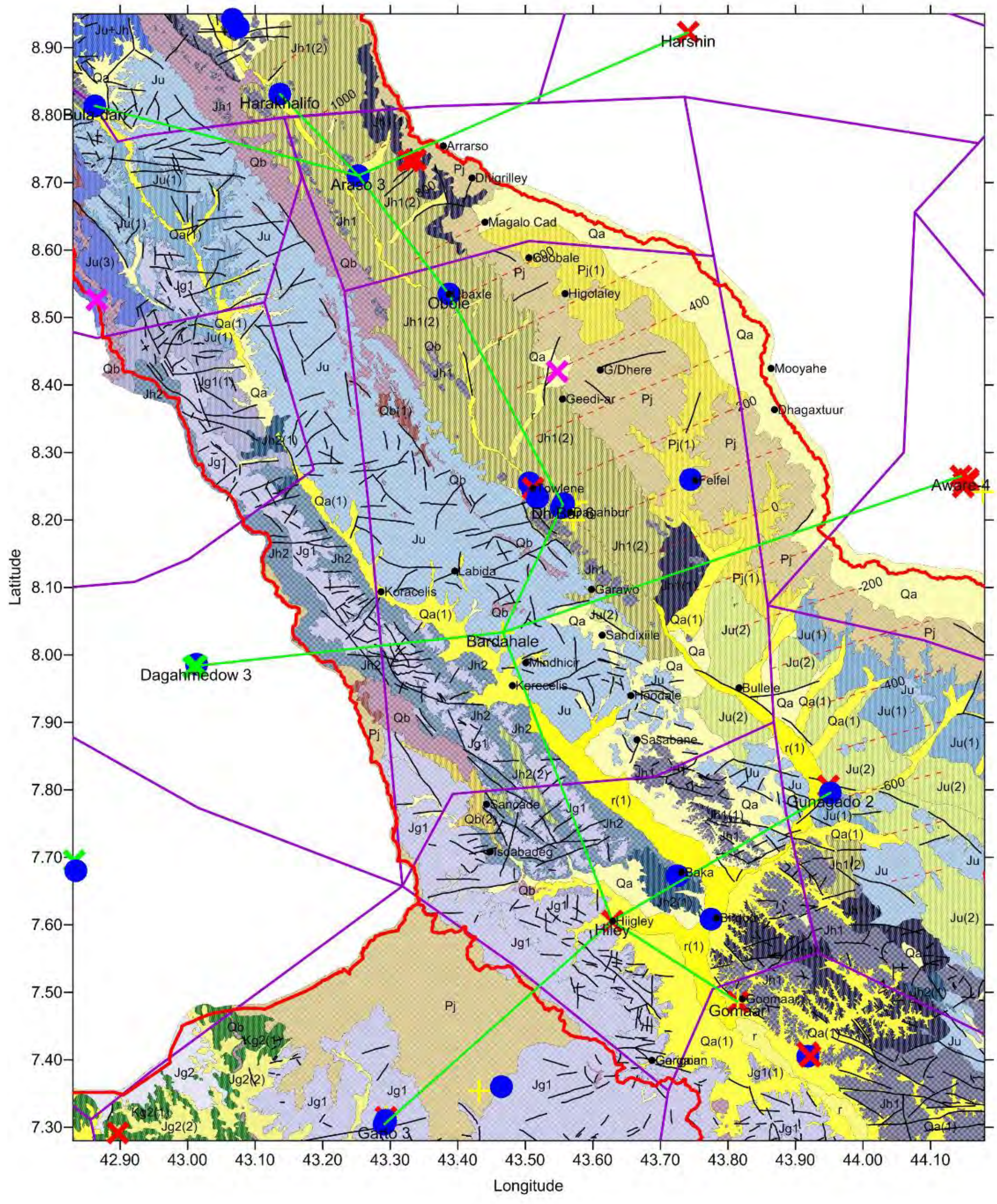


Figure 3.32: Landform and Schematic Geological Profile of Kabribeyah Woreda (across the river)

b. Araarso woreda

As landform and geological information of Araarso woreda, landform and geological classification map is shown in Figure 3.33, and landform and geological profile is shown in Figure 3.34 and Figure 3.35.



(⋯ : Distribution of upper depth of Adigrat sandstone, unit : m(amsl))

Figure 3.33: Landform and Geological Classification Map of Jarar Zone (Araarso, Dagahbur and Birqod woredas)

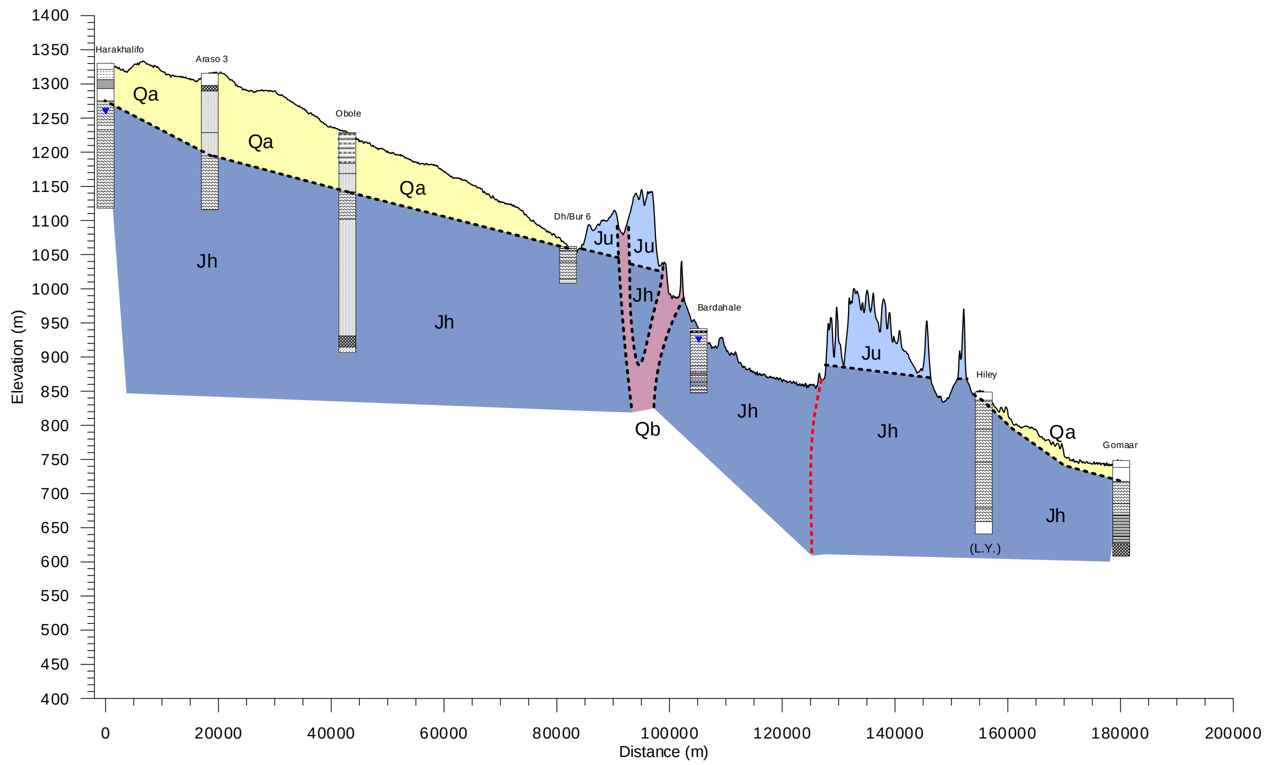


Figure 3.34: Landform and Schematic Geological Profile of Araarso, Dagahbur and Birqod Woredas (parallel to the river)

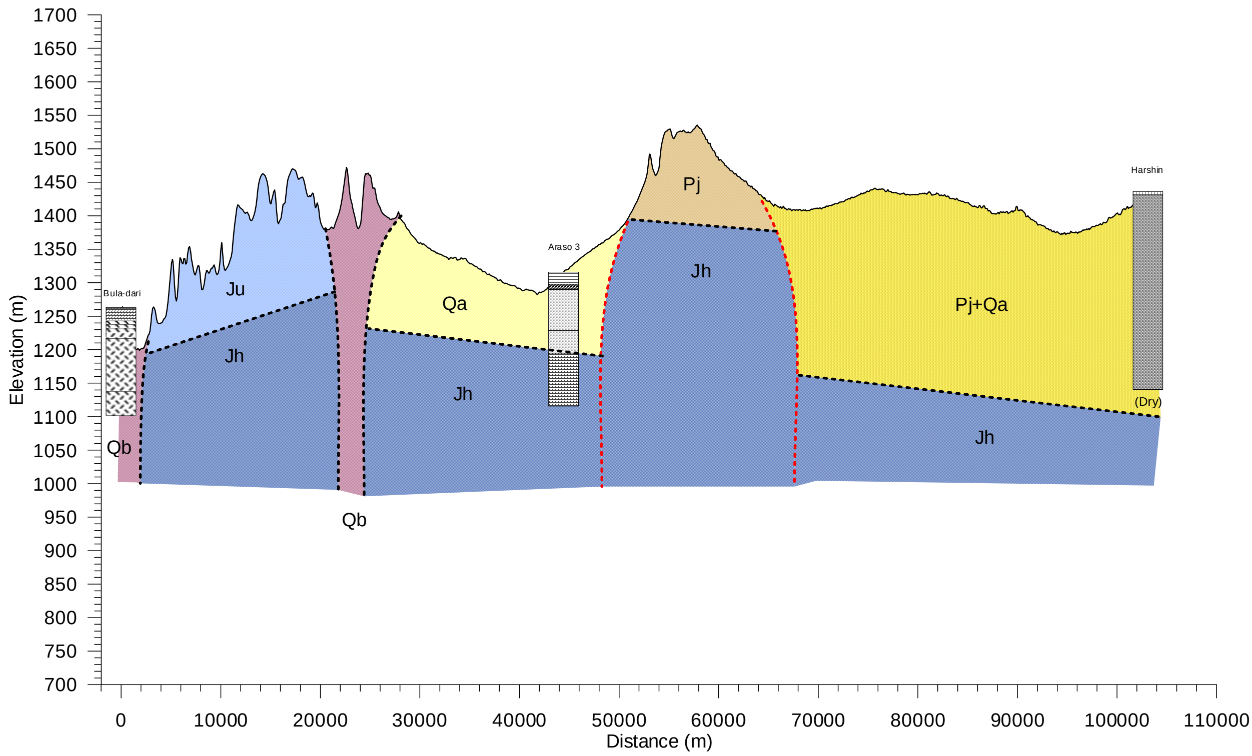


Figure 3.35: Landform and Schematic Geological Profile of Araarso Woreda (across the river)

c. Dagahbur woreda

As landform and geological information of Dagahbur woreda, landform and geological classification map is shown in Figure 3.33, landform and geological profile is shown in Figure 3.34 and Figure 3.36.

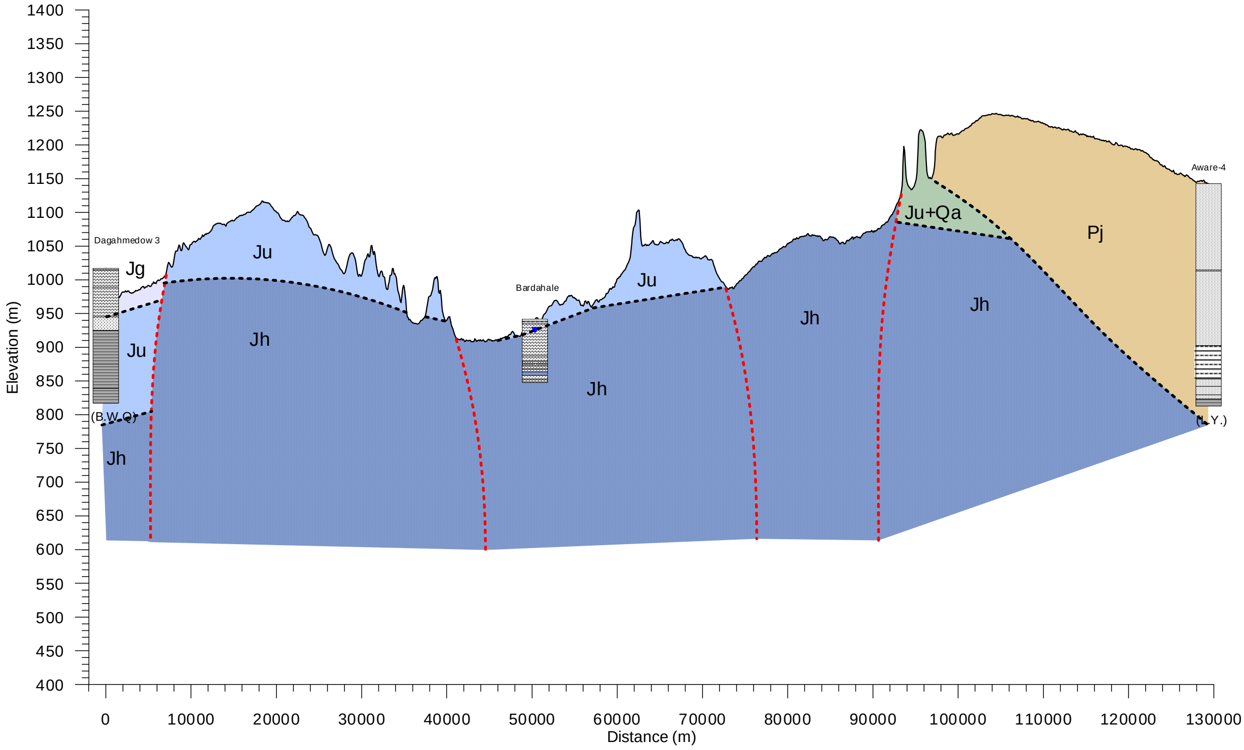


Figure 3.36: Landform and Schematic Geological Profile of Dagahbur Woreda (across the river)

d. Birqod woreda

As landform and geological information of Birqod woreda, landform and geological classification map is shown in Figure 3.33 , landform and geological profile is shown in Figure 3.34 and Figure 3.37.

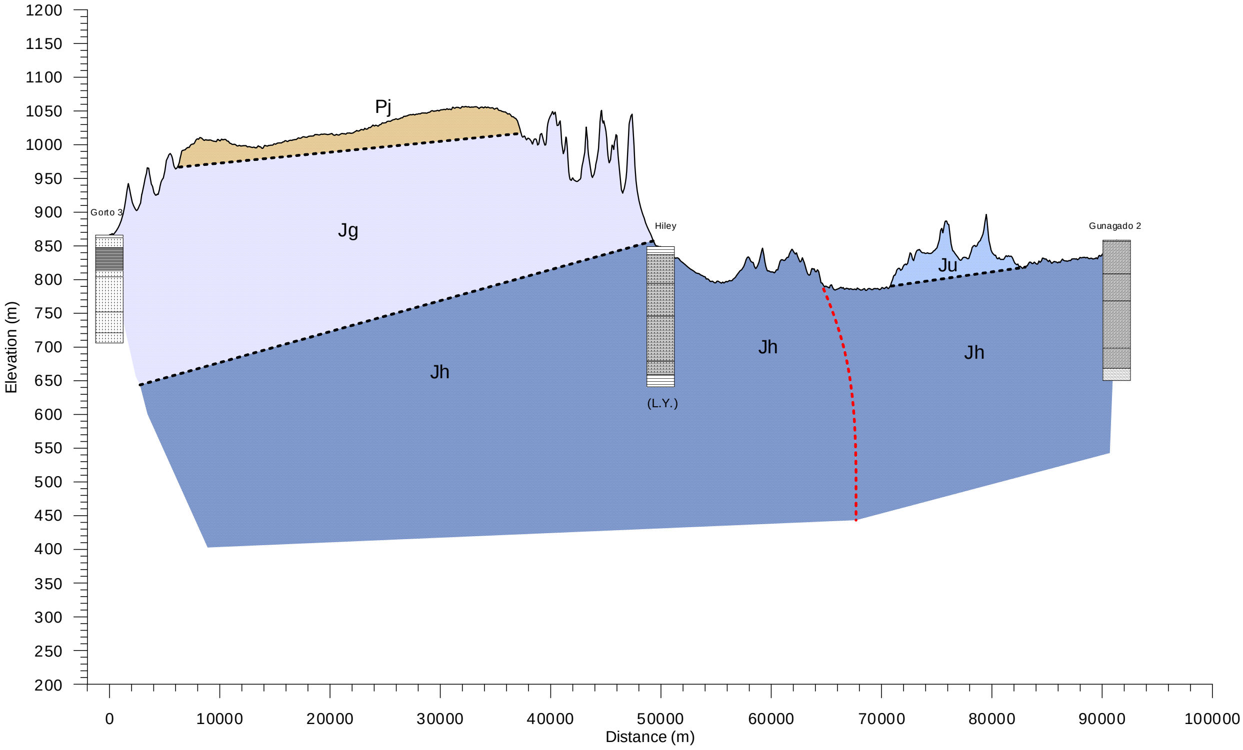
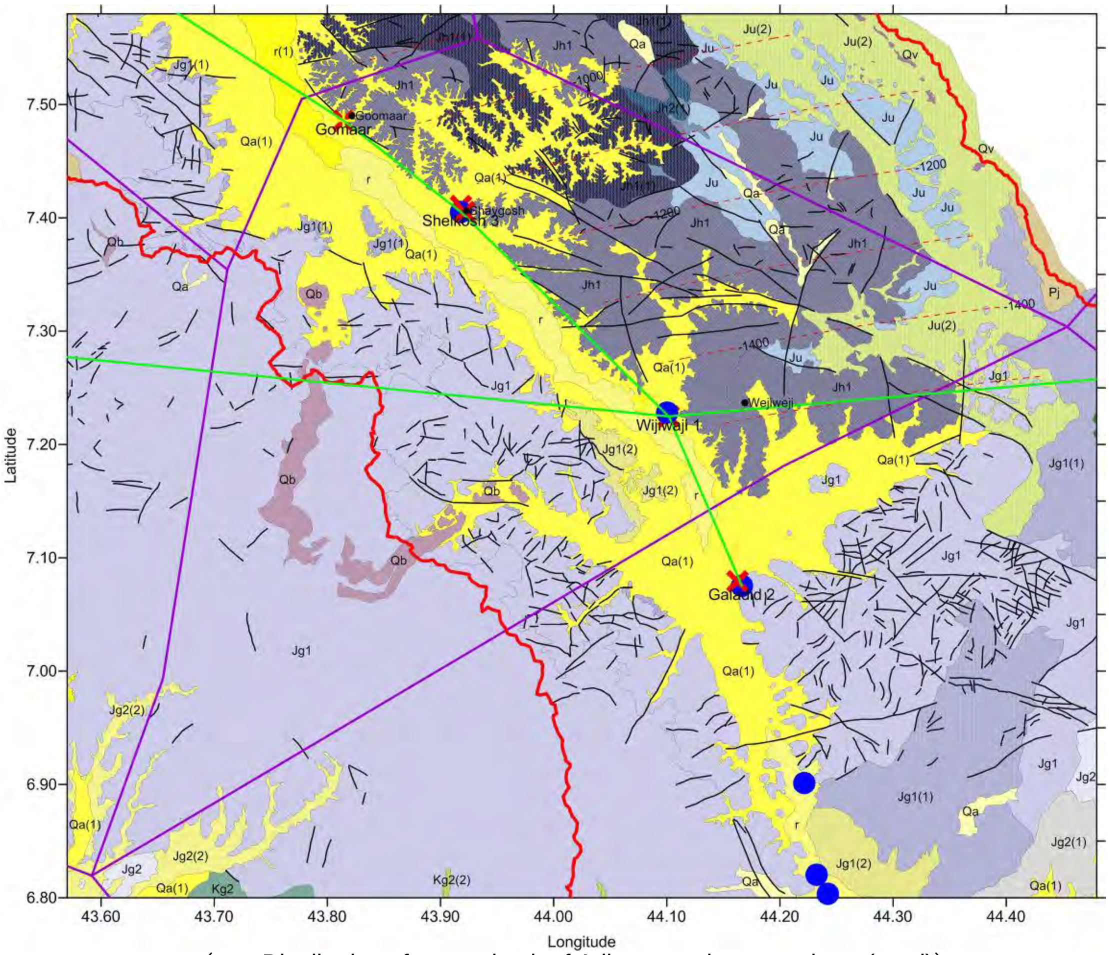


Figure 3.37: Landform and Schematic Geological Profile of Birqod Woreda (across the river)

e. Shaygosh woreda

As landform and geological information of Shaygosh woreda, landform and geological classification map is shown in Figure 3.38, landform and geological profile is shown in Figure 3.39 and Figure 3.40.



（⋯：Distribution of upper depth of Adigrat sandstone, unit：m(amsl)）

Figure 3.38: Landform and Geological Classification Map of Shaygosh Woreda

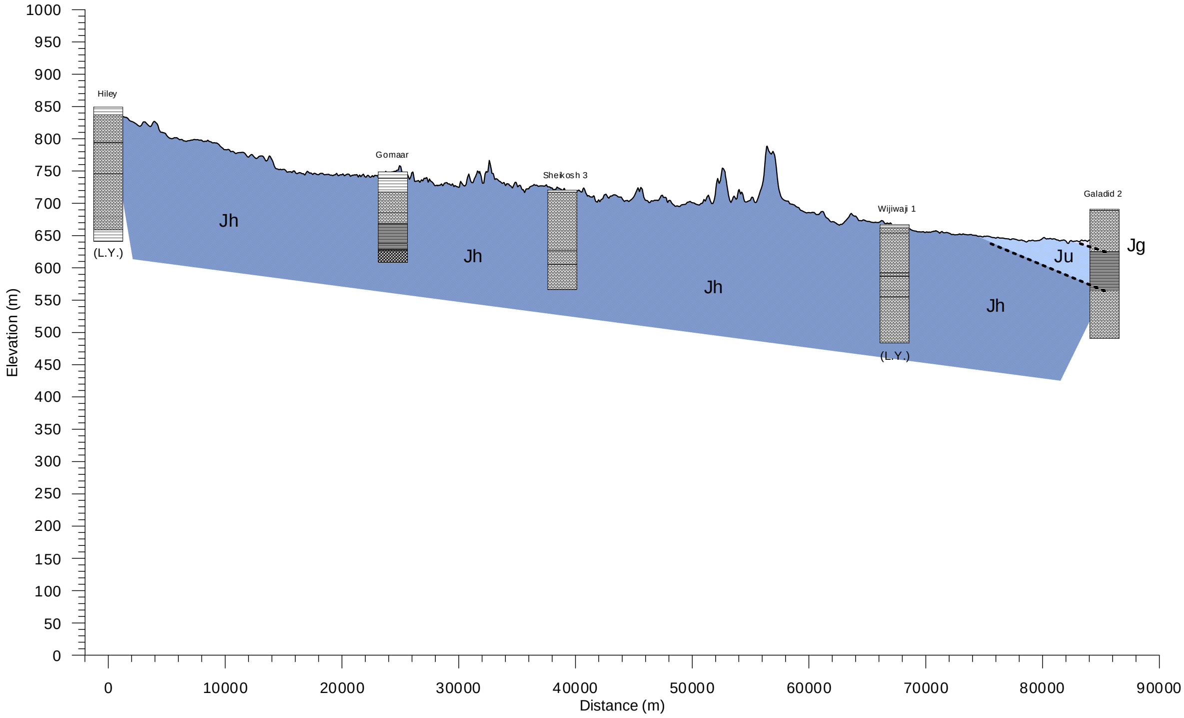


Figure 3.39: Landform and Schematic Geological Profile of Shaygosh Woreda (parallel to the river)

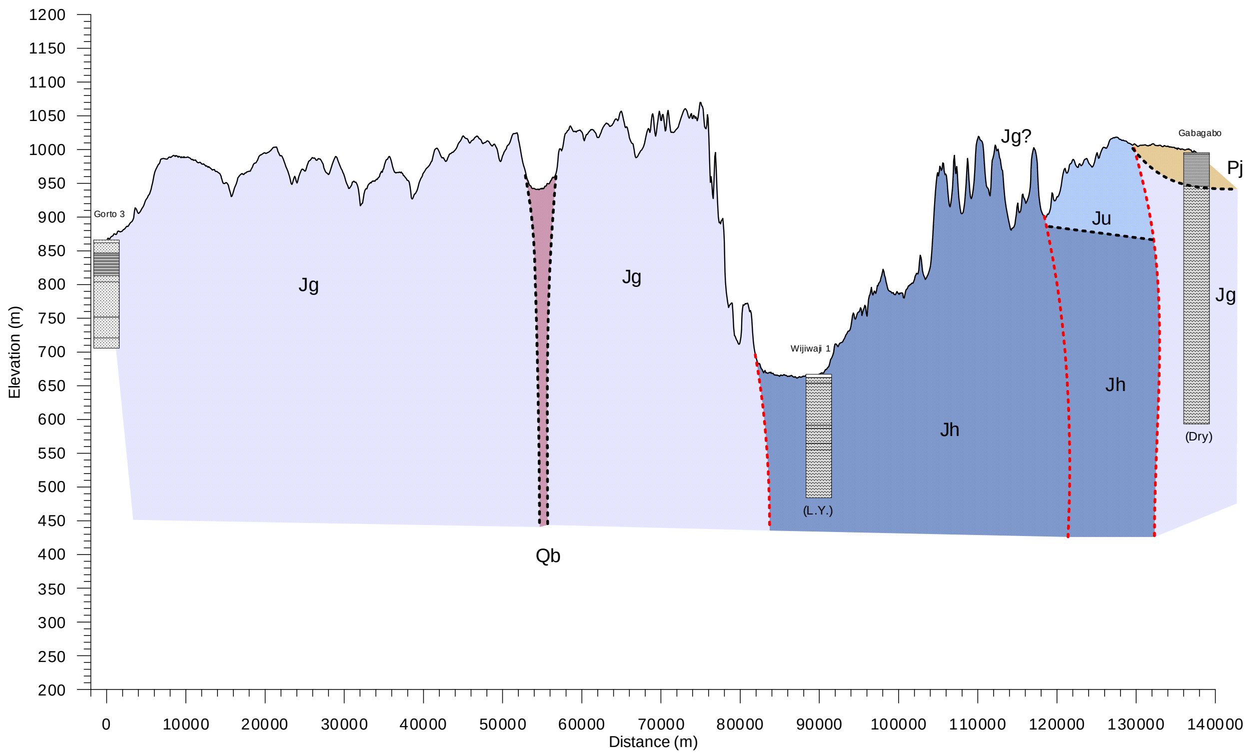
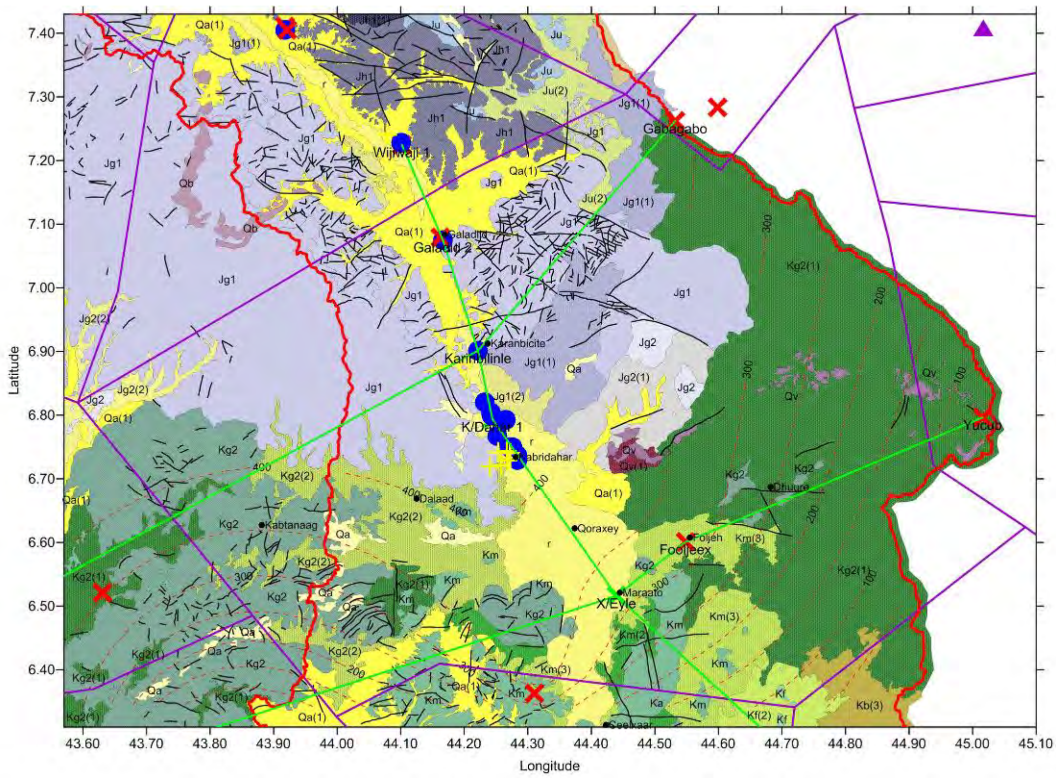


Figure 3.40: Landform and Preliminary Schematic Geological Profile of Shaygosh Woreda (across the river)

f. Kabridahar woreda

As landform and geological information of Kabridahar woreda, landform and geological classification map is shown in Figure 3.41, landform and geological profile is shown in Figure 3.42 to Figure 3.44.



(⋯ : Distribution of lower depth of Korahe Gypsum formation, unit : m(amsl))

Figure 3.41: Landform and Preliminary Geological Classification Map of Kabridahar Woreda

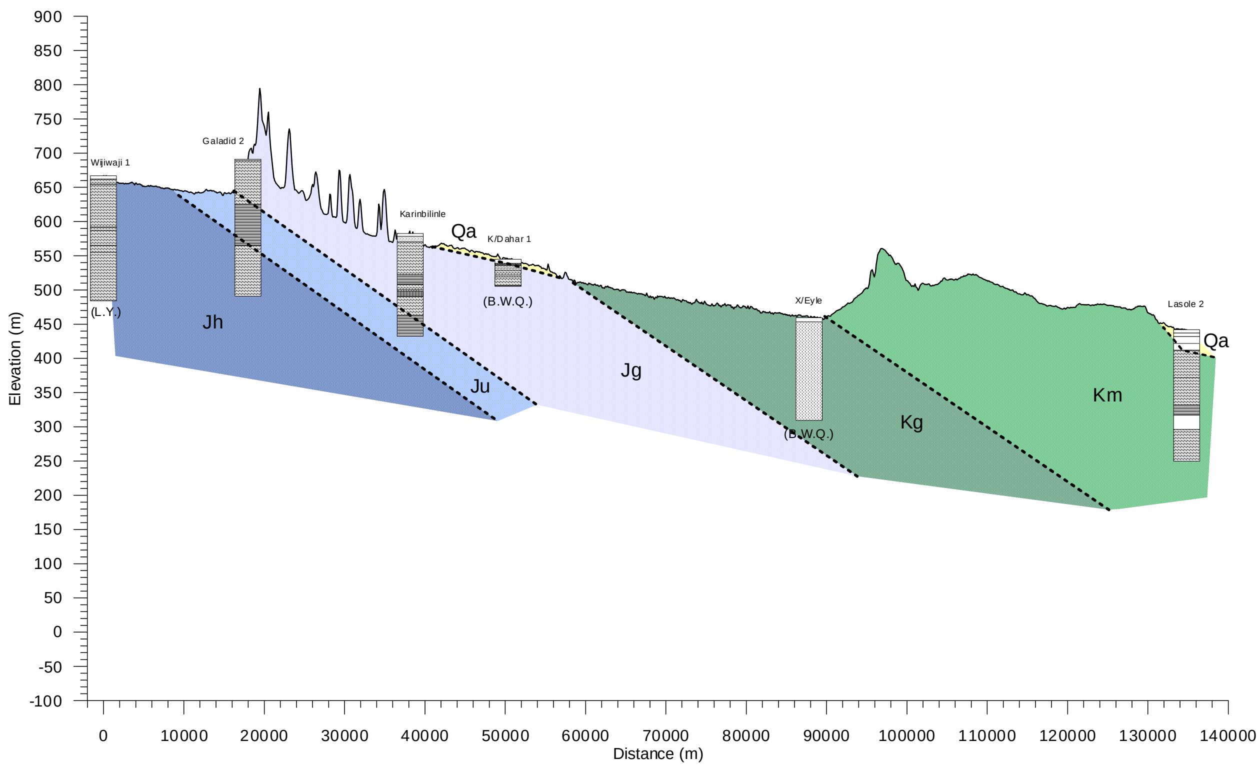


Figure 3.42: Landform and Schematic Geological Profile of Kabridahar Woreda (parallel to the river)

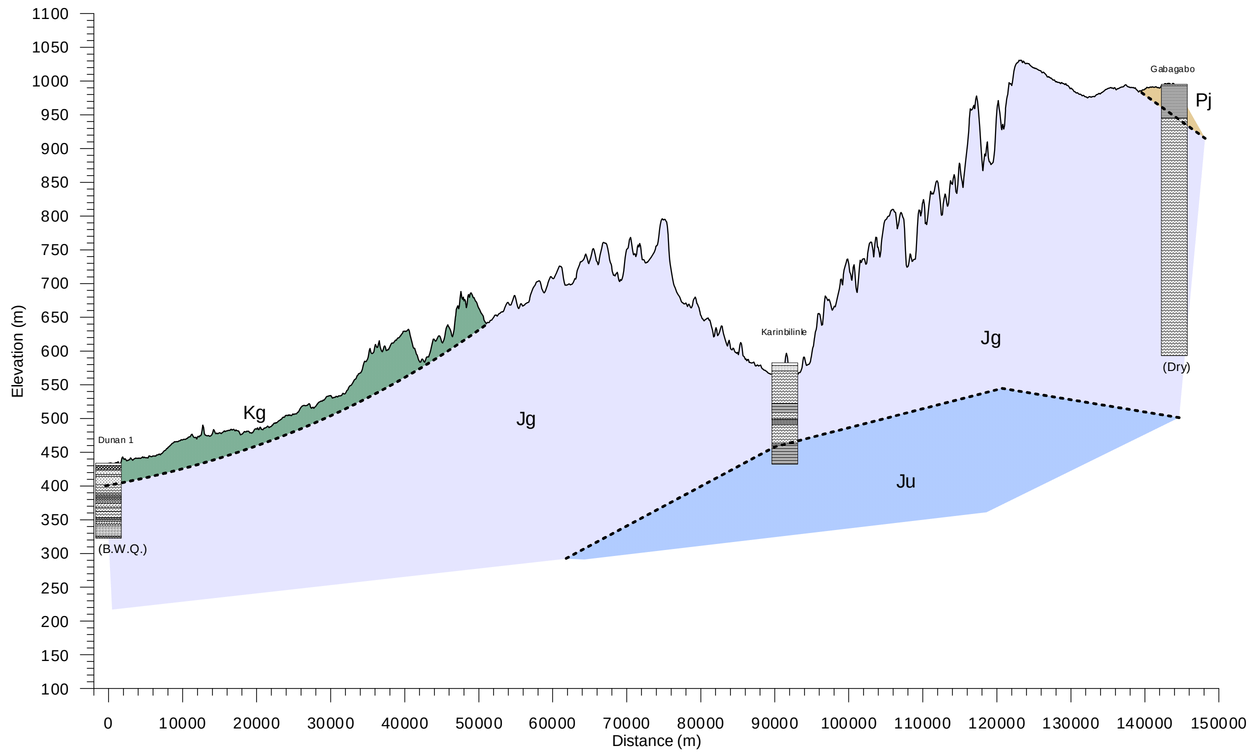


Figure 3.43: Landform and Geological Schematic Profile of Kabridahar Woreda (across the river - North)

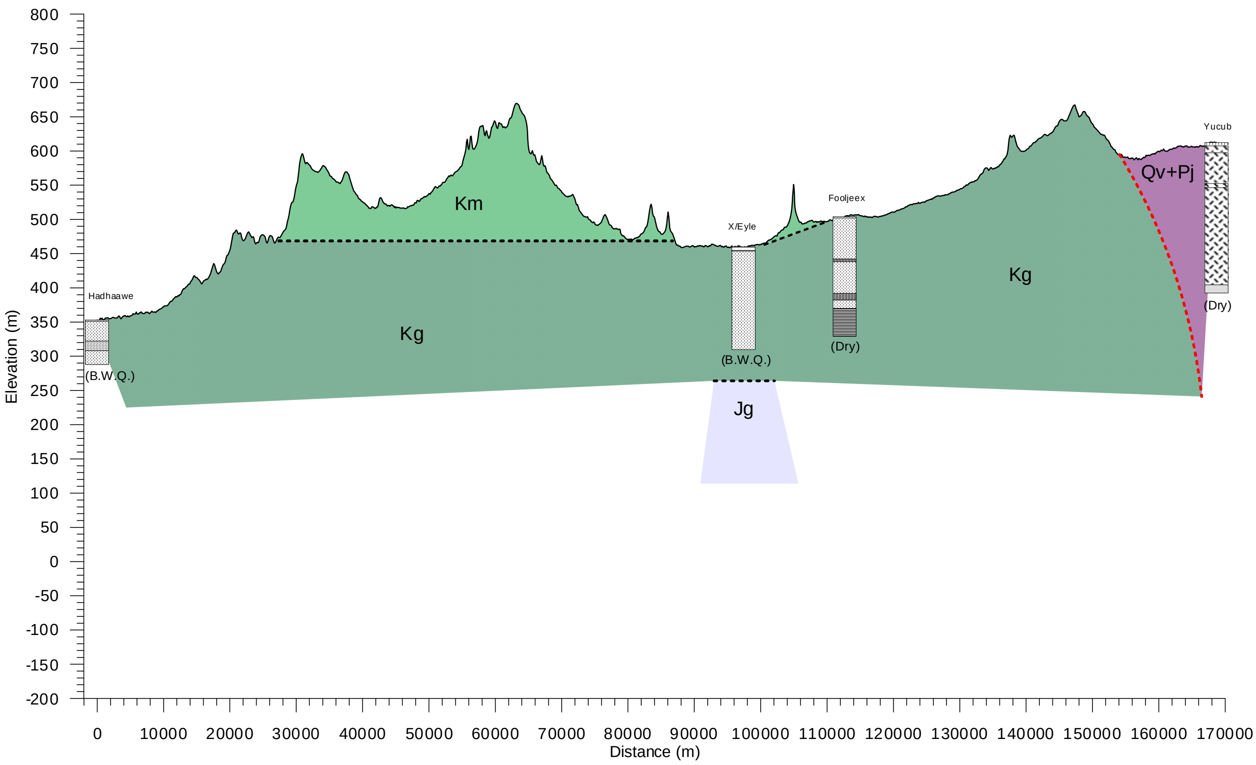


Figure 3.44: Landform and Schematic Geological Preliminary Profile of Kabridahar Woreda (across the river - South)

g. Doba wein woreda

As landform and geological information of Doba wein woreda, landform and geological classification map is shown in Figure 3.45, landform and geological profile is shown in Figure 3.46 and Figure 3.47.

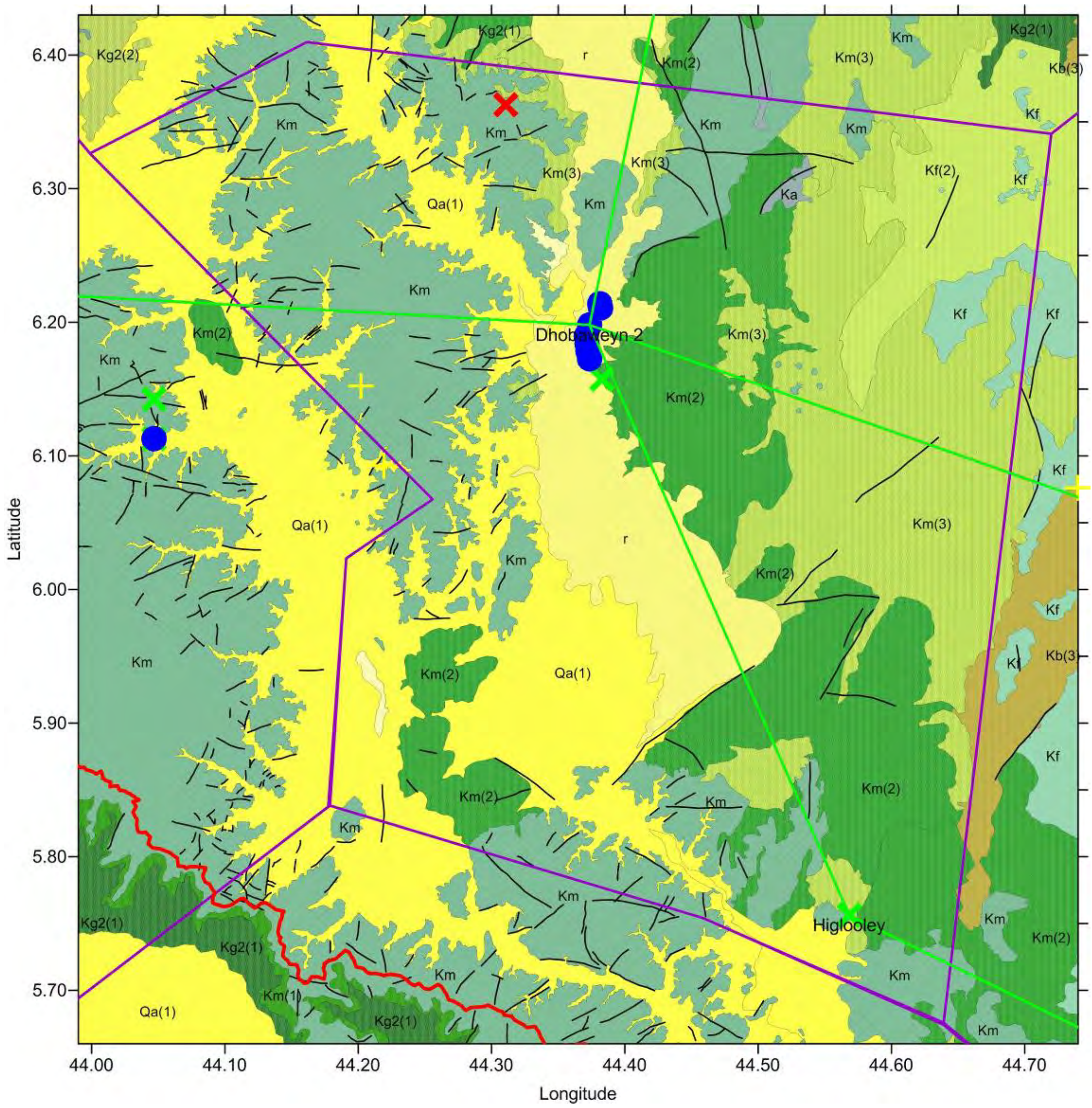


Figure 3.45: Landform and Geological Classification Map of Doba wein Woreda

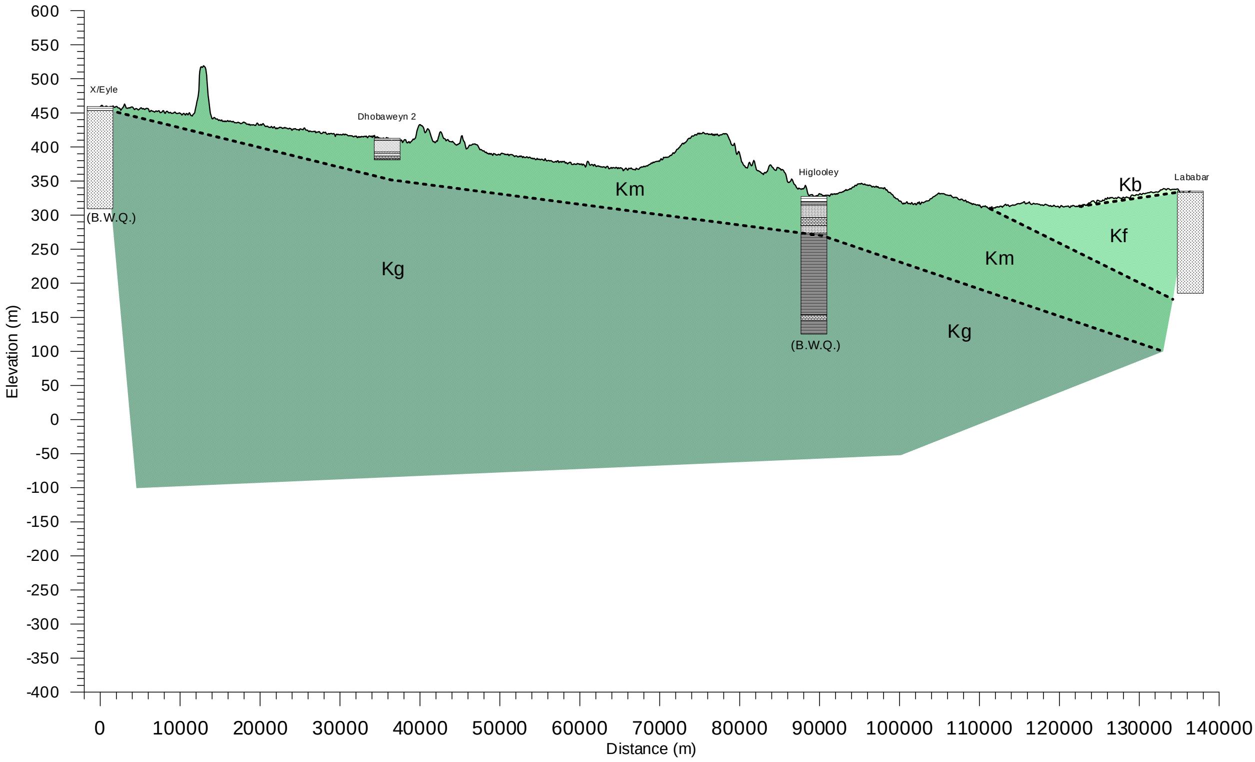


Figure 3.46: Landform and Schematic Geological Profile of Doba wein Woreda (parallel to the river)

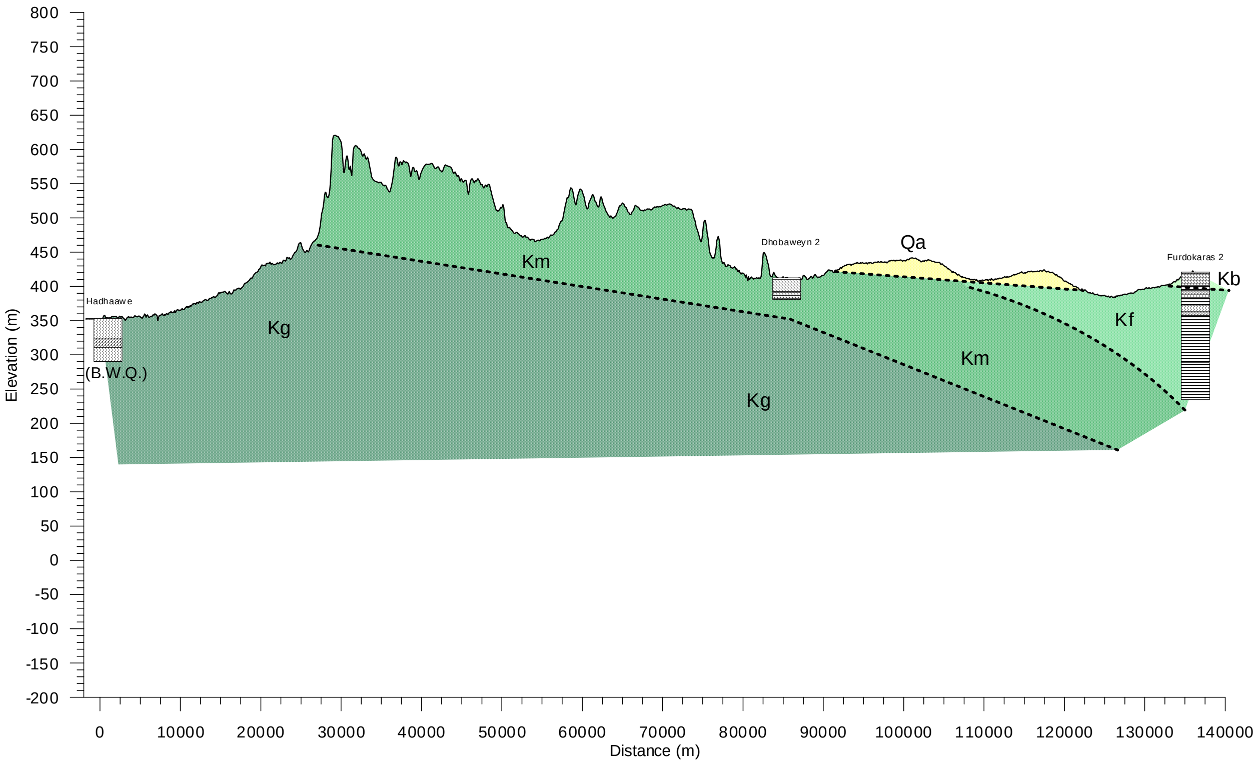


Figure 3.47: Landform and Schematic Geological Profile of Doba wein Woreda (across the river)

3.3.2 Shebele sub-basin

a. Rasso woreda

As landform and geological information of Rasso woreda, landform and geological classification map is shown in Figure 3.48.

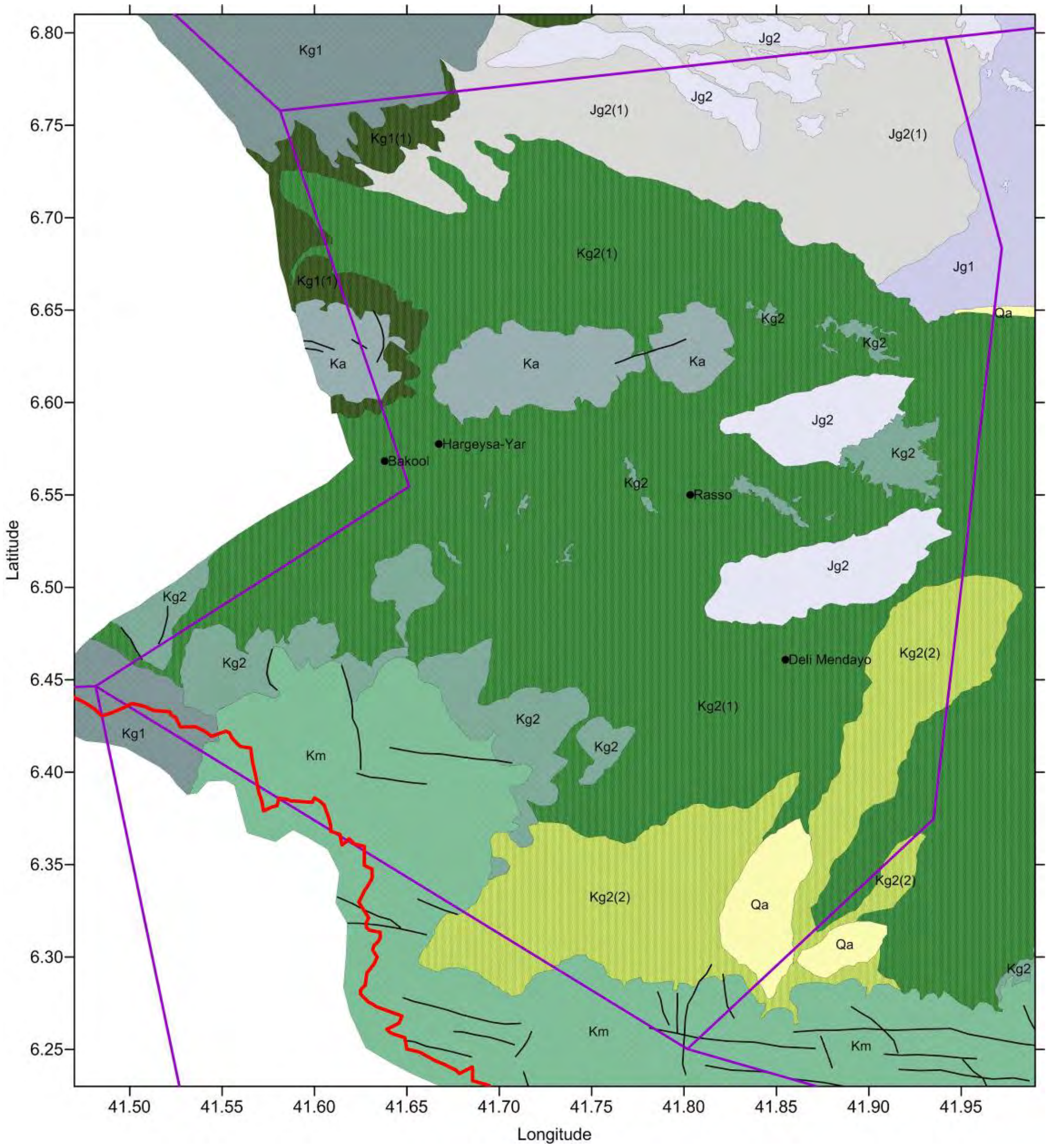


Figure 3.48: Landform and Geological Classification Map of Rasso Woreda

b. West Ime woreda

As landform and geological information of West Ime woreda, landform and geological classification map is shown in Figure 3.49.

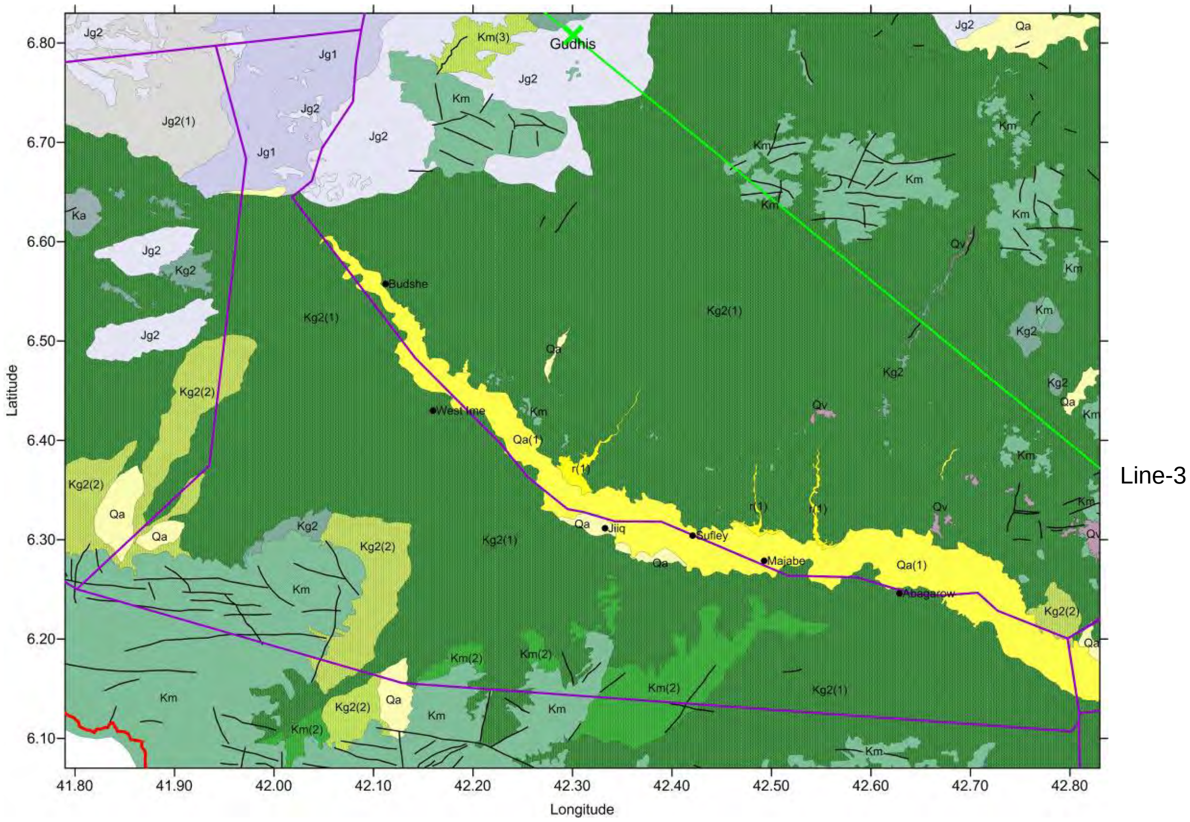


Figure 3.49: Landform and Geological Classification Map of West Ime Woreda

c. East Ime woreda

As landform and geological information of East Ime woreda, landform and geological classification map is shown in Figure 3.50.

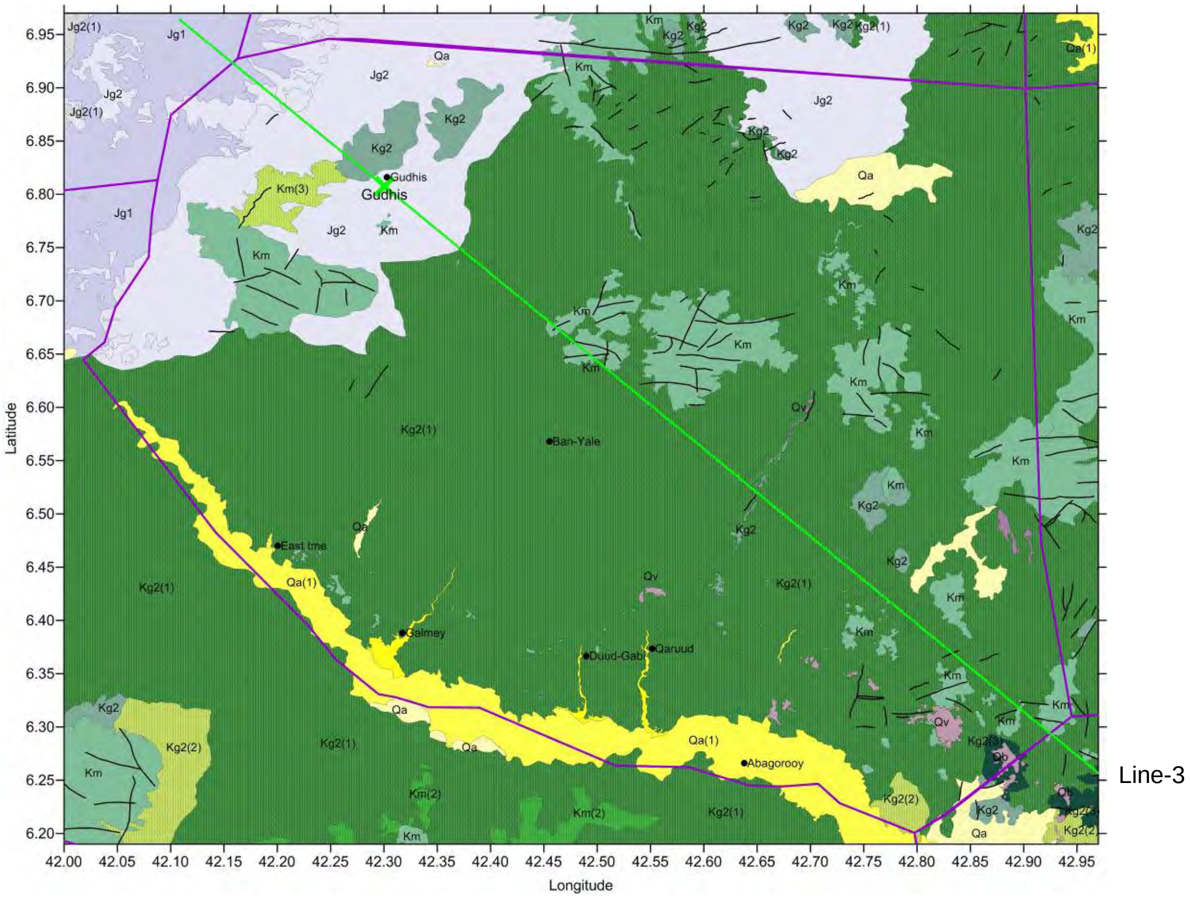


Figure 3.50: Landform and Geological Classification Map of East Ime Woreda

d. Adadle woreda

As landform and geological information of Adadle woreda, landform and geological classification map is shown in Figure 3.51.

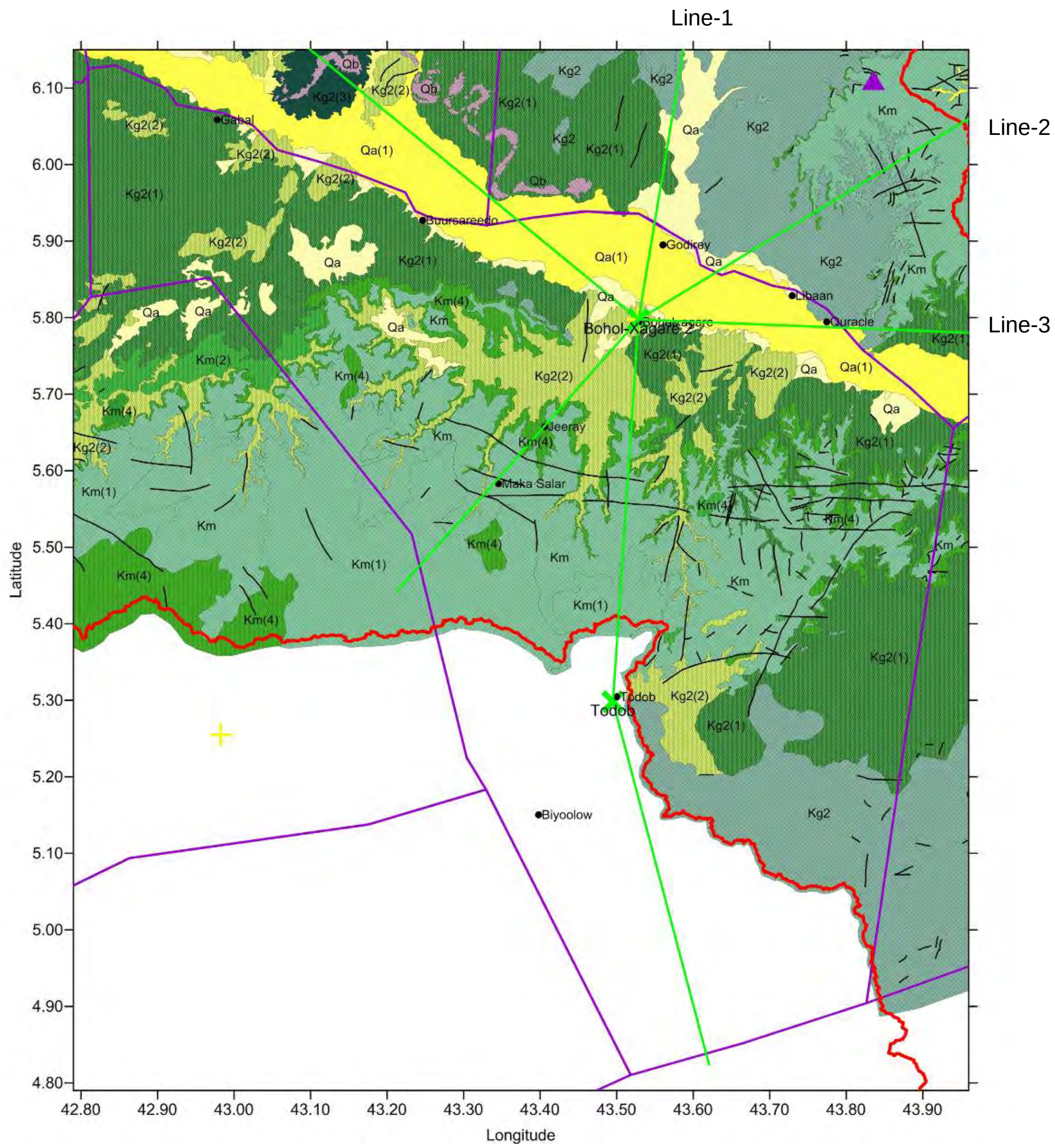


Figure 3.51: Landform and Geological Classification Map of Adadle Woreda

e. Danan woreda

As landform and geological information of Danan woreda, landform and geological classification map is shown in Figure 3.52.

Line-1

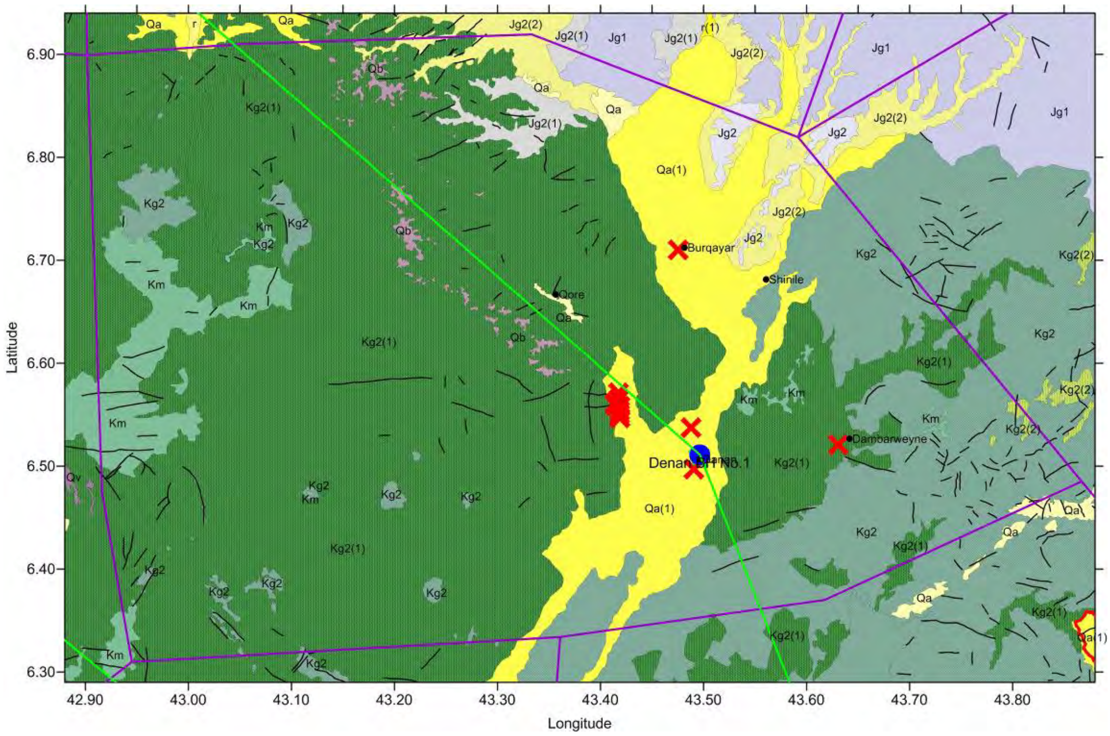


Figure 3.52: Landform and Geological Classification Map of Danan Woreda

f. Godey woreda

As landform and geological information of Godey woreda, landform and geological classification map is shown in Figure 3.53.

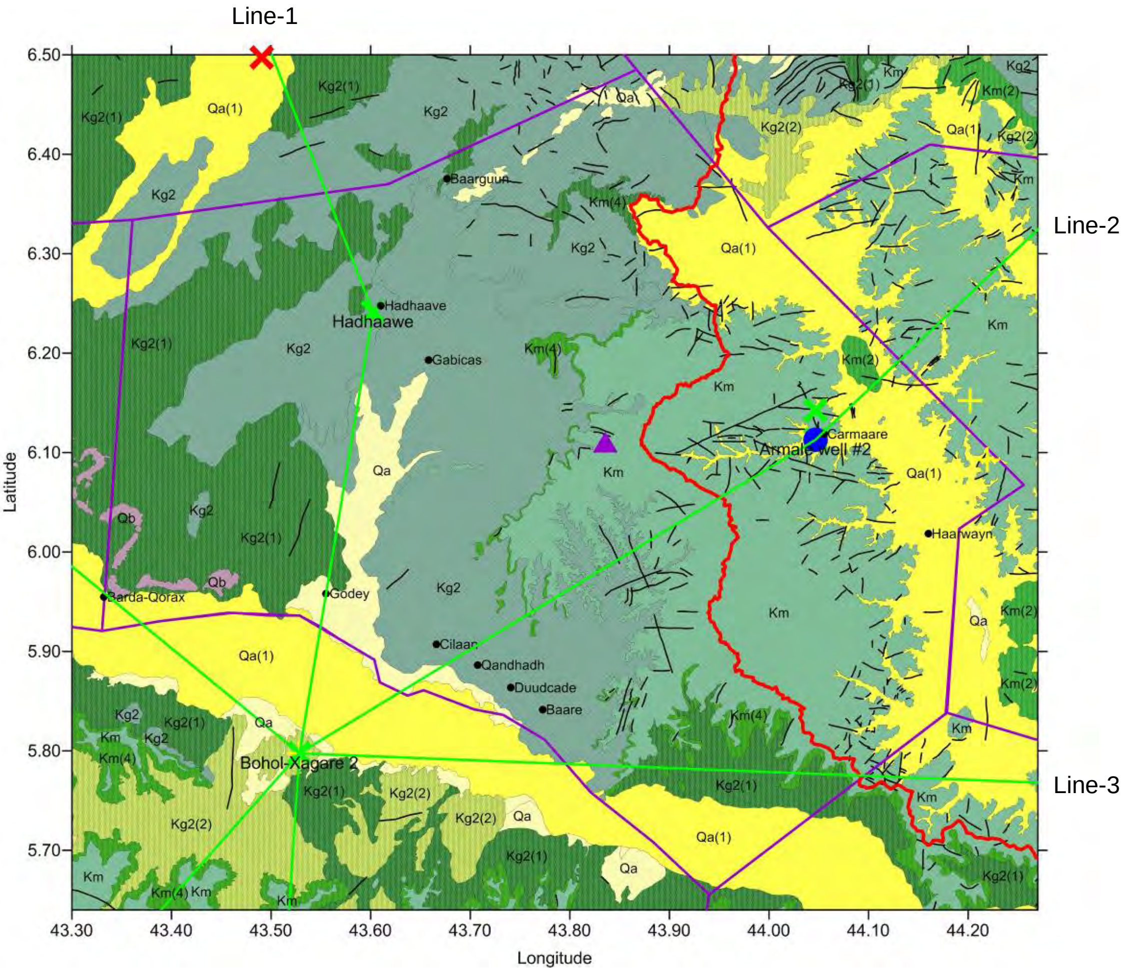


Figure 3.53: Landform and Geological Classification Map of Godey Woreda

g. Beercaano woreda

As landform and geological information of Beercaano woreda, landform and geological classification map is shown in Figure 3.54.

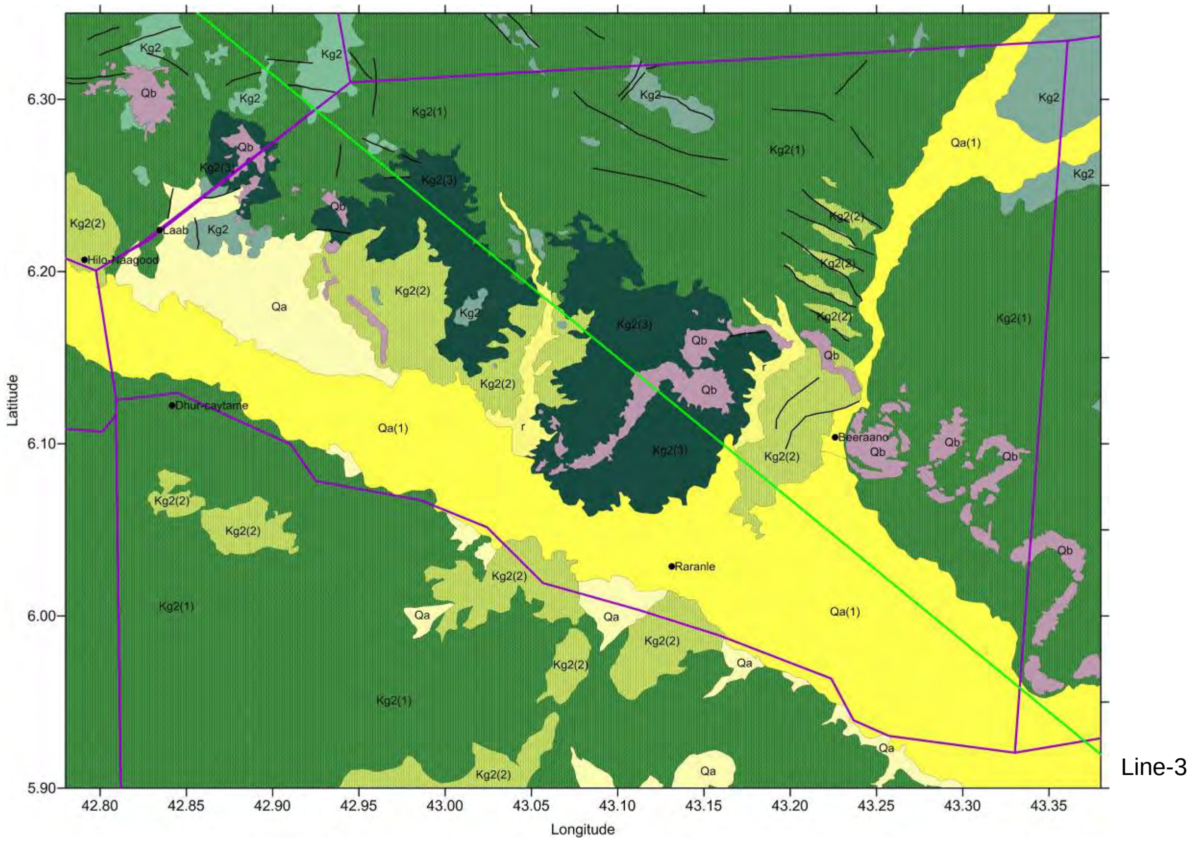


Figure 3.54: Landform and Geological Classification Map of Beercaano Woreda

h. Kalafo woreda

As landform and geological information of Kalafo woreda, landform and geological classification map is shown in Figure 3.55.

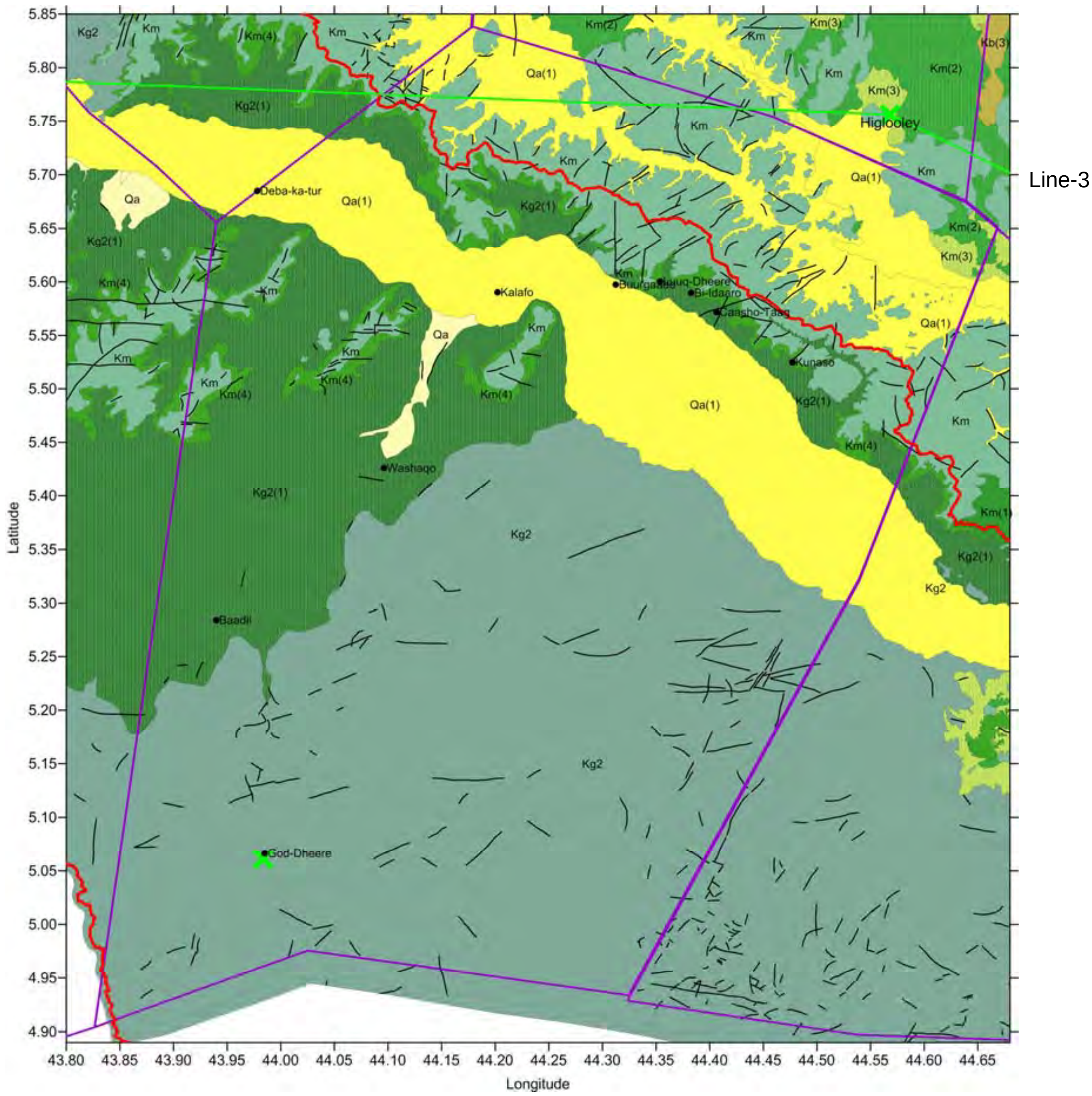


Figure 3.55: Landform and Geological Classification Map of Kalafo Woreda

i. Mustahil woreda

As landform and geological information of Mustahil woreda, landform and geological classification map is shown in Figure 3.56.

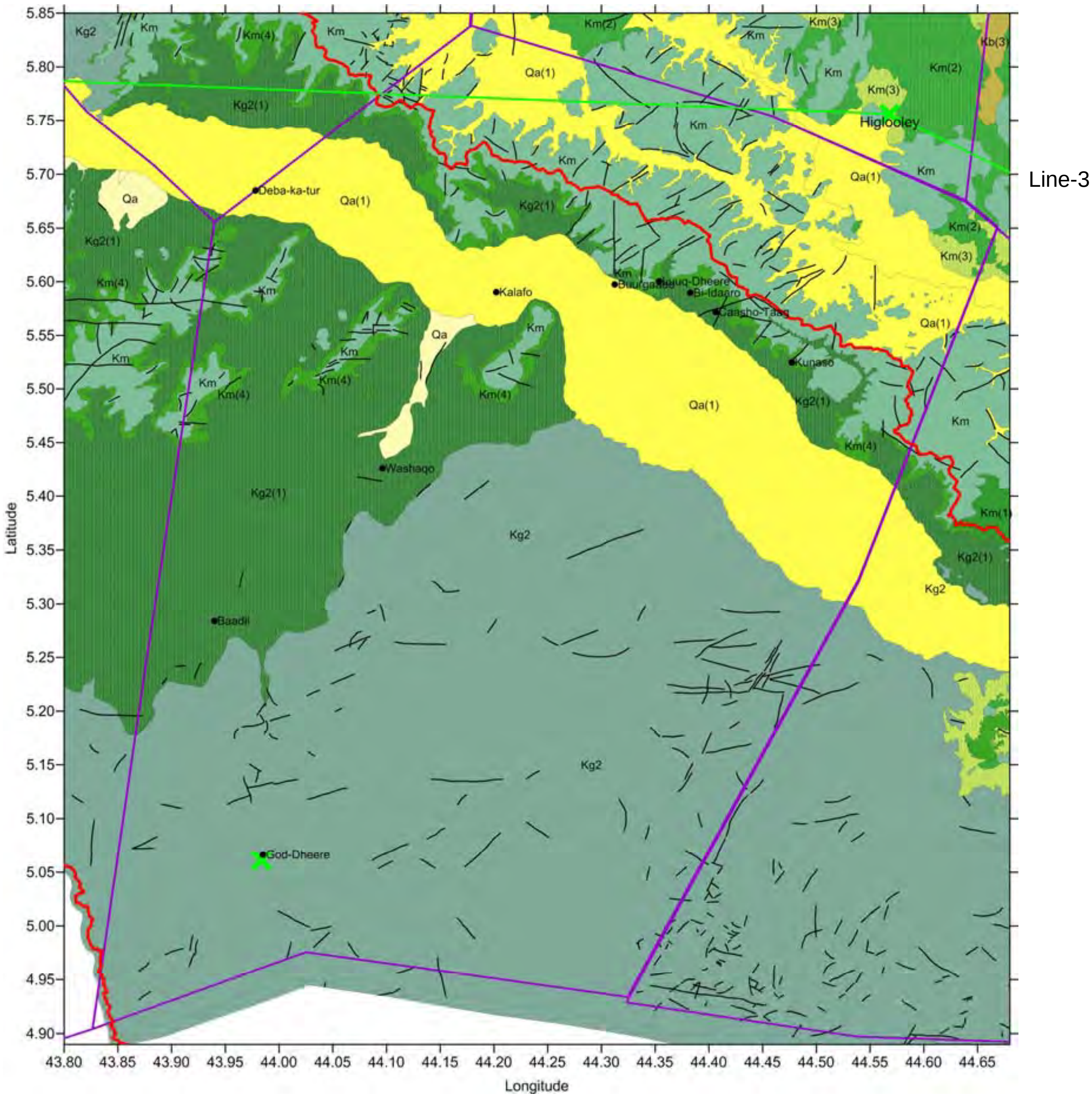


Figure 3.56: Landform and Geological Classification Map of Mustahil Woreda

j. Landform and geological profile

Landform and geological profile of three cross-sections are shown in Figure 3.57 in Shebele sub-basin is shown in Figure 3.58 to Figure 3.60.

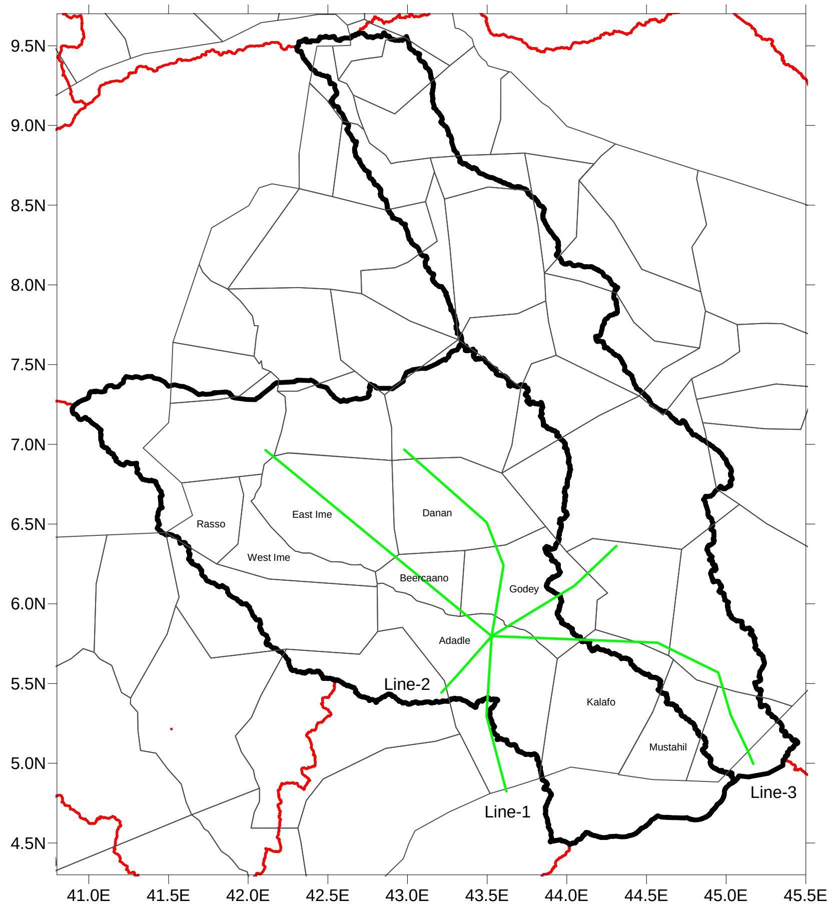


Figure 3.57: Location Map of Landform and Geological Profiles in Shebele Sub-Basin

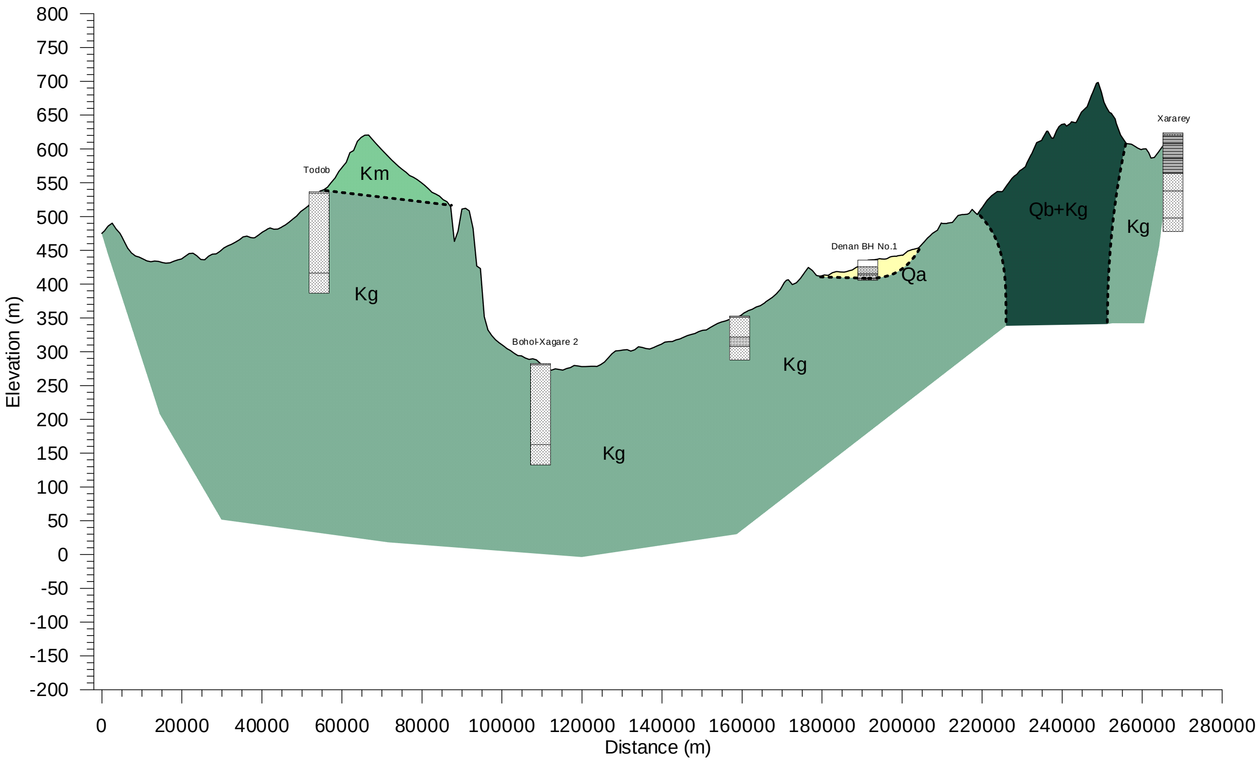


Figure 3.58: Landform and Schematic Geological Profile of Shebele sub-basin (line-1)

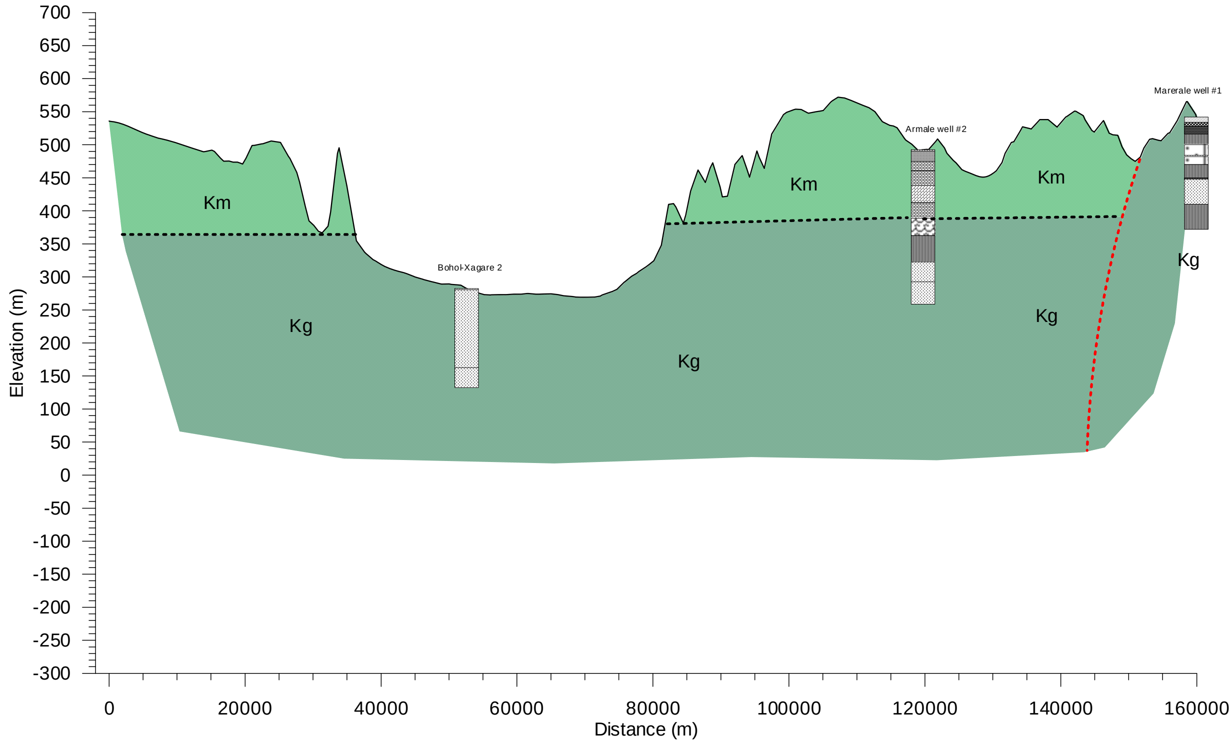


Figure 3.59: Landform and Schematic Geological Profile of Shebele sub-basin (line-2)

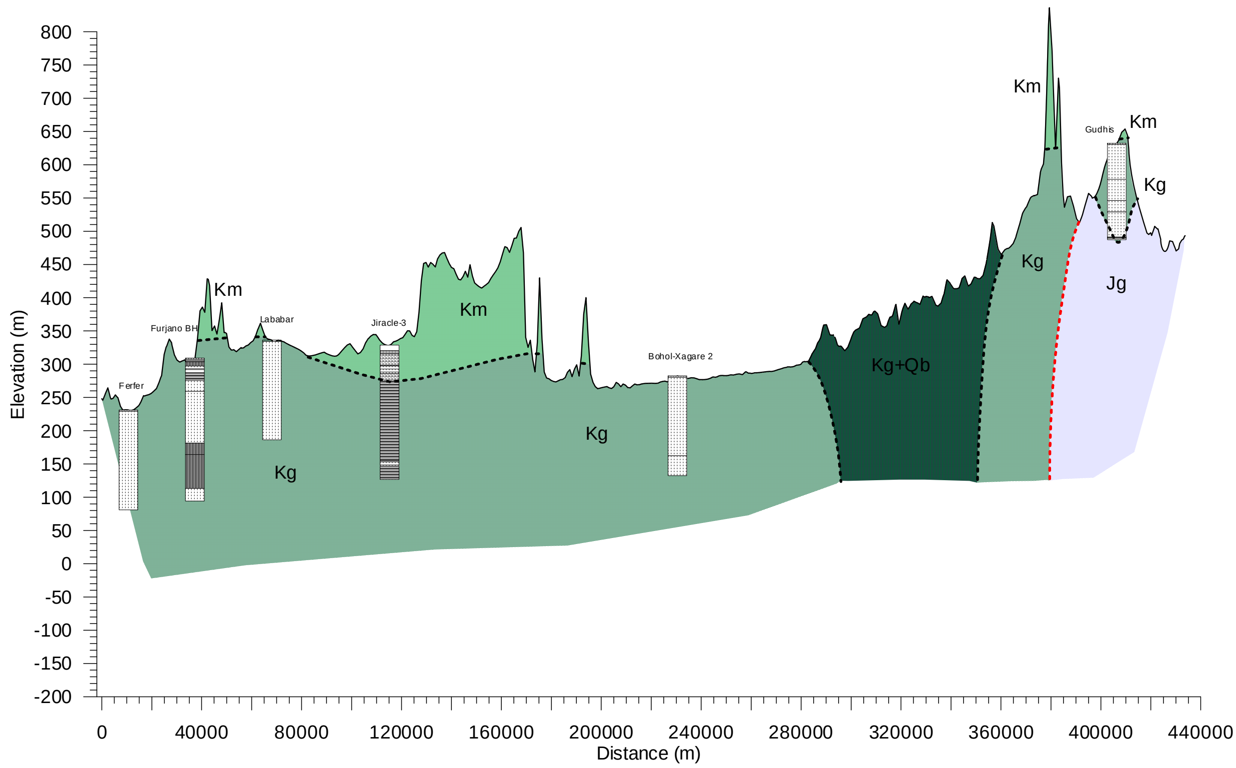


Figure 3.60: Landform and Schematic Geological Profile of Shebele sub-basin (line-3)

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Chapter 4

Hydrogeology

4 Hydrogeology

4.1 Hydrogeological data collection

4.1.1 Previous hydrogeological studies and mapping

According to Ministry of Agriculture (2012)[16], there are few hydrogeological studies conducted in Somali region. The available hydrogeological studies have been categorized in three parts and presented as Table 4.1 below.

Table 4.1: Major Examples of Hydrogeological Studies in Somali Region

i)	Hydrogeological studies conducted for water supplies of major towns and villages in the area
	Example • Water supply source verification of Jijiga, Warder and Filtu zonal administration towns; draft report, Water Mines and Energy Resources Development Bureau, Somali National State, 2002 [14] • Alternative water source investigation of 26 sites in Dhagahbur, Warder and Fik zones, SRS of Ethiopia, Final report, SHAAC Engineering Consulting plc, 2009 [6] • Hydrogeological investigation of 19 sites in Gode, Afder, Liban, Dhagahbur,Korahe, and Warder zones, SRS of Ethiopia, UNICEF, Final draft report, SHAAC Engineering Consulting plc, 2011 [8] • Site hydrogeological investigation, Jarar valley area, Final report, UNHCR, SHAAC Engineering Consulting plc, 2011 [9]
ii)	Various well completion reports
	Example • Final drilling report of Hadow boreholes; Drilling project well No-1, Water Works Construction Enterprise, Somali Regional State, 2007 [15] • Final drilling report of Fafan (Golo Ajo) boreholes; Drilling report of Well No-1 and No-2; Water Works Construction Enterprise, Somali Regional State, 2007 [16] • Fafan integrated development project, Water resources development subproject; Well completion report final of 4 boreholes in Kobijara, Hillini Water Well Drilling Company plc, 2011 [3]
iii)	Regional hydrogeological study
	Example • Wabi Shebelle river basin integrated master plan, Volume VII Water resources, Part 3 Hydrogeology, WWDSE, 2004 [9] • Hydrogeological mapping project report, UNICEF, SHAAC Engineering Consulting plc, 2009 [18]

As for published regional hydrogeological map, there is only hydrogeological map of the whole of Ethiopia as follows.

- Hydrogeological map of Ethiopia (1:2,000,000) compiled by Tesfaye Chernet and the Regional Geology Department, Ethiopian Institute of Geological Survey, 1988 [13]

4.1.2 Existing well data

The collected existing well data are i) Well inventories managed by Somali Regional Water Development Bureau (SRWDB), ii) Well records mentioned in existing reports and iii) Well drilling records including well columnar section.

Well inventories managed by SRWDB:

- Data from Somali Region Water Supply Inventory Database, 2002
- Borehole (BH, SW) List 1 (unknown creation date)
- Borehole (BH, SW) List 2 (unknown creation date)
- Water Source (BH, SW, Spring) List (unknown creation date)
- Water Table List (unknown creation date)

Well records mentioned in existing reports:

- Scheme Assessment Mapping Project Final Report (SHAAC, 2008) [5)]
- Hydrogeological Mapping Project Report (SHAAC, 2009) [7)]
- Other study report

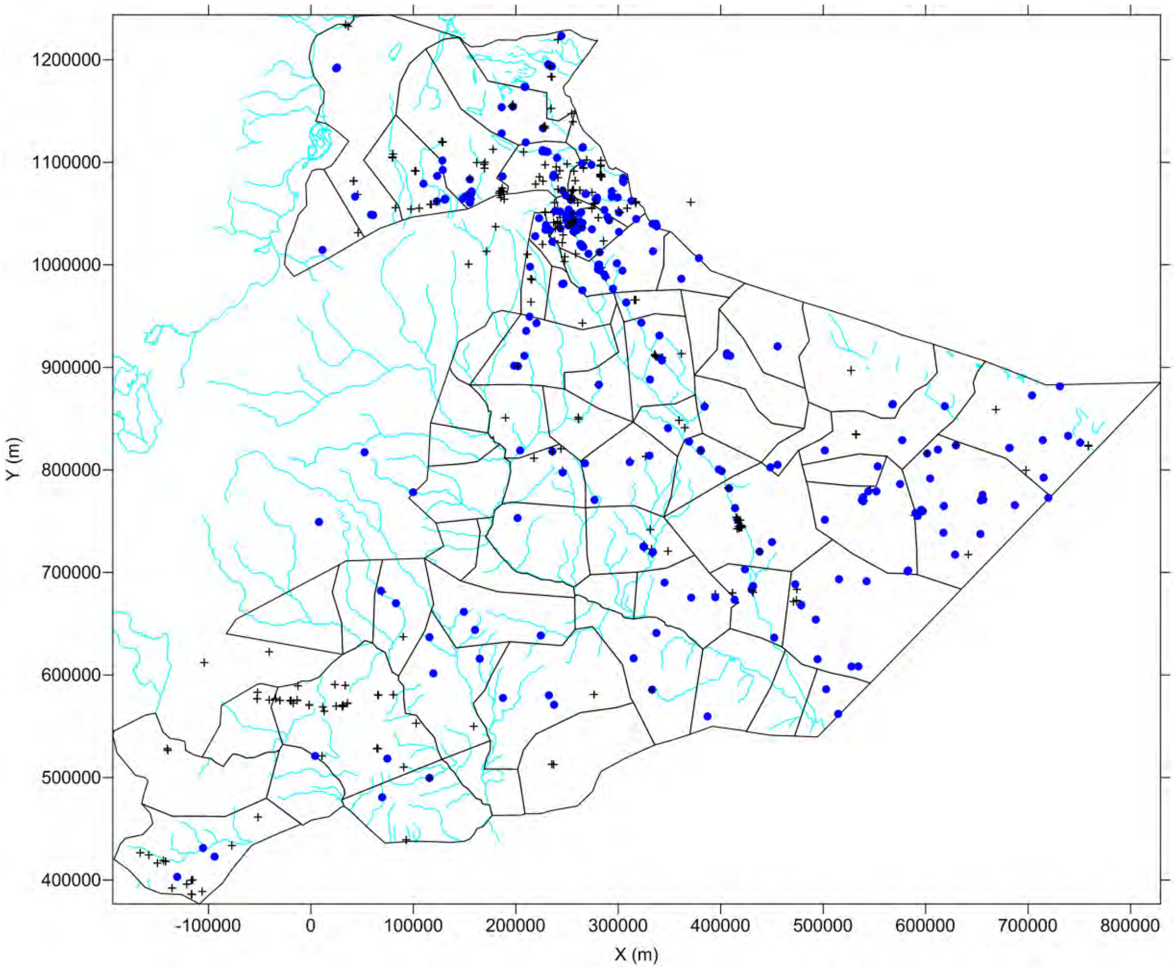
Well drilling records including well columnar section:

- Well records managed by UNHCR
- Well records managed local consultants
- Well records managed by organs concerned

An example of the well inventory prepared based on the analysis and compilation of the data above is shown in Chapter 6 of this volume or Data Book (for the target woredas in Jarar Valley area). This well inventory contains the following items.

- Temporary well name
- Location data (zone, woreda, coordination, elevation)
- Well type (BH, SW, other)
- Well depth
- Static water level
- Dynamic water level
- Yield
- Construction date
- Well owner
- Well columnar section (with or without)

As for wells for which the well columnar section information was obtained (refer to Figure 4.1), new well columnar sections were created and presented in the Data Book. Though the description of lithofacies follows the original data's recording, extrapolated formation name was added based on the feature of lithofacies, upper and lower layers, and drilling position.



(●: Wells with columnar section, +: Wells without columnar section)

Figure 4.1: Location of Constructed Wells with and without Columnar Section

4.1.3 Spring data

Only nine springs were recognized as water source (scheme) in Somali region, as shown in Table 4.2 below, though it is not recent data (arranged by SRWDB in 2003).

Table 4.2: Spring Information in Somali Region

Zone	Woreda	Site Name	Status (2003)
Afder	Elkare	Shakisa	Functional
Shinile	Afdem	Biyo kulul	Functional
Shinile	Erer	Magala-Add	Functional
Shinile	Erer	Halisho	Functional
Shinile	Erer	Bila	Functional
Shinile	Erer	Gota	Functional
Shinile	Erer	Garmaam	Non-functional
Shinile	Erer	Erer town 2	Functional
Shinile	Shinile	Adigala	Functional

4.2 Potential of groundwater

4.2.1 Classification and characteristics of aquifer units

Based on existing reports, the aquifer units and the feature of each aquifer are arranged as shown in Table 4.3.

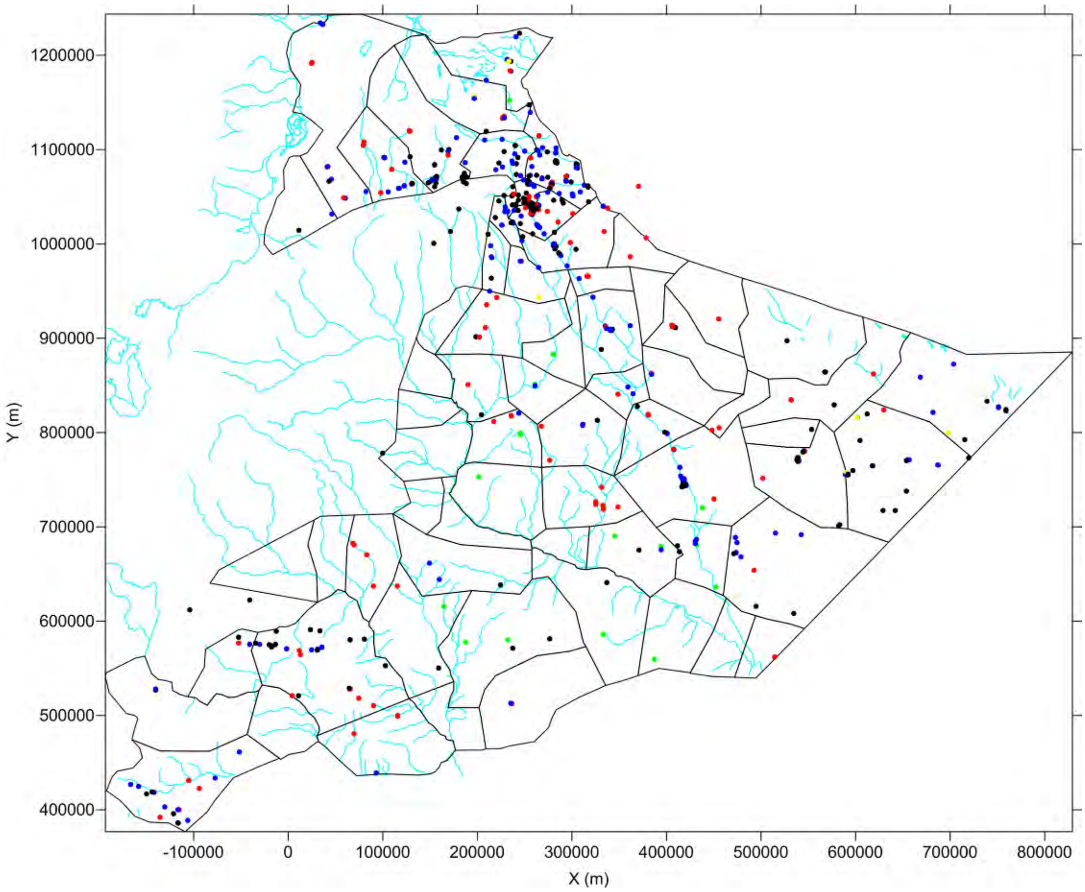
Table 4.3: Classification and Characteristics of Aquifer Units

Age	Aquifer Name	Symbol	Hydrogeological Characteristics
Quaternary	Quaternary	Qa, r (fluvial deposit)	• Alluvial deposit in the dry stream courses yields water for domestic use[7]. • The alluvial deposits can yield good quality and quantity of water that can be used both for domestic and livestock[7]. • Most hand-dug wells are located within this aquifer[7].
Quaternary-Tertiary	Basalt	Qb, Qv	• The upper part is found to be highly weathered; however the lower part is less weathered and fresh. • The weathered and fissured parts could be a good aquifer.
Tertiary	Karkar	Ek	• This aquifer is composed of limestone, marly limestone and clay[1]. • According to AQUATECH (1999)[1], the well at Galadi represents the hydrogeology of this aquifer. The presence of marls and clays at shallow depth render the possibility of harnessing low yielding perched aquifers in locally depressed areas of the proluvium and carbonates
	Talah	Et	• This aquifer is of alternating anhydrite, gypsum, and shale, with some thin interbeds of dolomite[2]. • Gypsum does not occur everywhere in the sequence, and several boreholes yield potable water[2].
Tertiary - Cretaceous	Auradu	Ea	• This aquifer consists of grey to white, hard and massive limestone which is often unbedded[7]. • This maintains a fair lithological uniformity throughout the eastern Warder zone. It is widely exposed in Galadi and Bokh area[7]. • The infiltration occurs along the faults and fractures[7].
Cretaceous (Tertiary?)	Jessoma	Pj	• This aquifer consists of gray and variegated sandstone with intercalations of variegated shale and lateritic horizons. The available data suggests that the grain size and the thickness progressively increase from west to east[7]. • The lithological properties of this aquifer tend to suggest that the water bearing characteristic of the sandstone could be very considerable in space both vertically and horizontally[7]. • In the eastern part of the region especially in Danot area, due to the absence of retaining layer at shallow depth, whatever recharge available for the aquifer tends to percolate to greater depth until retained by the underlying impervious limestone or clay horizons of the Upper Cetaceous Formations[7].
Cretaceous	Beletwein	Kb	• This aquifer is composed of massive limestone with intercalation of shale and brown sandstone[10]. • Boreholes drilled into the aquifer have met water of relatively fresh quality in the lower part of the succession but deteriorates in the upward sections[10].
	Ferfer	Kf	• This aquifer is made up of alternation of dolomite, marl and anhydride[10]. • Karstic features are not uncommon in places such as south of Shilabo village[10]. • The aquifer acts as an aquiclude or as a saline aquifer[10].
	Mustahil	Km	• Limestone interbeded with shale and marl is characteristic for the lower part whereas in the upper part reef limestone predominates[10]. • Many dug wells are known to exploit perched aquifers, especially around Kelafo and within Fafan valley towards Kabridahar[10]. • From lithological and some indirect permeability considerations, this aquifer presents hydraulic

			characteristics suitable for substantial exploitation of groundwater[1).] • Nevertheless, the fact that the aquifer is sandwiched between two evaporitic sequences; namely, Korahe and Ferfer aquifers, there could be some doubt as to the chemical suitability of groundwater within this aquifer[1)].
Cretaceous - Jurassic	Korahe	Kg	• The lower part is represented by alternation of dolomitic limestone, marl, shale and anhydride[7)]. • Fresh groundwater exploitation through tube wells is impossible due to the bad quality of the groundwater[7)]. • Therefore, any borehole drilled in such areas should be drilled until the under laying limestone formation is reached so as to obtain fresh water[7)]. • Most of the boreholes drilled in this aquifer especially in Afder and Godey zones are abandoned due to high salinity content[7)].
	Amba Aradam	Ka	• This aquifer consists of well washed, porous and friable sandstone[2)]. • Previous studies in Ogaden basin classified this unit as a poor aquifer (e.g. EIGS (1999)[11) in 12)].
Jurassic	Kabridahar	Jg	• It is a thick succession of limestone beds inter bedded with marl, shale and thin layer of gypsum that covers a large area of the study area[7)]. • This aquifer with near horizontal beds of limestone generally has very low primary porosity and permeability that are insignificant for groundwater conduit occurrence[7)]. • Secondary permeability due to fractures and solution openings along bedding planes is more important for groundwater occurrence and movement[7)]. • Water that enters along fractures causes dissolution in fracture zones that result in higher hydraulic conductivity than the un-fractured rocks, which create higher possibility for groundwater occurrence[7)]. • Vertical movement of groundwater in fracture zones can also result in solution openings along bedding planes for lateral movement of groundwater in the formation[7)].
	Urandab	Ju	• The aquifer conformably overlies the Hamanlei aquifer and is composed of well-bedded, fine-grained shaly limestone with alternating marl, gypsiferous clays and massive gypsum[7)]. • Boreholes drilled in this aquifer mostly were abandoned because of being dry. The lack of groundwater in this aquifer is due to presence of shale and this prevents vertical and lateral recharge[7)].
	Hamanlei	Jh	• The rocks in this aquifer are predominantly limestone and dolomite having gradational contact with the Adigrat aquifer and with the overlaying Urandab aquifer. It is divided into 5 units[7)]. • Abundant fresh water has been met in many boreholes in outcrop areas[7)].
Jurassic - Triassic (?)	Adigrat	Ja	• It is represented by medium to coarse grain, red to brown sandstone with some shale and laterite bands[18)]. • It is generally categorized as a unit with medium to high permeability and high infiltration capacity[3)].
Precambrian	Basement Rocks	PC	• High grade metamorphic rocks (Granite, migmatite, etc.). • Poor aquifer[2)]. Water yields only in fractures or weathered zones.

4.2.2 Review of aquifer potential

The features of the aquifer units in Somali region based on well records (well inventory, well columnar section, etc.) are shown in Figure 4.2 to Figure 4.45.



(●: Success, ●: Dry and low yield, ●: Bad water quality, ●: Failure of construction, ●: Insufficient information)

Figure 4.2: Borehole Status

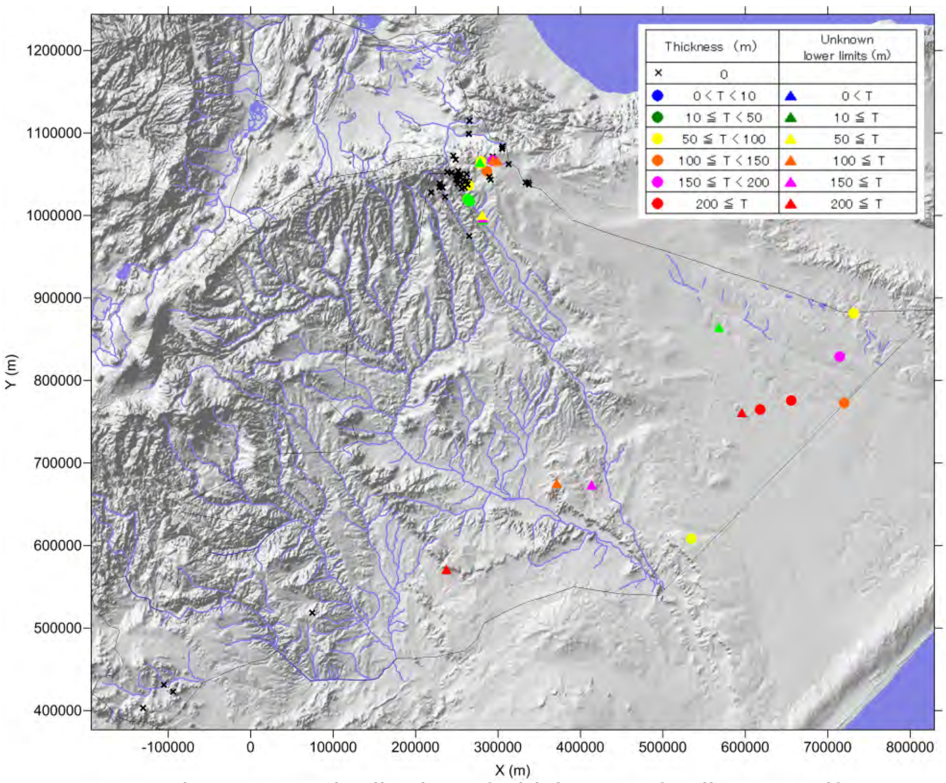


Figure 4.3: Distribution of Thickness of Adigrat Aquifer

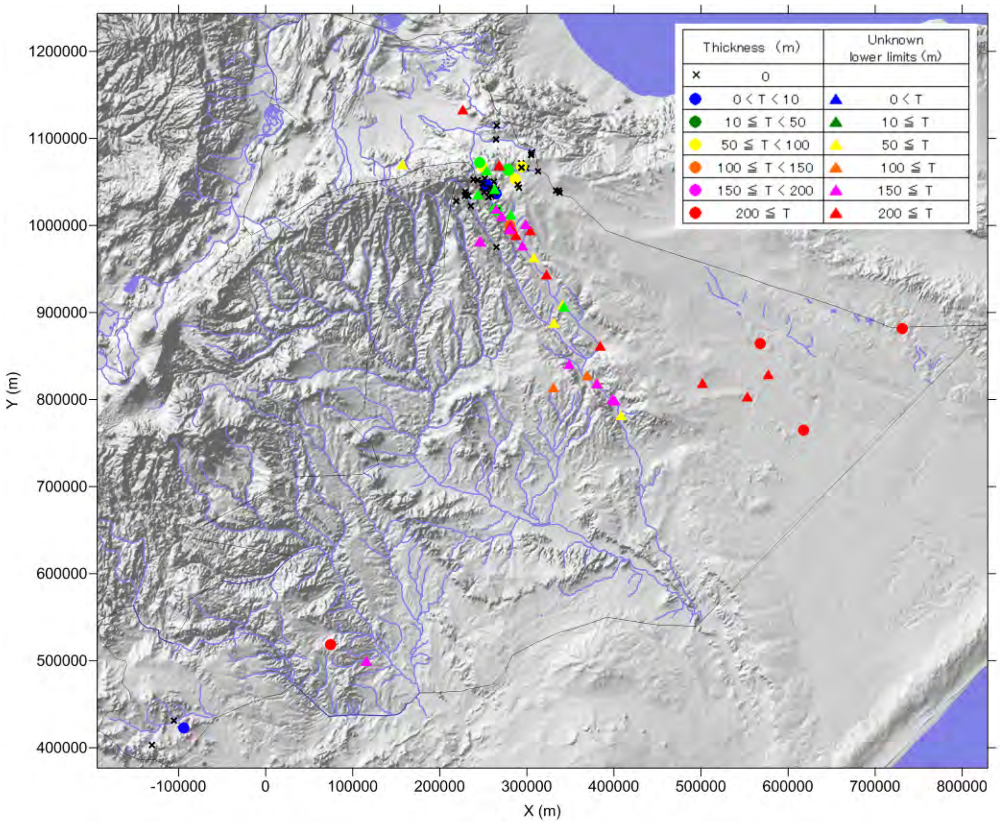


Figure 4.4: Distribution of Thickness of Hamanlei Aquifer

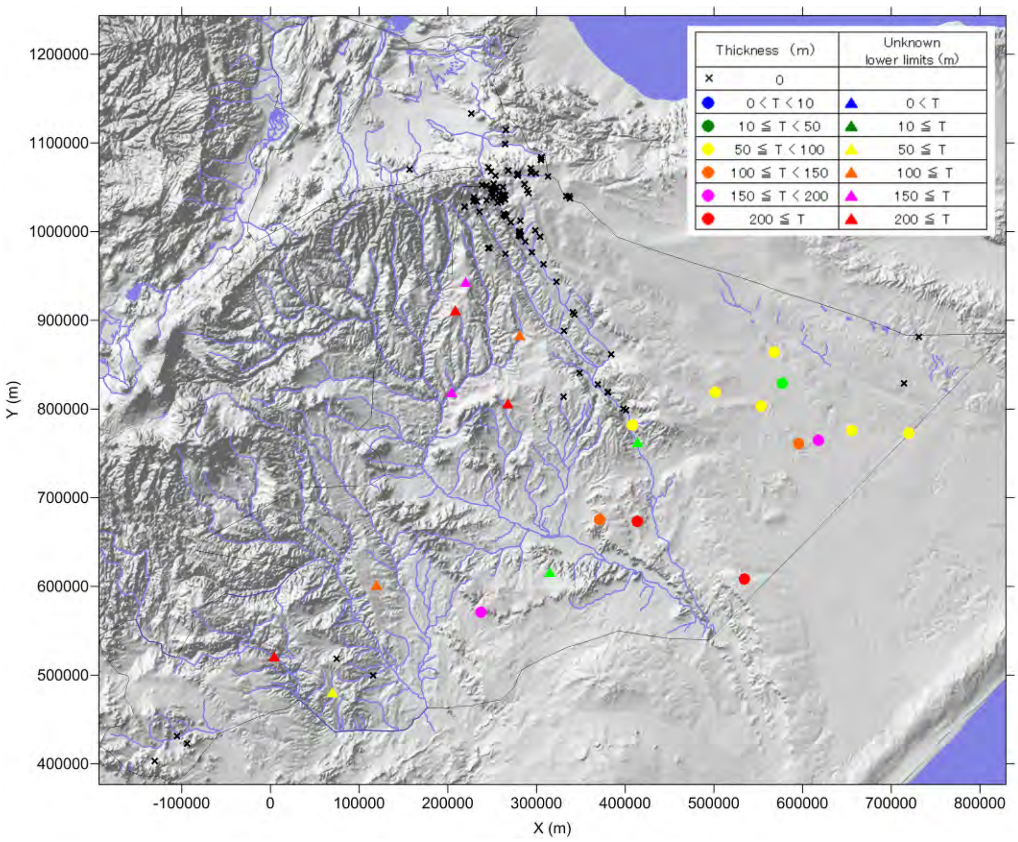


Figure 4.5: Distribution of Thickness of Urandab Aquifer

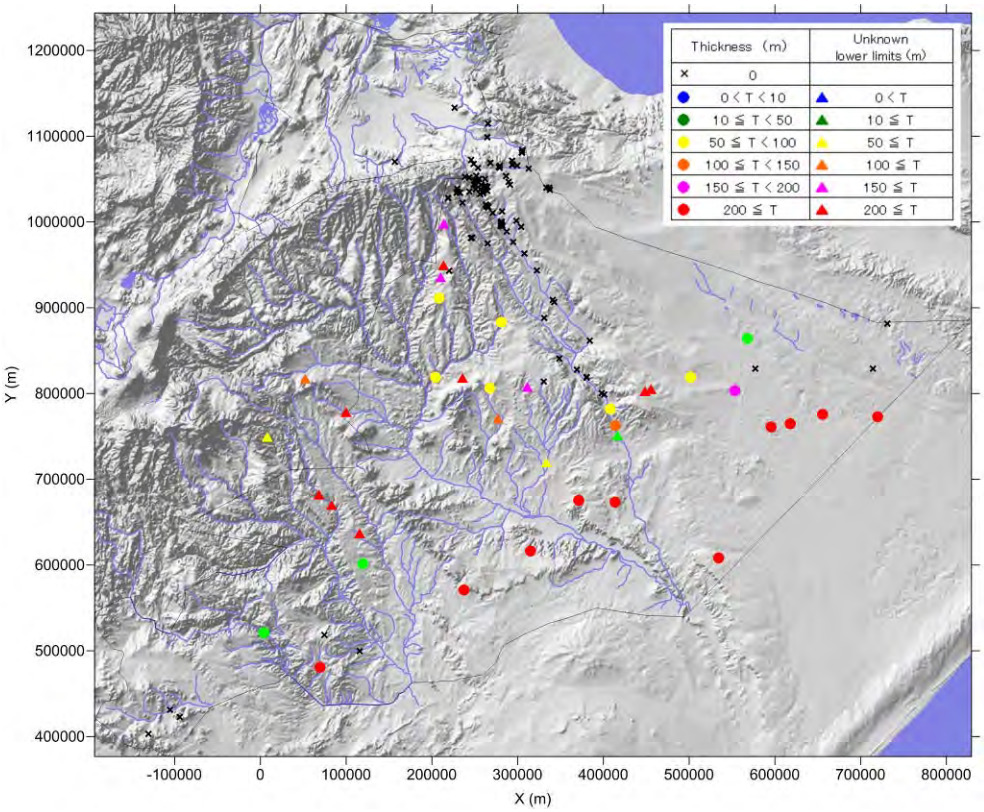


Figure 4.6: Distribution of Thickness of Kabridahar Aquifer

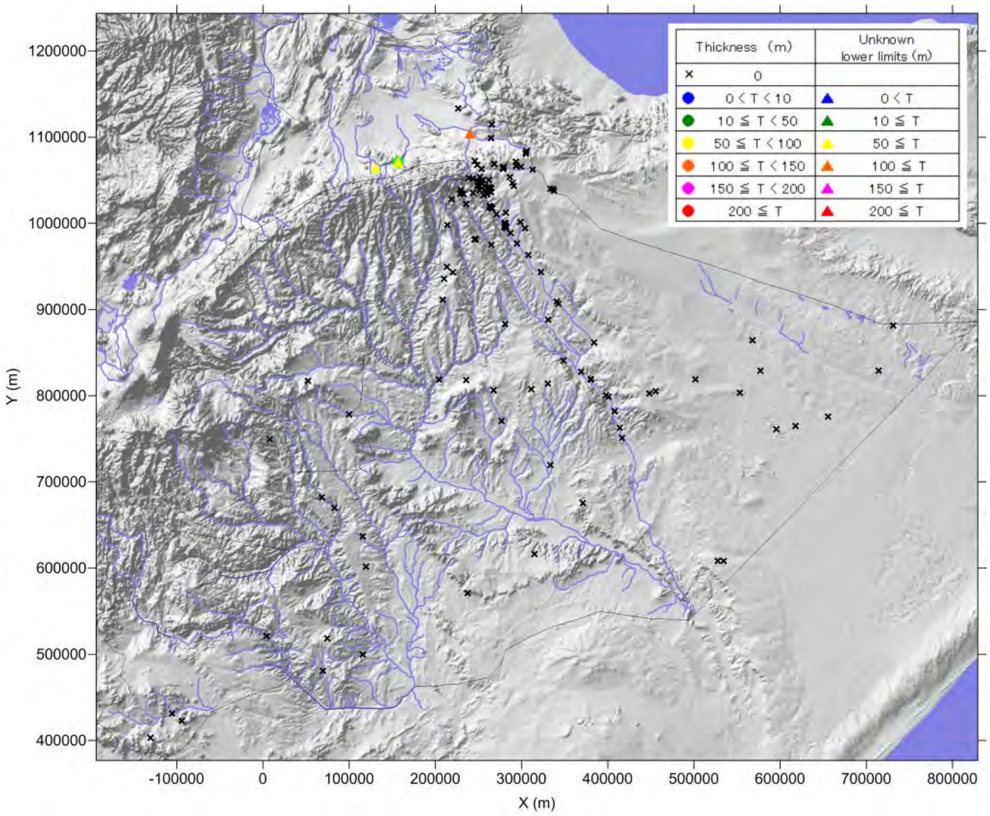


Figure 4.7: Distribution of Thickness of Amba Aradam Aquifer

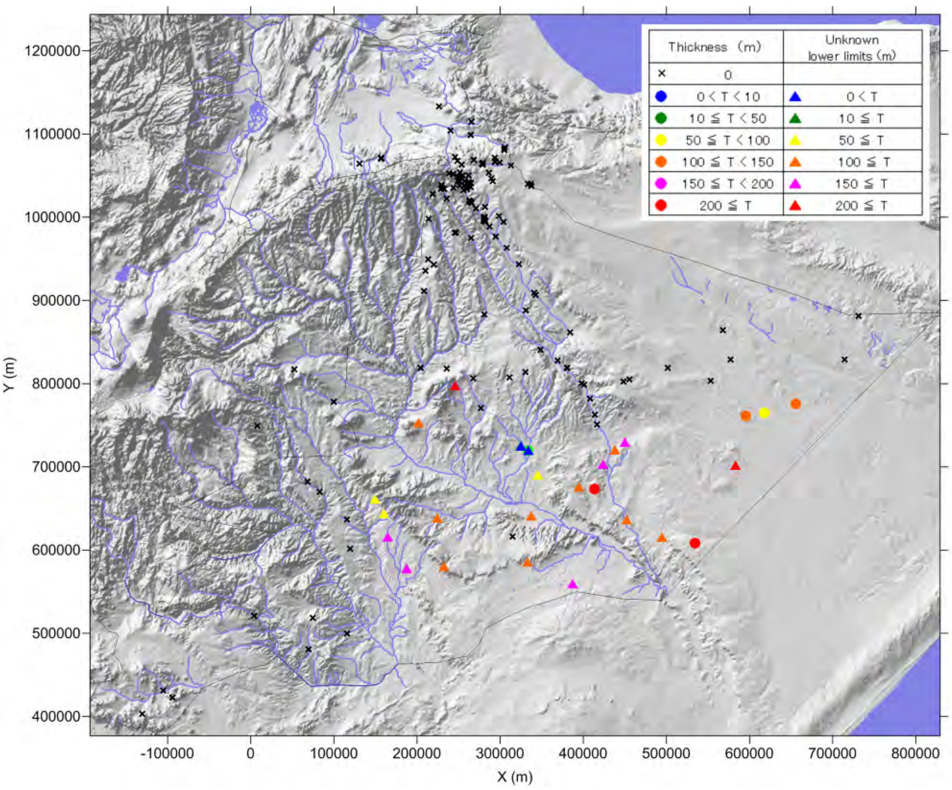


Figure 4.8: Distribution of Thickness of Korahe Aquifer

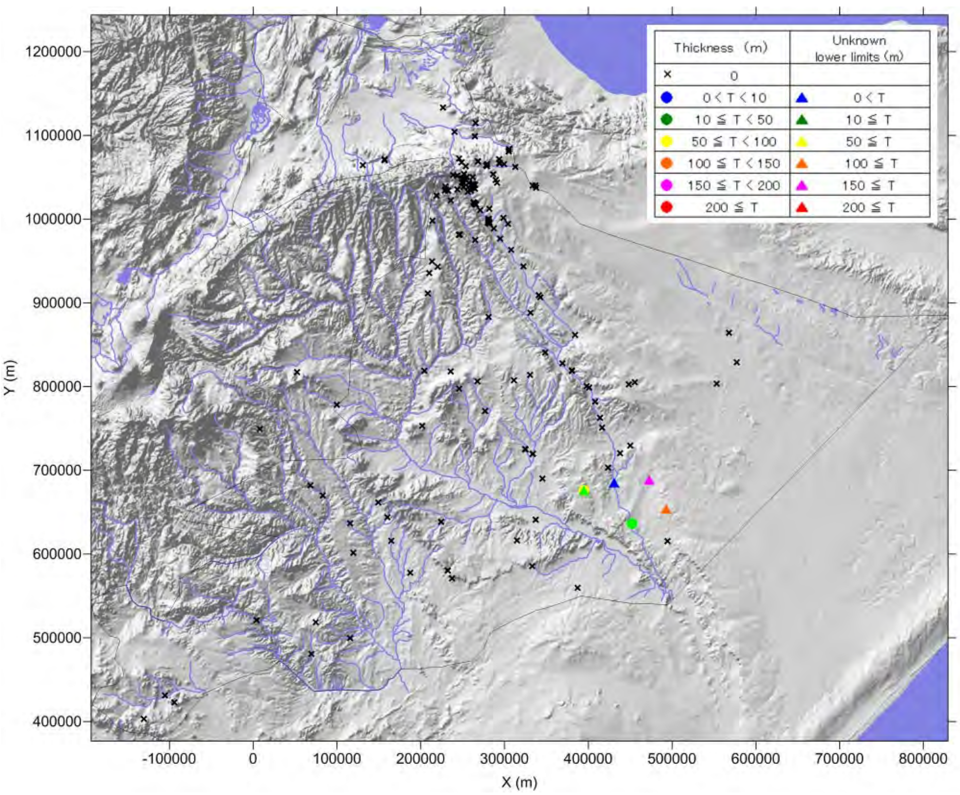


Figure 4.9: Distribution of Thickness of Mustahil Aquifer

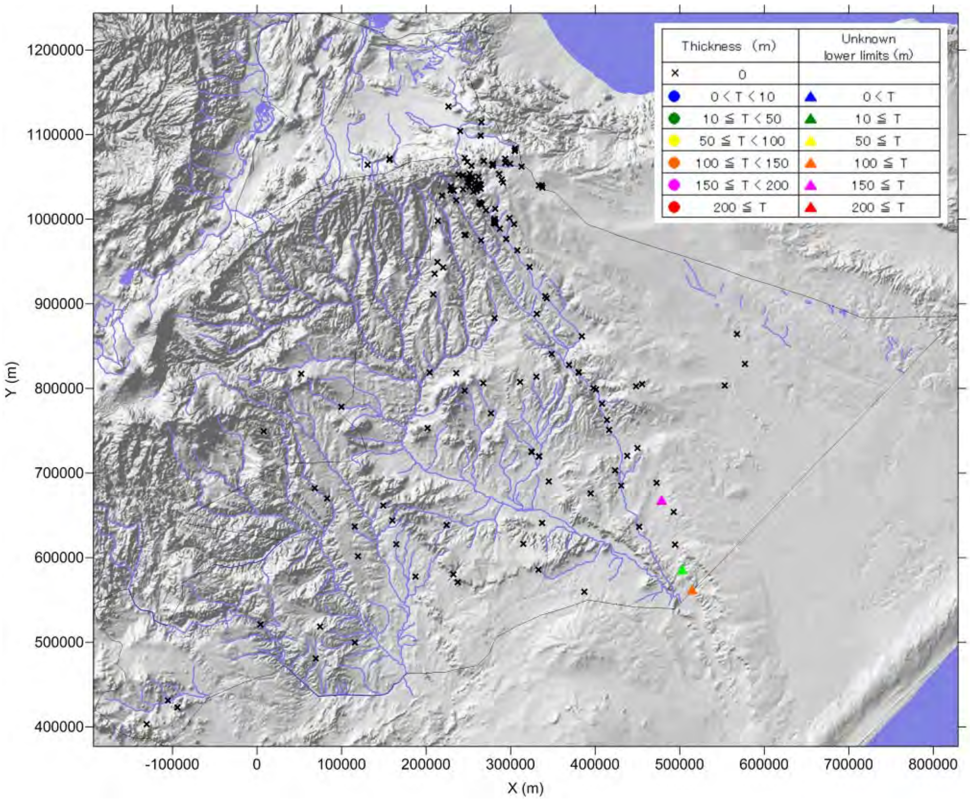


Figure 4.10: Distribution of Thickness of Ferfer Aquifer

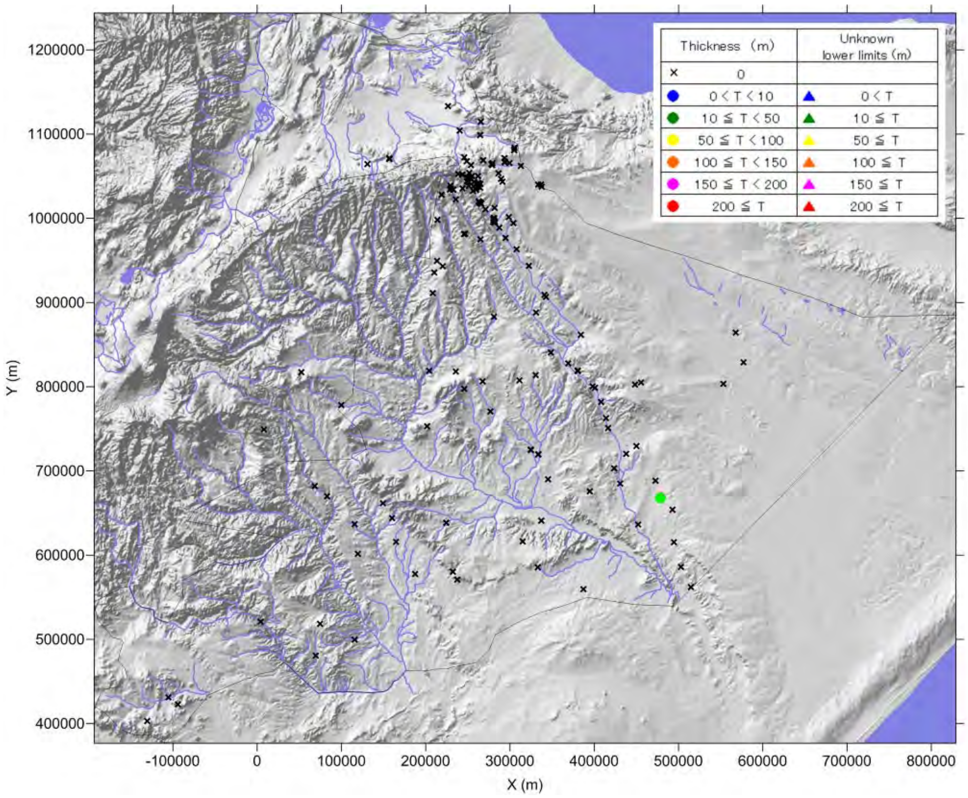


Figure 4.11: Distribution of Thickness of Beletwein Aquifer

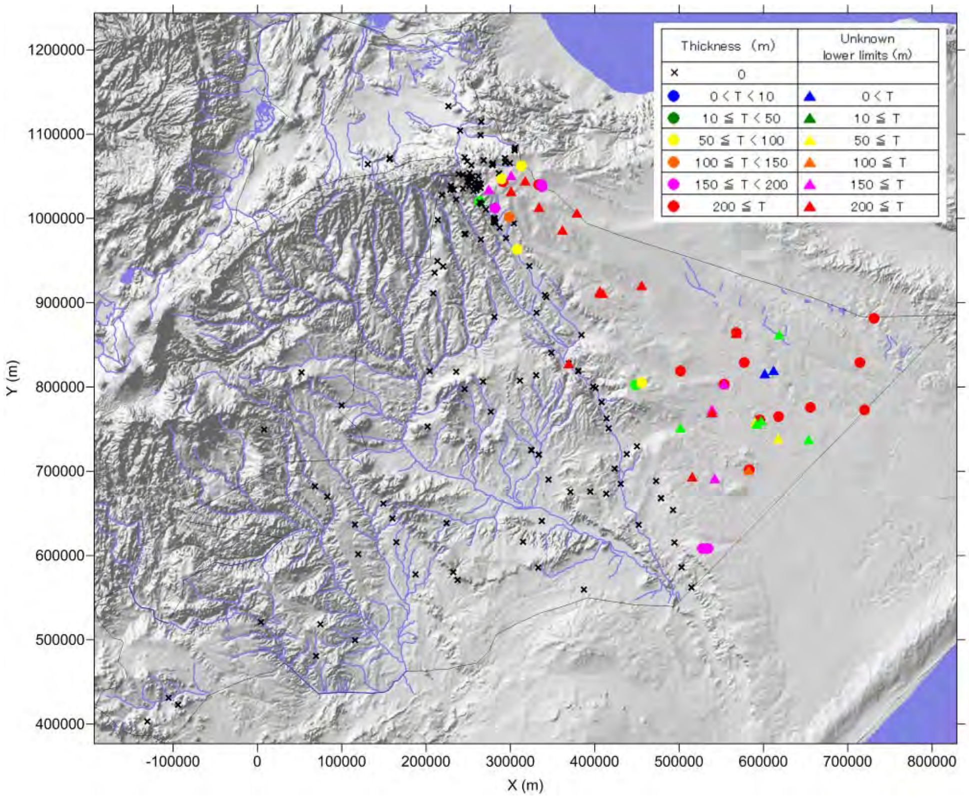


Figure 4.12: Distribution of Thickness of Jessoma Aquifer

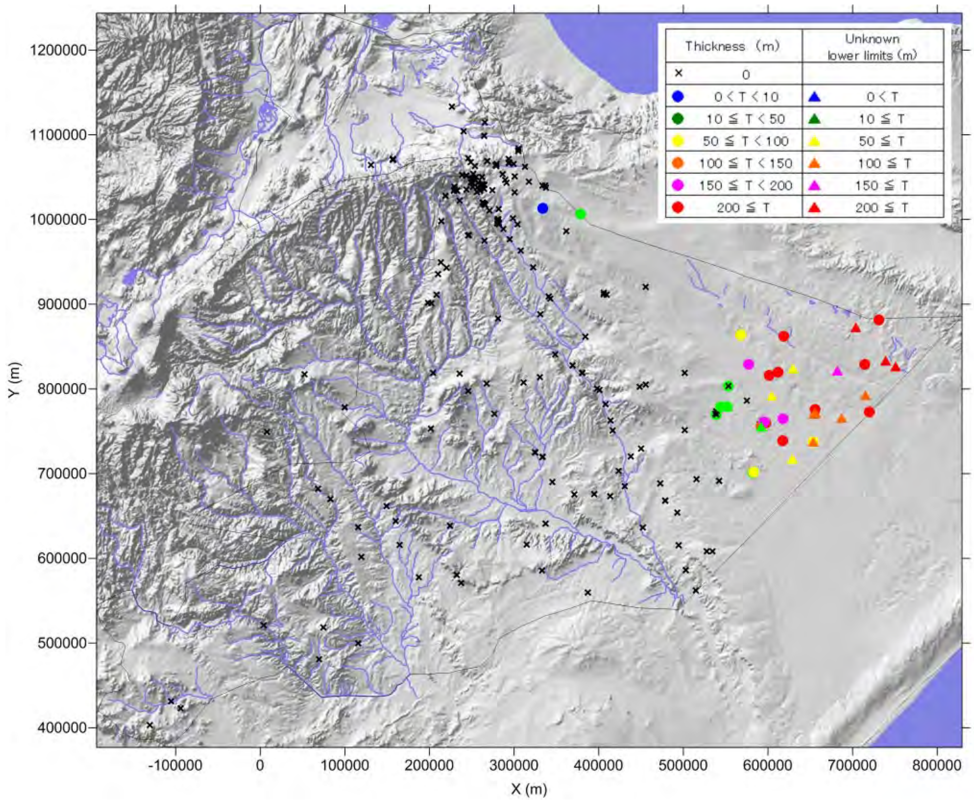


Figure 4.13: Distribution of Thickness of Auradu Aquifer

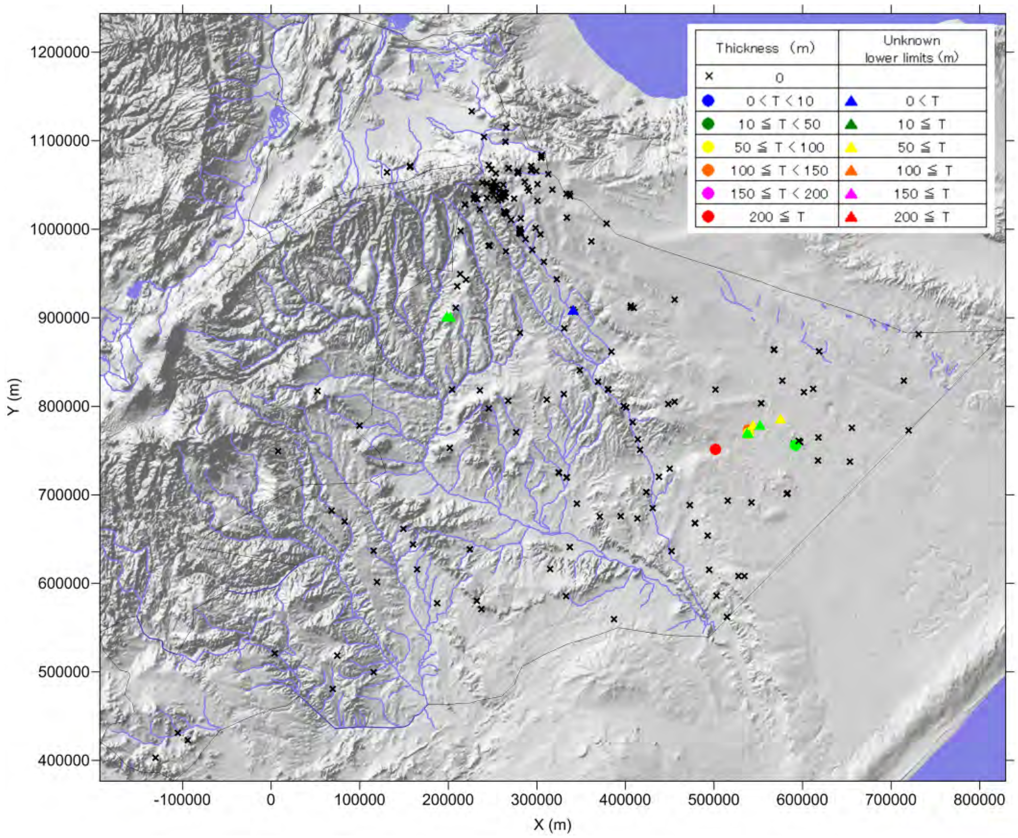


Figure 4.14: Distribution of Thickness of Basalt Aquifer (Old Basalt)

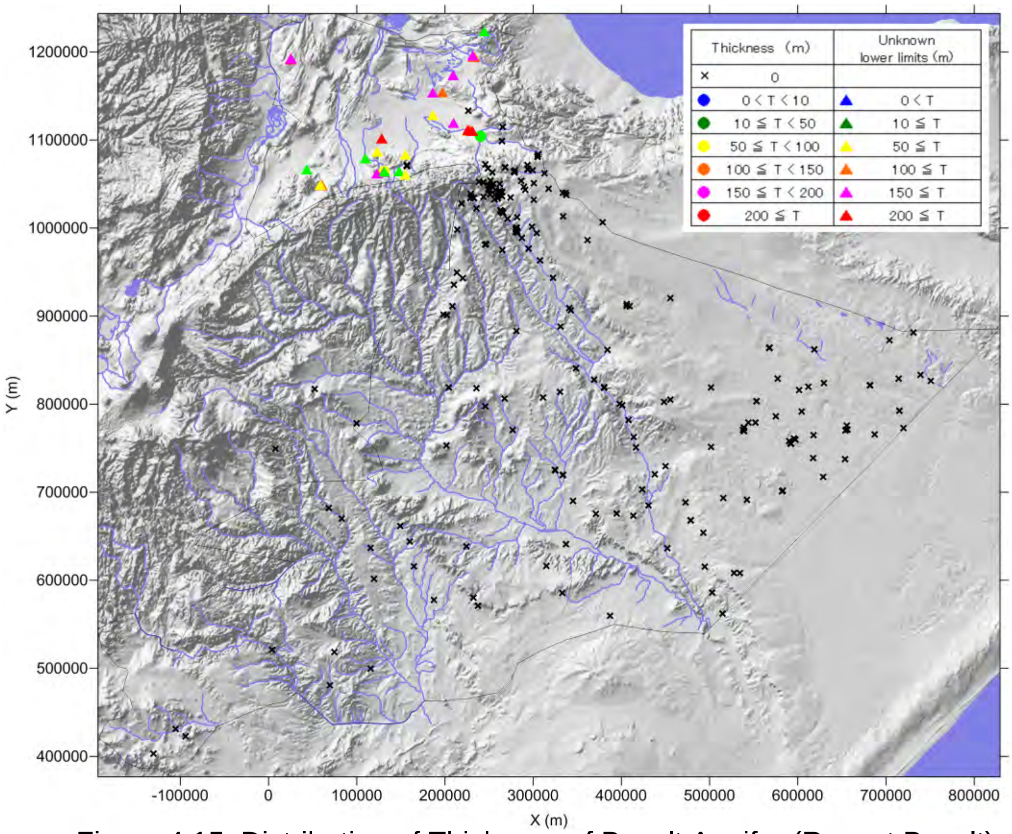


Figure 4.15: Distribution of Thickness of Basalt Aquifer (Recent Basalt)

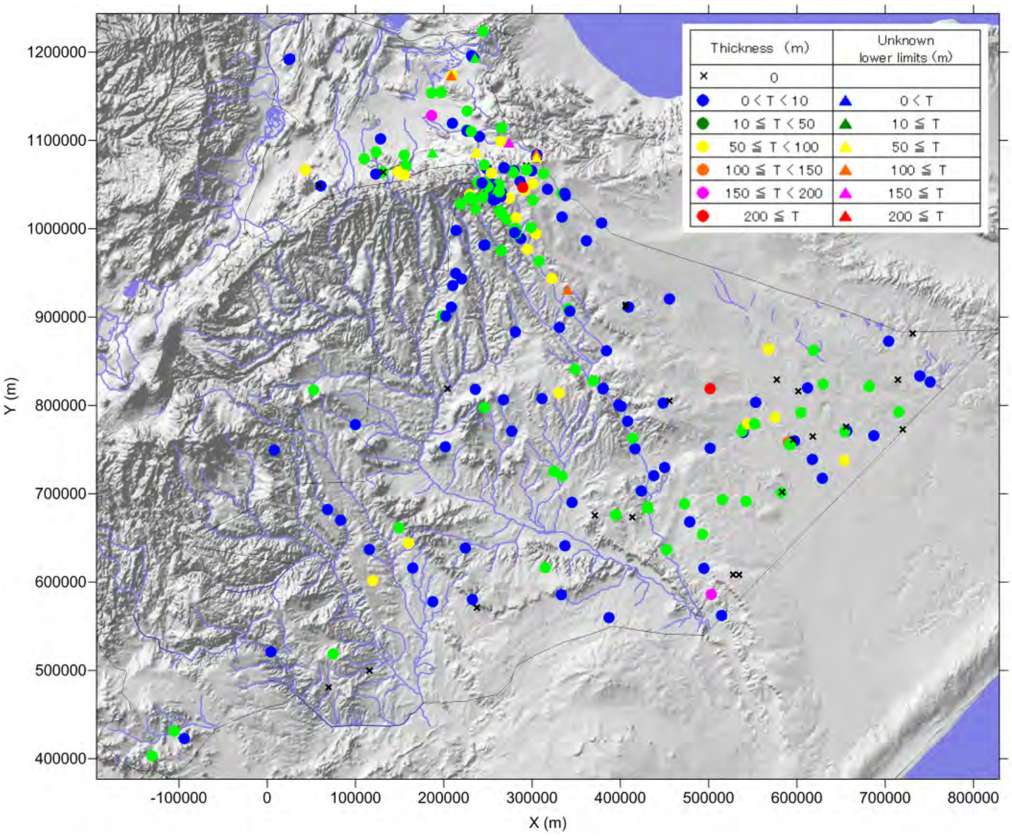


Figure 4.16: Distribution of Thickness of Quaternary Aquifer

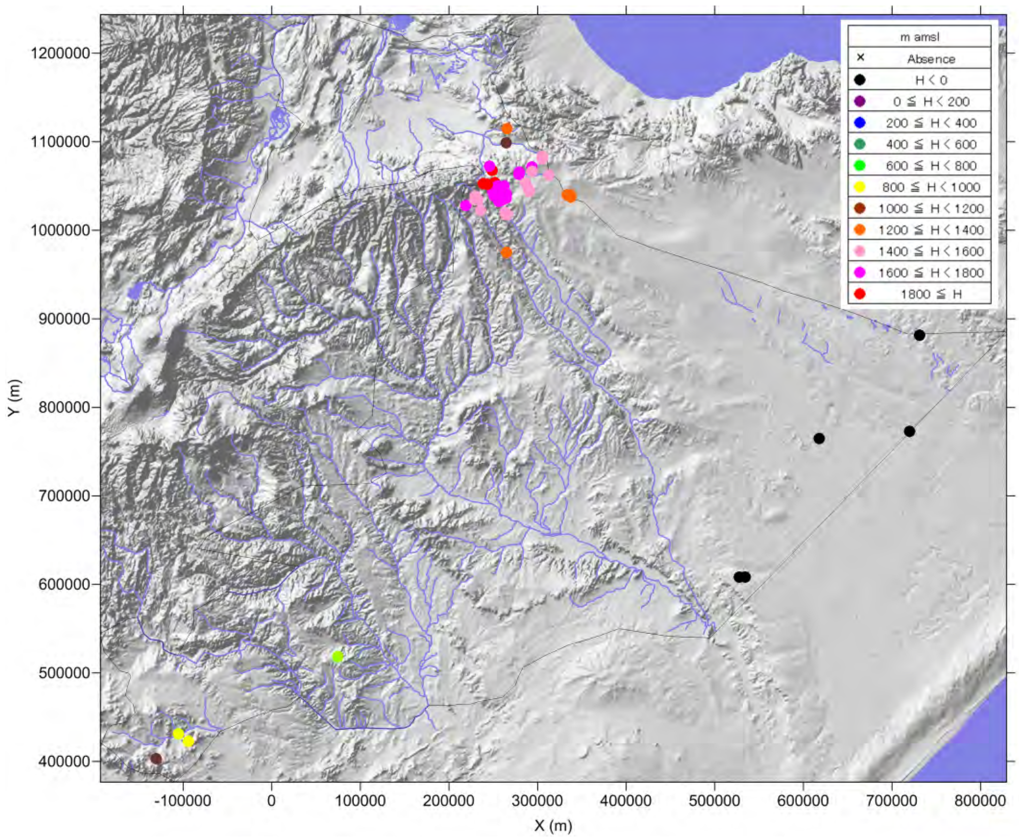


Figure 4.17: Distribution of Upper Surface Depth of Basement Rocks

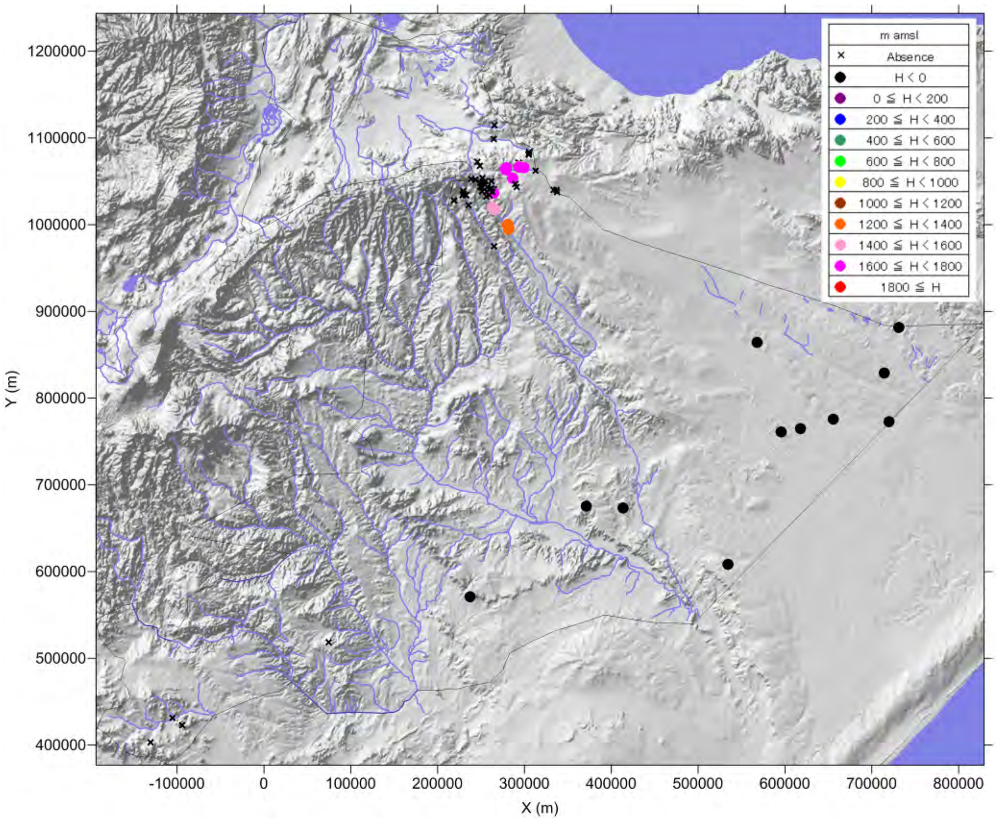


Figure 4.18: Distribution of Upper Surface Depth of Adigrat Aquifer

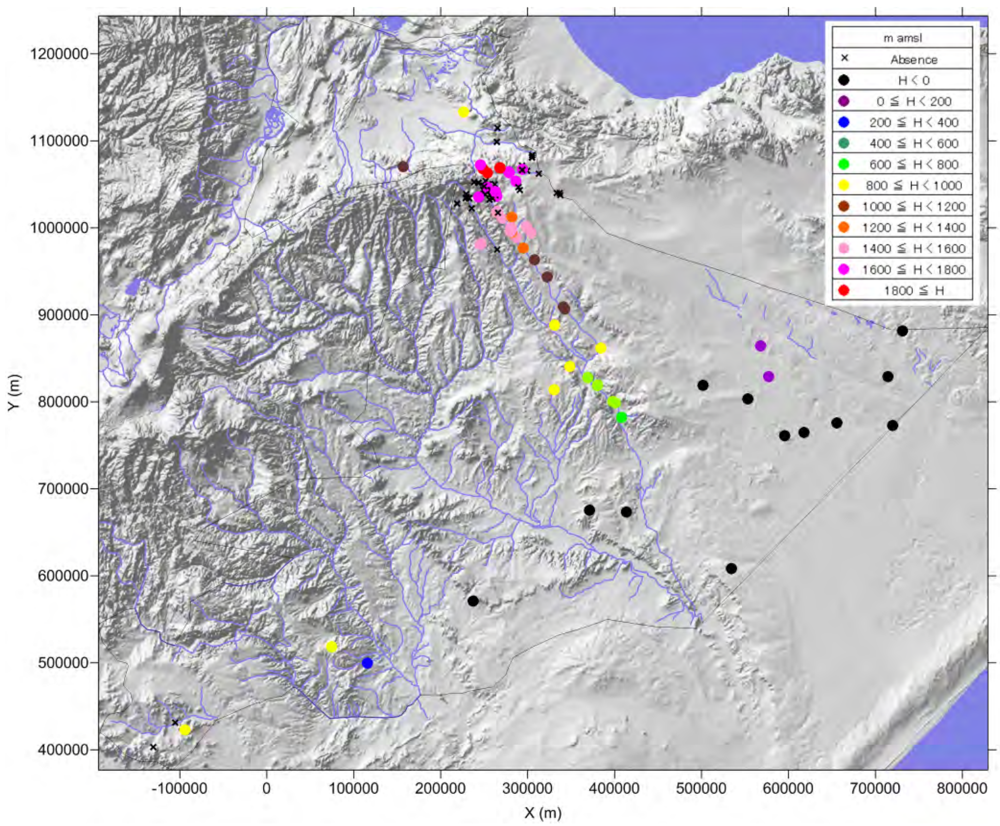


Figure 4.19: Distribution of Upper Surface Depth of Hamanlei Aquifer

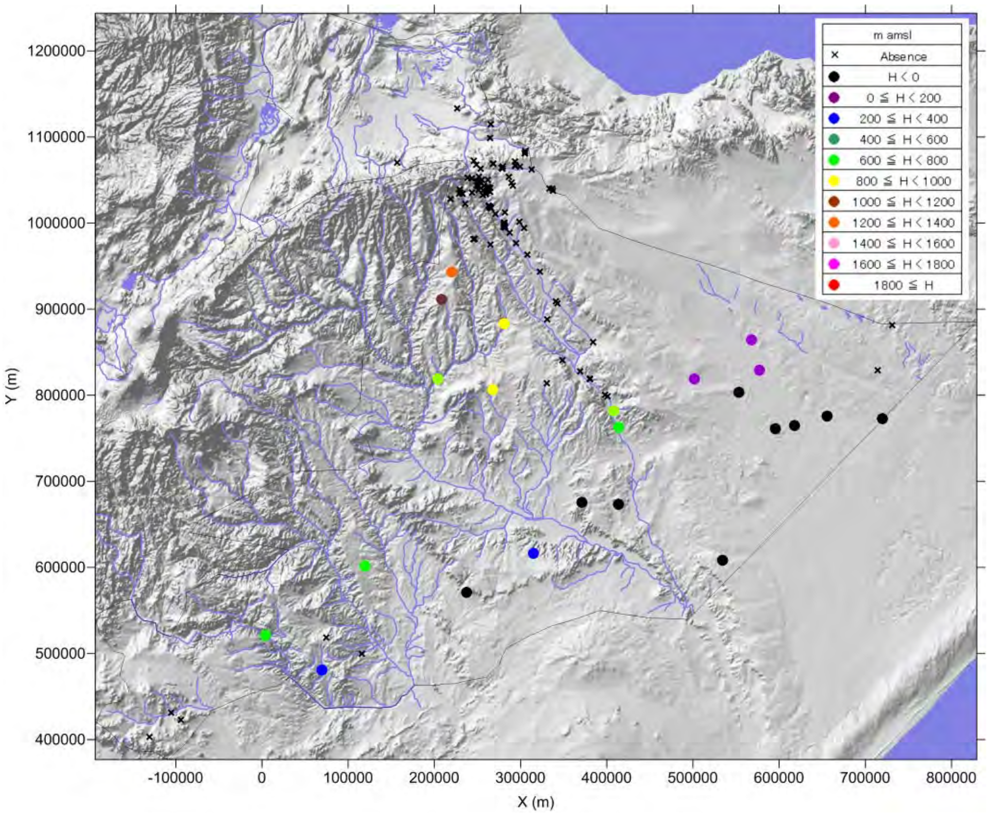


Figure 4.20: Distribution of Upper Surface Depth of Urandab Aquifer

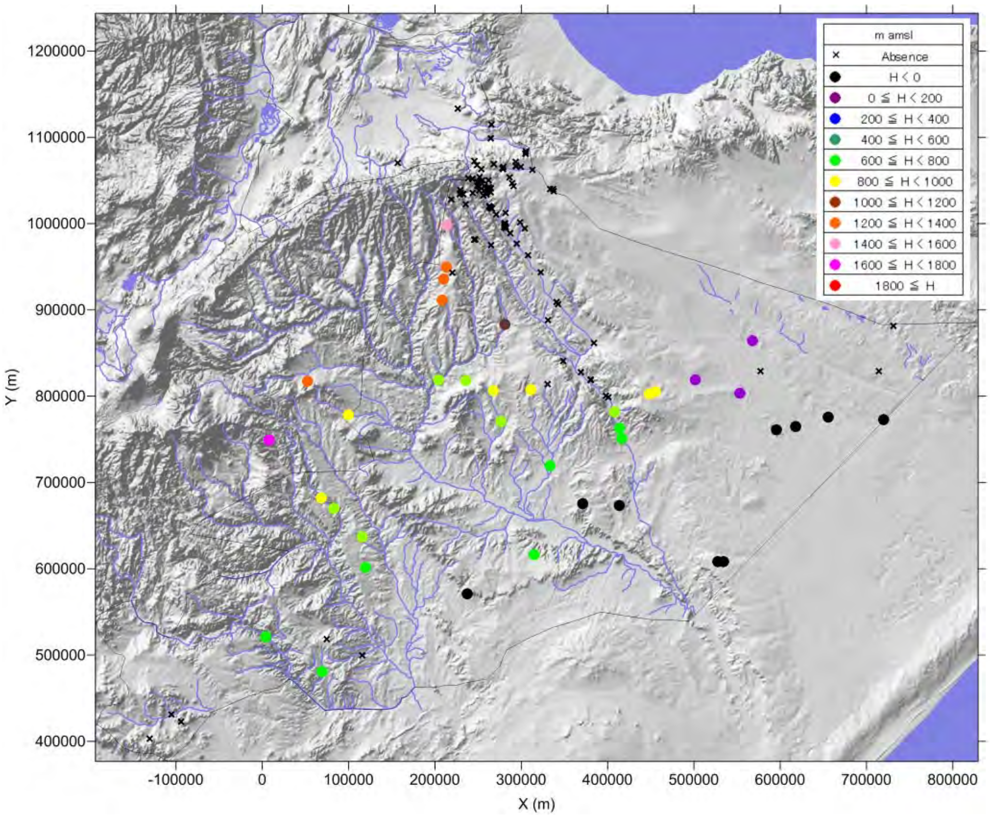


Figure 4.21: Distribution of Upper Surface Depth of Kabridahar Aquifer

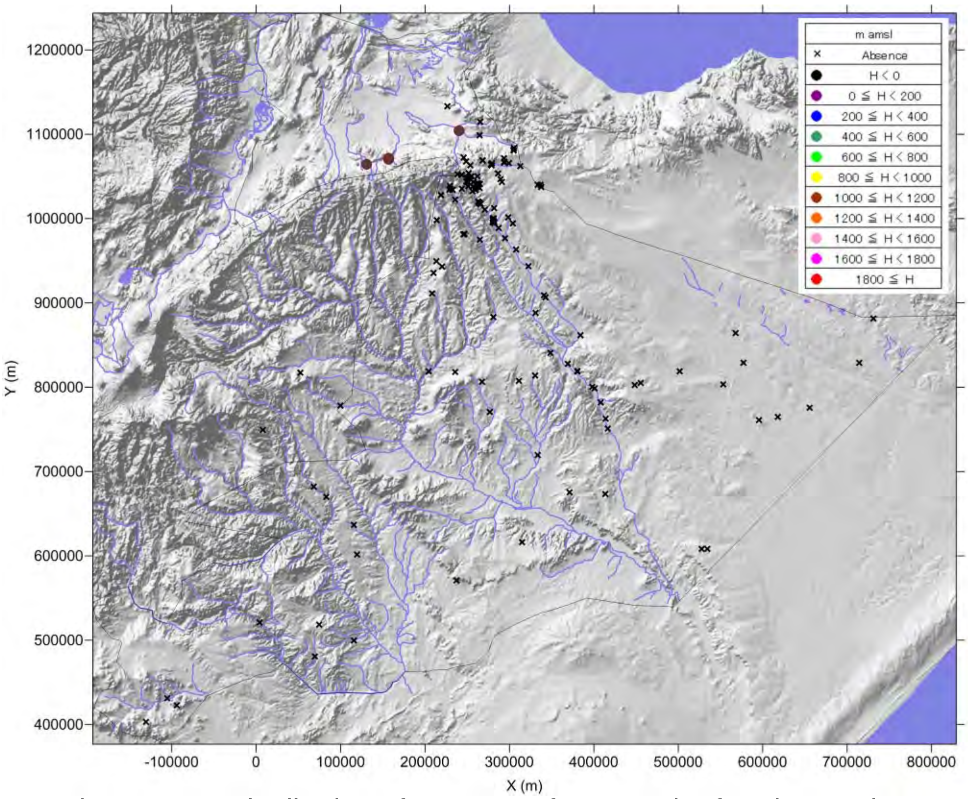


Figure 4.22: Distribution of Upper Surface Depth of Amba Aradam Aquifer

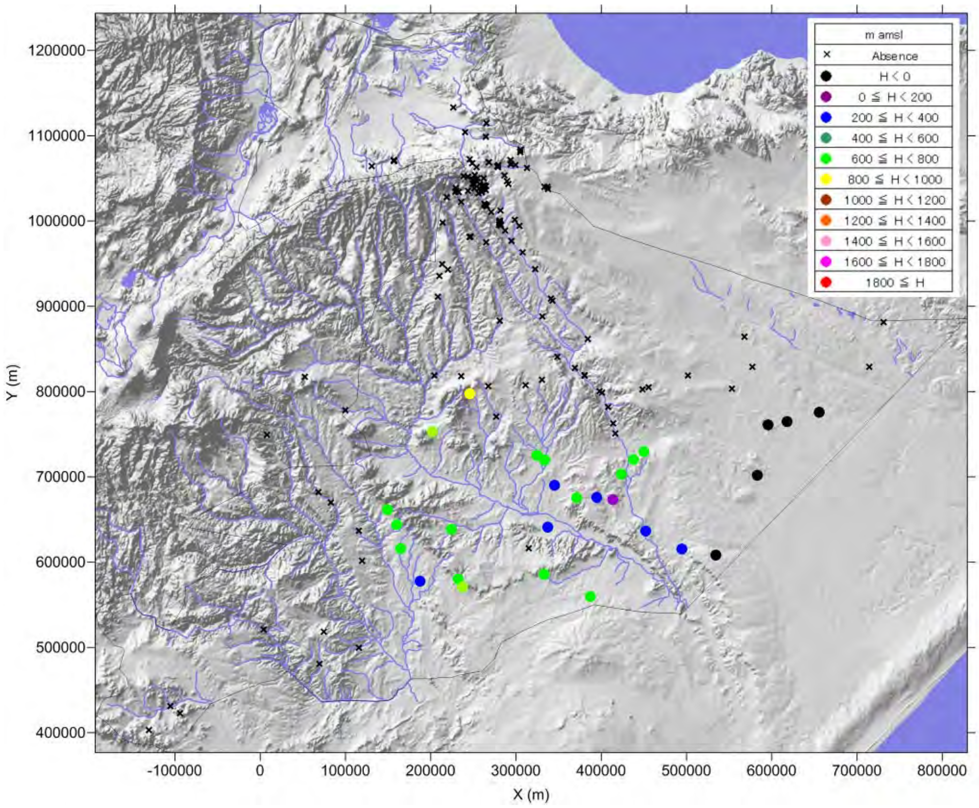


Figure 4.23: Distribution of Upper Surface Depth of Korahe Aquifer

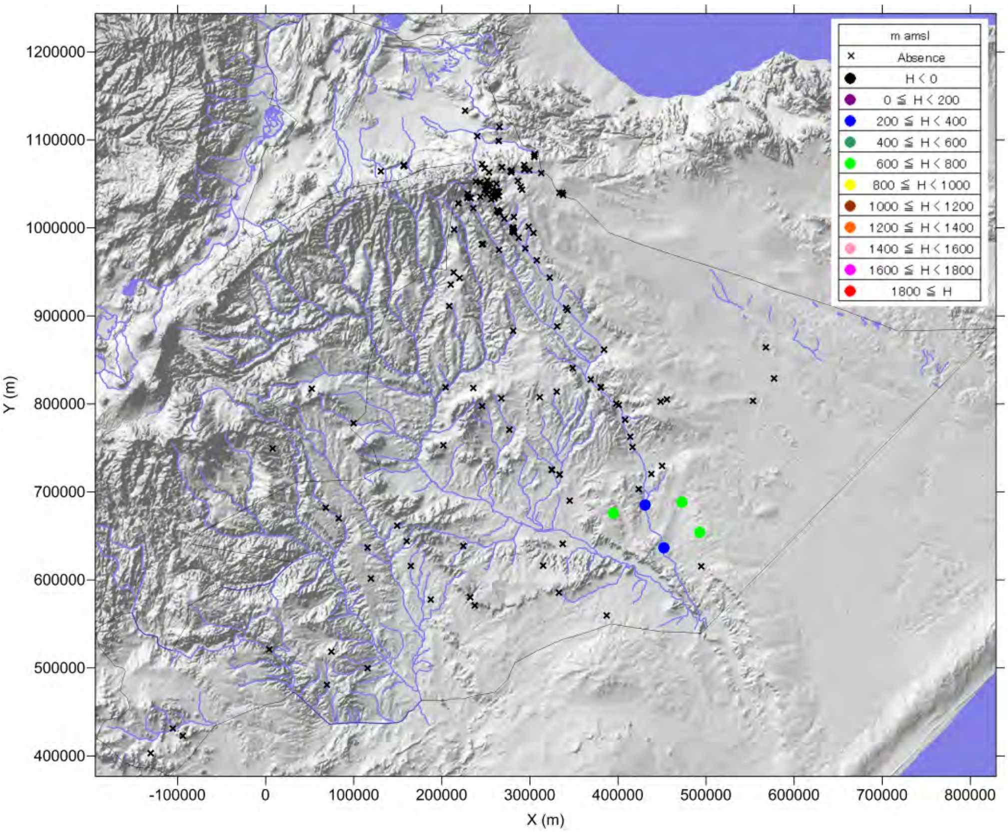


Figure 4.24: Distribution of Upper Surface Depth of Mustahil Aquifer

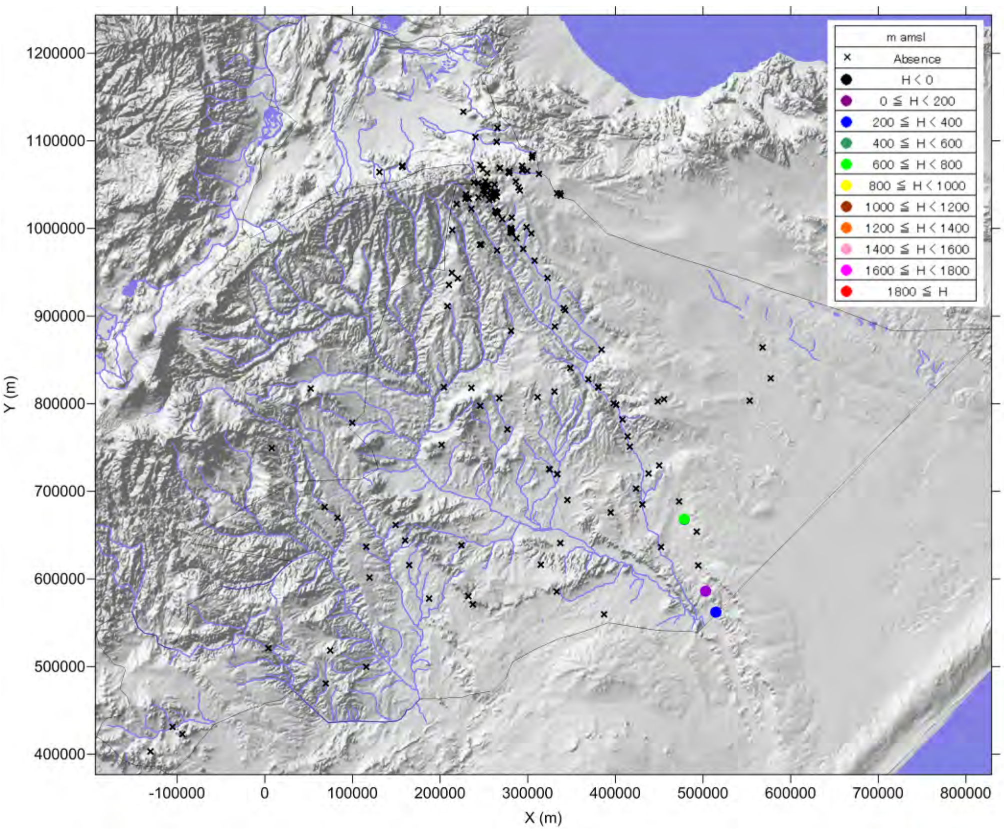


Figure 4.25: Distribution of Upper Surface Depth of Ferfer Aquifer

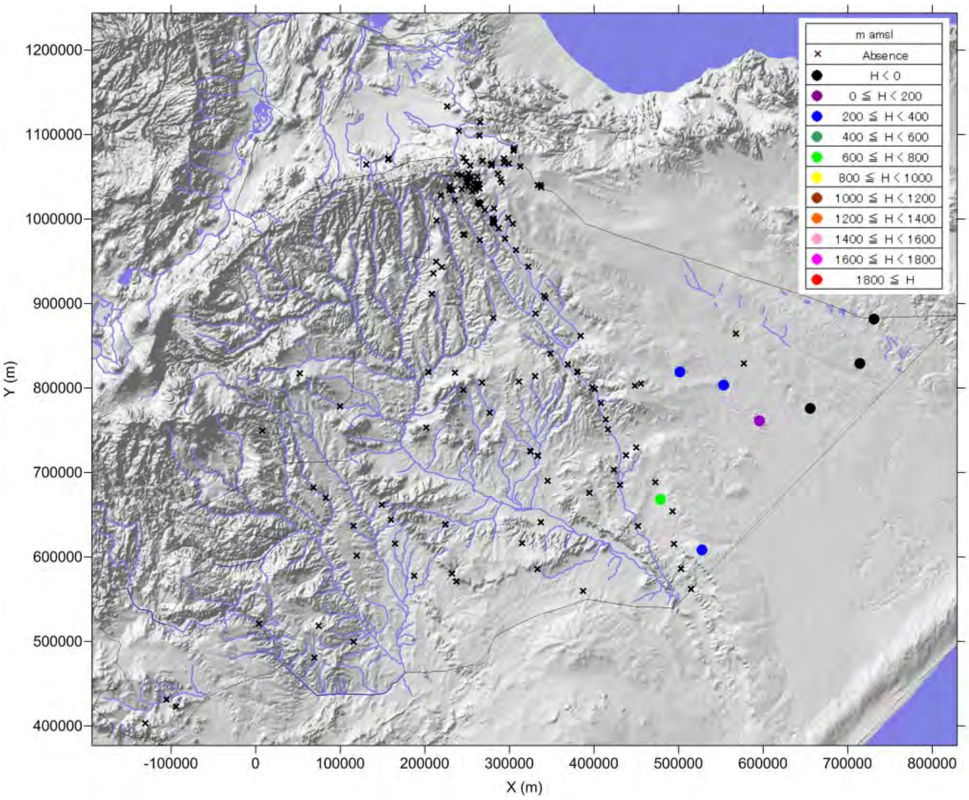


Figure 4.26: Distribution of Upper Surface Depth of Beletwein Aquifer

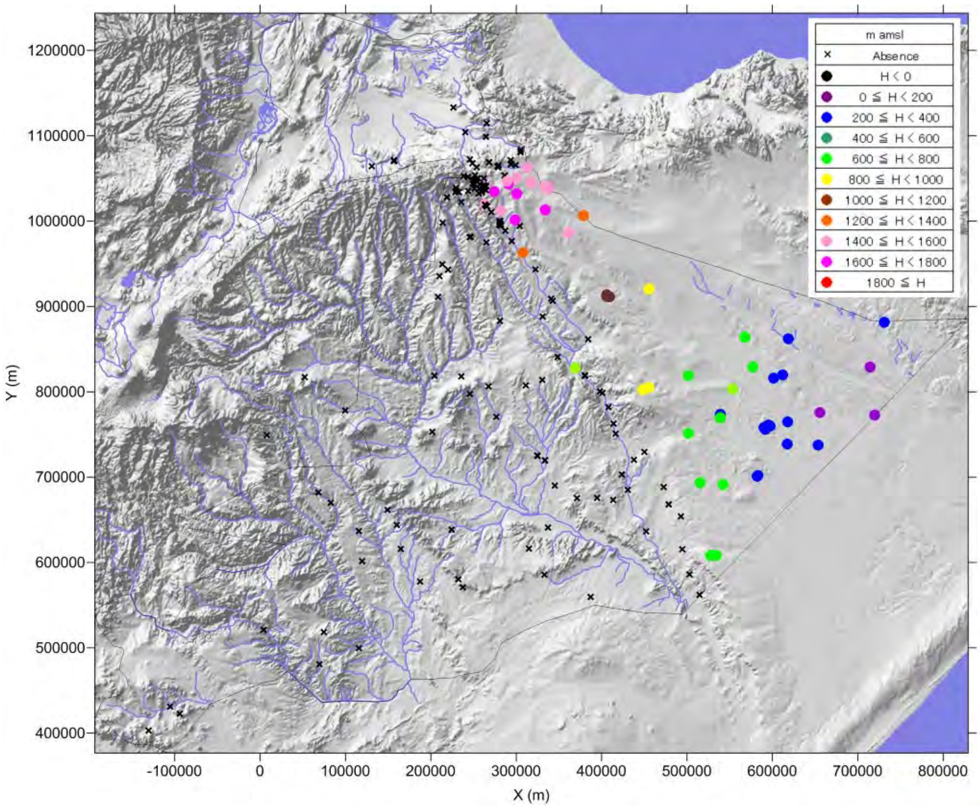


Figure 4.27: Distribution of Upper Surface Depth of Jessoma Aquifer

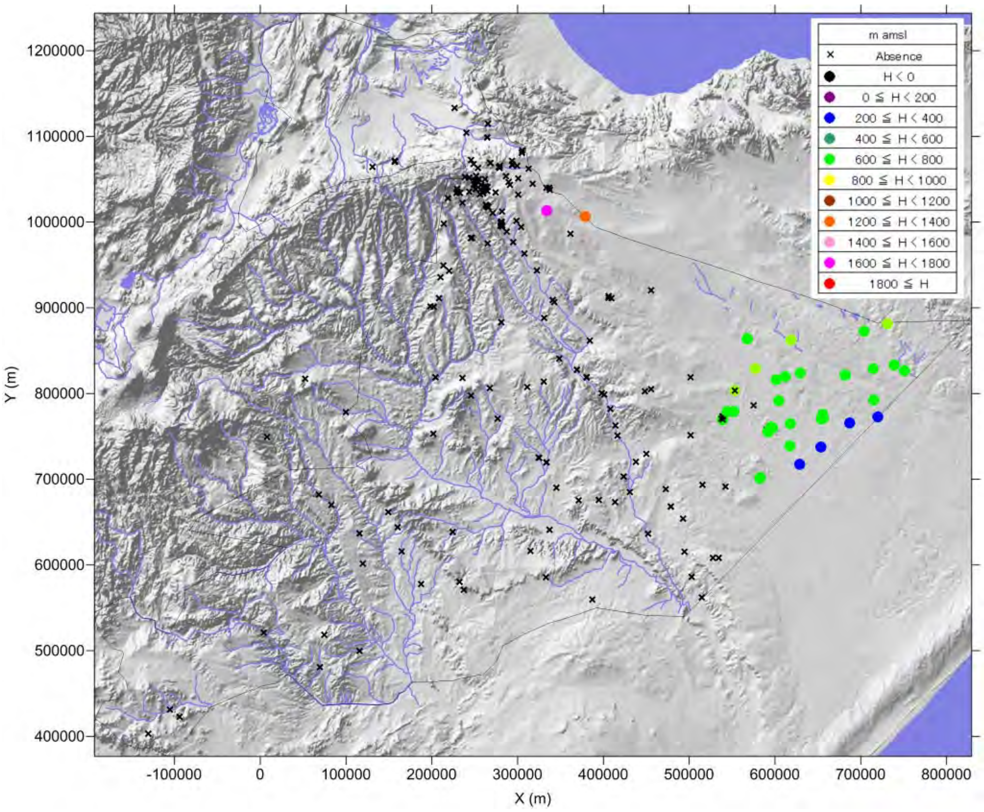


Figure 4.28: Distribution of Upper Surface Depth of Auradu Aquifer

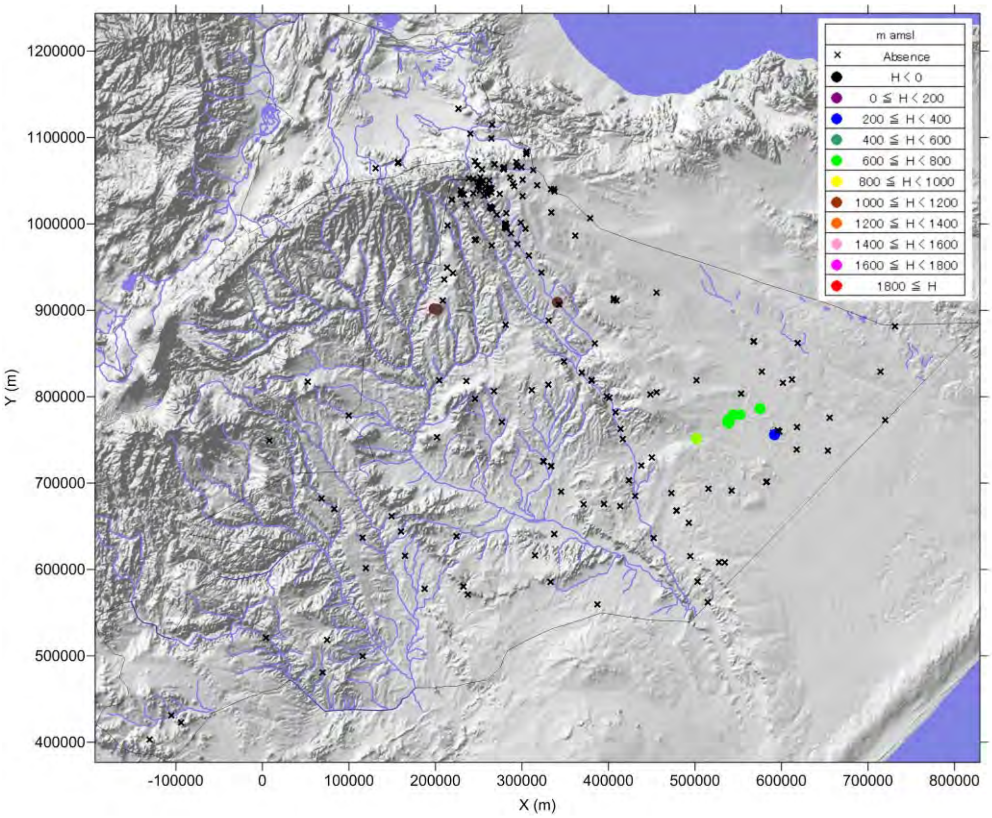


Figure 4.29: Distribution of Upper Surface Depth of Basalt Aquifer (Old Basalt)

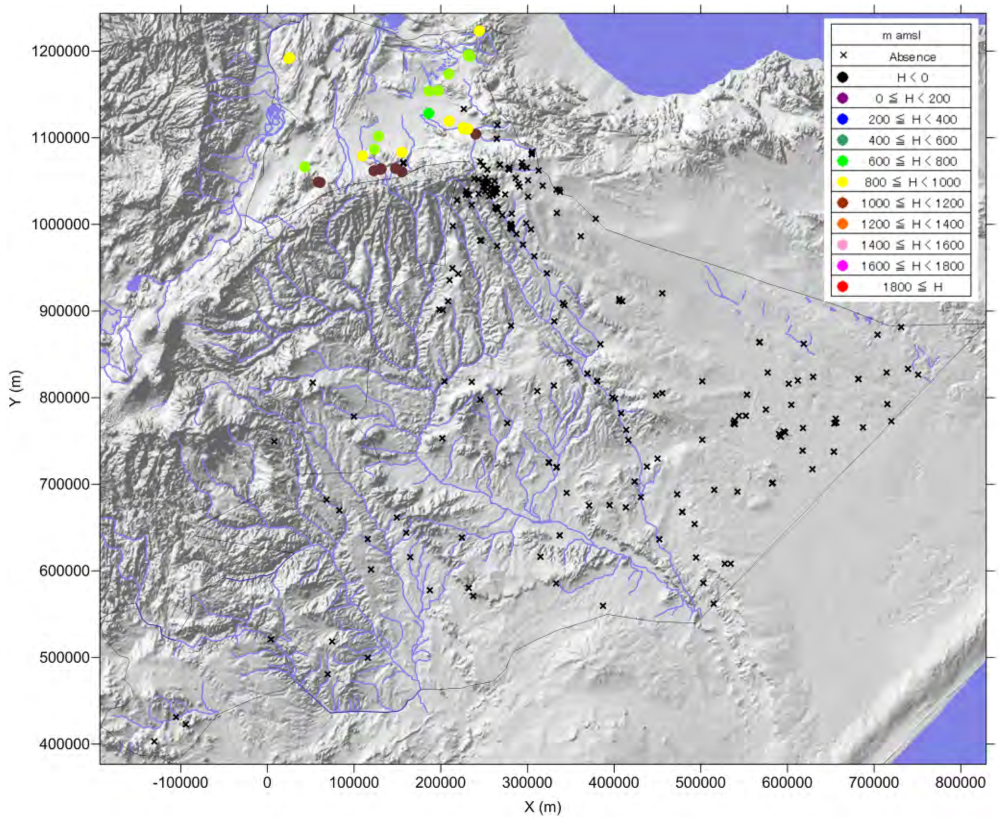


Figure 4.30: Distribution of Upper Surface Depth of Basalt Aquifer (Recent Basalt)

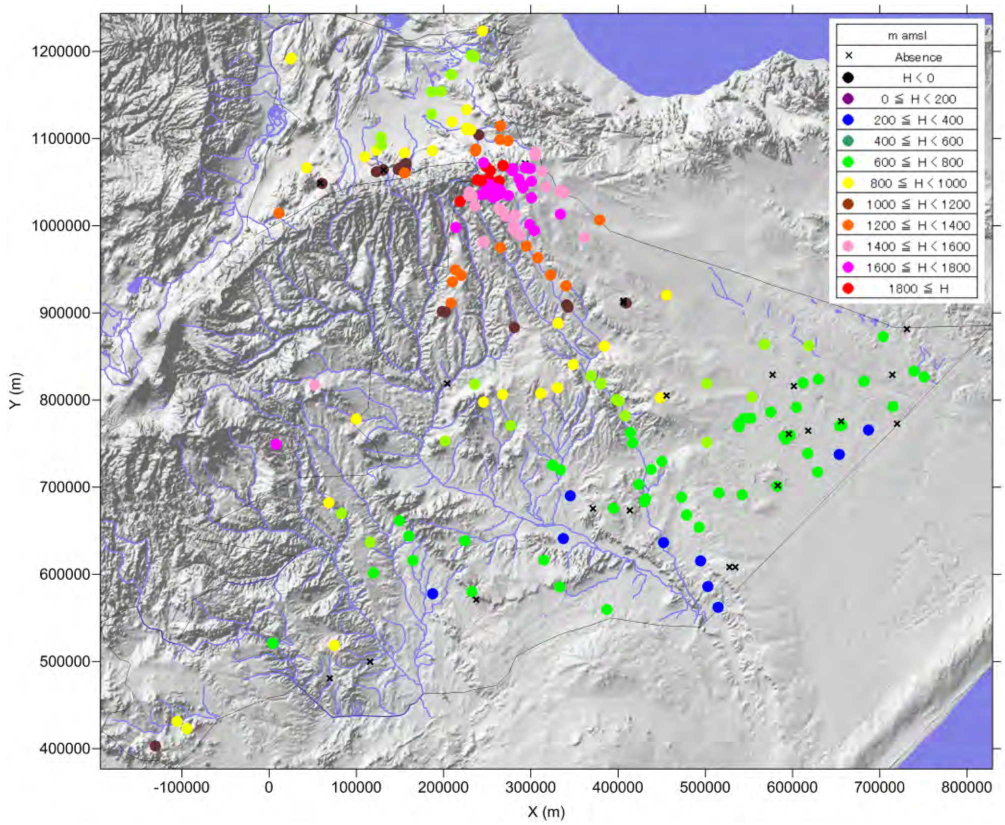


Figure 4.31: Distribution of Upper Surface Depth of Quaternary Aquifer

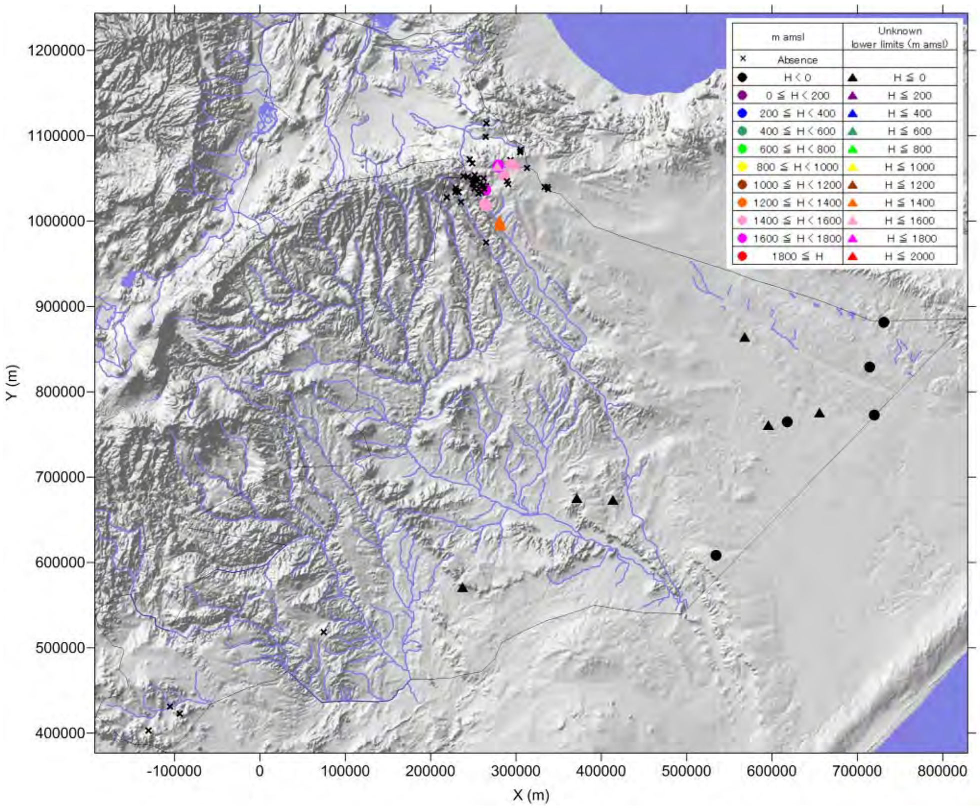


Figure 4.32: Distribution of Bottom Surface Depth of Adigrat Aquifer

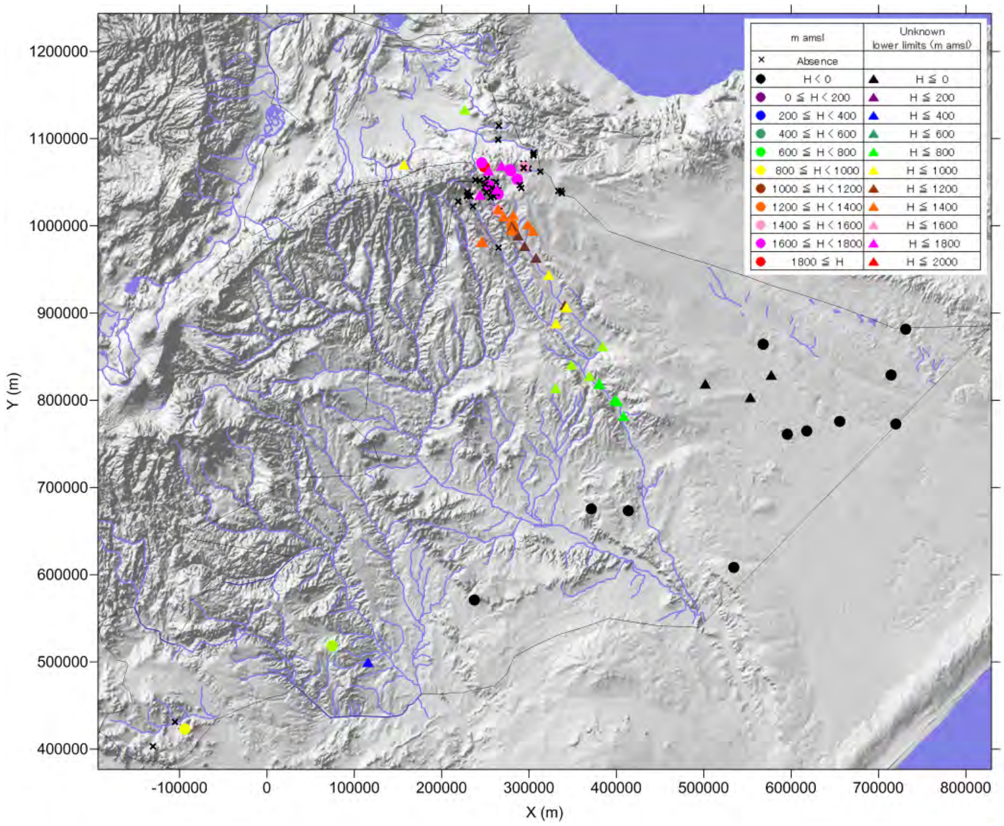


Figure 4.33: Distribution of Bottom Surface Depth of Hamanlei Aquifer

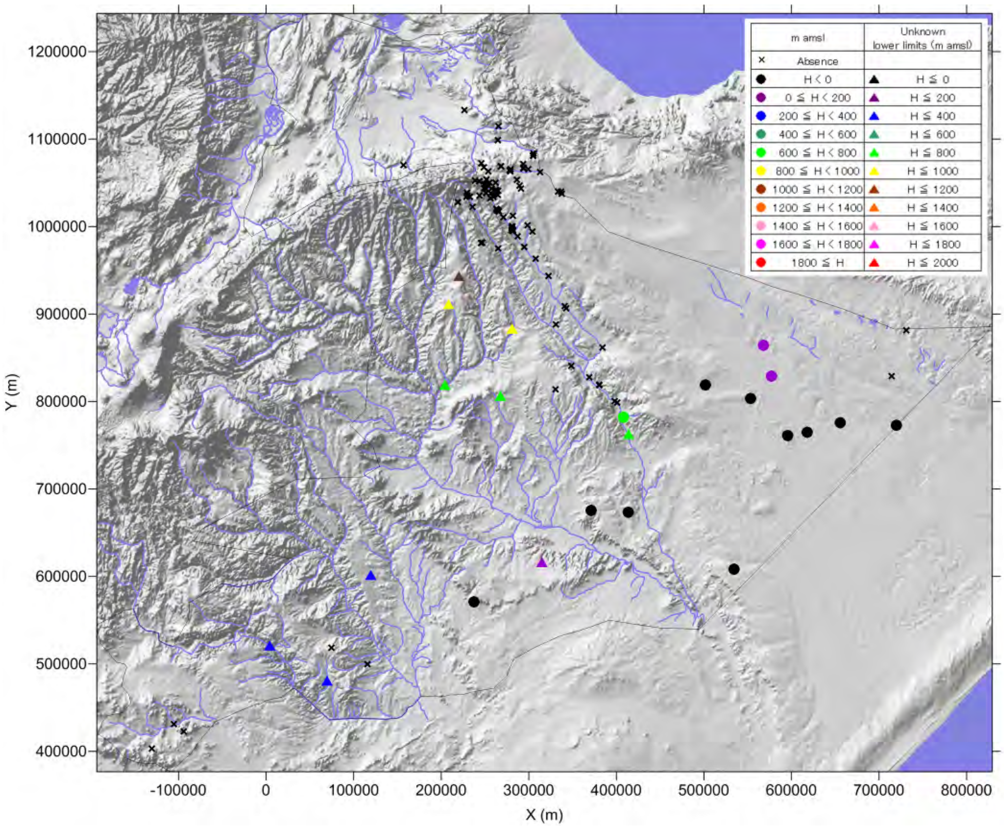


Figure 4.34: Distribution of Bottom Surface Depth of Urandab Aquifer

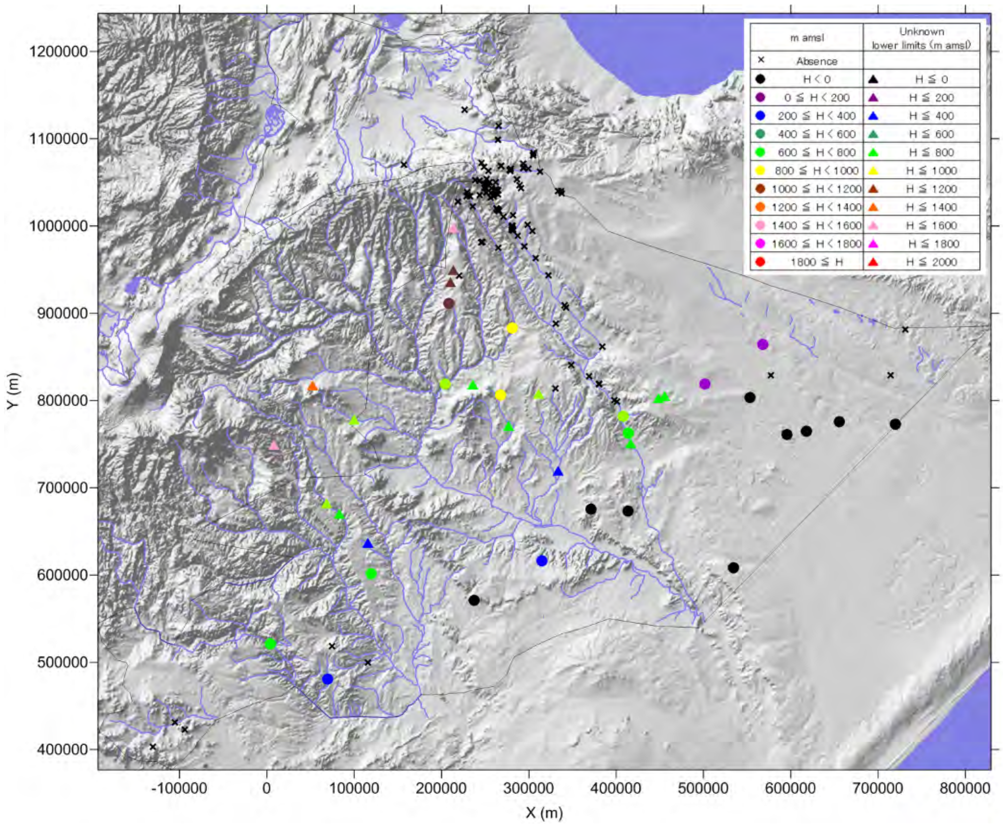


Figure 4.35: Distribution of Bottom Surface Depth of Kabridahar Aquifer

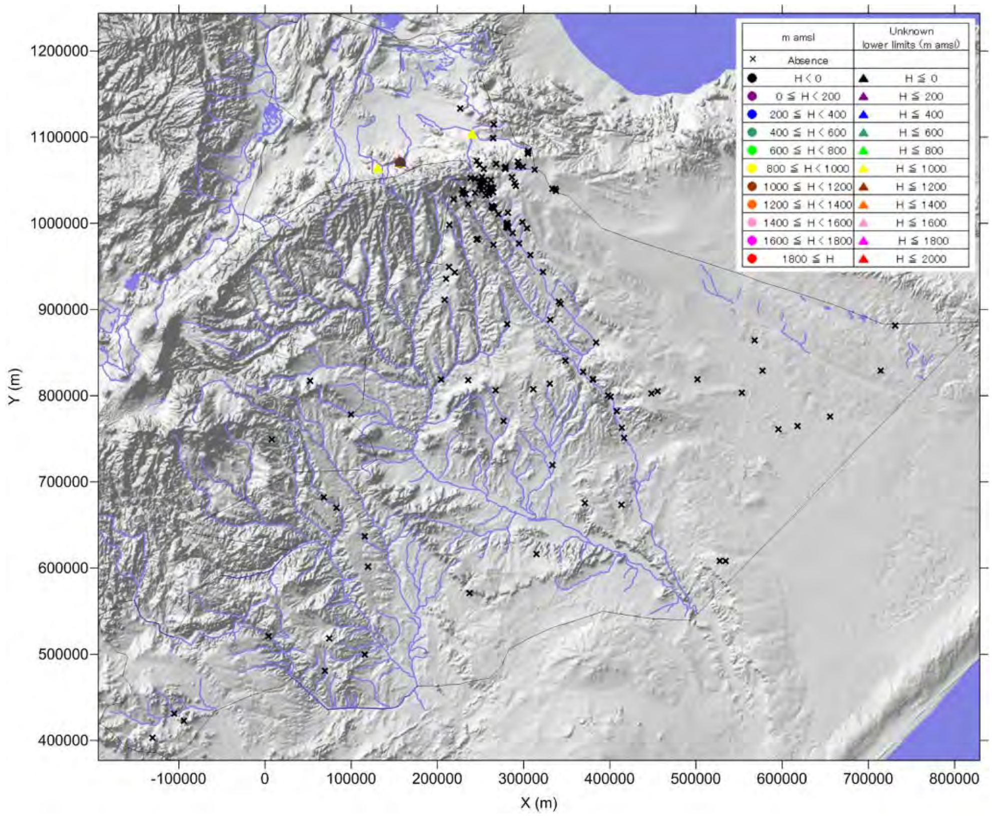


Figure 4.36: Distribution of Bottom Surface Depth of Amba Aradam Aquifer

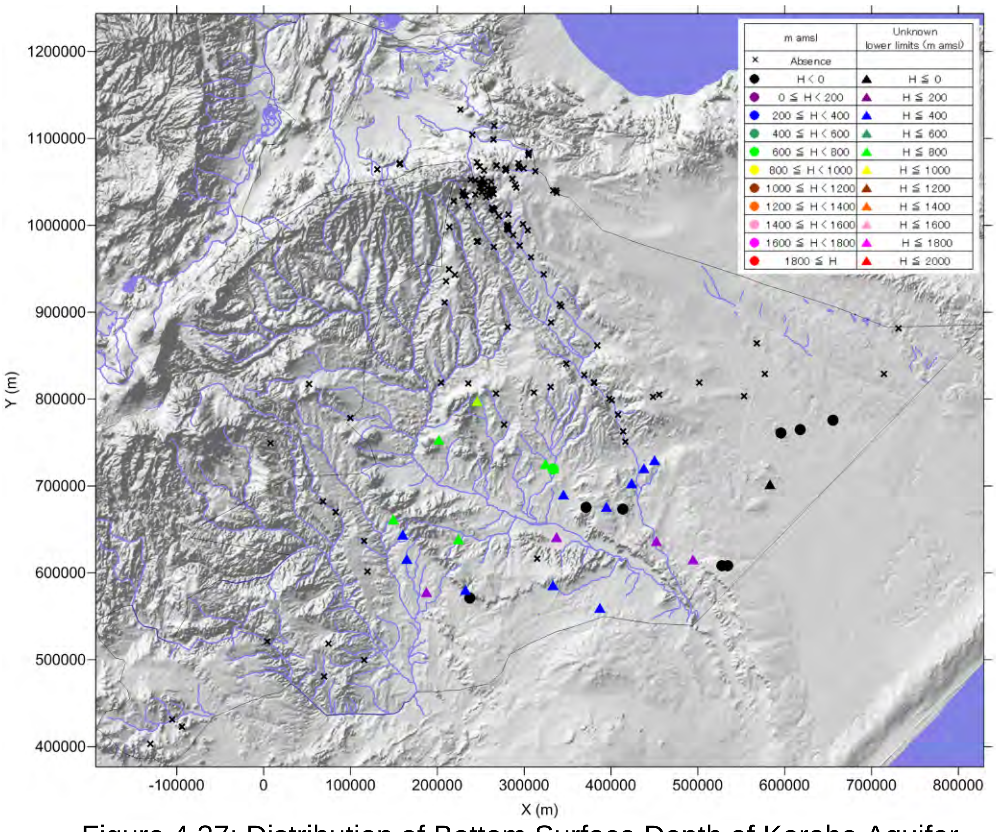


Figure 4.37: Distribution of Bottom Surface Depth of Korahe Aquifer

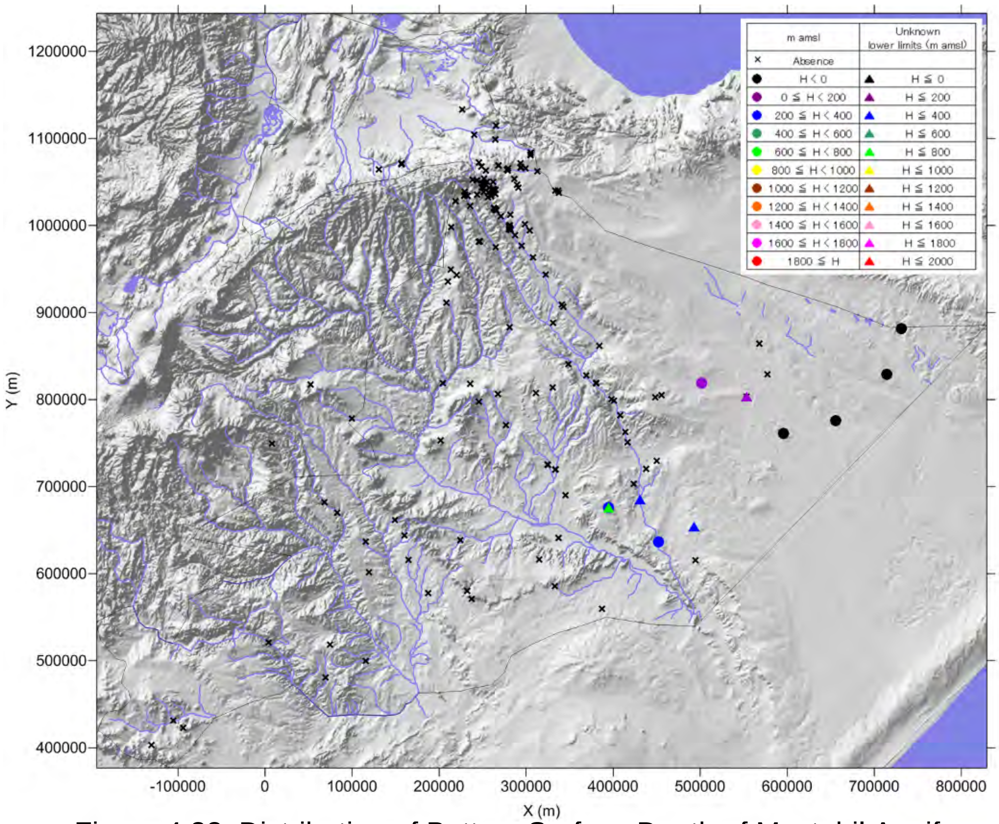


Figure 4.38: Distribution of Bottom Surface Depth of Mustahil Aquifer

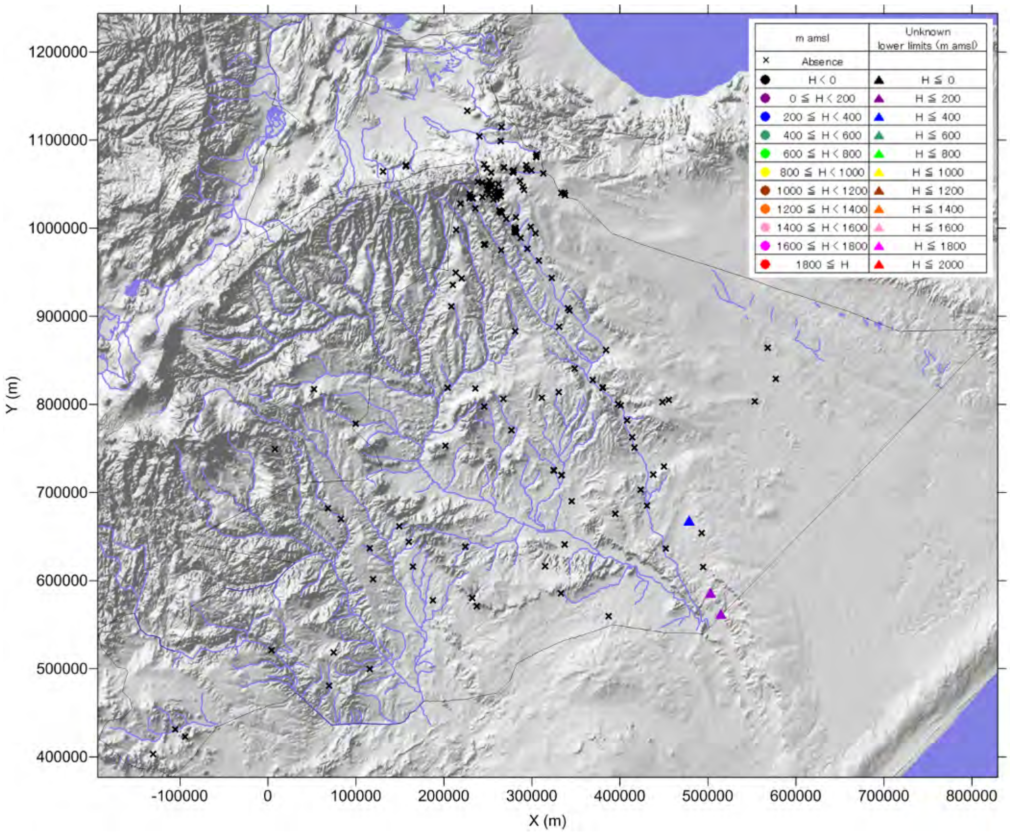


Figure 4.39: Distribution of Bottom Surface Depth of Ferfer Aquifer

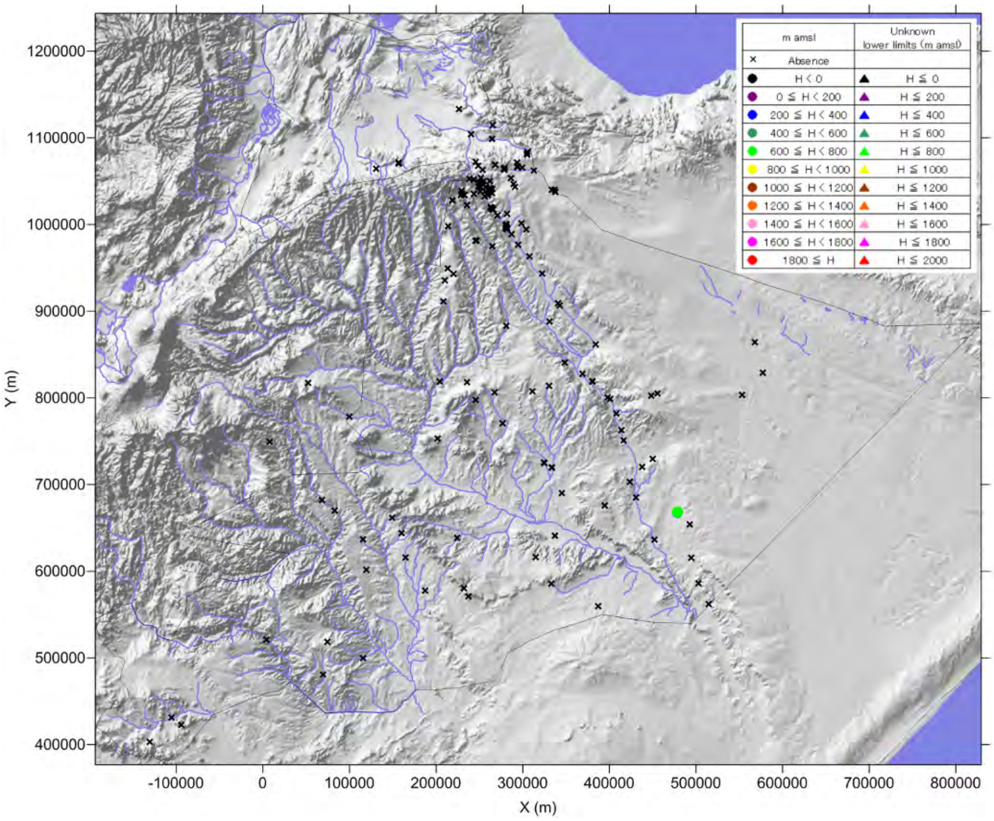


Figure 4.40: Distribution of Bottom Surface Depth of Beletwein Aquifer

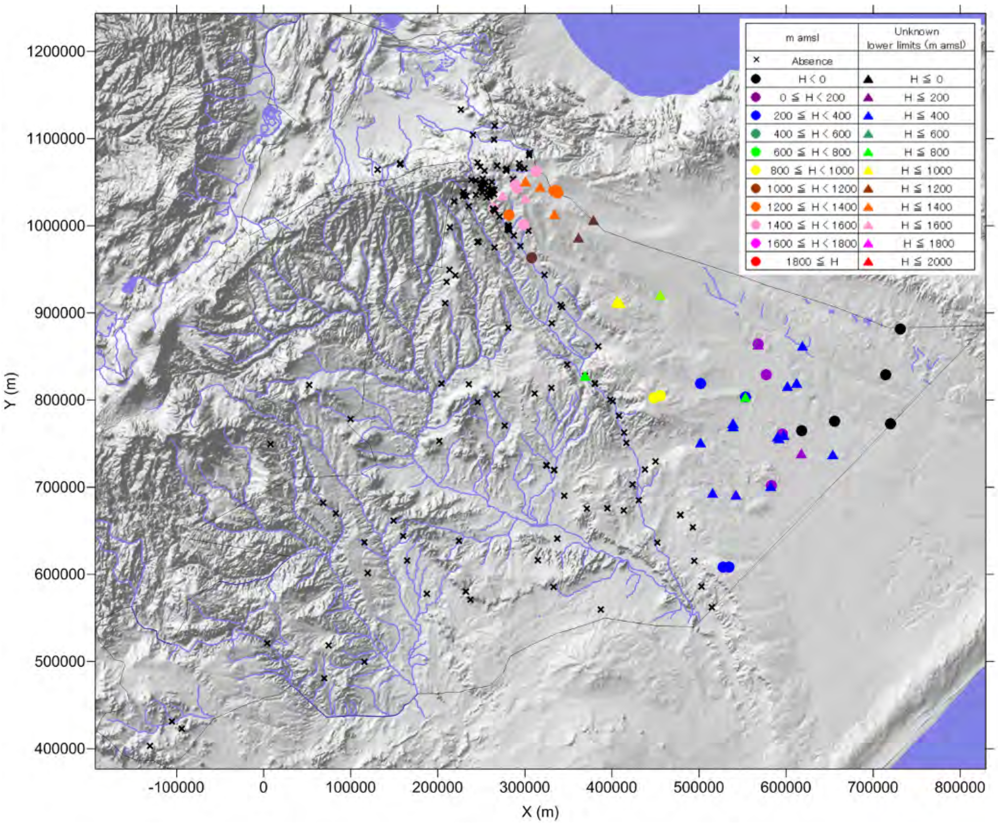


Figure 4.41: Distribution of Bottom Surface Depth of Jessoma Aquifer

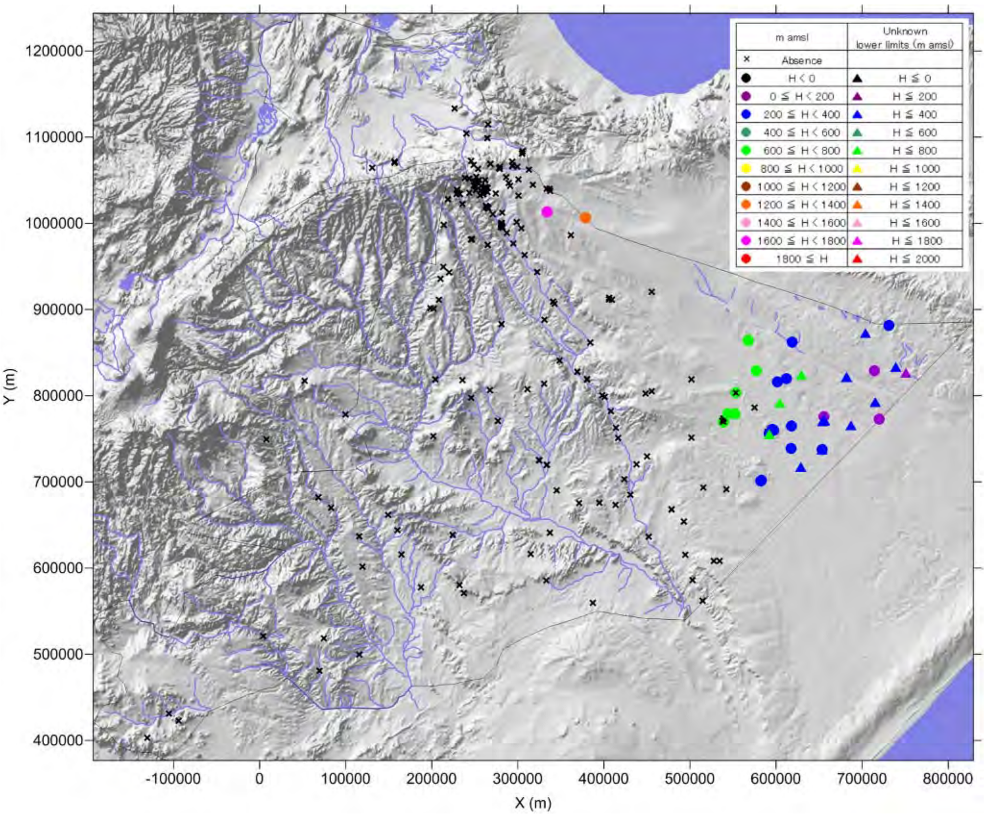


Figure 4.42: Distribution of Bottom Surface Depth of Auradu Aquifer

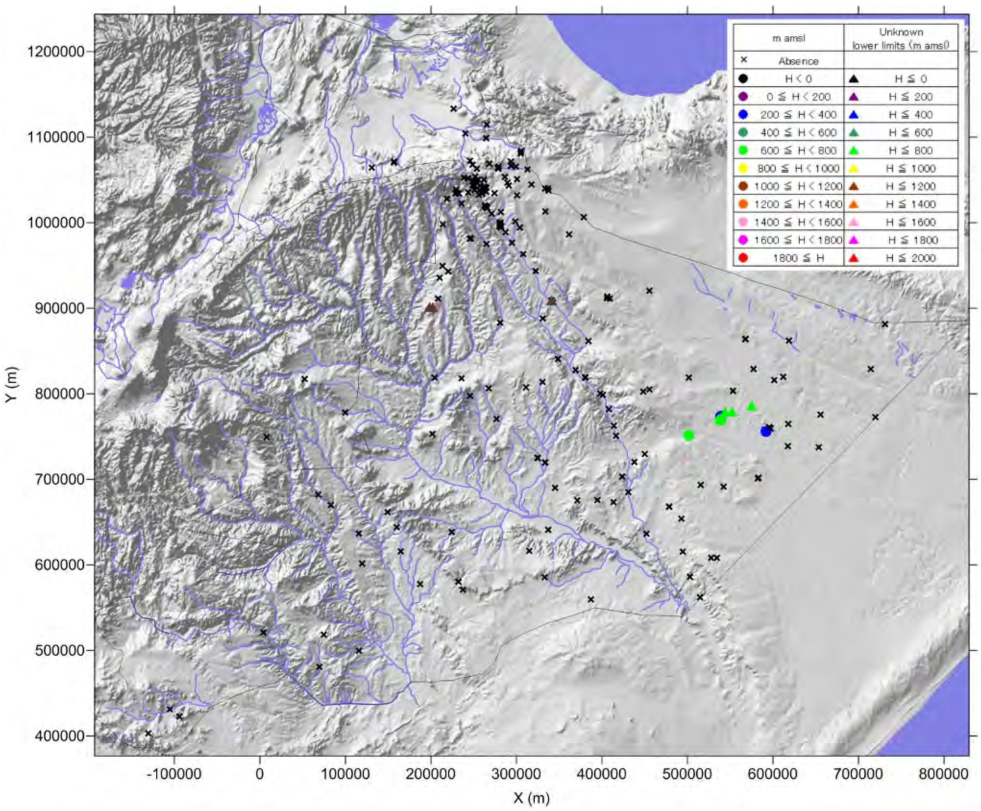


Figure 4.43: Distribution of Bottom Surface Depth of Basalt Aquifer (Old Basalt)

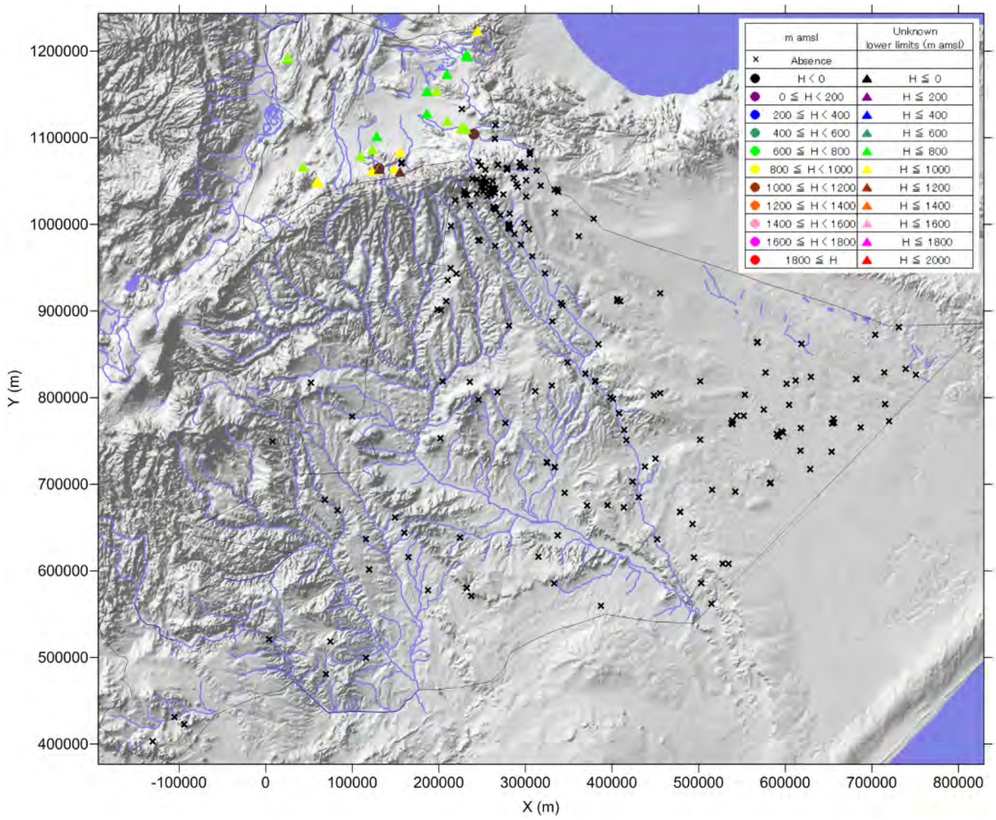


Figure 4.44: Distribution of Bottom Surface Depth of Basalt Aquifer (Recent Basalt)

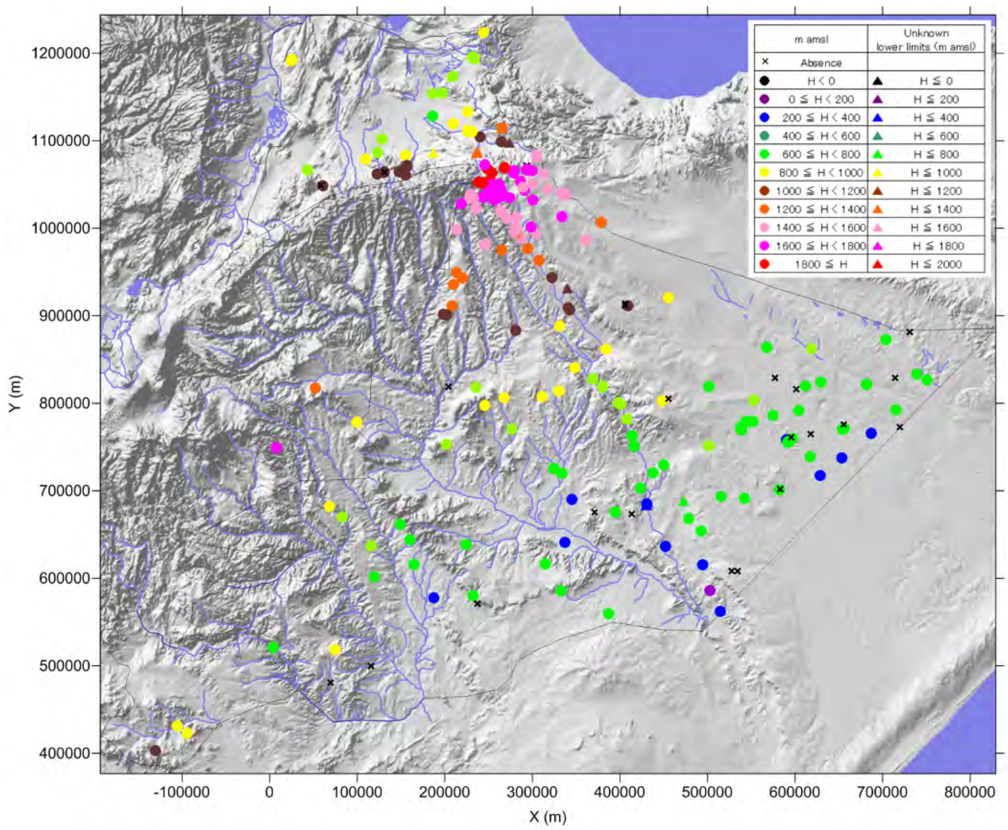


Figure 4.45: Distribution of Bottom Surface Depth of Quaternary Aquifer

4.3 References

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Chapter 5

Water Quality Analysis

5 Water Quality Analysis

5.1 Sampling points selection

The sampling points for water quality analysis are shown in Figure 5.1 and to Table 5.3. Doba Wein woreda is omitted from the sampling area for safety reasons, though this woreda is a target woreda of water supply M/P.

Moreover, three types of water (raw water, treated water and tap water (in the case of level 2 facilities)) are sampled for analysis at points with a water treatment facility.

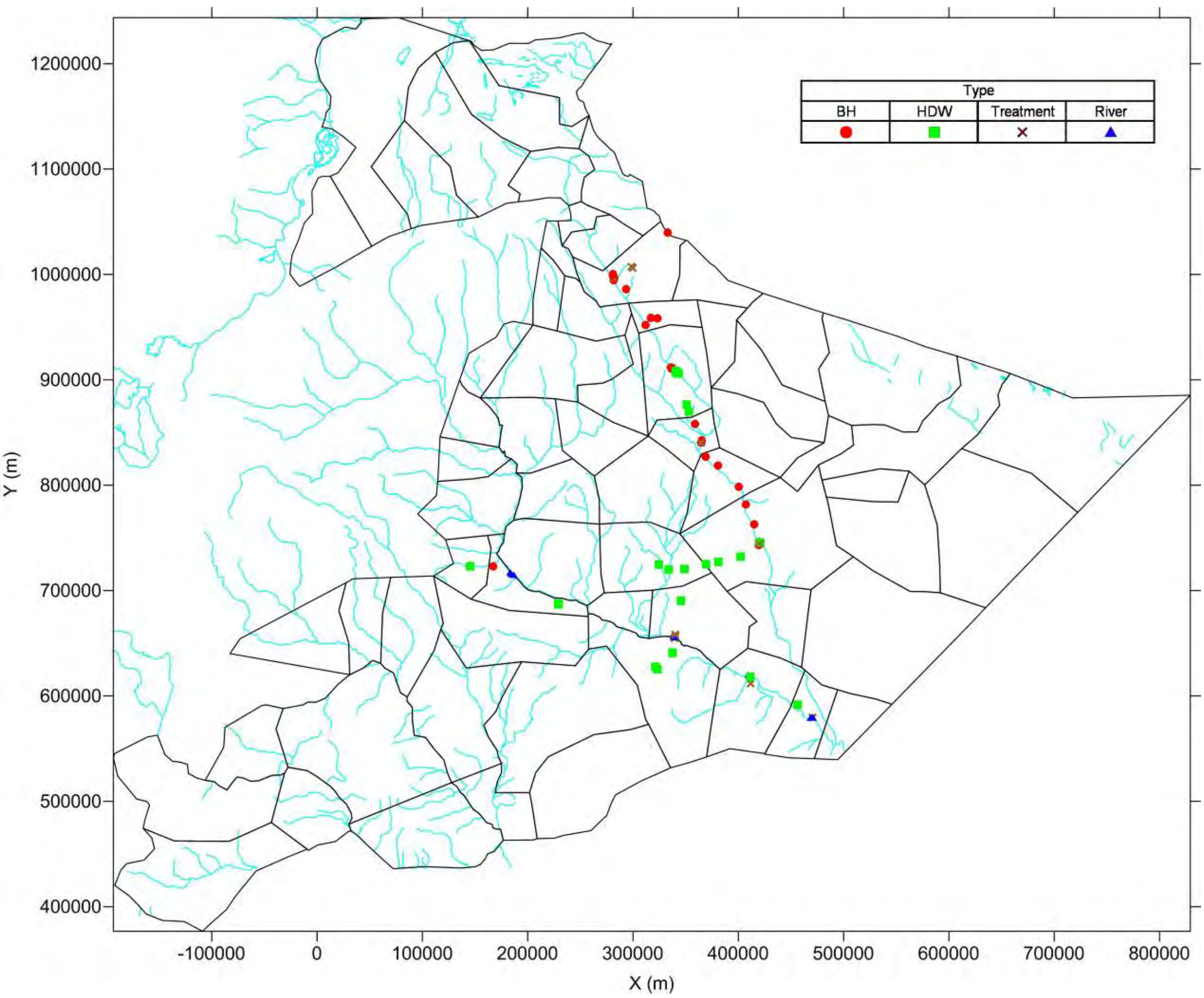


Figure 5.1: Sampling Points for Water Quality Analysis

Table 5.1: Outline of Sampling Points for Water Quality Analysis (1/3)

S/No	Code	Site	Source Type	Kabale	Woreda	Sampling Date	Longitude	Latitude
1	JV001	Qaaxo	BH	Kabribeyah Town	Kabribeyah	5/28/2012	43.01315	8.990637
2	JV002	UNHCR-BH2	BH			5/29/2012	43.00675	9.033903
3	JV003	EB2	BH			5/29/2012	43.01681	9.008257
4	JV004	Treatment	Treatment			6/29/2012	43.01886	9.010175
5	JV005	KB Reserviour	Treatment			5/29/2012	43.16678	9.108825
6	JV006	KB Tap water	Treatment			5/30/2012	43.17947	9.097877

Table 5.2: Outline of Sampling Points for Water Quality Analysis (2/3)

S/No	Code	Site	Source Type	Kabale	Woreda	Sampling Date	Longitude	Latitude
7	JV007	Dameerboob	BH	Alleybadey	Kabribeyah	5/30/2012	43.47856	9.402940
8	JV008a	Alelaleh	BH	Alelaleh		4/6/2012	43.12268	8.916600
9	JV009	Sangumare	BH	Sangumare	Araarso	4/6/2012	43.33764	8.671703
10	JV010	Holjiid	BH	Holjiid		4/6/2012	43.29067	8.609164
11	JV011	Dikrelay BH	BH	Dikrelay BH		4/6/2012	43.39554	8.666236
12	JV012	Towlane	BH	Dagahbur Town	Dagahbur	5/6/2012	43.52682	8.230041
13	JV012a	Towlabe BH8	BH			7/7/2012	43.51130	8.246660
14	JV013	Horwarableh	BH			5/6/2012	43.57342	8.203686
15	JV014	Horwarableh	BH			5/6/2012	43.57241	8.201992
16	JV015	Horwarableh	BH			5/6/2012	43.57335	8.200223
17	JV016	Horwarableh	BH			5/6/2012	43.57437	8.205444
18	JV017	Horwarableh HDW	HDW			5/6/2012	43.57763	8.192841
19	JV018	Horwarable HDW	HDW			5/6/2012	43.57606	8.195358
20	JV019	Horadini HDW	HDW			5/6/2012	43.55771	8.209445
21	JV020	Hormaan HDW	HDW			5/6/2012	43.55673	8.209776
22	JV021	Horwaraable HDW	HDW			6/6/2012	43.57037	8.198087
23	JV022	Horwarable HDW	HDW			6/6/2012	43.57008	8.198285
24	JV023	Horwarable HDW	HDW			6/6/2012	43.56368	8.204104
25	JV024	Horwarable HDW	HDW			6/6/2012	43.56934	8.200236
26	JV025	Hormaan HDW	HDW			6/6/2012	43.55758	8.209833
27	JV026	Hormaan R/Bed	HDW			6/6/2012	43.55695	8.209623
28	JV027	Towlane Res	Treatment			4/6/2012	43.52140	8.242726
29	JV028	Towlane BH3	BH			6/6/2012	43.51657	8.235564
30	JV029	Horwarable HDW	HDW			6/6/2012	43.57303	8.198133
31	JV030	Horwarable HDW	HDW			6/6/2012	43.56509	8.200700
32	JV031	Haro-Yusuf HDW	HDW			6/6/2012	43.55213	8.213458
33	JV032	Haro-Yasuf-HDW	HDW			6/6/2012	43.55158	8.214197
34	JV033	Hodale HDW	HDW	Hodaale		7/6/2012	43.64764	7.928164
35	JV034	Hodale HDW2	HDW			7/6/2012	43.64769	7.928698
36	JV035	Hodaale HDW3	HDW			7/6/2012	43.64797	7.929024
37	JV036	Hodaale HDW3	HDW			7/6/2012	43.64802	7.929088
38	JV037	Sasabane HDW	HDW	Sasabane		7/6/2012	43.66898	7.868204
39	JV038	Bake BH	BH	Baka	Birqot	7/6/2012	43.7214	7.761365
40	JV039	Birkot BH1	BH	Birkot Town		7/6/2012	43.77345	7.602069
41	JV040	Birkot BH2	BH			7/6/2012	43.77650	7.620409
42	JV041	Birkot Res	Treatment			7/6/2012	43.77324	7.602186
43	JV042	Gomar BH	BH	Gomar	Shaygosh	7/6/2012	43.81268	7.481253
44	JV043	Shagosh BH	BH	Shaygosh town		7/6/2012	43.91955	7.406424
45	JV044	Wijiwaji BH	BH	Wijiwaji		8/6/2012	44.09884	7.223387
46	JV045	Galadid BH	BH	Galadid	Kabridahar	8/6/2012	44.16101	7.071279
47	JV046	Karinbilcinle BH	BH	Karinbilcinle		8/6/2012	44.23169	6.902690
48	JV047	Kabridahar BH1	BH	Kabridahar Town		8/6/2012	44.28269	6.735313
49	JV048	Kabridahar BH2	BH			8/6/2012	44.26901	6.720965
50	JV049	Kabridahar BH3	BH			9/6/2012	44.27491	6.747513
51	JV050	K/Dahar HDW1	HDW			9/6/2012	44.27789	6.745346
52	JV051	K/Dahar HDW2	HDW			9/6/2012	44.27854	6.744768
53	JV052	K/Dahar HDW3	HDW			9/6/2112	44.28462	6.743158
54	JV053	K/Dahar Res	Treatment			9/6/2012	44.27707	6.736046
55	JV054	Dalad HDW	HDW	Dalad		10/6/2012	44.11548	6.624454
56	JV055	Kabtinag HDW	HDW	Kabtinag	Kabridahar	10/6/2012	43.92428	6.579478
57	JV056	Lasdhankeyrle HDW	HDW	Lasdhankeyrle		10/6/2012	43.81938	6.560384
58	SB001	Danbarweyne HDW	HDW	Danbarweyne	Danan	10/6/2012	43.63270	6.517993
59	SB002	Koore HDW1	HDW	Koore		11/6/2012	43.41272	6.551983
60	SB003	Koore HDW2	HDW	Koore		11/6/2012	43.41418	6.554763
61	SB004	Danan HDW	HDW	Danan Town		11/6/2012	43.49640	6.510506
62	SB005	Hadhawe HDW	HDW	Hadhawe	Godey	11/6/2012	43.60365	6.242139
63	SB006	Gode Intake (River)	RIVER	Godey Town		11/6/2012	43.54671	5.923539
64	SB007	River	RIVER			11/6/2012	43.54480	5.926446
65	SB008	River	RIVER			11/6/2012	43.53997	5.928875
66	SB009	River	RIVER			11/6/2012	43.54154	5.932949
67	SB010	Clear Water Gode	Treatment			11/6/2012	43.54761	5.923804
68	SB011	Agriculture Tap Water Gode	Treatment			16/6/2012	43.55913	5.938023
69	SB012	Agriculture Clear Water	Treatment			16/6/2013	43.55213	5.922983
70	SB013	Agriculture Intake (River)	RIVER			16/6/2014	43.55116	5.922275
71	SB014	Kalafo Intake (River)	RIVER	Kalafo Town	Kalafo	16/6/2015	44.19996	5.587188
72	SB015	Kalafo Clera Water	Treatment			12/6/2012	44.20104	5.588718

Table 5.3: Outline of Sampling Points for Water Quality Analysis (3/3)

S/No	Code	Site	Source Type	Kabale	Woreda	Sampling Date	Longitude	Latitude
73	SB016	Kalafo Tap Water	Treatment	Kalafo Town	Kalafo	12/6/2012	44.20299	5.533606
74	SB017	River	RIVER			13/6/2012	44.19626	5.591615
75	SB018	River	RIVER			13/6/2012	44.19260	5.592361
76	SB019	River	RIVER			13/6/2012	44.18262	5.598580
77	SB020	Kalafo HDW	HDW			13/6/2012	44.19976	5.590951
78	SB021	Mustahil Intake (River)	RIVER	Mustahil Town	Mustahil	14/6/2012	44.73387	5.241222
79	SB022	Mustahil Clear Water	Treatment			14/6/2012	44.73376	5.241539
80	SB023	Mustahil Tap Water	Treatment			14/6/2012	44.73376	5.241684
81	SB024	River	RIVER			14/6/2012	44.73352	5.239476
82	SB025	River	RIVER			14/6/2012	44.73155	5.23725
83	SB026	River	RIVER			14/6/2012	44.71619	5.230938
84	SB027	Kunaso HDW	HDW	Kunaso		15/6/2012	44.60693	5.353248
85	SB028	Adadle HDW1	HDW	Adadle	Adadle	17/6/2012	43.53263	5.793873
86	SB029	Adadle HDW2	HDW			17/6/2012	43.53150	5.798347
87	SB030	Gode Tap Water	Treatment	Godey Town	Godey	17/6/2012	43.55352	5.956683
88	SB031	River	RIVER	West-Ime	West Ime	20/6/2012	42.14716	6.456044
89	SB032	River	RIVER			20/6/2012	42.14757	6.459326
90	SB033	River	RIVER			20/6/2012	42.13420	6.471421
91	SB034	Bula BH	BH	Bula		20/6/2012	41.02133	7.510862
92	SB035	Raaso BH	BH	Raaso	Raaso	20/6/2012	41.02015	7.312984
93	SB036	Raaso HDW	HDW			20/6/2012	41.79504	6.530456
94	SB037	River	RIVER	East Ime	East Ime	22/6/2012	42.16685	6.449982
95	SB038	River	RIVER			22/6/2012	42.16586	6.450122
96	SB039	River	RIVER			22/6/2012	42.16834	6.449792
97	SB040	River	RIVER			22/6/2012	42.16874	6.449677
98	SB041	Laab HDW1	HDW	Laab	Beercaano	22/6/2012	42.55444	6.209163
99	SB042	Laab HDW2	HDW			22/6/2012	42.55209	6.217079
100	SB043	Biroleys HDW1	HDW	Biroleys	Adadle	26/6/2012	43.40299	5.654632
101	SB044	Biroleys HDW2	HDW			26/6/2012	43.38513	5.678248
102	JICABH1	JICA Well No.-1	BH	Kabribeyah	Kabribeyah	5/8 2012	43.0087	9.0435
103	JICABH2	JICA Well No.-2	BH	Kabribeyah	Kabribeyah	27/7 2012	43.0054	9.0420

Note: No 102 and 103 are the wells that were drilled in this study

5.2 Parameters and methodology of water quality analysis, quality control

Water quality work was conducted by sub-contractor (executing agency: SHAAC Consulting Company, analysis agency: Haramaya University).

Field analysis parameters by simple method (analysis kits: PACK TEST, portable measuring meter of pH and EC, etc.) are as follows.

- Temperature, Electric Conductivity (EC), pH, Iron, Mn, F, Nitric acid (HNO_3), As, NH_4, COD, Residual chlorine, Coliform, General bacteria（Total 13 items）

Meanwhile, the following parameters were analyzed by Haramaya University laboratory by the methods of water analysis was shown in Table 5.4.

- Turbidity, Total Dissolved Solids (TDS), Suspended Solids (SS), pH, Electric Conductivity (EC), Total hardness ($CaCO_3$), Ca, Mg, K, Na, Fe, Mn, Cl, SO_4, NO_3, Alkalinity (CO_3^{2-}, HCO_3^-), F, T-P, Ammonium ion (NH_3+NH_4)（Total 21 items）

Table 5.4: Methods of Water Analysis for Each Parameter

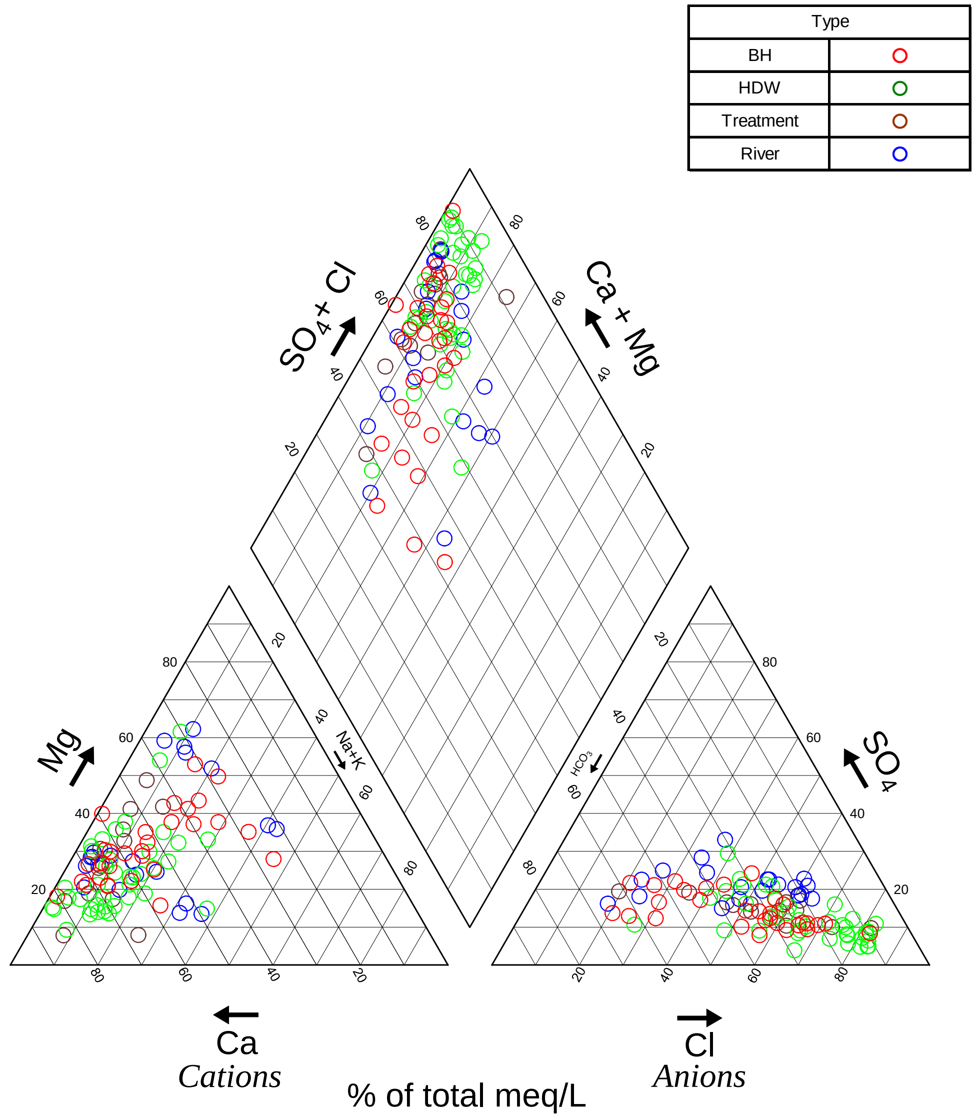
S.N	**Parameters**	**Methods**
1	Turbidity (FTU)	Nephlometric Method
2	TDS (ppm)	HI 9635 Portable Waterproof Multi-Range Conductivity/TDS meter
3	TSS (mg/l)	APHA, 1992
4	pH	APHA, 1998: Electrometric method
5	EC(mS/cm)	APHA, 1998: Electrometric method
6	Hardness (mg/l $CaCO_3$)	APHA, 1998: EDTA Titrimetric method
7	Ca(ppm)	EPA Method # 215.1. AAS
8	Mg(ppm)	EPA Method # 242.1. AAS
9	K(ppm)	APHA, 1998: Flame photometerric Method
10	Na(ppm)	APHA, 1998: Flame photometric Method
11	Fe(ppm)	EPA Method # 236.1. AAS
12	Mn(ppm)	EPA Method # 243.1. AAS
13	Cl^-(ppm)	APHA, 1998: Argentometric method
14	SO_4^{2-}(ppm)	APHA, 1998: Turbidimetric Method
15	NO_3^-(ppm)	APHA, 1998: UV spectrophotometric screening method
16	Alkalinity (CO_3^{2-} and HCO_3^-) meq/l	APHA, 1998: Titration Method
17	F^- (mg/l)	Ion selective electrode Method
18	T.P (ppm)	EPA Method # 365.4Colorimetric Method
19	NH_4^+(ppm)	APHA, 1998: Phenate Method

5.3 Results of water quality analysis

5.3.1 Trilinear diagrams showing interpretation results

The results of chemical analysis by laboratory are attached in the Data Book, and trilinear diagrams are shown in Figure 5.2 to Figure 5.6.

The table appended in the Data Book shows the water type of an individual sample. Moreover, the characteristics of the water type in the target area are discussed in a comprehensive method with the results shown in hexadiagrams in the next section.



Trilinear Diagram (ALL DATA)

The Study on Jarar Valley and Shebele Sub-basin Water Supply Development Plan, and Emergency Water Supplyin in the Federal Democratic Republic of Ethiopia

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Figure 5.2: Trilinear Diagram (All Data)

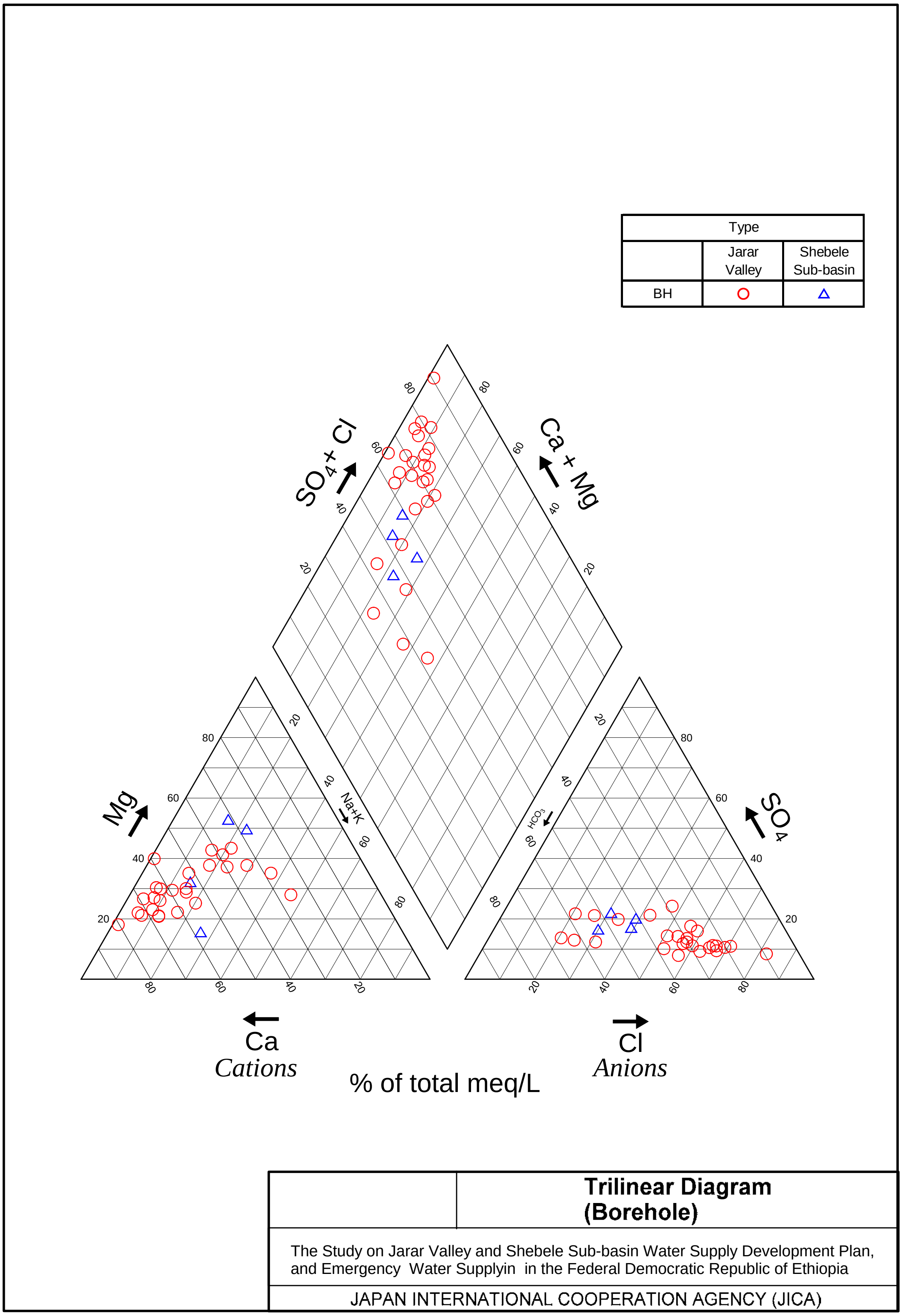


Figure 5.3: Trilinear Diagram (Borehole Data)

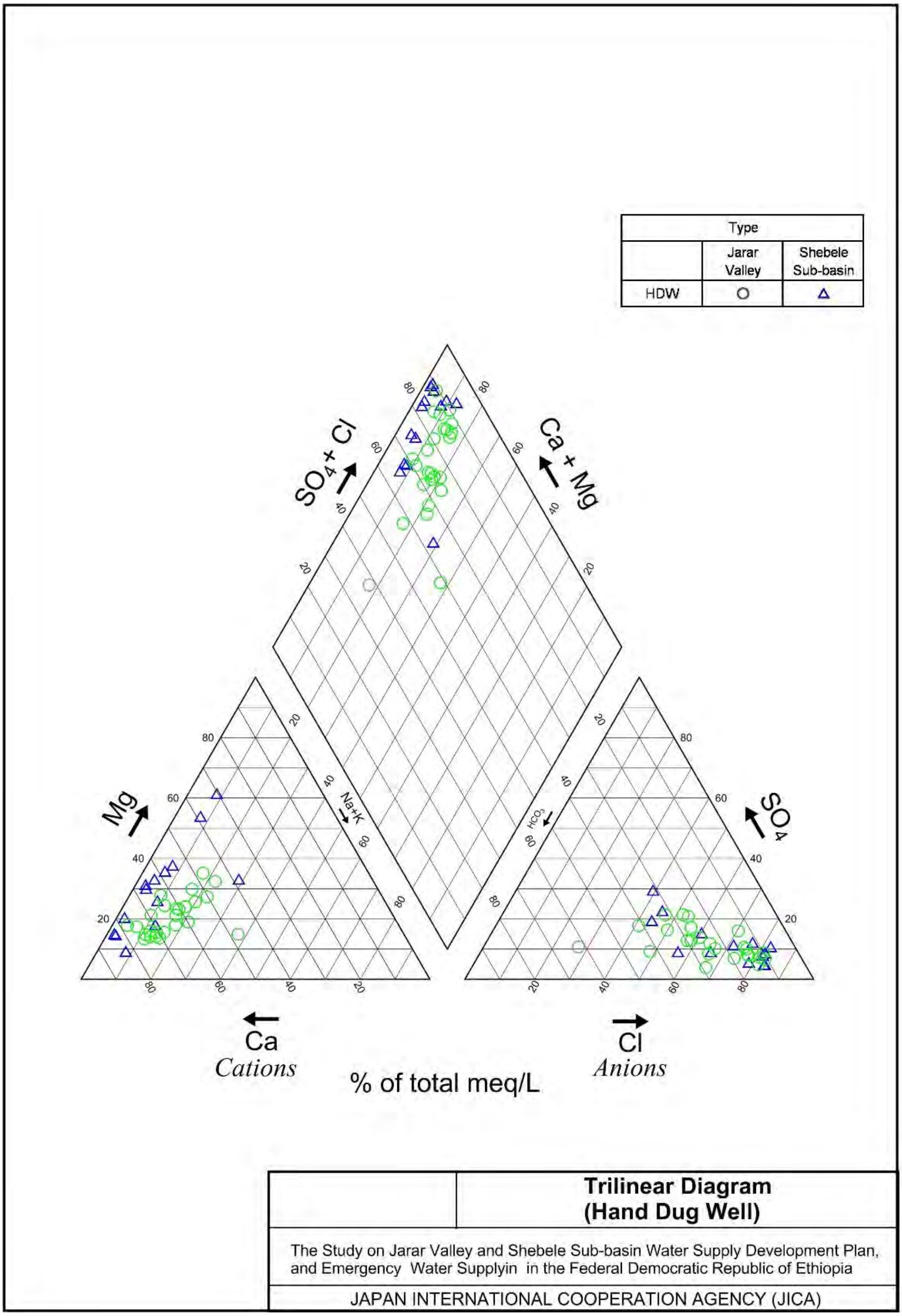


Figure 5.4: Trilinear Diagram (Hand-dug Well Data)

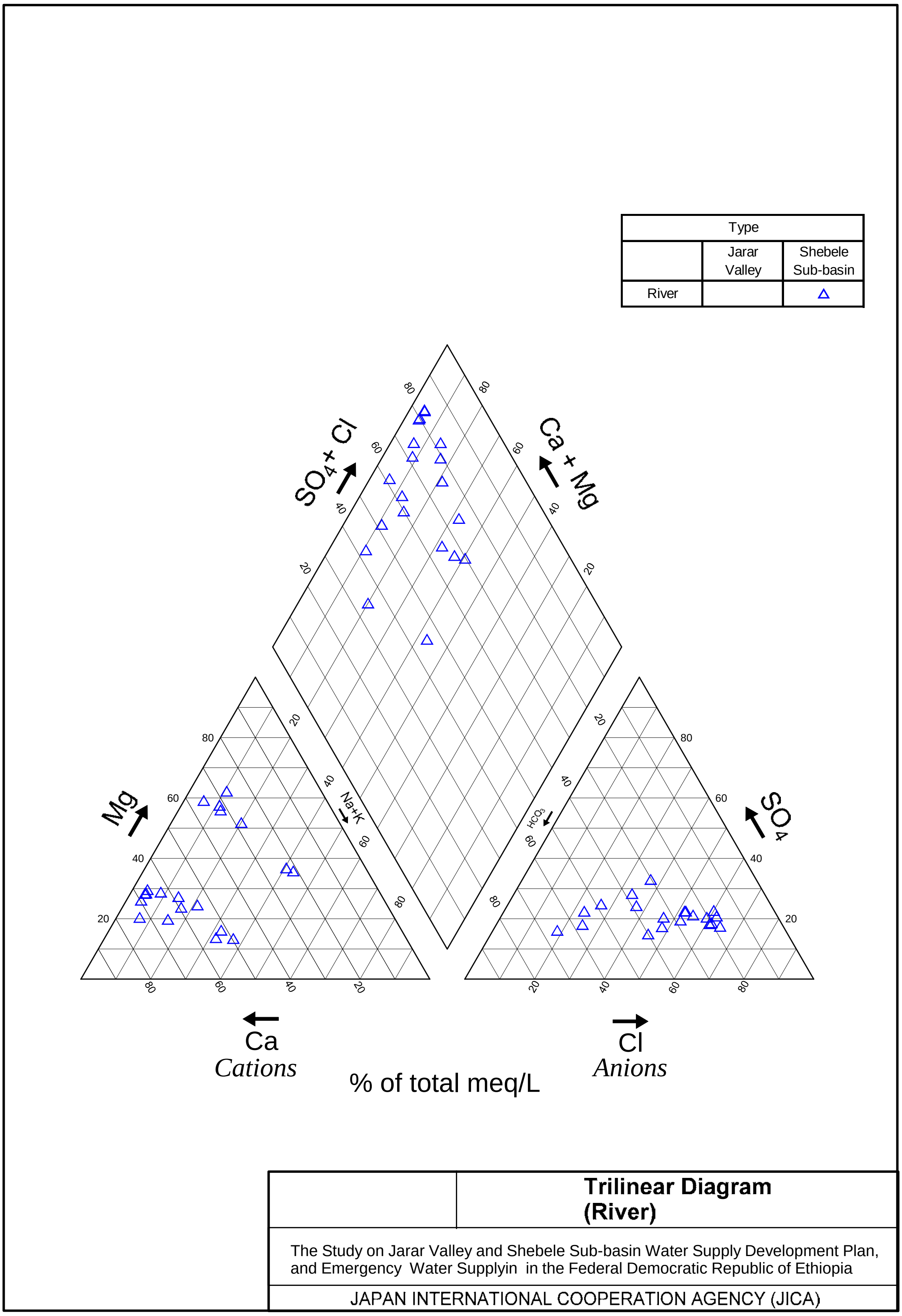
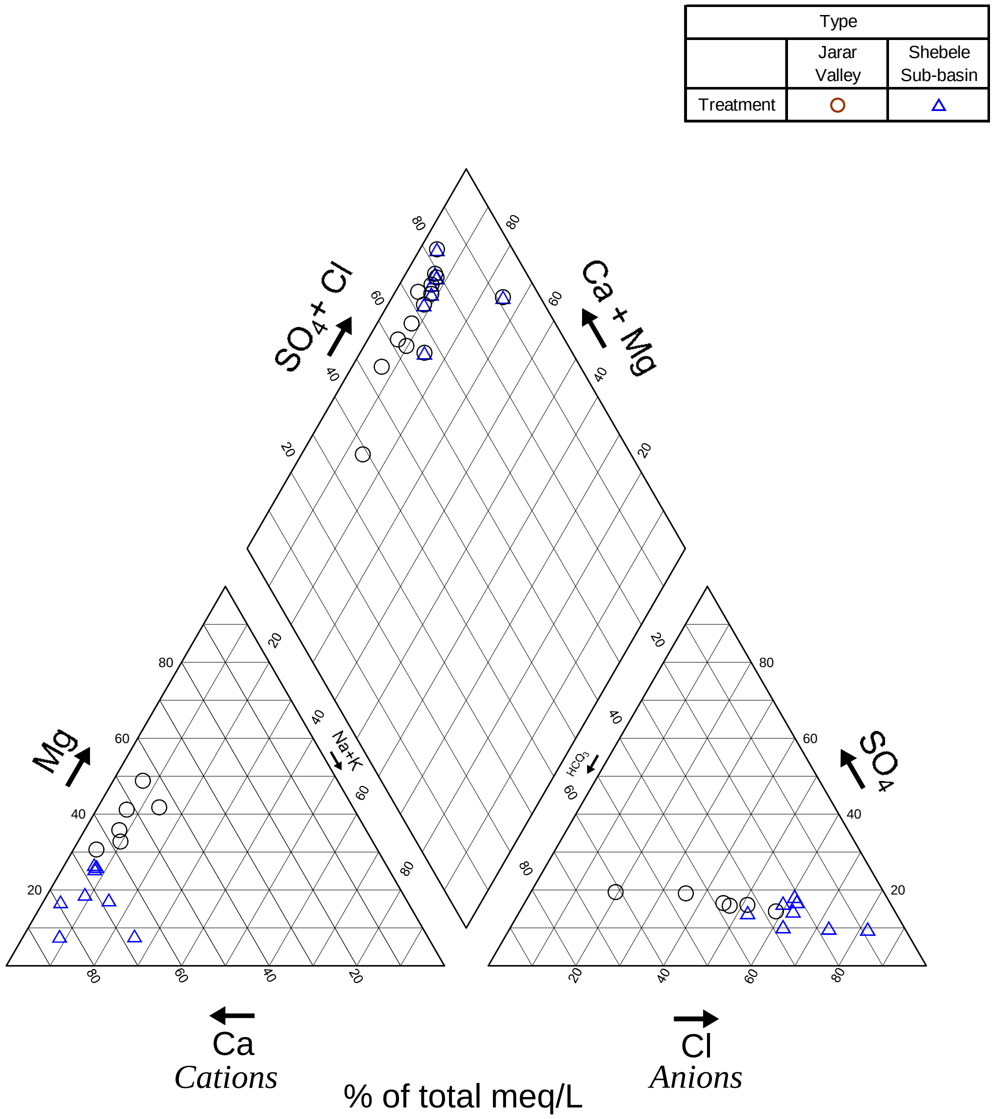


Figure 5.5: Trilinear Diagram (River Data)



Trilinear Diagram (Treatment Water)

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Figure 5.6: Trilinear Diagram (Treated Water Data)

5.3.2 Hexadiagrams showing interpretation results

As mentioned in the previous section, the results of chemical analysis by laboratory are attached in the Data Book, and hexadiagrams are shown in Figure 5.7 to Figure 5.11.

The water type of the analysis samples is summarized as follows by the result of characteristics of trilinear diagram in the previous section and hexadiagram.

- 25% of water samples have a water type of Ca-Mg type water (25 samples) 17% of the samples are Ca-Mg-Cl type water (17 samples), and 17% are Ca-Mg-Na-Cl type water, hence almost 60% of the water samples was dominated by Ca-Mg, Ca-Mg-Cl, and Ca-Mg-Na-Cl water types.
- The water type of the boreholes was dominated by Ca-Mg-Na-Cl water type (9 samples, 32.14%) and Ca-Mg-Cl water type (6 samples, 21.43%).
- The water type of the hand-dug wells was dominated by Ca-Mg water type (11 samples, 28.12%), Ca-Mg-Cl water type (10 samples, 25.64%) and Ca-Mg-Na-Cl water type (6 samples, 15.38%).
- The water type of river water was dominated by Ca-Mg water type (6 samples, 30%) and Ca-Mg- SO_4 water type (4 samples, 20%).

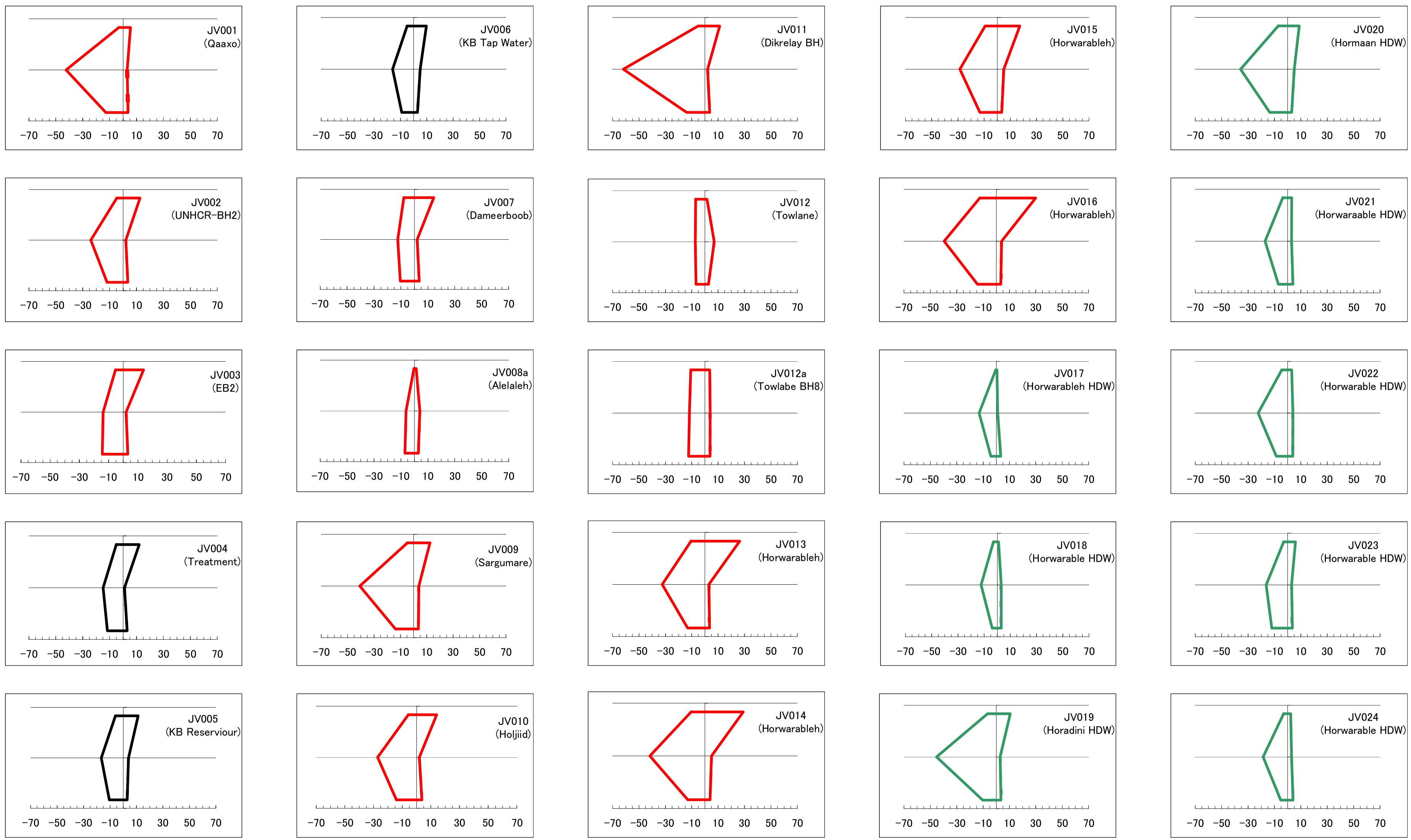


Figure 5.7: Hexadiagrams (1/5)

Figure 5.8: Hexadiagrams (2/5)

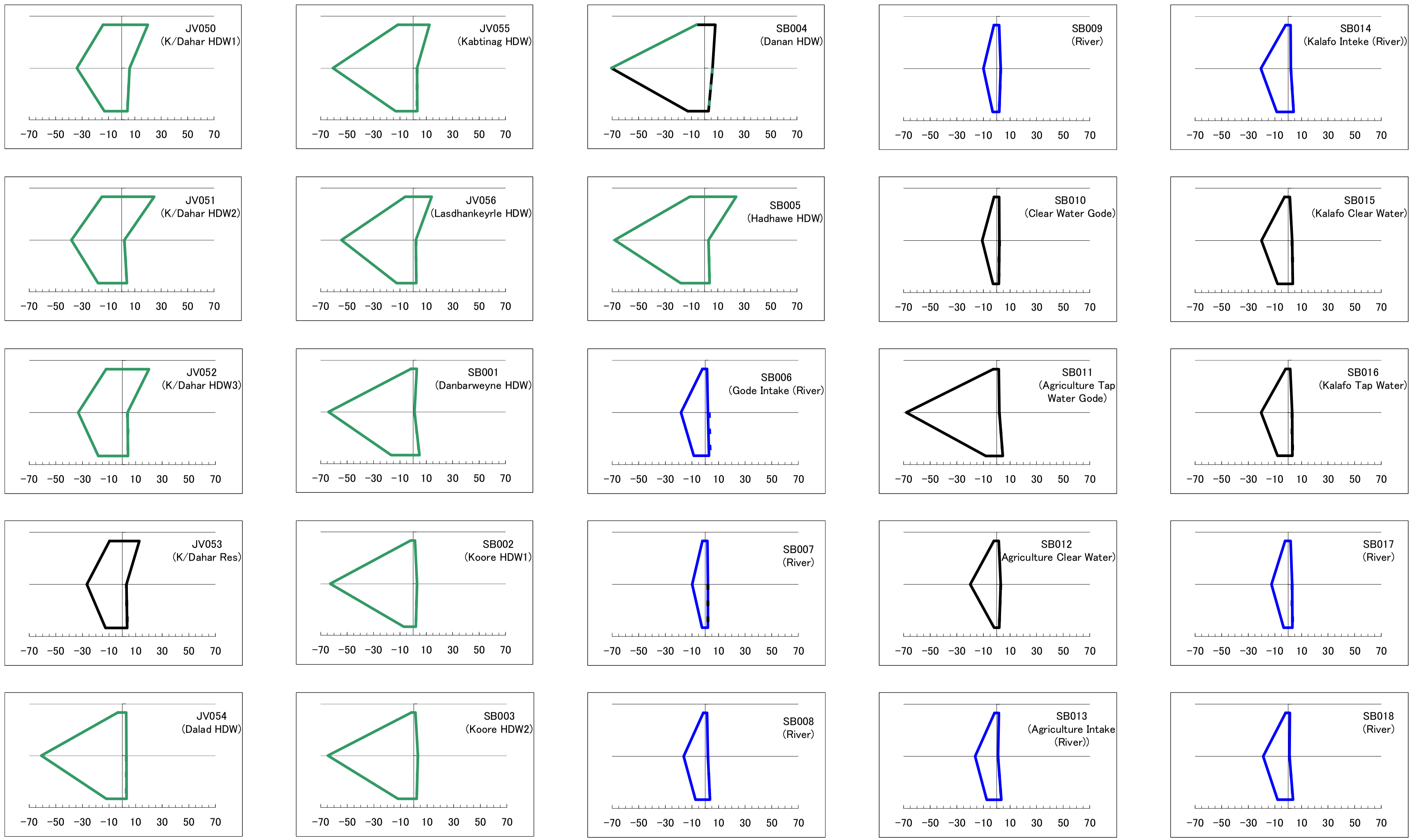


Figure 5.9: Hexadiagrams (3/5)

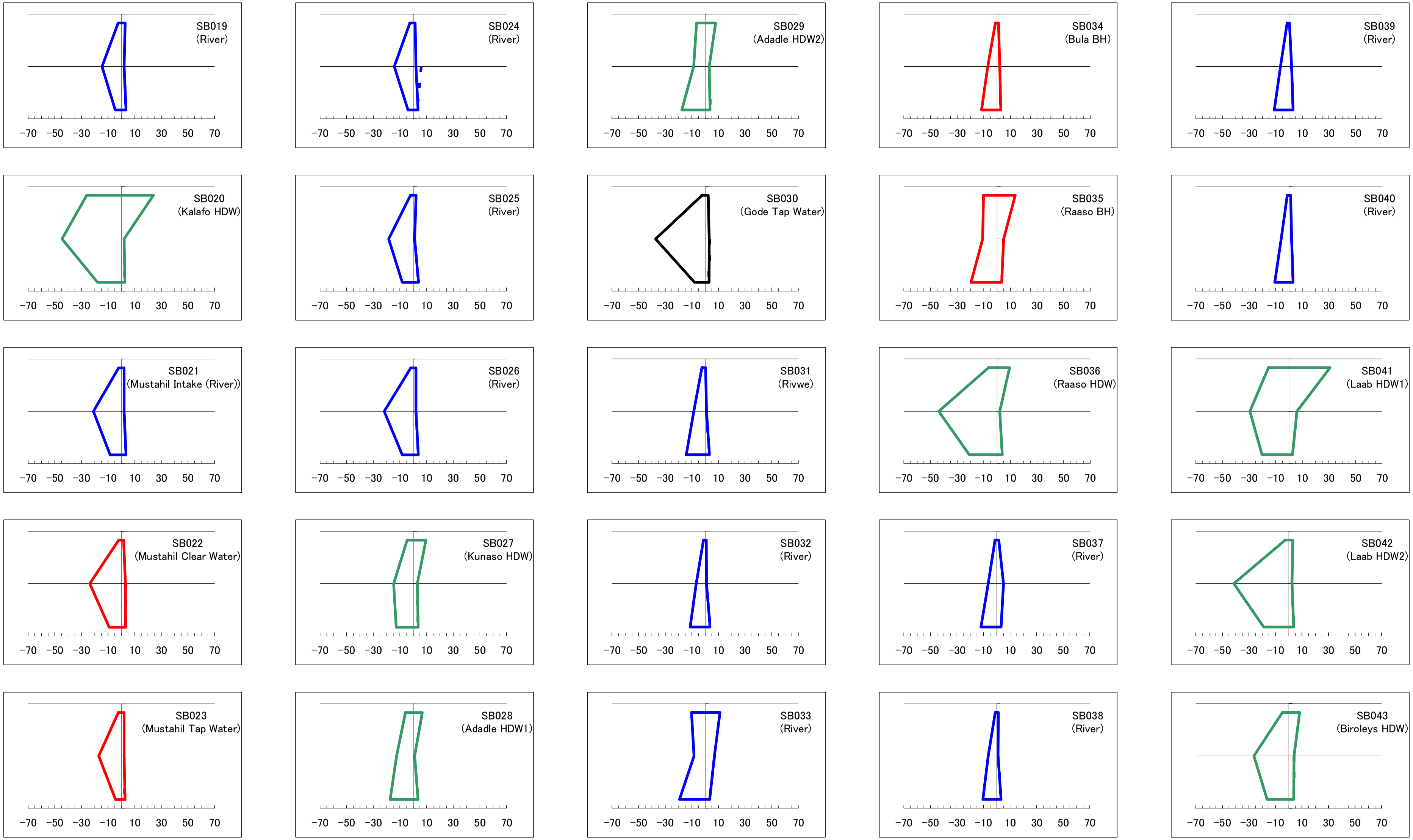
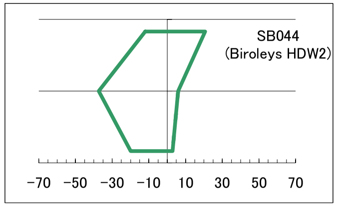
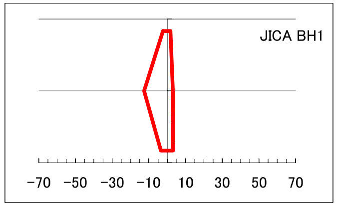
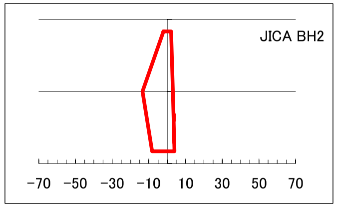
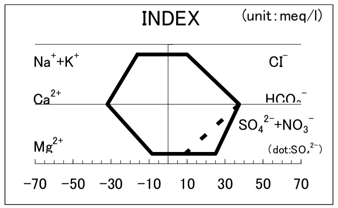


Figure 5.10: Hexadiagram (4/5)









(Red: Borehole water, Green: Hand-dug well water, Blue: River water, Black: Treated water)

Figure 5.11: Hexadiagrams (5/5)

5.4 Evaluation of water quality

5.4.1 Interpretation of the results for water quality standard

a. Water quality standard

The comparison between the water quality analysis results and “WHO Guidelines for drinking-water quality” and “Ethiopian Guidelines” is discussed in the following and also shown in Figure 5.12 to Figure 5.23.

a.1 Ammonium (NH_4)

The maximum acceptable level of ammonium ion under WHO standards is 1.5 mg/l and that of Ethiopian drinking water standard is 2 mg/l. Only one (Araarso woreda) borehole exceeded the concentration of 1.5 mg/l, and two samples (Dhagahbur and Beercaano woredas) of the hand-dug wells exceeded the WHO standard. Samples from both rivers and treatment plants have no problem of high NH_4 concentration.

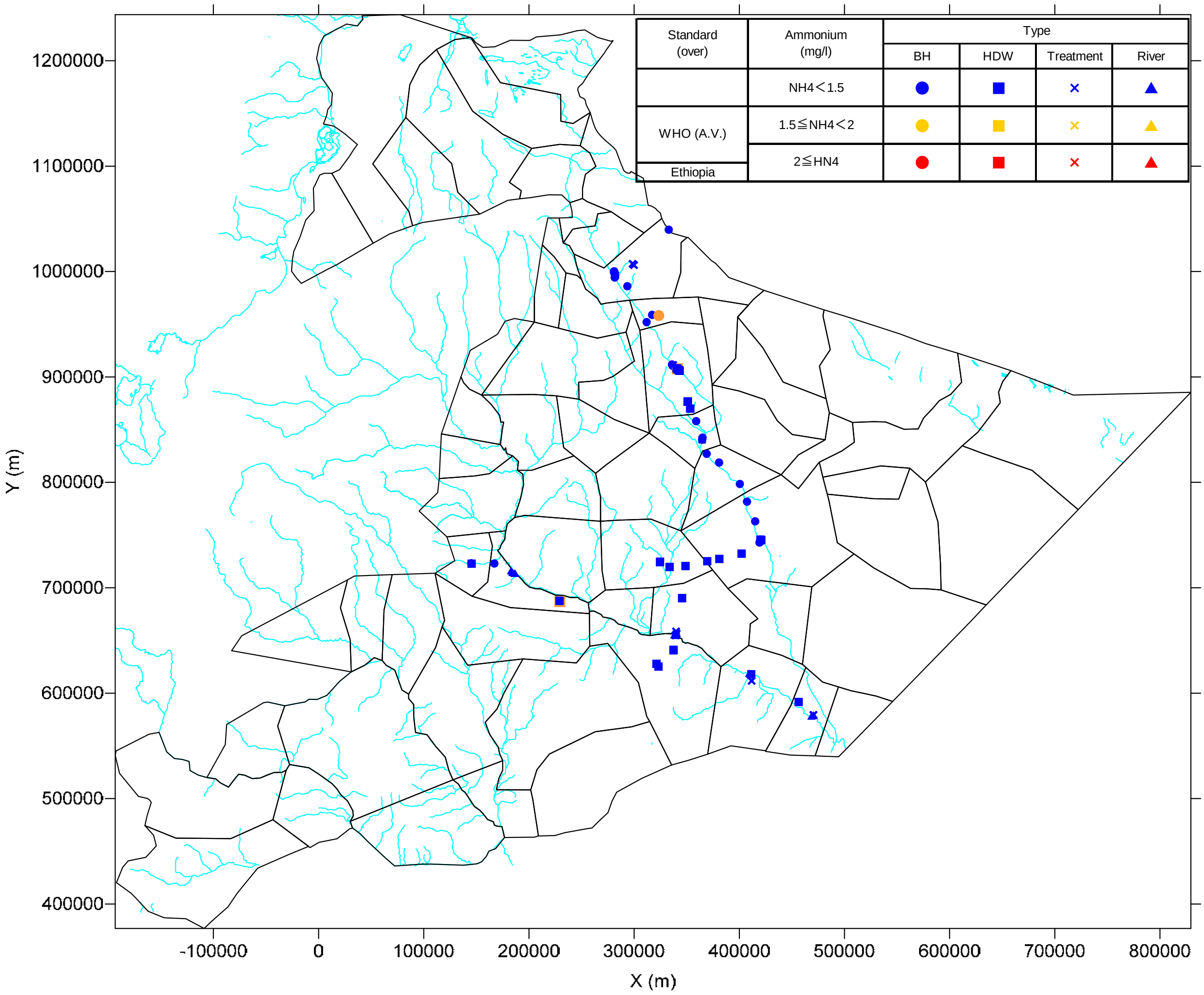


Figure 5.12: Ammonium Concentration Map

a.2 Sulfate (SO_4)

The maximum acceptable level of sulfate under WHO standards is 250 mg/l and that of Ethiopian drinking water standard is 483 mg/l. All the water samples complied with the WHO standards.

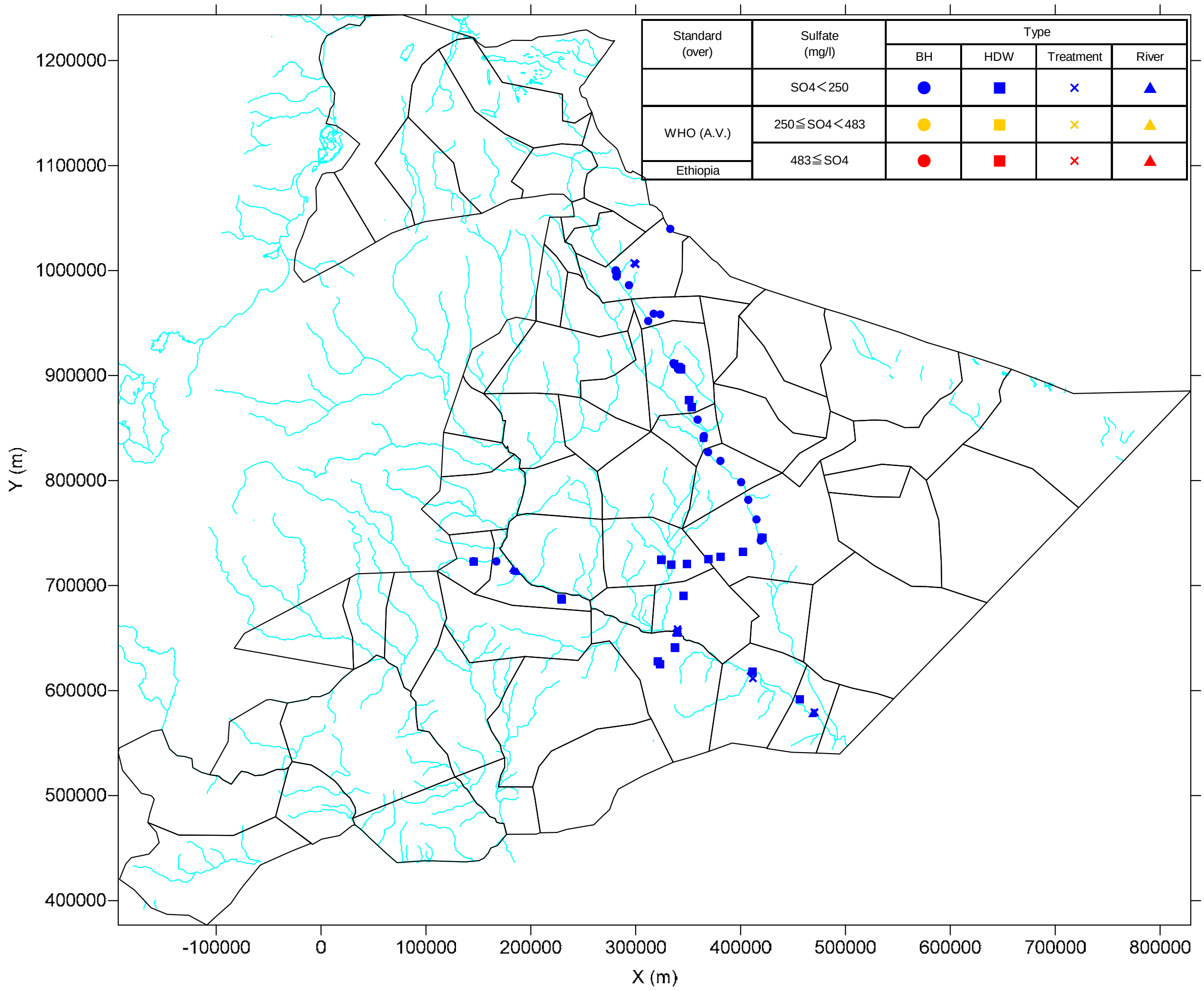


Figure 5.13: Sulfate Concentration Map

a.3 Nitrate (NO_3)

Based on the Ethiopian and WHO standards, the maximum acceptable concentration of Nitrate (NO_3) is 50 mg/l. In the study area, NO_3 values of both groundwater and surface waters were very low.

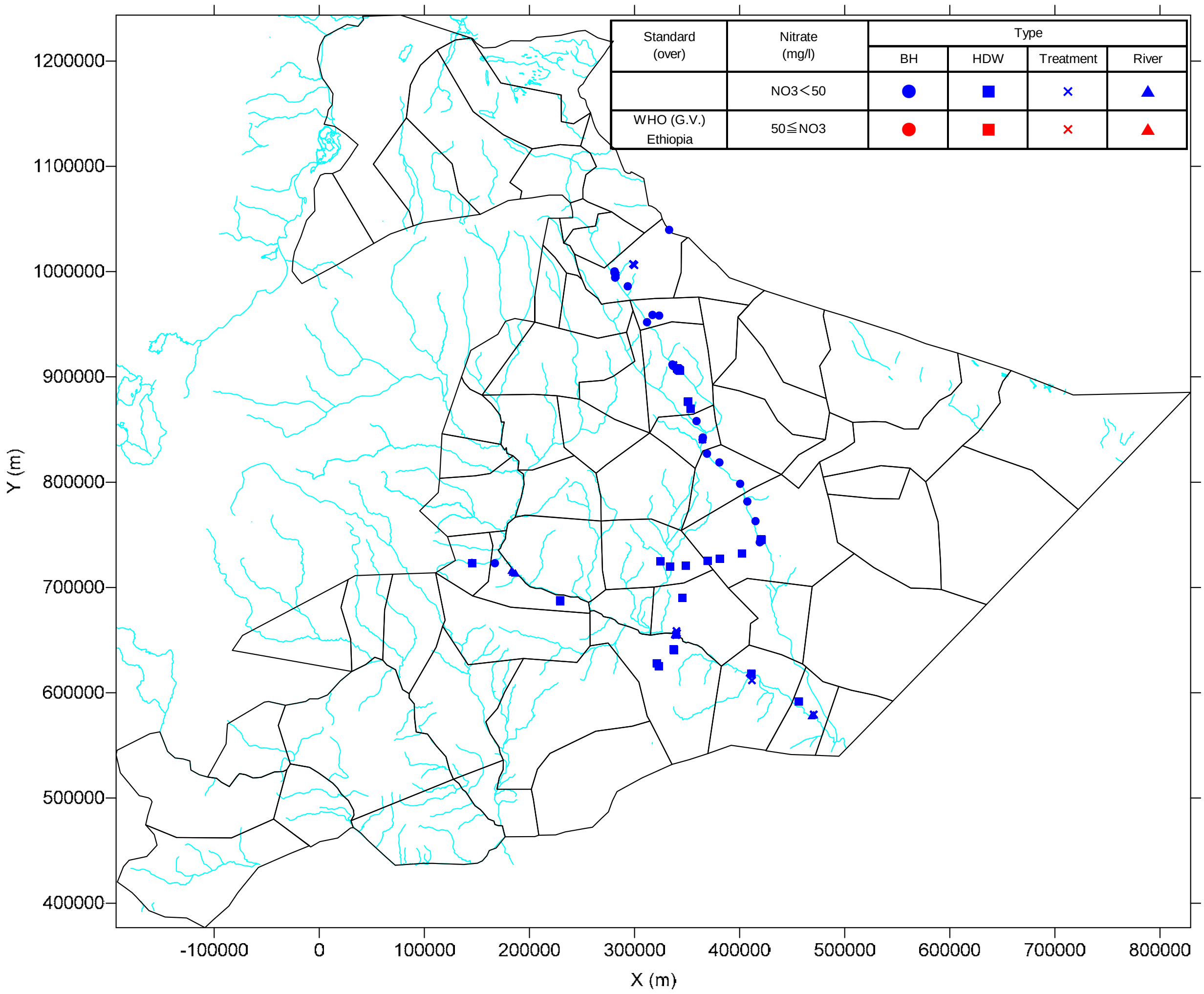


Figure 5.14: Nitrate Concentration Map

a.4 Turbidity

According to WHO guidelines for drinking water, 5 NTU is the maximum acceptable limit for turbidity. 12 boreholes (40% of the total 30 wells) complied with the WHO requirement and the remaining 47% exceeded the WHO standard. Similarly, 56% of the samples from hand-dug wells complied with the WHO standard and 57% of samples collected from the treatment plant complied with the drinking water standard. In rivers, 95% (19 out of 20 samples) exceeded the WHO acceptable value.

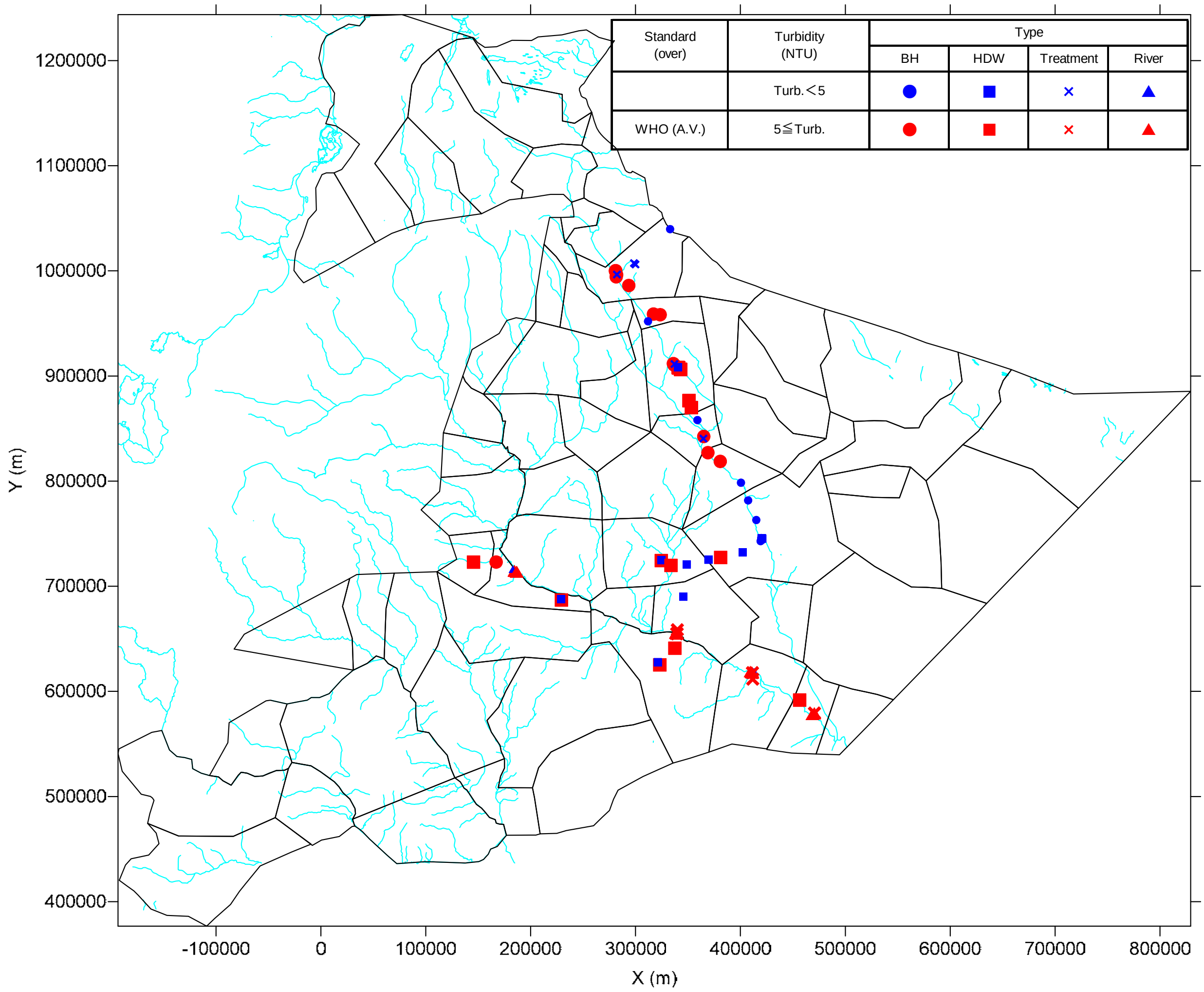


Figure 5.15: Turbidity Concentration Map

a.5 Fluoride (F)

WHO standard for fluoride is 1.5 mg/l and that of Ethiopian drinking water standard is 3.0 mg/l. The maximum concentration of 1.84 mg/l (Birqod woreda) was detected from the boreholes, and maximum concentration of 2.007 mg/l was found from HDW in Rasso woreda. As for river water samples, the maximum concentration of Fluoride of 2.141 mg/l was found in sample water from Ime. In the tributary of Shebele River, samples collected from water resources in East Ime, West Ime and Rasso woredas indicated high concentrations of Fluoride, which is indicative of the presence of Fluoride bearing formations in these areas.

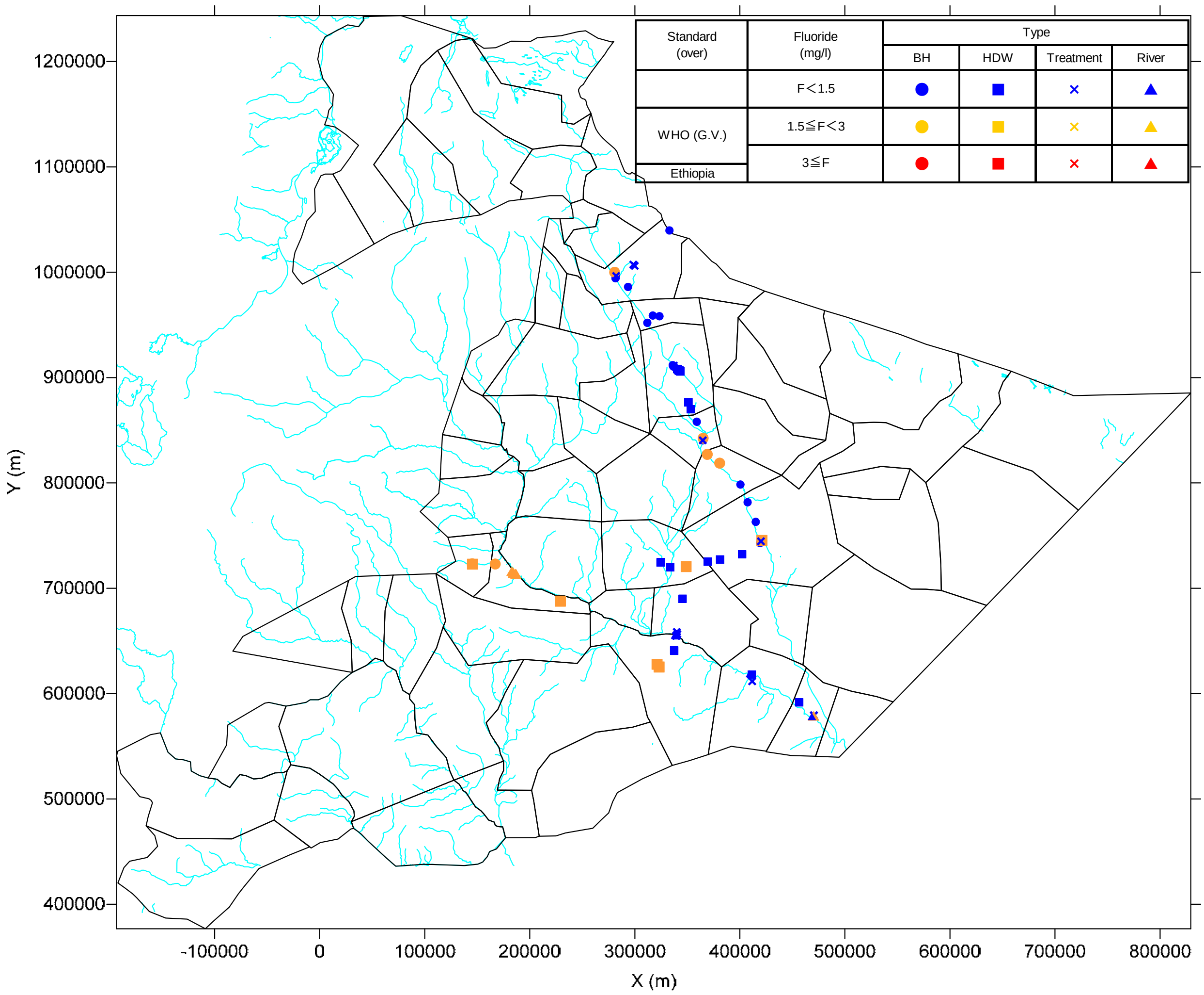


Figure 5.16: Fluoride Concentration Map

a.6 TDS

Maximum acceptable level of WHO for TDS is 1,000 mg/l and that of Ethiopian drinking water standard is 1,776 mg/l. Only 20% of the water samples of boreholes were below the WHO maximum acceptable limit and water samples of 8% hand-dug wells were below WHO acceptable value. Only one sample (West Ime woreda) of river water indicated below 1,000 mg/l, and five samples of the treatment plant exceeded the WHO standard.

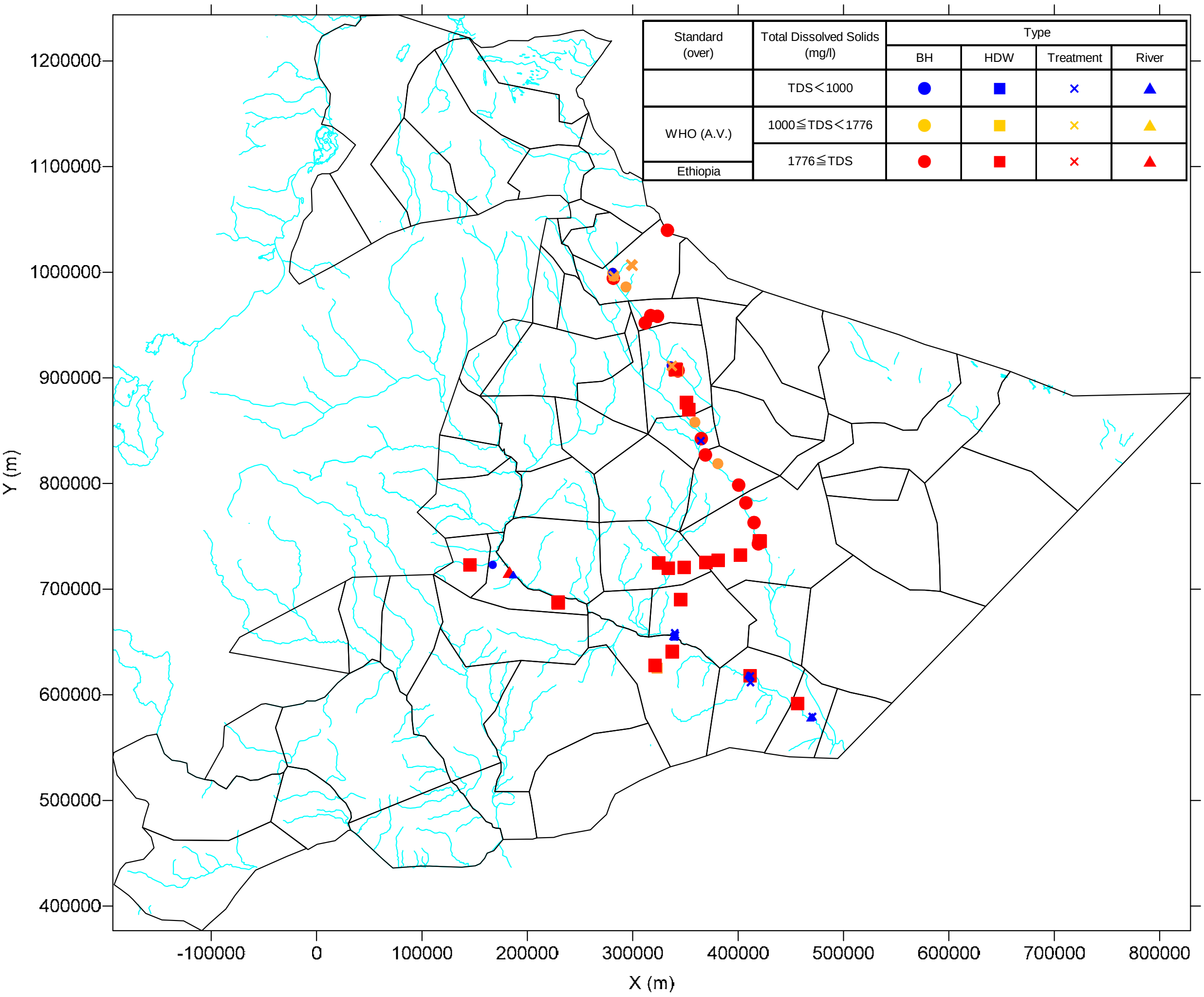


Figure 5.17: TDS Concentration Map

a.7 pH

All the water samples were found to be within the acceptable range of pH in terms of both WHO and Ethiopian water standard guidelines.

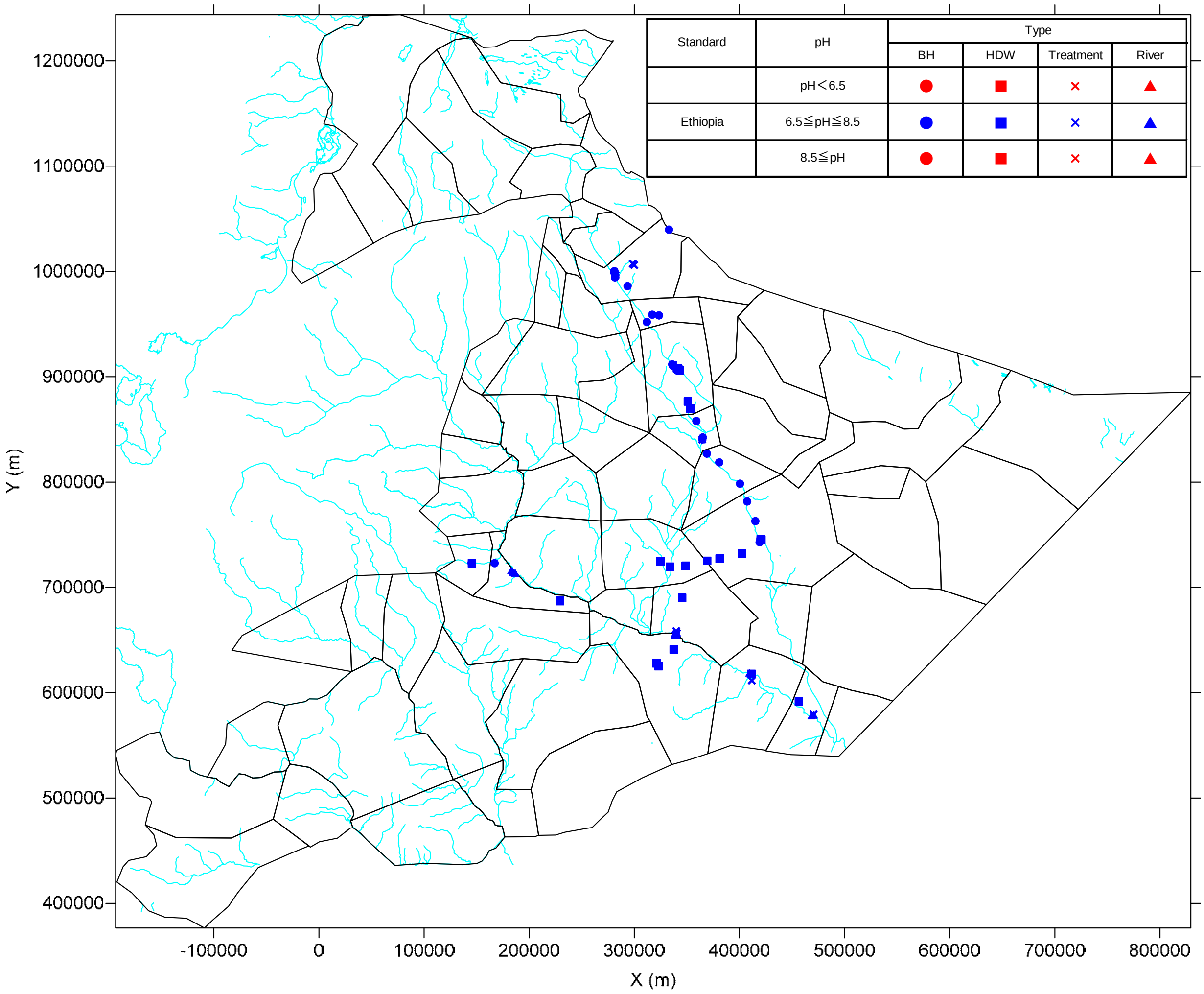


Figure 5.18: pH Concentration Map

a.8 Chloride (Cl)

Maximum acceptable Chloride level under WHO standards is 250 mg/l and that of Ethiopian drinking water standards is 533 mg/l. Ten (10) boreholes (33% of the total 30 boreholes) complied with the WHO requirement and 19 hand-dug wells (49% out of total 39) exceeded the WHO standard. As for river water, one (1) sample indicated above 392 mg/l value, and four samples of the treatment plant exceeded the WHO standard.

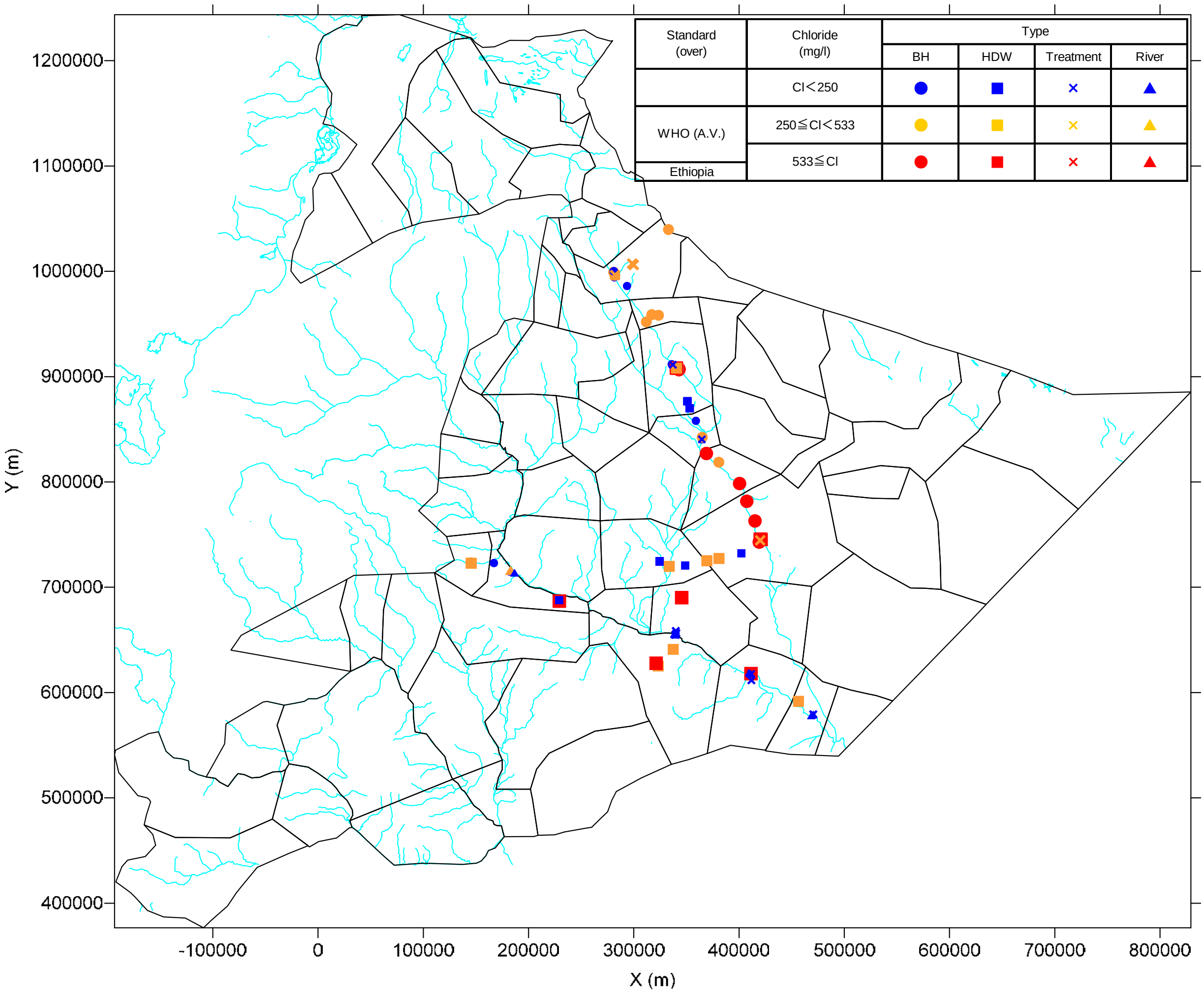


Figure 5.19: Chloride Concentration Map

a.9 Sodium (Na)

WHO acceptable value of Na is 200 mg/l and that of Ethiopian Drinking Water Guideline limit of 358 mg/l. It was found that 13 samples from the boreholes (43%) exceeded the WHO standard and all samples (100%) complied with the Ethiopian guideline. For hand-dug wells, only 74% of the water samples complied with the WHO standard, and both river samples and the treated water samples except one sample respectively (more than 200mg/l) complied with both the Ethiopian and WHO standard.

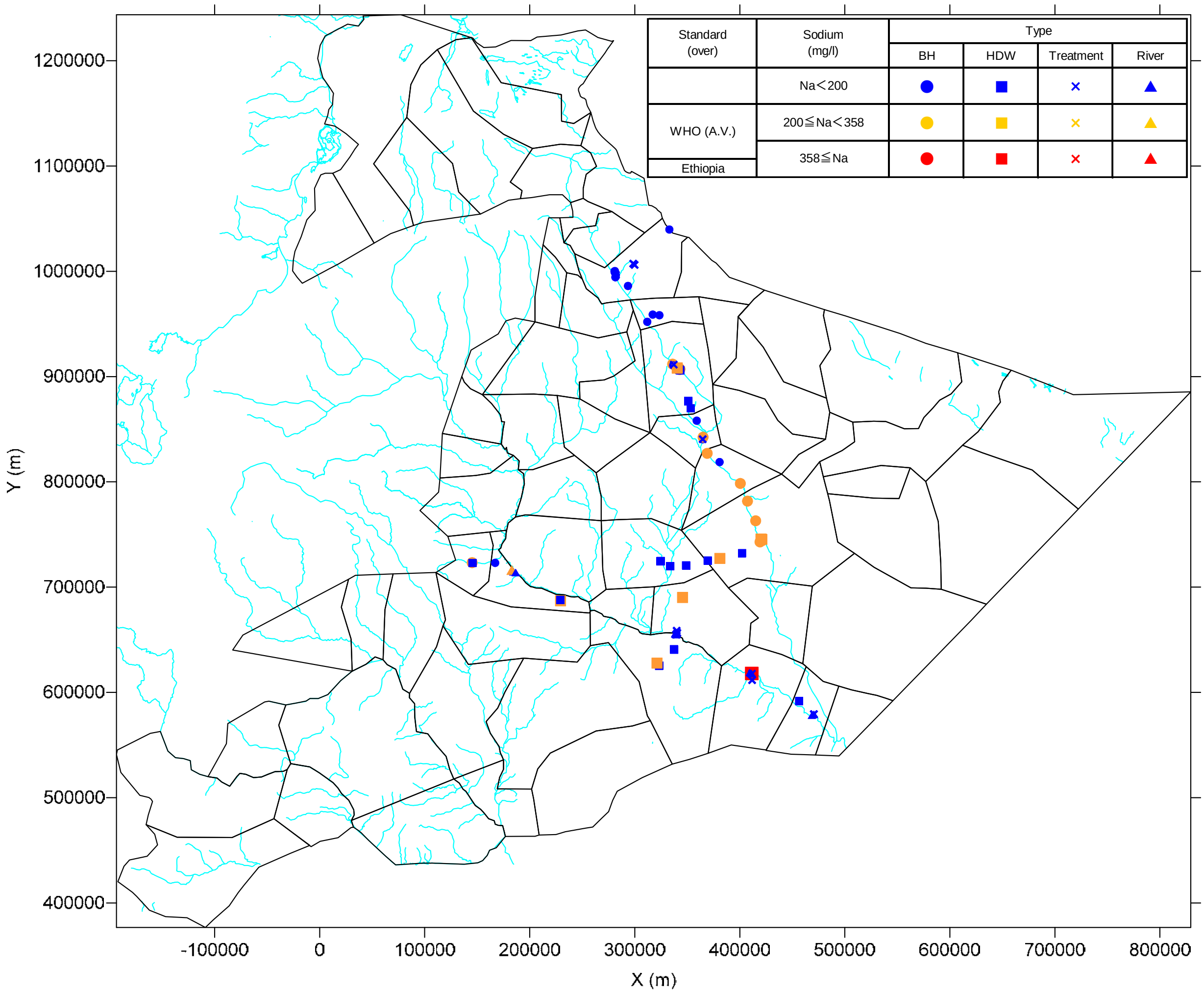


Figure 5.20: Sodium Concentration Map

a.10 Manganese (Mn)

Maximum acceptable level of Manganese under WHO standards is 0.1 mg/l (guideline value 0.4mg/l) and that of Ethiopian drinking water standard is 0.13 mg/l. As for boreholes, two wells (Araarso and Dagahbur woredas) exceeded the Ethiopian standard. Eight samples of hand-dug wells did not comply with the Ethiopian standard. Both river and treatment plant samples have no problem for manganese concentration.

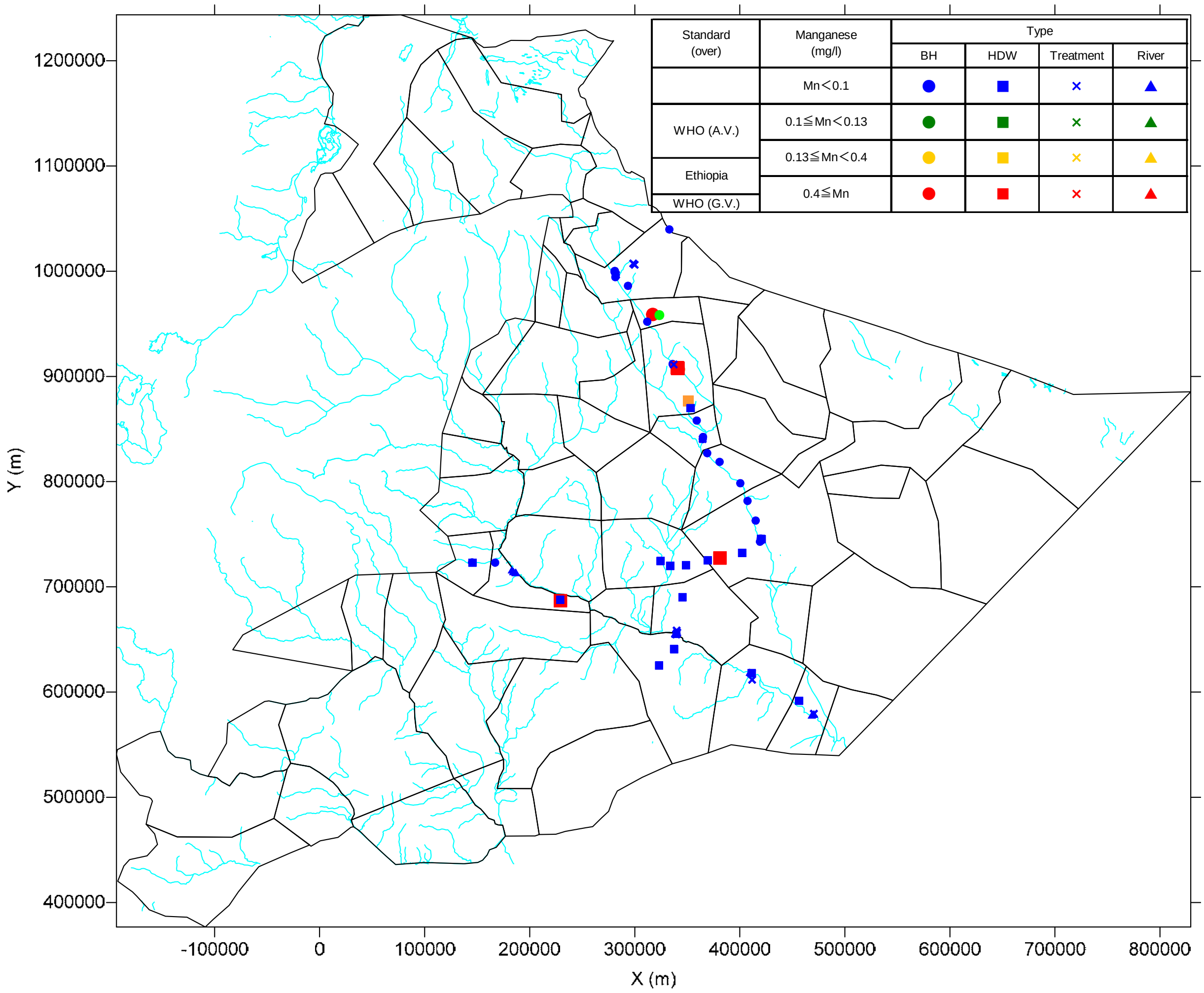


Figure 5.21: Manganese Concentration Map

a.11 Iron (Fe)

Maximum acceptable level of Iron under WHO standards is 0.3 mg/l and that of Ethiopian drinking water standard is 0.4 mg/l. As for boreholes, six wells exceeded the WHO standard, and five samples of hand-dug wells did not comply with the WHO standard. 35% of river samples exceeded the WHO standard for Iron. All the water samples of treatment system complied with the WHO standard (compliance level is 100%).

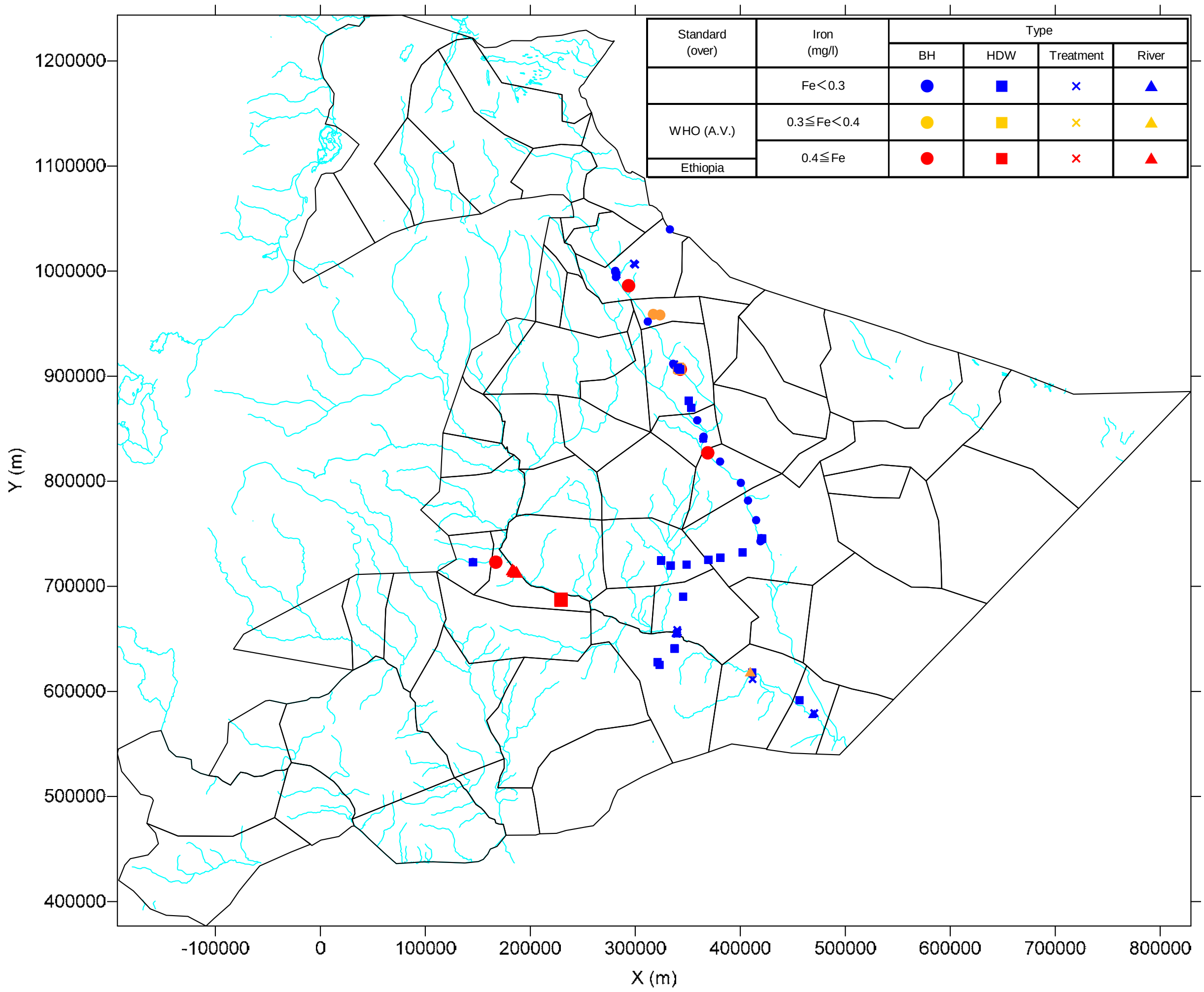


Figure 5.22: Iron Concentration Map

a.12 Hardness ($CaCO_3$)

The Ethiopian drinking water standard of hardness ($CaCO_3$) is 392 mg/l. 93% of boreholes exceeded the Ethiopian drinking water standard. All samples from hand-dug wells also did not comply with the Ethiopian standard. Six samples of river water exceeded the Ethiopian standard, and treatment plant samples have the highest compliance level of 29%.

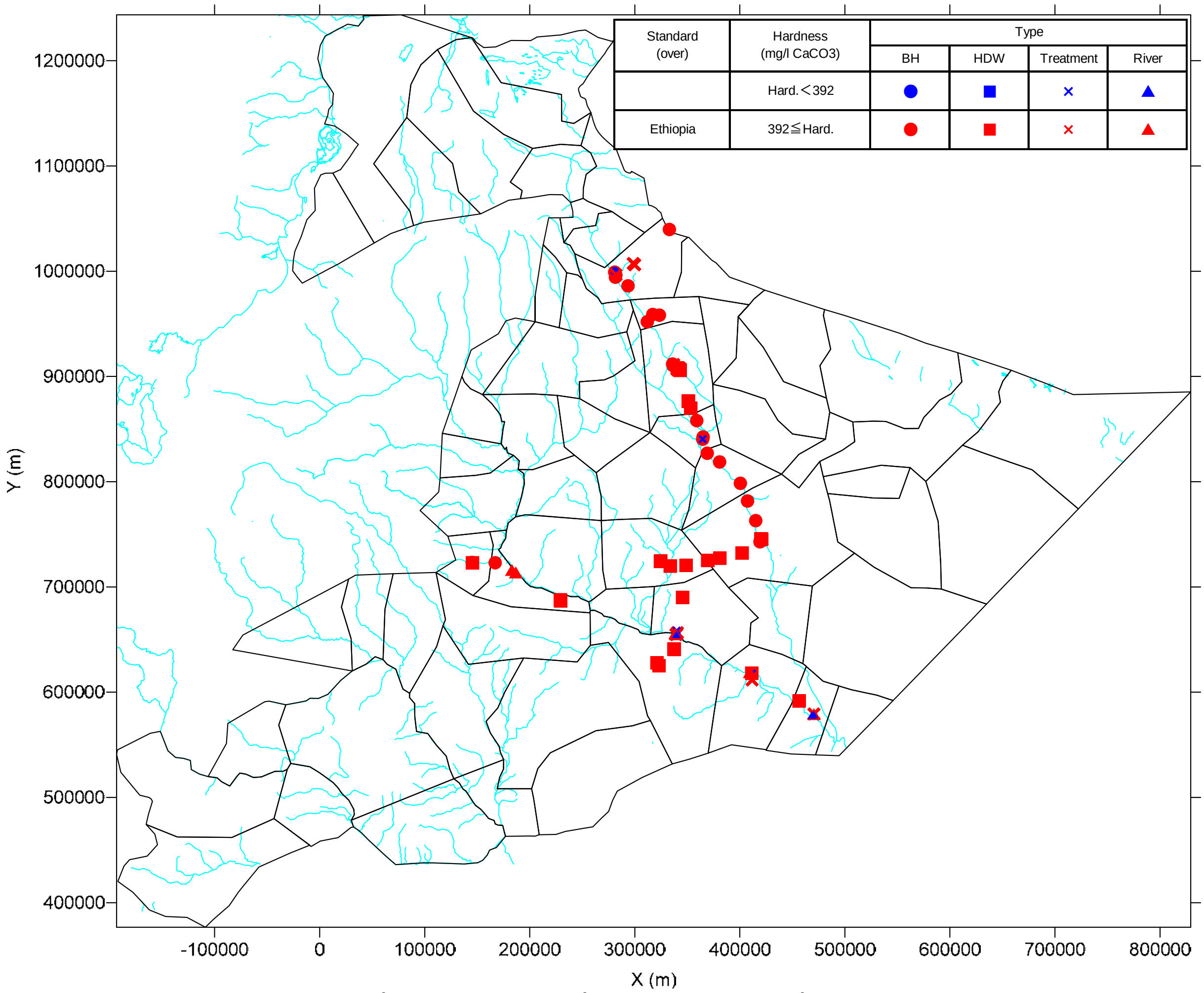


Figure 5.23: Hardness Concentration Map

5.4.2 Interpretation of the results of the cluster analysis

The result of the cluster analysis of main ions (Ca, Mg, Na, K, Cl, HCO_3, SO_4, NO_3) is shown in Figure 5.24 and Figure 5.25. The classification based on the water source and based on the cluster is attached in the Data Book.

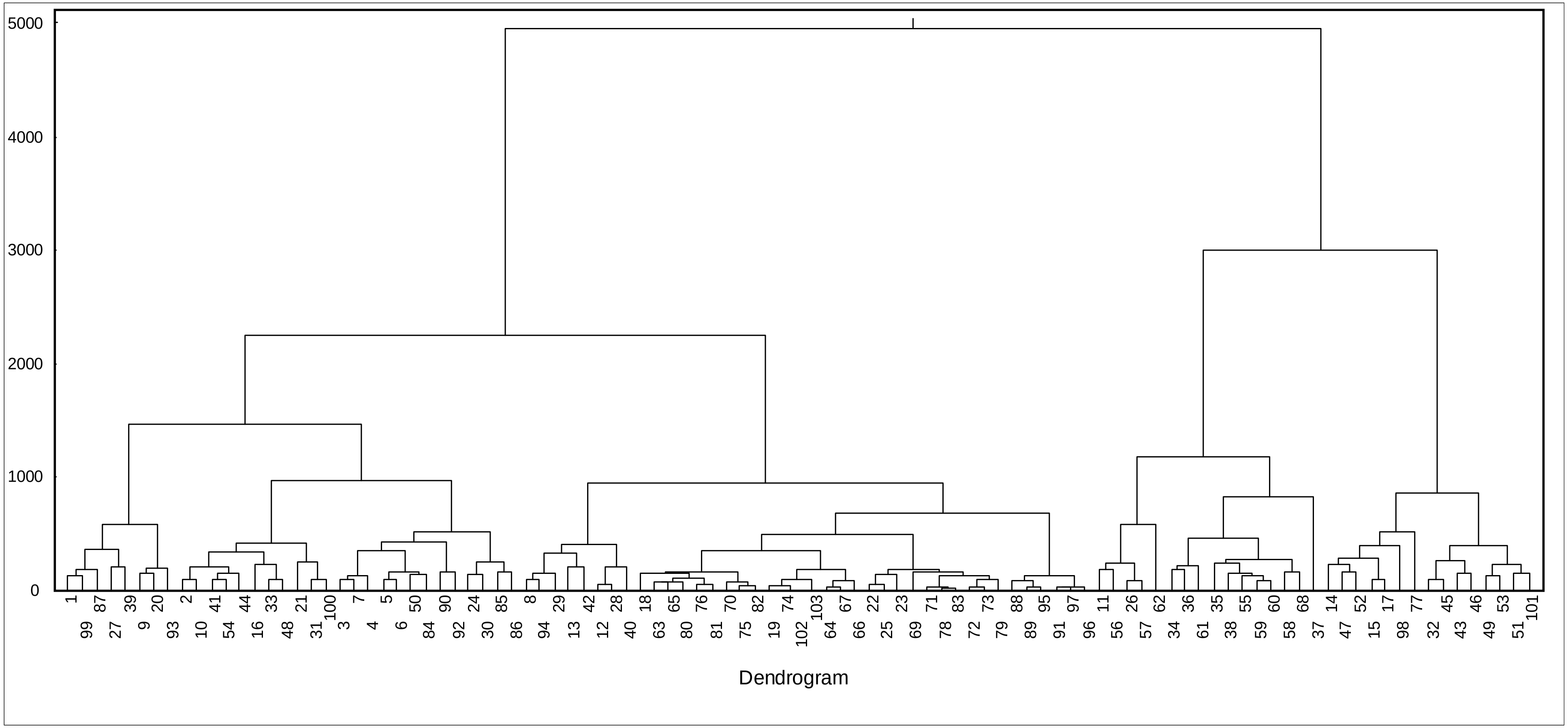


Figure 5.24: Cluster Analysis of Main Ions (1/2)

Average Value

Max. Cluster
Min. Cluster

	Cluster-1	Cluster-2	Cluster-3	Cluster-4	Cluster-5	Cluster-6	Cluster-7	Cluster-8	Cluster-9	Cluster-10
Ca^{2+}	778.800	539.636	273.354	170.500	297.275	1203.84	1300.00	1235.20	770.743	788.200
K^{+}	10.855	12.660	16.554	6.836	4.363	18.766	11.850	7.950	27.549	22.928
Na^{+}	92.156	165.205	135.713	112.004	45.604	185.780	86.588	135.060	318.323	264.081
Mg^{2+}	168.433	170.809	173.262	119.400	86.221	171.332	143.936	149.520	198.844	192.204
Cl^{-}	226.250	417.273	356.923	65.750	58.125	536.000	122.500	140.000	967.857	678.125
SO_4^{2-}	180.000	168.555	164.600	161.338	155.047	156.480	163.500	97.500	159.757	185.075
HCO_3^{-}	156.325	244.064	192.423	350.850	133.441	146.400	195.230	793.200	217.457	320.338
NO_3^{-}	0.208	0.606	0.388	0.436	0.933	2.166	3.425	0.082	0.619	2.045
Water	1 JV001	2 JV002	3 JV003	8 JV008a	18 JV017	11 JV011	34 JV033	37 JV036	14 JV013	32 JV031
Sample No	9 JV009	10 JV010	4 JV004	12 JV012	19 JV018	26 JV025	35 JV034		15 JV014	43 JV042
and	20 JV019	16 JV015	5 JV005	13 JV012a	22 JV021	56 JV055	36 JV035		17 JV016	45 JV044
Code	27 JV026	21 JV020	6 JV006	28 JV027	23 JV022	57 JV056	38 JV037		47 JV046	46 JV045
Refered to	39 JV038	31 JV030	7 JV007	29 JV028	25 JV024	62 SB005	55 JV054		52 JV051	49 JV048
Table 5.1	87 SB030	33 JV032	24 JV023	40 JV039	63 SB006		58 SB001		77 SB020	51 JV050
	93 SB036	41 JV040	30 JV029	42 JV041	64 SB007		59 SB002		98 SB041	53 JV052
	99 SB042	44 JV043	50 JV049	94 SB037	65 SB008		60 SB003			101 SB044
		48 JV047	84 SB027		66 SB009		61 SB004			
		54 JV053	85 SB028		67 SB010		68 SB011			
		100 SB043	86 SB029		69 SB012					
			90 SB033		70 SB013					
			92 SB035		71 SB014					
					72 SB015					
					73 SB016					
					74 SB017					
					75 SB018					
					76 SB019					
					78 SB021					
					79 SB022					
					80 SB023					
					81 SB024					
					82 SB025					
					83 SB026					
					88 SB031					
					89 SB032					
					91 SB034					
					95 SB038					
					96 SB039					
					97 SB040					
					102 JICA BH1					
					103 JICA BH2					

Figure 5.25: Cluster Analysis of Main Ions (2/2)

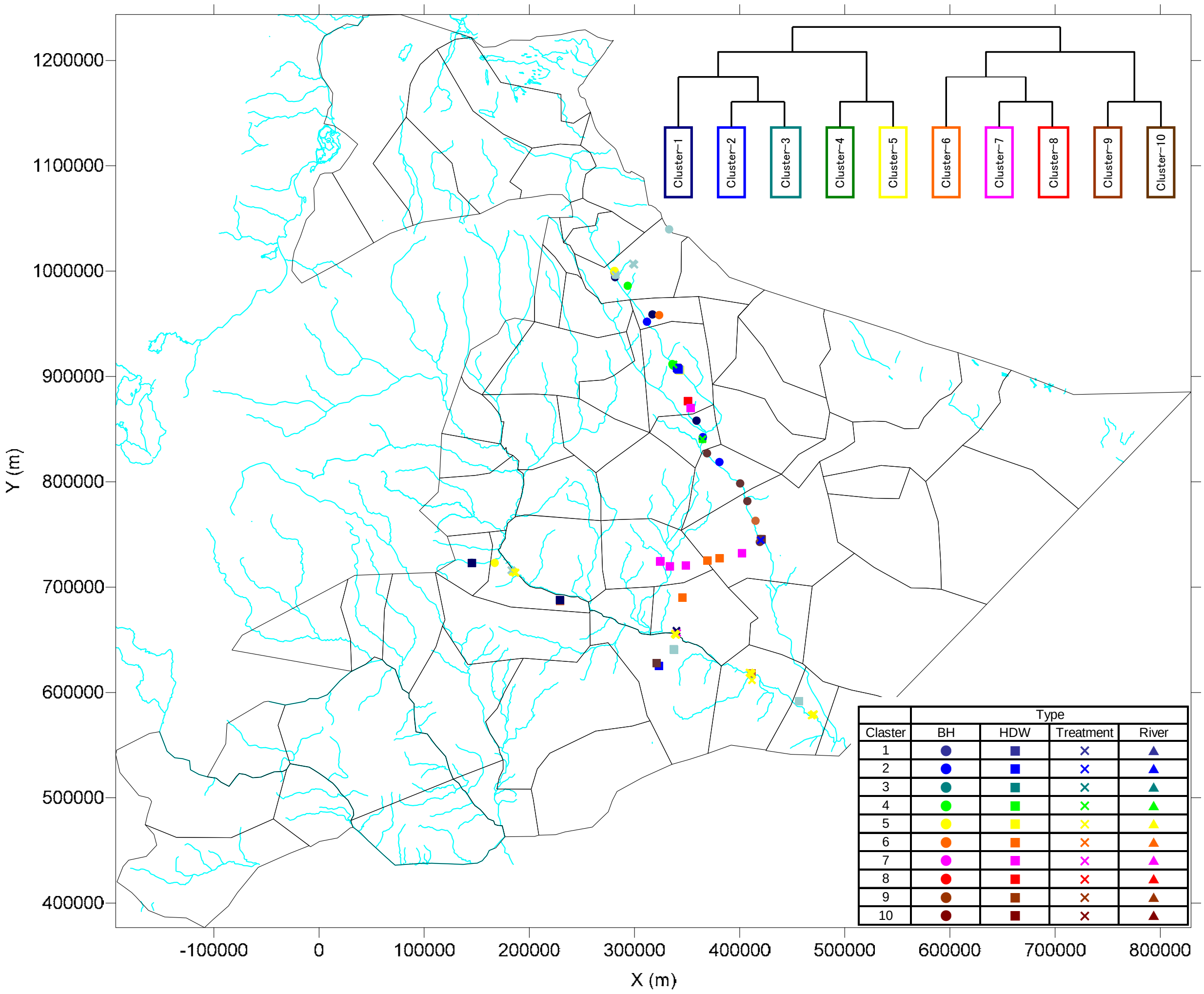


Figure 5.26: Cluster Analysis (All Data)

Chapter 6

Groundwater Utilization Potential Evaluation Map

6 Groundwater Utilization Potential Evaluation Map

6.1 Legend and evaluation of aquifer potential

This study classified the aquifer distributed in the target area in terms of i) productivity and groundwater level and ii) water quality.

a. Productivity and groundwater level

In terms of the productivity, aquifers were classified based on the lithofacies and existing hydrogeological maps. In a special case, the productivity of Jessoma sandstone was assumed to be low because the groundwater level of Jessoma sandstone is very deep. And thus Jessoma sandstone belongs to the “poor to low productivity” classification.

- Medium to High productivity (Yield: more than 3 ℓ/sec)
- Low to Medium productivity (Yield: 1 to 3 ℓ/sec)
- Poor to Low productivity (Yield: less than 1 ℓ/sec)

b. Water quality

Aquifers were classified into three categories based on the lithofacies, existing hydrogeological maps and water quality analysis results of each aquifer are as follows.

- Excellent to good: The gypseous layers are not placed or are hardly interbedded (TDS < about 750 mg/l).
- Low to Medium productivity: The gypseous layers are interbedded partly (TDS ranges between 750 mg/l and 3,000 mg/l).
- Poor to Low productivity: The gypseous layers are interbedded in all stratigraphic horizon (TDS> 3,000 mg/l, TDS exceeds 10,000 mg/l in partially of Quaternary system in Shebele Sub-basin).

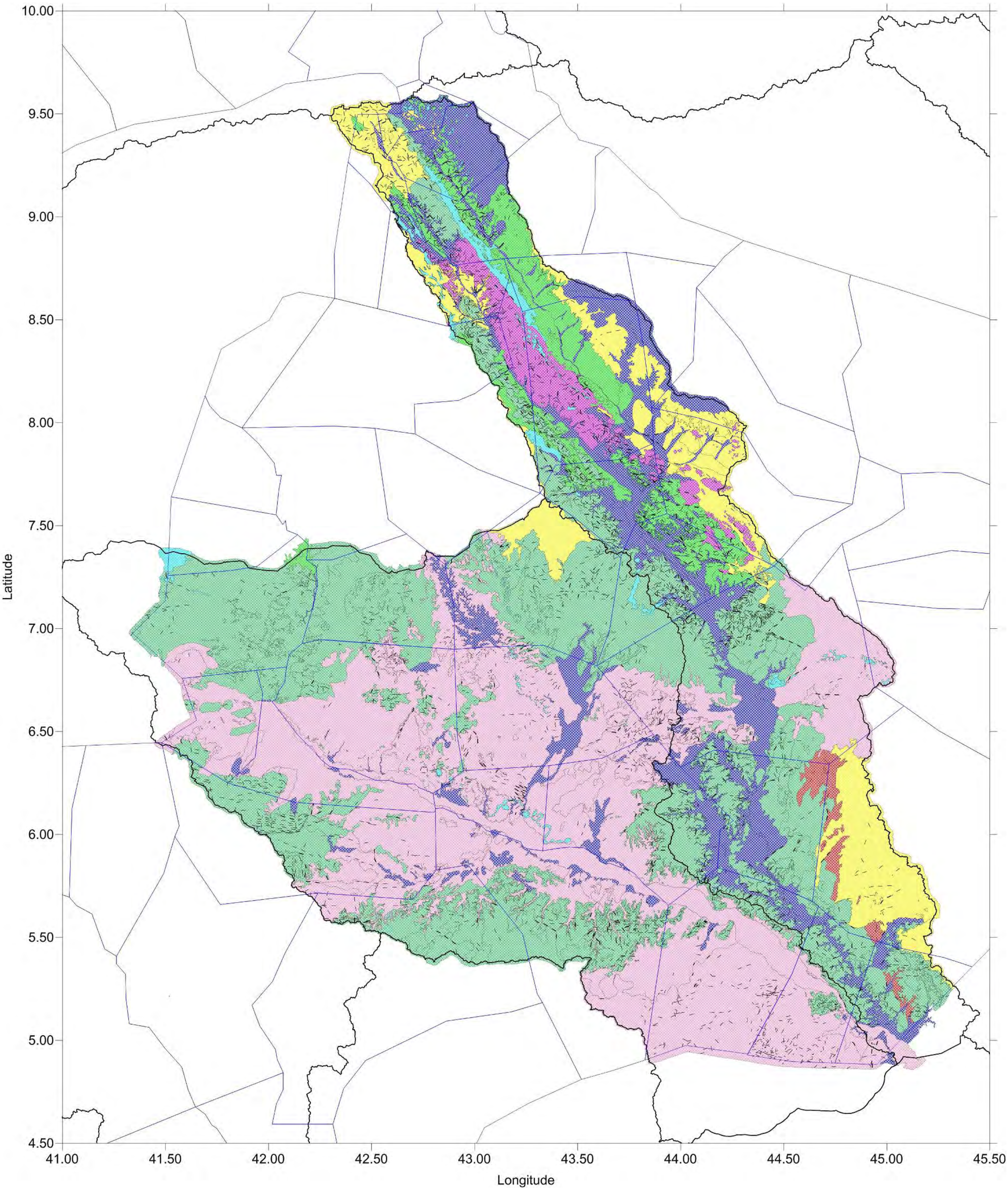
c. Aquifer potential evaluation

The classification of aquifer potential evaluation as shown in was conducted according to the combined evaluation of productivity and groundwater level and the evaluation of water quality.

Generally, groundwater quality produced from Quaternary system (Qa) is good. However, Quaternary system distributed along the main stream of Shebele is evaluated as the same level of underlying Korahe formation (Kg), because the groundwater and surface water along this area is saline.

Table 6.1: Aquifer Potential Classification Table

Geological Classification	Yield (ℓ/sec.)	Water Quality
Qa, r	Medium - High: More than 3ℓ/sec.	Excellent - Good: TDS Less than 750mg/ℓ.
Ja		
Qc, Qb, Qv	Low - Medium: 1 - 3ℓ/sec.	Excellent - Good: TDS Less than 750mg/ℓ.
Pj, PC	Poor - Low: Less than 1ℓ/sec.	Excellent - Good: TDS Less than 750mg/ℓ.
Km, Jh	Medium - High: More than 3ℓ/sec.	Partly Poor: TDS from 750 - 3,000mg/ℓ.
Kb, Ka, Jg	Low - Medium: 1 - 3ℓ/sec.	Partly Poor: TDS from 750 - 3,000mg/ℓ.
Ju	Poor - Low: Less than 1ℓ/sec.	Partly Poor: TDS from 750 - 3,000mg/ℓ.
Kg	Low - Medium: 1 - 3ℓ/sec.	Poor: TDS from 3,000 - 10,000mg/ℓ.
Kf	Poor - Low: Less than 1ℓ/sec.	Poor: TDS from 3,000 - 10,000mg/ℓ.



(The color of aquifer potential map refers to)

Figure 6.1: Aquifer Potential Map

6.2 Drawing and utilization method (explication)

Groundwater utilization potential evaluation map, groundwater utilization potential evaluation profile and well construction information are shown below for the target woredas of the water supply master plan.

Groundwater utilization potential evaluation map contains the aquifer unit evaluation of and other information of . Groundwater utilization potential evaluation profile also contains the aquifer unit evaluation and other information of Table 6.3.

The integrated evaluations of these data is a basic information for the preparation of water supply plan (refer to volume 2).

Table 6.2: Index of the Groundwater Utilization Potential Evaluation Map

INDEX	
Basin Boundary	Successful Well
Woreda Boundary	Abandoned Well (Dry and Low Yield)
Town/Village	Abandoned Well (Bad Water Quality)
Landform & Geological Boundary	Abandoned Well (Failure of Construction)
Lineament	Abandoned Well (Unknown Reasons)
Profile line	Oil Well
	Insufficient Information Well

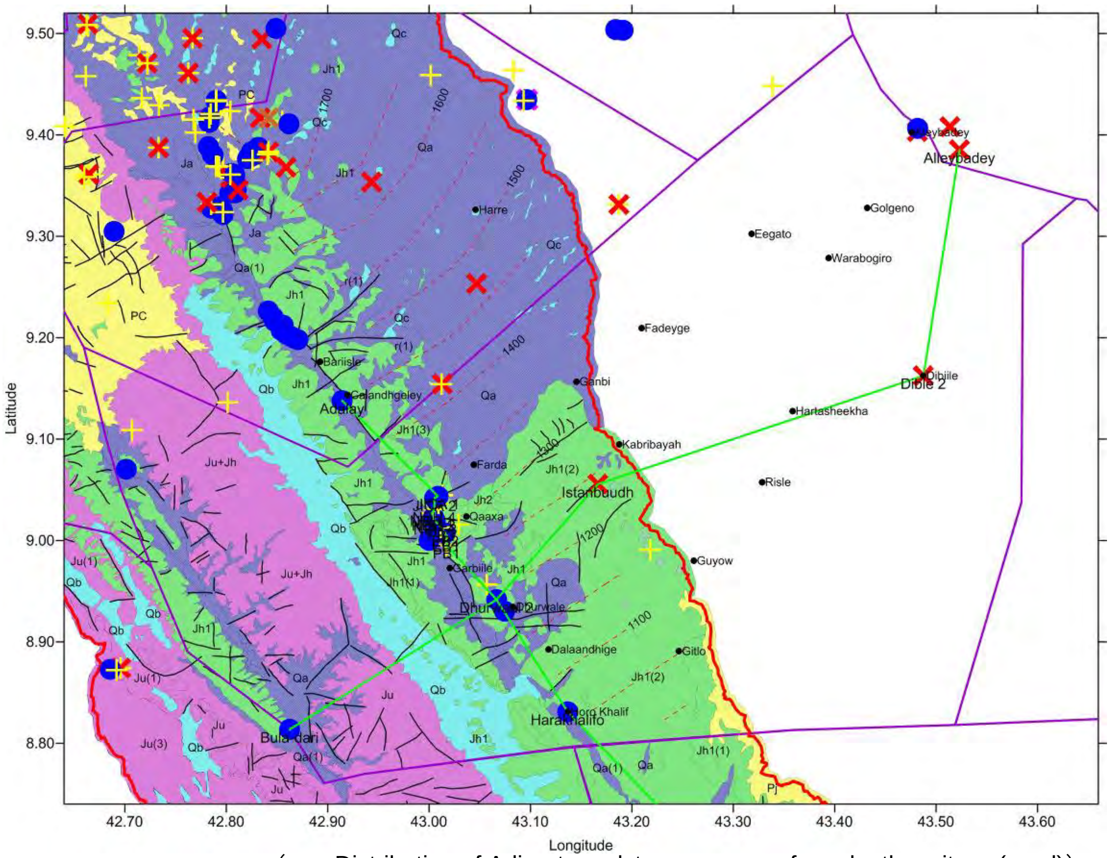
Table 6.3: Index of the Groundwater Utilization Potential Evaluation Profile

INDEX		
Topographic Profile		**Geological Columnar Section**
Geological Boundary	L.Y.	**Low Yield**
Probable Fault	B.W.Q.	**Bad Water Quality**

a. Jarar Valley

a.1 Kabribeyah woreda

Groundwater utilization potential evaluation map of Kabribeyah woreda, is shown in Figure 6.2. Groundwater utilization potential evaluation profile is shown in Figure 6.3 and Figure 6.4. Well construction record for the area is shown in Table 6.4.



(···: Distribution of Adigrat sandstone upper surface depth, unit: m(amsl))

Figure 6.2: Groundwater Utilization Potential Evaluation Map of Kabribeya Woreda

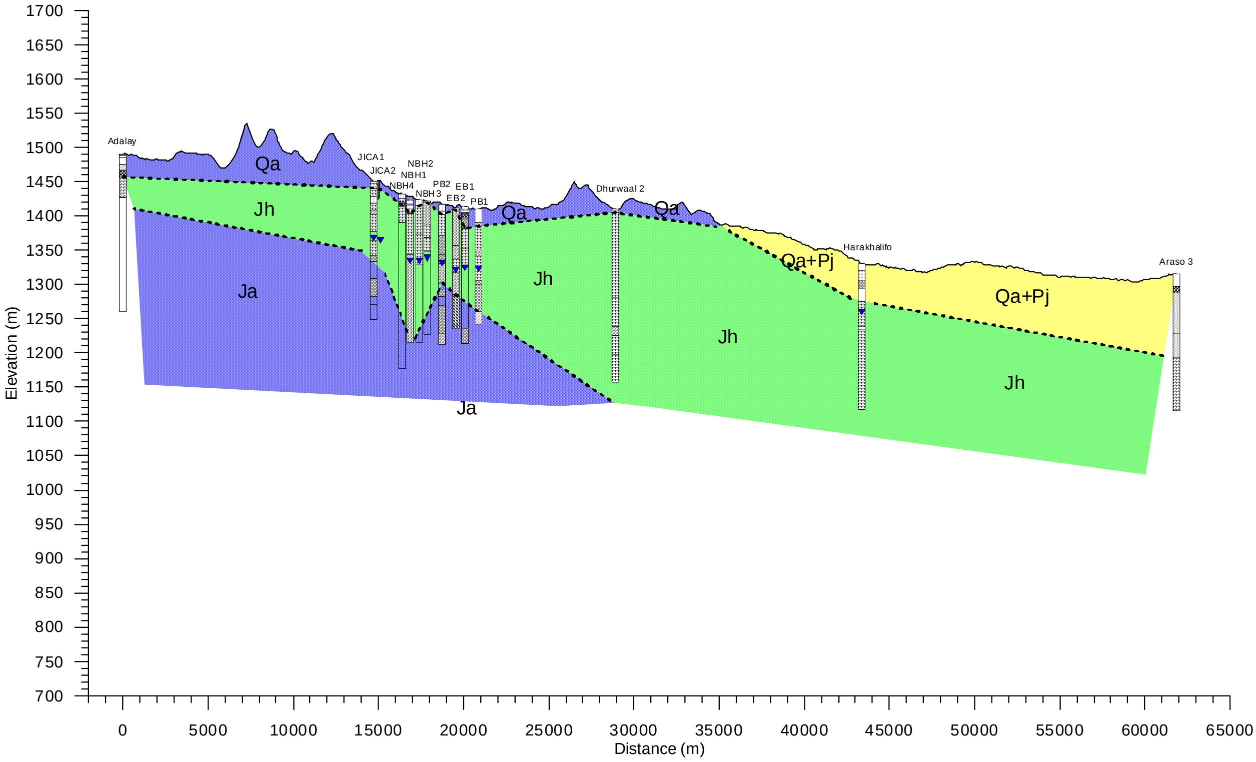


Figure 6.3: Groundwater Utilization Potential Evaluation Profile in Kabribeyah Woreda (parallel to the river)

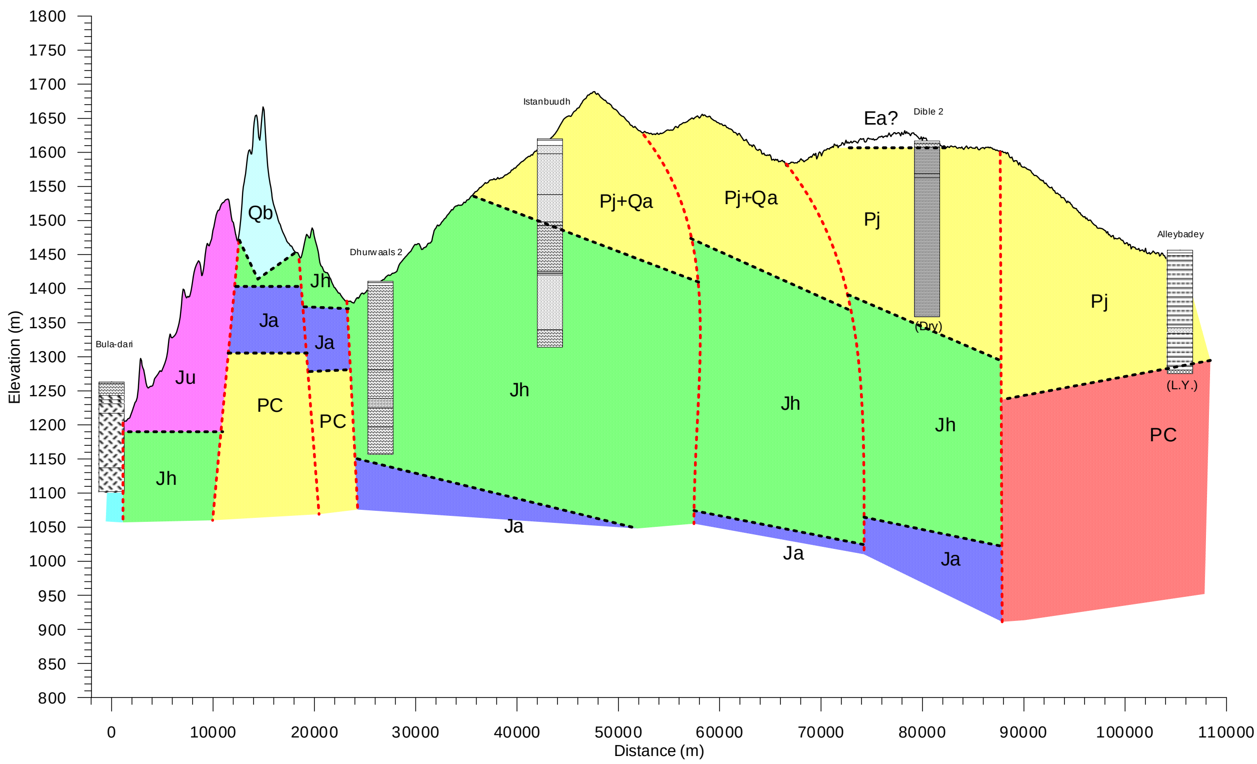


Figure 6.4: Groundwater Utilization Potential Evaluation Profile in Kabribeyah Woreda (across the river)

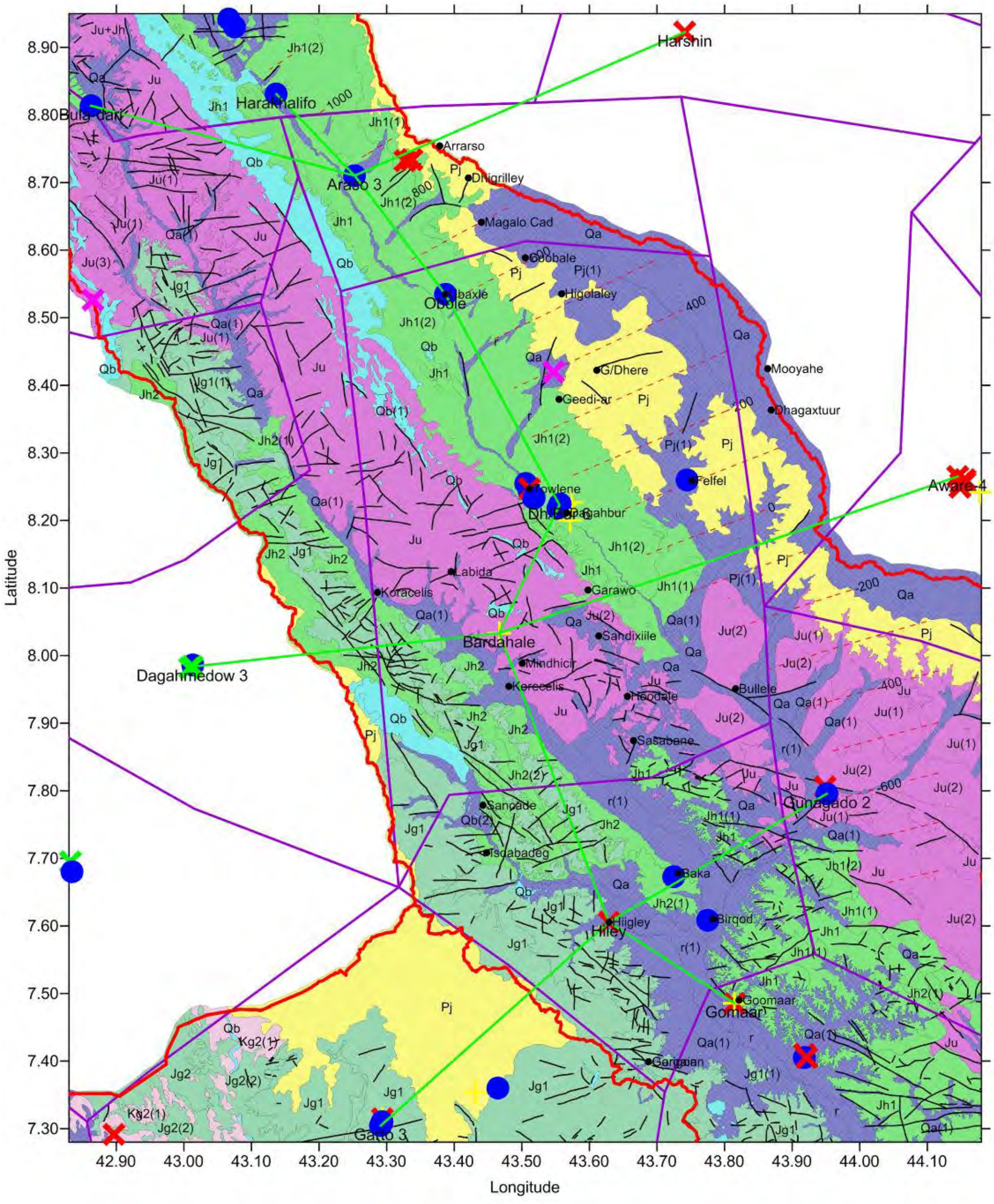
Table 6.4: Record of Wells Constructed in Kabribeyah Woreda

Temp. ID	Long. (°)	Lat. (°)	UTM-X (m)	UTM-Y (m)	Elev. (m)	Type	Depth (m)	SWL (GL-m)	DWL (GL-m)	Yield (L/sec.)	Date of Const.	Const. by	Status	Well log
Allaybadey BH	43.5137	9.4080	336799	1040216	1475	-	203	175	-	-	2003	-	A (L.Y.)	○
Alleybadey (Damerjoog)	43.4817	9.4064	333286	1040046	1472	BH	250	-	-	-	-	-	S	○
Aleybadey (1)	43.4814	9.4031	333252	1039691	1463	BH	250	-	-	-	2000	Waheen-	A (L.Y.)	-
Aleybadey (2)	43.5231	9.3853	337823	1037695	1456	BH	181	-	-	-	-	-	A (L.Y.)	○
Dibile	43.4875	9.1625	333808	1013075	1618	BH	258	-	-	-	1995	EWWCA	A (Dry)	○
Istanbuudh	43.1665	9.0556	298467	1001411	1619	BH	306	-	-	-	-	-	A (L.Y.)	○
Farda	43.0129	9.0445	281572	1000278	1451	BH	180	85	-	-	2005	Waheen	S	○
JICA-No-1	43.0087	9.0436	281111	1000180	1450	BH	200	85.23	32.5	6.5	2012	JICA	S	○
JICA-No-2	43.0054	9.0420	280743	1000004	1452	BH	200	88.40	17.65	5.4	2012	JICA	S	○
NBH-5	43.0091	9.0367	281148	999416	1442	BH	-	-	-	-	-	-	-	-
NBH-4	43.0052	9.0307	280716	998755	1432	BH	255	-	-	-	-	-	-	○
NBH-1	43.0028	9.0270	280449	998348	1428	BH	212	-	-	-	-	-	-	○
NBH-2	43.0045	9.0228	280634	997876	1423	BH	208	-	-	-	-	-	-	○
NBH-3	43.0062	9.0190	280818	997455	1422	BH	195	-	-	-	-	-	-	○
Qaaxo	43.0292	9.0157	283346	997084	1470	BH	220	84	-	-	2000	Waheen	S	-
Qaaxo (PB2)	43.0117	9.0128	281423	996766	1417	BH	-	-	-	-	-	-	S	○
Qaaxo (EB2)	43.0159	9.0073	281874	996159	1413	BH	177.5	-	-	-	-	-	S	○
Qaaxo (EB1)	43.0168	9.0022	281973	995591	1413	BH	200	-	-	-	-	-	S	○
Qaaxo (PB1)	43.0172	8.9951	282019	994809	1410	BH	186.5	-	-	-	-	-	S	○
Aranadka	43.2182	8.9908	304116	994222	1615	BH	292	-	-	-	-	-	S	○
Xaaxi	43.0570	8.9564	286358	990509	1446	BH	250	-	-	-	-	-	-	-
Dhurwaale 2	43.0665	8.9417	287405	988876	1411	BH	254	-	-	-	-	-	-	○
Dhurwaale 1	43.0665	8.9417	287405	988876	1420	BH	235	92	-	-	2004	Whaeen	S	-
Horakhalifo	43.1367	8.8310	295065	976594	1330	BH	212	70	-	-	2004	WRDB	S	-
Hiley	43.6289	7.6056	348747	840854	849	BH	-	-	-	-	2000	Rabah	A (L.Y.)	○
PB3	43.0000	9.0000	280125	995362	1432	-	267	77.4	-	-	1992	-	S	○
Buladari	42.8625?	8.8137?	264883?	974836?	1272	BH	161	-	-	-	-	-	S	○
Gebigebo	42.7069?	9.1087?	247968?	1007580?	1476	-	-	-	-	-	-	-	-	-
Horahowd	42.7015?	9.0701?	247342?	1003310?	1364	BH	-	-	-	-	-	-	S	-

* S: Successful, A: Abandoned, L.Y.: Low yield

a.2 Araarso woreda

Groundwater utilization potential evaluation map of Araarso woreda, is shown in Figure 6.5. Groundwater utilization potential evaluation profile is shown in Figure 6.6 and Figure 6.7. Well construction record for the area is shown in Table 6.5.



(⋯ : Distribution of Adigrat sandstone upper surface depth, unit : m(amsl))

Figure 6.5: Groundwater Utilization Potential Evaluation Map of Araarso Woreda、Dagahbur Woreda and Birqod Woreda

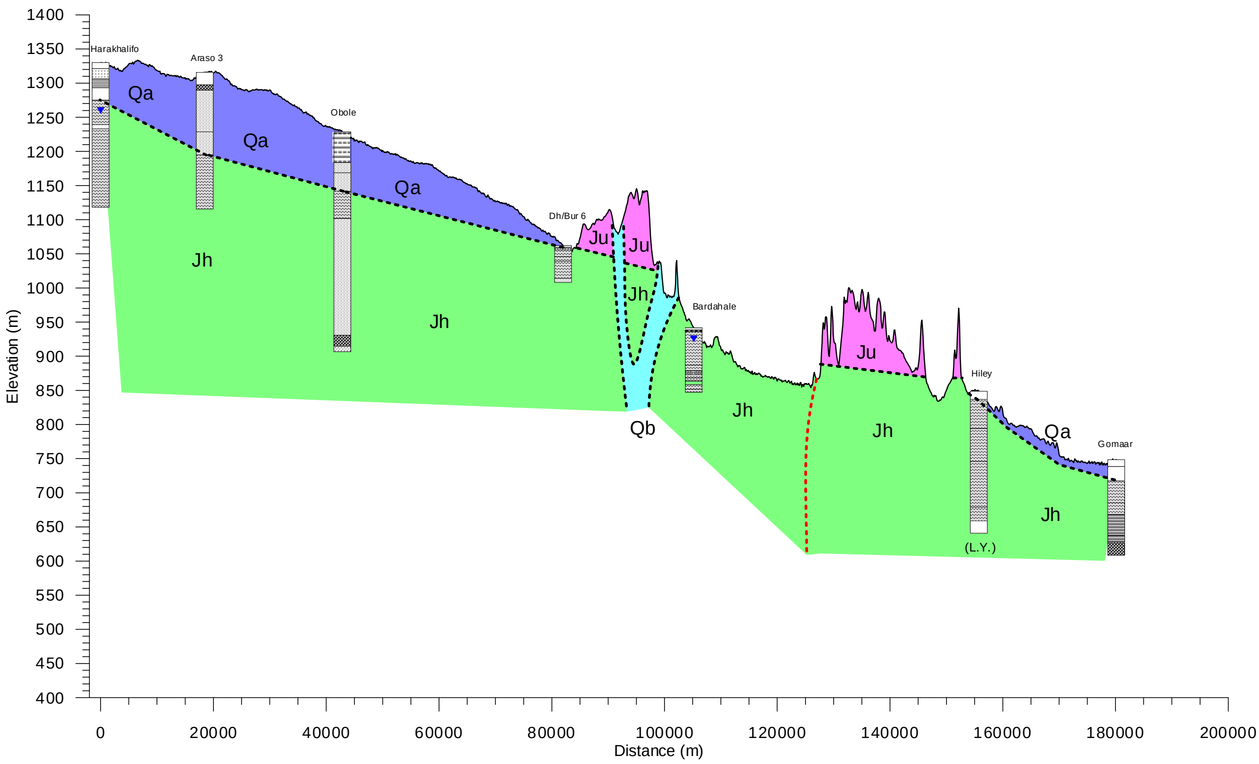


Figure 6.6: Groundwater Utilization Potential Evaluation Profile of Araarso Woreda-Dagahbur Woreda-Birqod Woreda (parallel to the river)

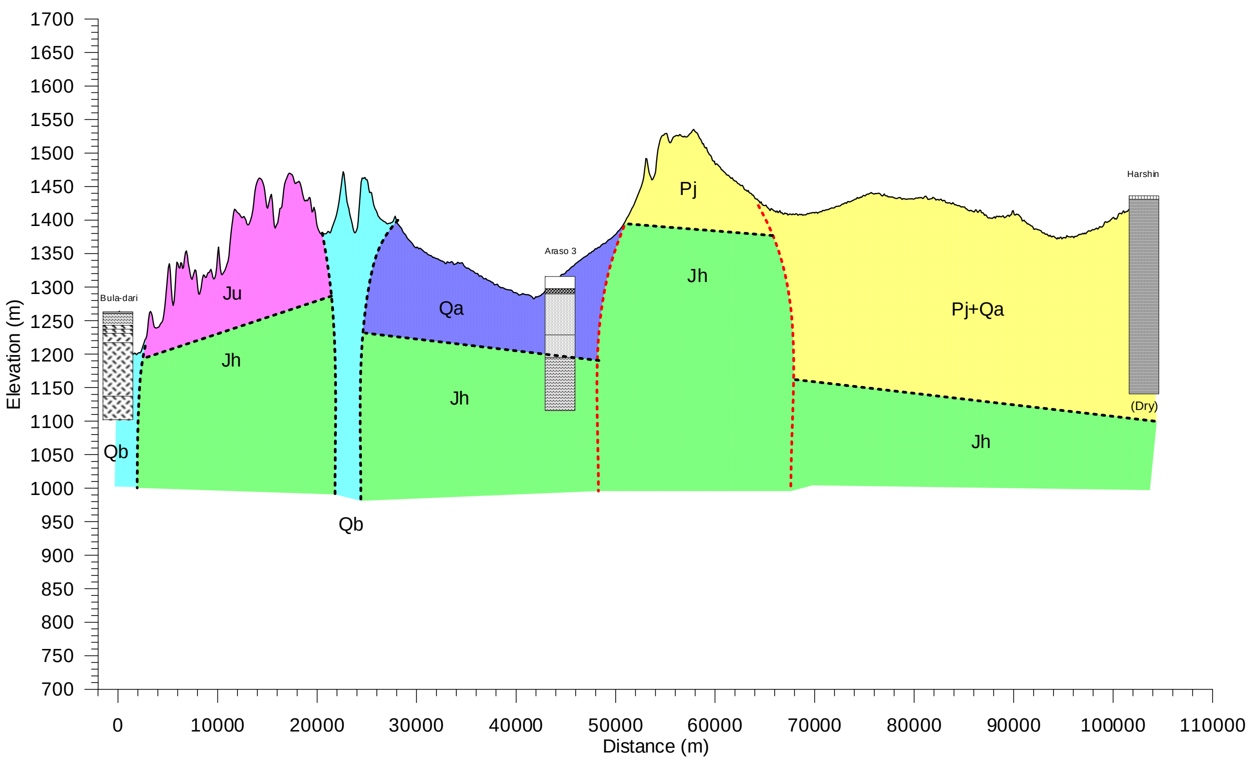


Figure 6.7: Groundwater Utilization Potential Evaluation Profile of Araarso Woreda (across the river)

Table 6.5: Record of Wells Constructed in Araarso Woreda

Temp. ID	Long. (°)	Lat. (°)	UTM-X (m)	UTM-Y (m)	Elev. (m)	Type	Depth (m)	SWL (GL-m)	DWL (GL-m)	Yield (L/sec.)	Date of Const.	Const. by	Status	Well log
Ararso	43.3372	8.7341	317075	965765	1464	BH	-	-	-	-	1979	EWWCA	A (L.Y.)	-
Ararso (2)	43.3372	8.7341	317075	965765	1464	BH	300	-	-	-	2002	WRDB	A (L.Y.)	-
Ararso 2	43.3273	8.7324	315985	965583	1448	BH	-	-	-	-	-	-	A (L.Y.)	-
Ararso 3	43.2526	8.7101	307754	963163	1316	BH	200	-	-	-	2005	Waheen	S	○

* S: Successful, A: Abandoned, L.Y.: Low yield

a.3 Dagahbur woreda

Groundwater utilization potential evaluation map of Dagahbur woreda, is shown in Figure 6.5. Groundwater utilization potential evaluation profile is shown in Figure 6.8. Well construction record for the area is shown in Table 6.6.

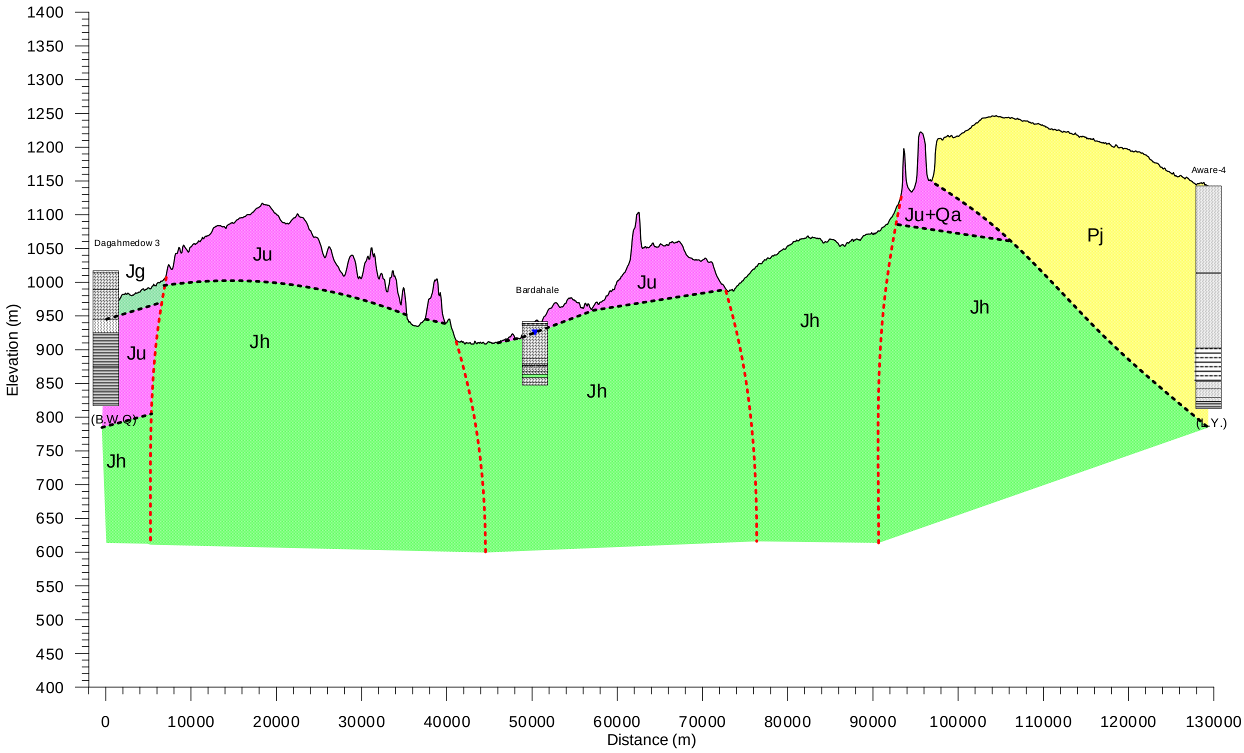


Figure 6.8: Groundwater Utilization Potential Evaluation Profile of Dagahbur Woreda (across the river)

Table 6.6: Record of Wells Constructed in Dagahbur Woreda

Temp. ID	Long. (°)	Lat. (°)	UTM-X (m)	UTM-Y (m)	Elev. (m)	Type	Depth (m)	SWL (GL-m)	DWL (GL-m)	Yield (L/sec.)	Date of Const.	Const. by	Status *	Well log
Obole	43.2869	8.5345	322451	943675	1229	BH	322	-	-	-	-	-	S	○
Falfal	43.7747	8.2598	361743	913153	1155	BH	-	-	-	-	-	EWWCA	S	-
Towlane 1	43.5060	8.2547	335445	912682	1078	SW	-	-	-	-	-	-	S	-
Towlane 8	43.5113	8.2467	446026	911789	1975	SW	-	-	-	-	-	-	A (L.Y.)	-
Towlane 2	43.5108	8.2537	335969	911462	1072	SW	-	-	-	-	-	-	S	-
Towlane 3	43.5167	8.2355	82355	336616	1073	SW	-	-	-	-	-	-	S	-
Towlane 9	43.5184	8.2338	336803	910360	1070	SW	-	-	-	-	-	-	S	-
Towlane 4	43.5176	8.2329	336714	910267	1069	SW	-	-	-	-	-	-	S	-
Daghabur 3	43.5744	8.2264	342969	909522	1077	BH	60	-	25	4	1962	EWRDA	S	-
Dh/Bur 7	43.5570	8.2242	341051	909292	1063	BH	-	-	-	10	1988E	-	S	○
Daghabur 2	43.5643	8.2231	341855	909157	1067	BH	47	-	23	3	1962	EWRDA	S	-
Dh/Bur 6	43.5557	8.2230	340908	909151	1062	BH	54	-	-	-	1979E	-	S	○
Dh/Bur 5	43.5535	8.2182	340663	908267	1052	BH	47	-	-	-	-	-	S	-
Daghabur 7	43.5543	8.2164	340751	908422	1049	BH	54	12	-	10	1996	WRDB	S	-
Daghabur 1	43.5643	8.2164	341853	908418	1060	BH	94	-	-	3	1980	EWWCA	S	-
Bardahale	43.4667	8.0333	331023	888218	942	-	94	16	58	3	-	-	-	○
D-bur town well	43.5715	8.1997	342644	906574	1033	-	50	-	-	-	2011	-	-	○
Higlalye well	43.5472	8.4199	340051	930928	1252	-	104	-	-	-	2003(EC)	-	A (Collapse)	○

* S: Successful, A: Abandoned, L.Y.: Low yield

a.4 Birqod woreda

Groundwater utilization potential evaluation map of Birqod woreda, is shown in Figure 6.5. Groundwater utilization potential evaluation profile is shown in Figure 6.9. Well construction record for the area is shown in Table 6.7.

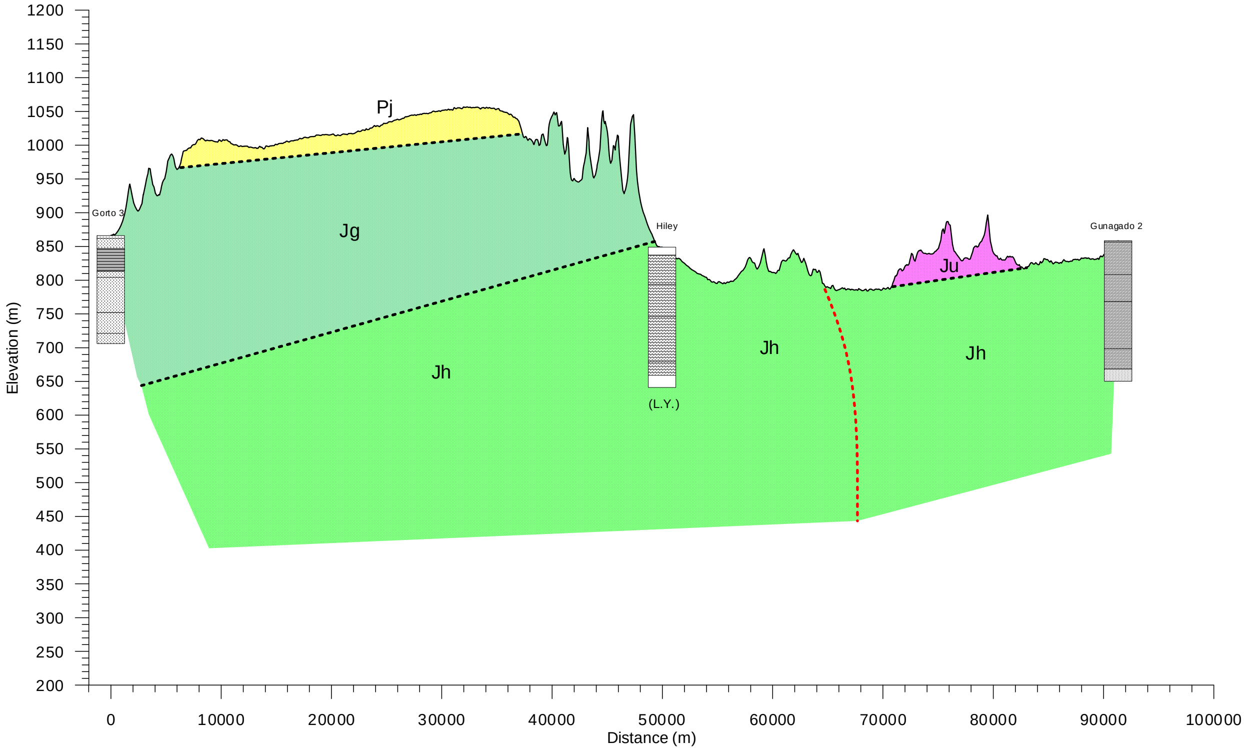


Figure 6.9: Groundwater Utilization Potential Evaluation Profile of Birqod Woreda (across the river)

Table 6.7: Record of Wells Constructed in Birqod Woreda

Temp. ID	Long. (°)	Lat. (°)	UTM-X (m)	UTM-Y (m)	Elev. (m)	Type	Depth (m)	SWL (GL-m)	DWL (GL-m)	Yield (L/sec.)	Date of Const.	Const. by	Status*	Well log
Baka	43.7245	7.6728	359317	848252	809	BH	-	-	-	-	-	-	S	-
Birqot	43.7748	7.6085	364846	841133	764	BH	-	-	-	-	1970	EWWCA	S	-
Hiley	43.6289	7.6056	348747	840854	849	BH	-	-	-	-	2000	Rabah	A (L.Y.)	○

* S: Successful, A: Abandoned, L.Y.: Low yield

a.5 Shaygosh woreda

Groundwater utilization potential evaluation map of Shaygosh woreda, is shown in Figure 6.10. Groundwater utilization potential evaluation profile is shown in Figure 6.11 and Figure 6.12. Well construction record for the area is shown in Table 6.8.

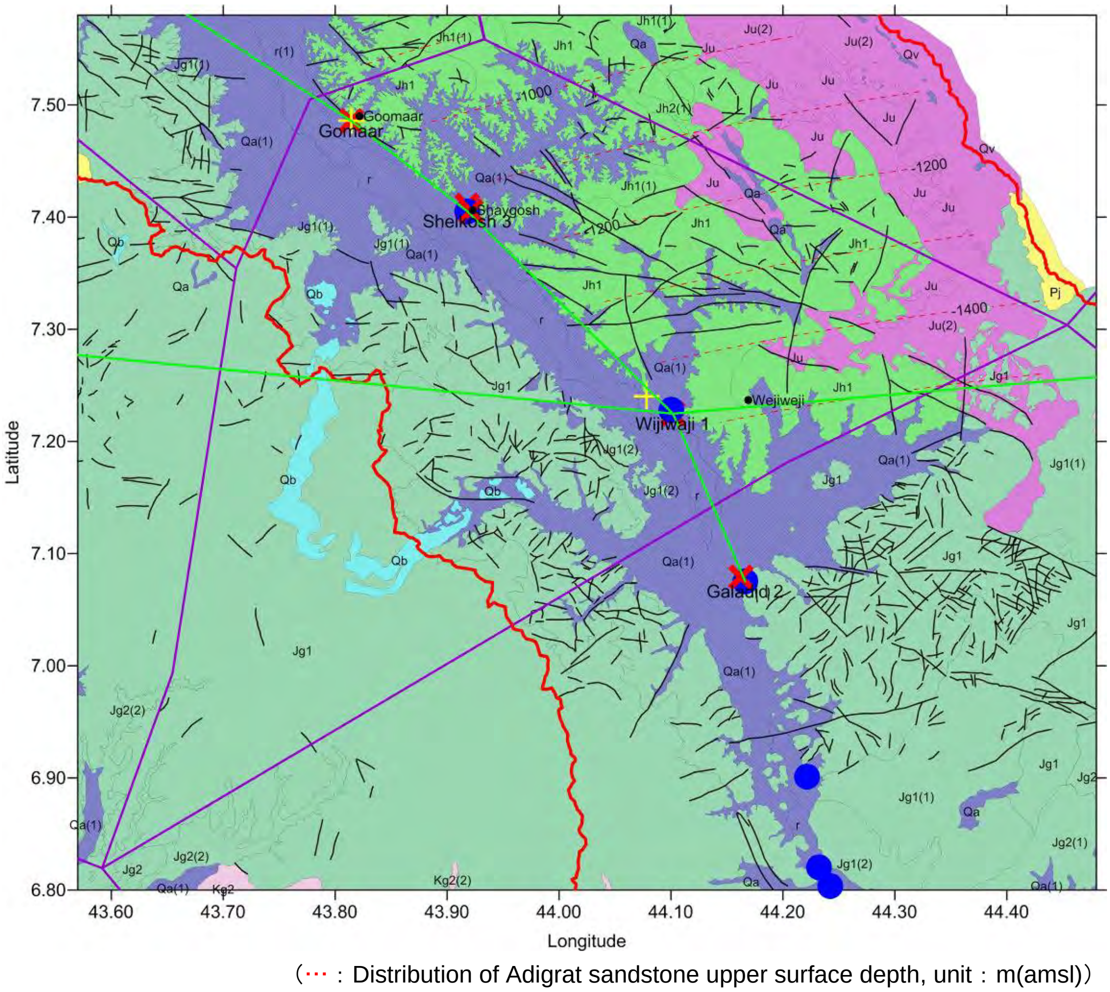


Figure 6.10: Groundwater Utilization Potential Evaluation Map of Shaygosh Woreda

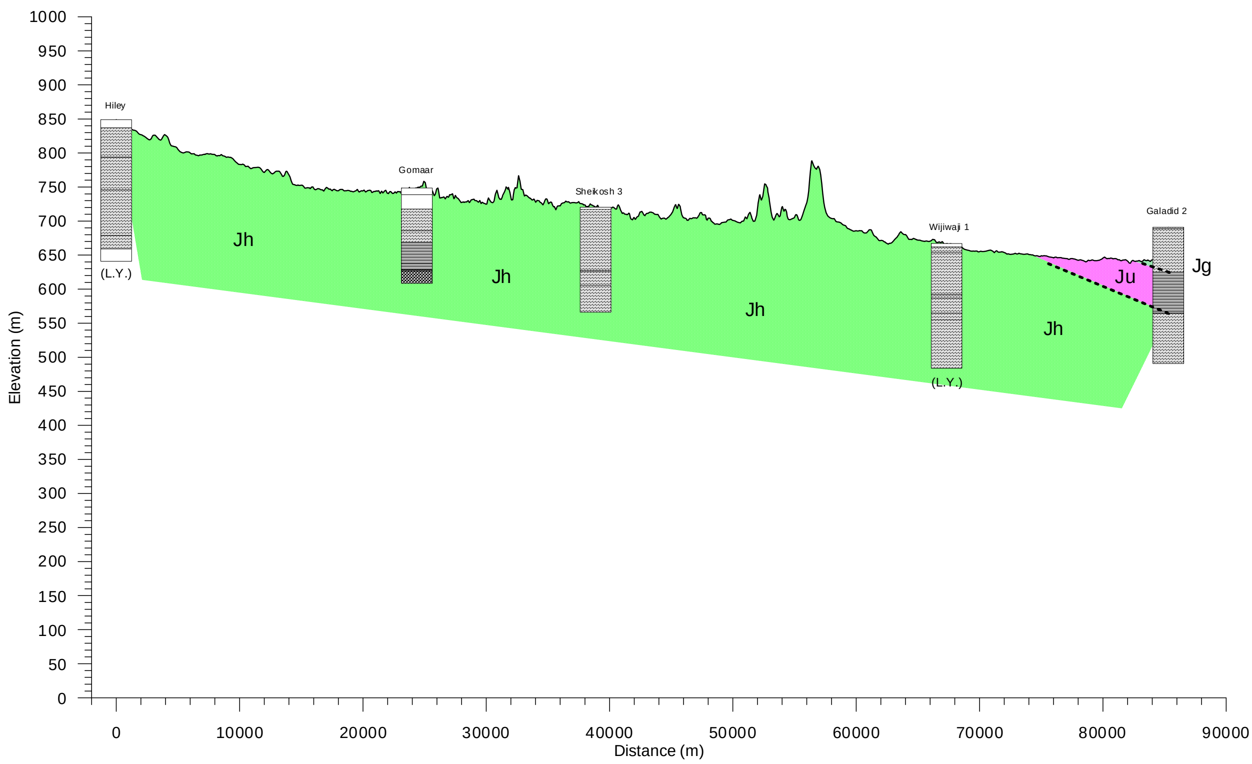


Figure 6.11: Groundwater Utilization Potential Evaluation Profile of Shaygosh Woreda (parallel to the river)

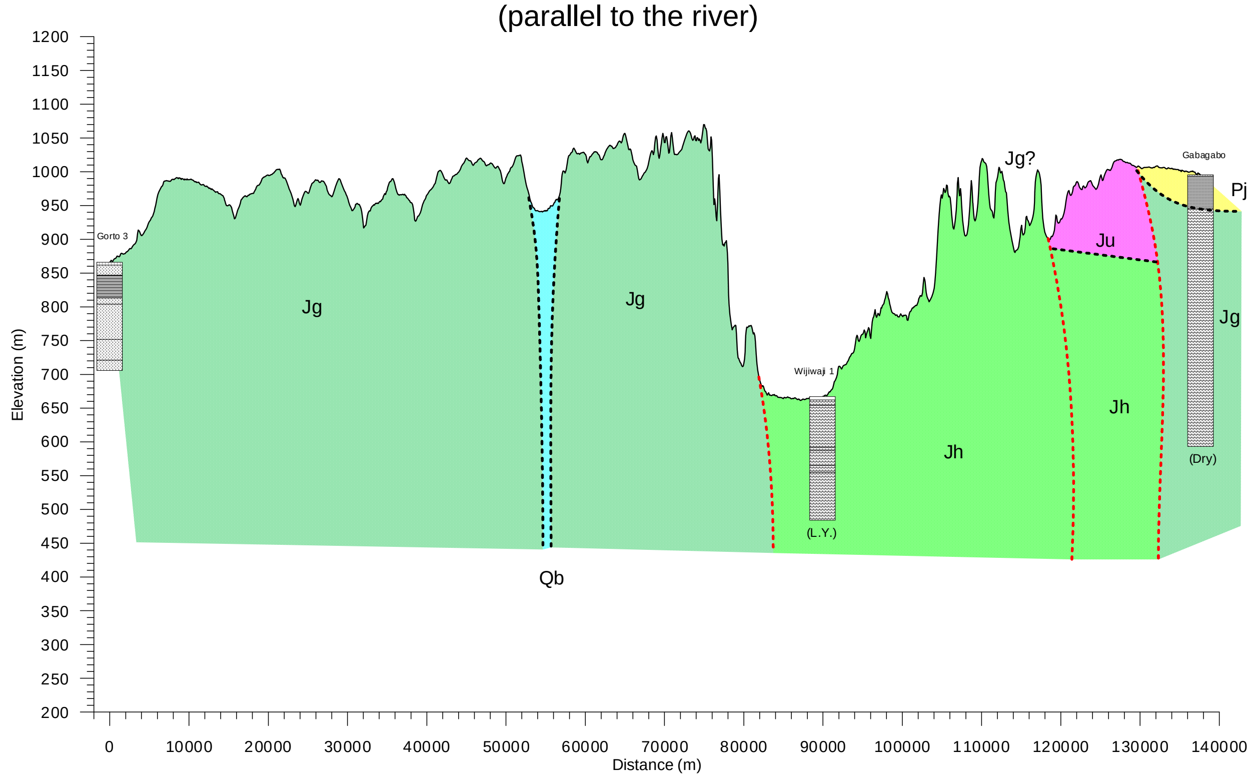


Figure 6.12: Groundwater Utilization Potential Evaluation Profile of Shaygosh Woreda (across the river)

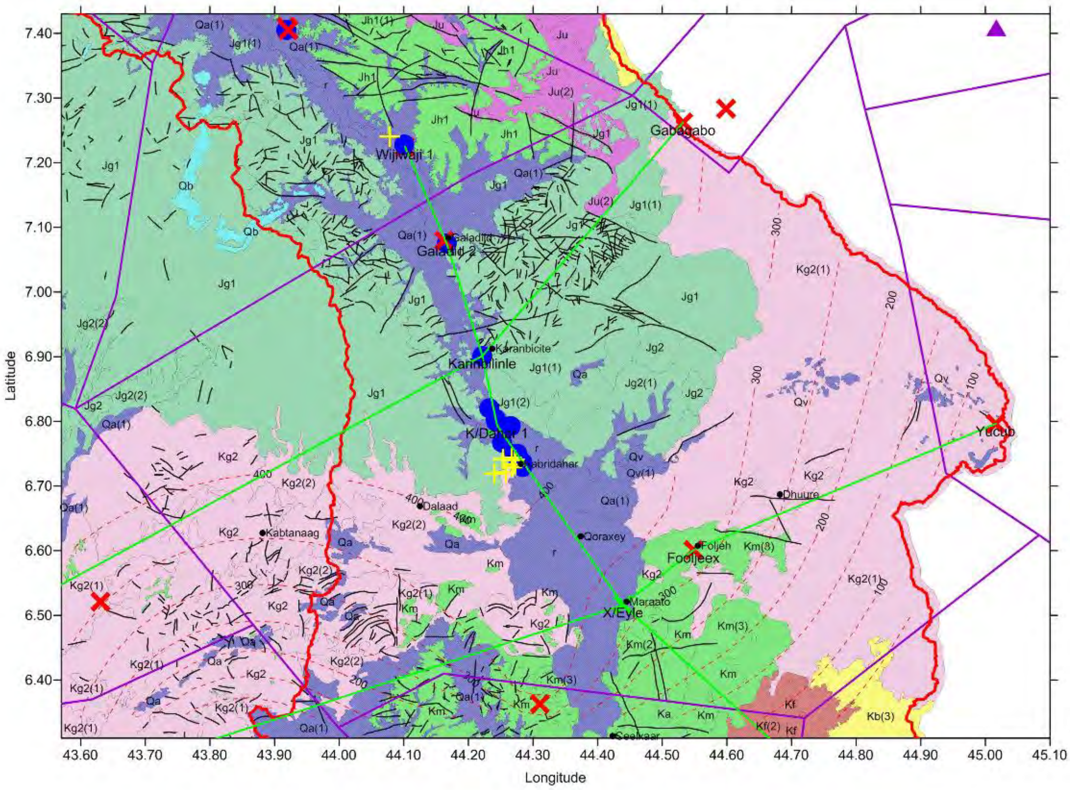
Table 6.8: Record of Wells Constructed in Shaygosh Woreda

Temp. ID	Long. (°)	Lat. (°)	UTM-X (m)	UTM-Y (m)	Elev. (m)	Type	Depth (m)	SWL (GL-m)	DWL (GL-m)	Yield (L/sec.)	Date of Const.	Const. by	Status	Well log
Gomaar	43.8144	7.4858	369178	827551	749	BH	140	120	-	-	2003	Rabah	A (L.Y.)	○
GOMER	43.8144	7.4858	369178	827551	749	BH	242	-	-	-	-	-	-	○
Sheikosh 2	43.9180	7.4104	380590	819190	726	BH	140.5	-	-	-	1999	EWWCA (WRDB)	A (L.Y.)	○
Sheikosh 3	43.9180	7.4052	380589	818614	720	BH	154	-	-	-	1999	EWWCA (WRDB)	S	○
Sheikosh 4	43.9213	7.4051	380953	818596	722	BH	140.5	-	-	-	-	-	A (L.Y.)	○
Maskar	43.4317	7.3539	326889	813099	992	-	-	-	-	-	-	EWWCA	-	-
Masker Well No1	44.0783	7.2403	398244	800343	673	BH	183	76.92	-	-	1980EC	-	-	○
Wijiwaji 1	44.1018	7.2247	400832	798616	667	BH	183	-	-	-	-	-	A (L.Y.)	○
Wijiwaji 2	44.1004	7.2281	400681	798989	673	BH	-	-	-	-	-	EWWCA	S	-

* S: Successful, A: Abandoned, L.Y.: Low yield

a.6 Kabridahar woreda

Groundwater utilization potential evaluation map of Kabridahar woreda, is shown in Figure 6.13. Groundwater utilization potential evaluation profile is shown in Figure 6.14 to Figure 6.16. Well construction record for the area is shown in Table 6.9.



（··· : Distribution of Korahe gypsum bottom surface depth, unit : m(amsl)）

Figure 6.13: Groundwater Utilization Potential Evaluation Map of Kabridahar Woreda

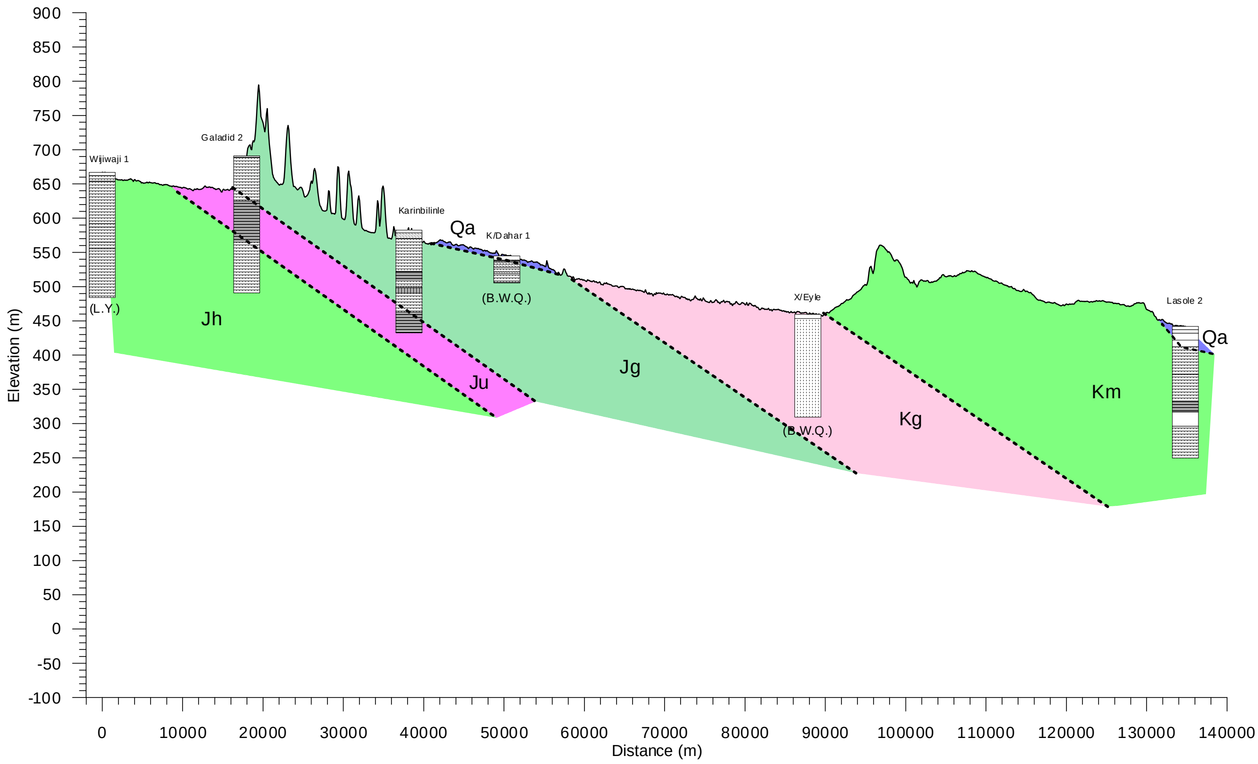


Figure 6.14: Groundwater Utilization Potential Evaluation Profile of Kabridahar Woreda (parallel to the river)

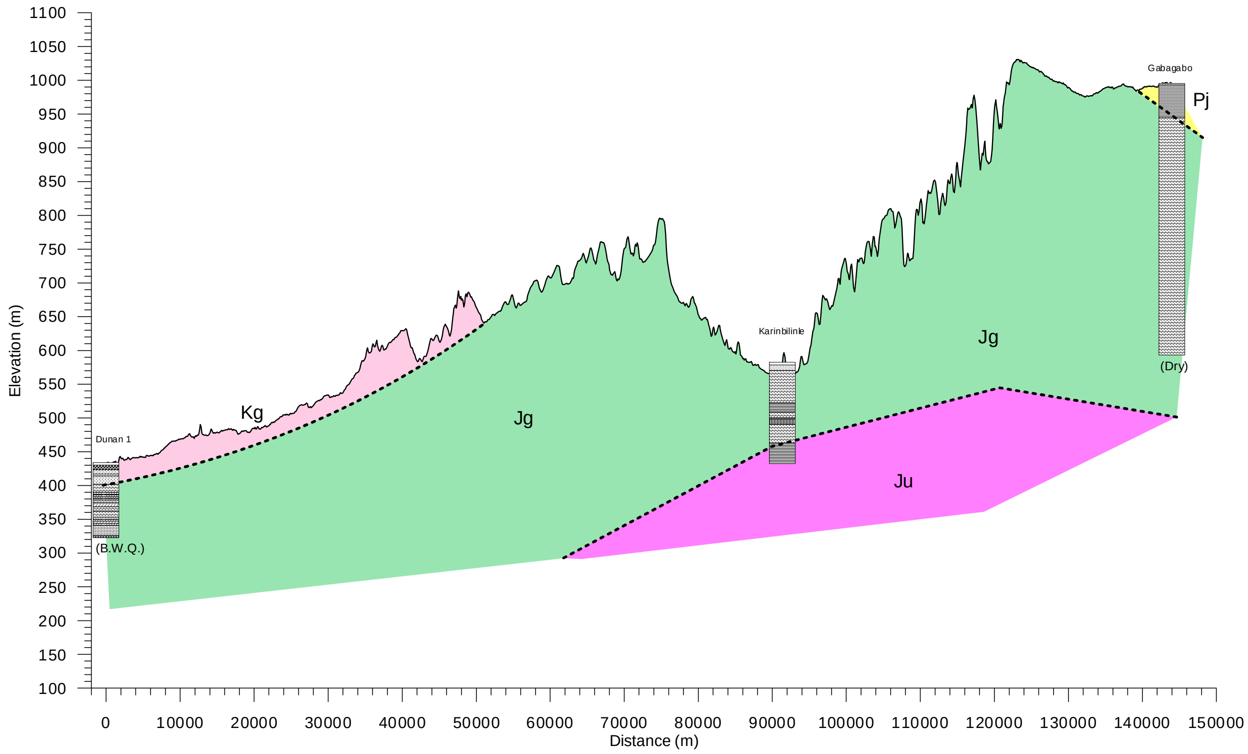


Figure 6.15: Groundwater Utilization Potential Evaluation Profile of Kabridahar Woreda (across the river-North)

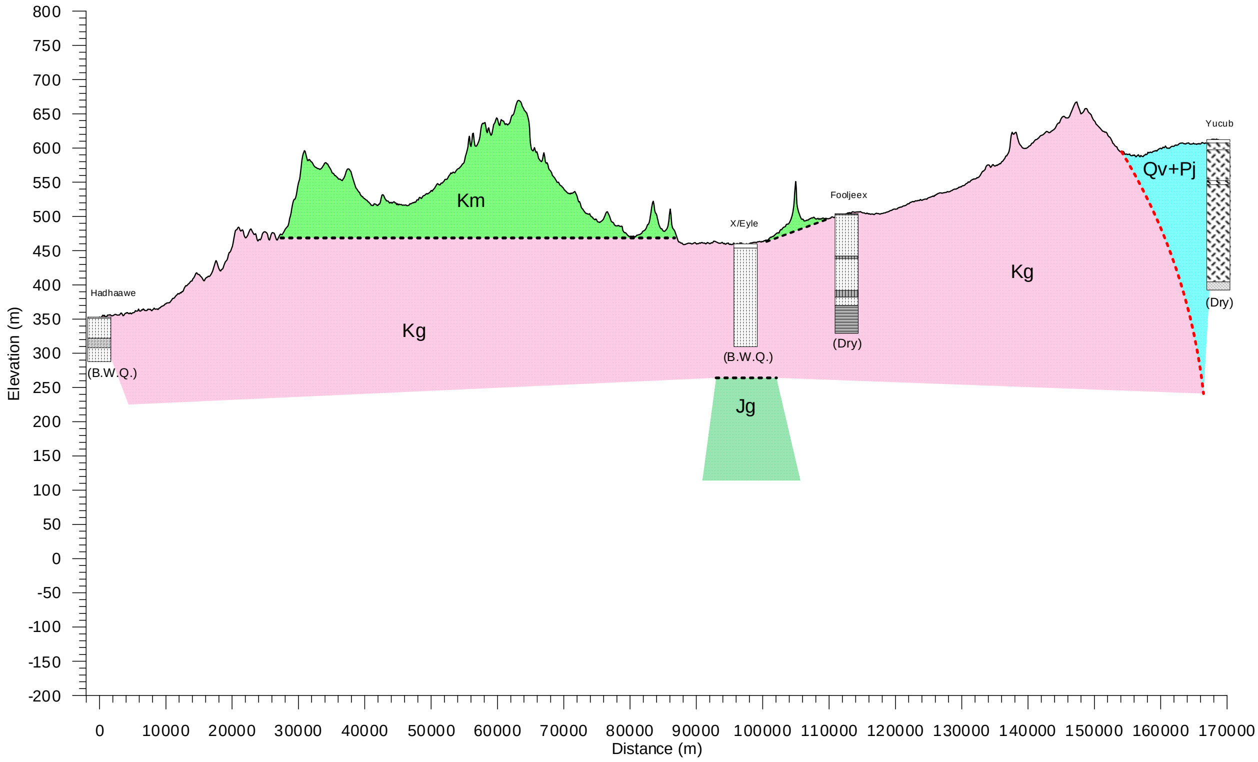


Figure 6.16: Groundwater Utilization Potential Evaluation Profile of Kabridahar Woreda (across the river-South)

Table 6.9: Record of Wells Constructed in Kabridahar Woreda

Temp. ID	Long. (°)	Lat. (°)	UTM-X (m)	UTM-Y (m)	Elev. (m)	Type	Depth (m)	SWL (GL-m)	DWL (GL-m)	Yield (L/sec.)	Date of Const.	Const. by	Status*	Well log
Galadid 1	44.1623	7.0790	407486	782496	634	BH	-	-	-	-	-	-	A (L.Y.)	-
Galadid 2	44.1663	7.0753	407927	782083	691	BH-	200-	-	-	4.4-	-	EWWCA	S	○
Karinbilinl	44.2216	6.9012	414003	762826	583	BH	150	-	-	-	2005	Rabah-	S	○
K/Dahar 3	44.2323	6.8203	415171	753884	553	BH	24	-	-	-	-	-	S	-
K/Dahar 4	44.2422	6.8034	416262	752014	549	BH	-	-	-	-	-	-	S	-
K/Dahar 2	44.2430	6.7955	416349	751577	546	BH	-	-	-	-	-	-	S	-
K/Dahar 1	44.2422	6.7933	416503	750900	545	BH	39.62	-	-	-	-	-	A (Salt)	○
K/Dahar 5	44.2655	6.7928	418835	750839	543	BH	-	-	-	-	-	-	S	-
K/Dahar	44.2519	6.7672	417327	748004	538	BH	-	-	-	-	-	-	S	-
K/Dahar	44.2710	6.7497	419435	746066	524	BH	-	-	-	-	-	-	S	-
K/Dahar	44.2759	6.7494	419977	746037	522	BH	-	-	-	-	-	-	S	-
K/Dahar	44.2759	6.7493	419977	746029	522	BH	-	-	-	-	-	-	S	-
K/Dahar	44.2721	6.7489	419557	745978	522	BH	-	-	-	-	-	-	S	-
K/Dahar	44.2738	6.7476	419745	745839	522	BH	-	-	-	-	-	-	S	-
Kabridahar	44.2671	6.7436	419003	745401	528	-	-	-	-	-	1993	WRDB	-	-
Kabridahar	44.2537	6.7420	417522	745220	557	-	-	-	-	-	-	EWW	-	-
Kabridahar	44.2723	6.7402	419578	745015	522	-	-	-	-	-	1993	WRDB	-	-
K/Dahar 9	44.2823	6.7368	420848	744641	515	BH	-	-	-	-	-	-	S	-
Kabridahar	44.2723	6.7332	419576	744248	535	-	-	-	-	-	1993	WRDB	-	-
Kabridahar	44.2723	6.7332	419576	744248	535	BH	54	-	-	-	2001	WRDB	-	-
Kabridahar	44.2723	6.7332	419576	744248	535	-	-	-	-	-	1993	WRDB	-	-
K/Dahar	44.2836	6.7296	420825	743846	514	BH							S	
Kabridahar	44.2679	6.7288	419089	743756	527	-	-	-	-	-	1993	EWW	-	-
Kabridahar	44.2576	6.7212	417950	742925	509	-	-	-	-	-	-	EWW	-	-
Kabridahar	44.2406	6.7188	416070	742660	526	-	-	-	-	-	-	EWW	-	-
Fooljeex	44.5482	6.6008	450056	729579	504	BH	175	-	-	-	2005-	Rabah-	A (Dry)	○
X/Eyle	44.4349	6.5162	438017	720232	459	BH	150	-	-	-	-	-	A (Salt)	○

* S: Successful, A: Abandoned, L.Y.: Low yield

a.7 Doba wein woreda

Groundwater utilization potential evaluation map of Doba wein woreda, is shown in Figure 6.17. Groundwater utilization potential evaluation profile is shown in Figure 6.18 and Figure 6.19. Well construction record for the area is shown in Table 6.10.

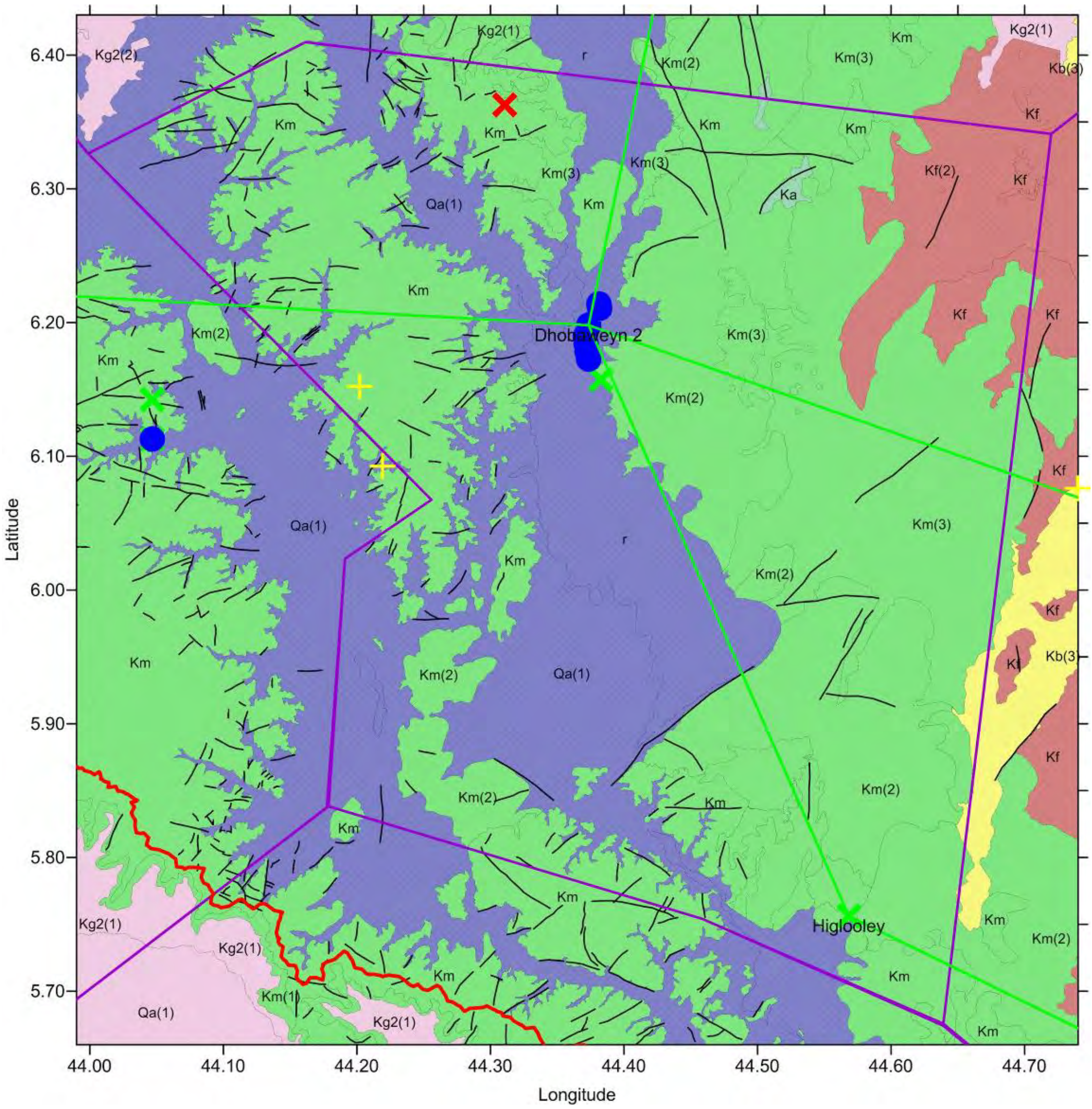


Figure 6.17: Groundwater Utilization Potential Evaluation Map of Doba Wein Woreda

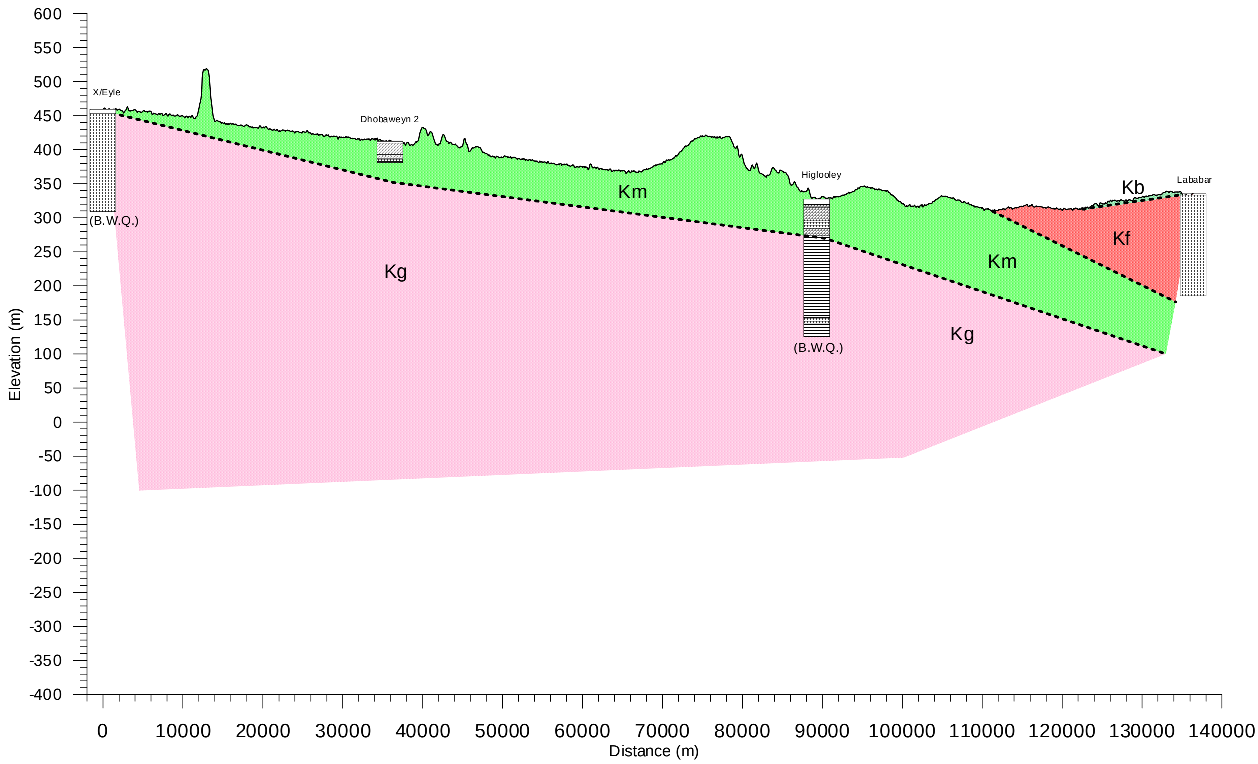


Figure 6.18: Groundwater Utilization Potential Evaluation Profile of Doba Wein Woreda (parallel to the river)

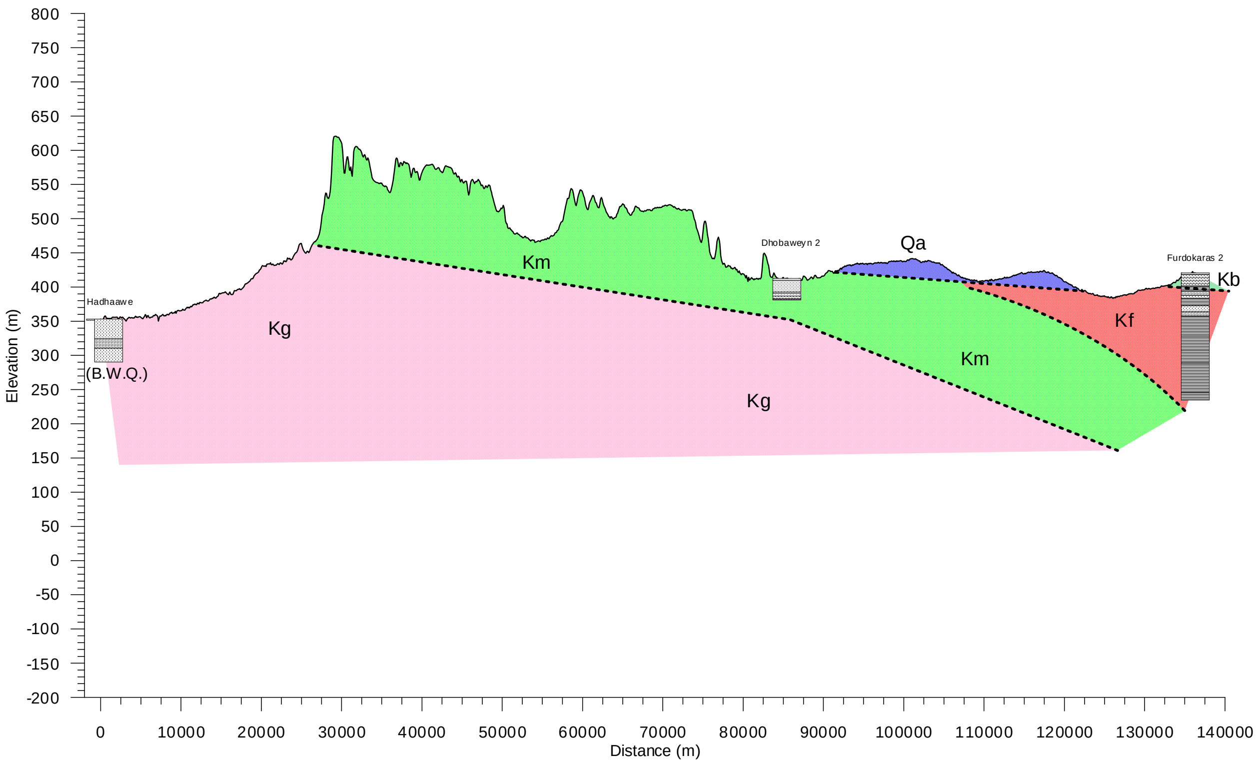


Figure 6.19: Groundwater Utilization Potential Evaluation Profile of Doba Wein Woreda (across the river)

Table 6.10: Record of Wells Constructed in Doba Wein Woreda

Temp. ID	Long. (°)	Lat. (°)	UTM-X (m)	UTM-Y (m)	Elev. (m)	Type	Depth (m)	SWL (GL-m)	DWL (GL-m)	Yield (L/sec.)	Date of Const.	Const. by	Status	Well log
Jiracle	44.3817	6.2105	431597	686455	416	SW	-	-	-	-	1991	EWWCA	S	-
Jeracle	44.3817	6.2105	431597	686455	416	SW	-	-	-	-	1996	EWWCA	-	-
Dhobaweyn 2	44.3735	6.1980	430688	685067	412	SW	31.6	-	-	-	-	-	S	○
Dhobaweyn 3	44.3712	6.1899	430433	684173	410	SW	24	-	-	-	-	-	S	○
Dhobaweyn 4	44.3715	6.1841	430465	683537	410	SW	24.9	-	-	-	-	-	S	○
Dhobaweyn 5	44.3722	6.1786	430542	682921	407	SW	-	-	-	-	-	-	S	-
Dhobaweyn 6	44.3735	6.1726	430685	682267	410	SW	-	-	-	-	-	-	S	-
Dhobaweyn 1	44.3829	6.1574	431723	680575	413	BH	-	-	-	-	1991	EWWCA	A (Salt)	-
Higlooley	44.5684	5.7562	452213	636214	327	BH	202	-	-	-	2000	Rabah	A (Salt)	○
Jiracle-3	44.3812	6.2139	431542	686829	410	-	24.8	7	-	-	2006	-	S	○
Marerale well #1	44.3108	6.3628	423772	703296	549	-	170	-	-	-	2002(EC)	-	A (Salt)	○

* S: Successful, A: Abandoned

b. Shebele sub-basin

b.1 Rasso woreda

Groundwater utilization potential evaluation map of Rasso woreda, is shown in Figure 6.20. Well construction record for the area is shown in Table 6.11.

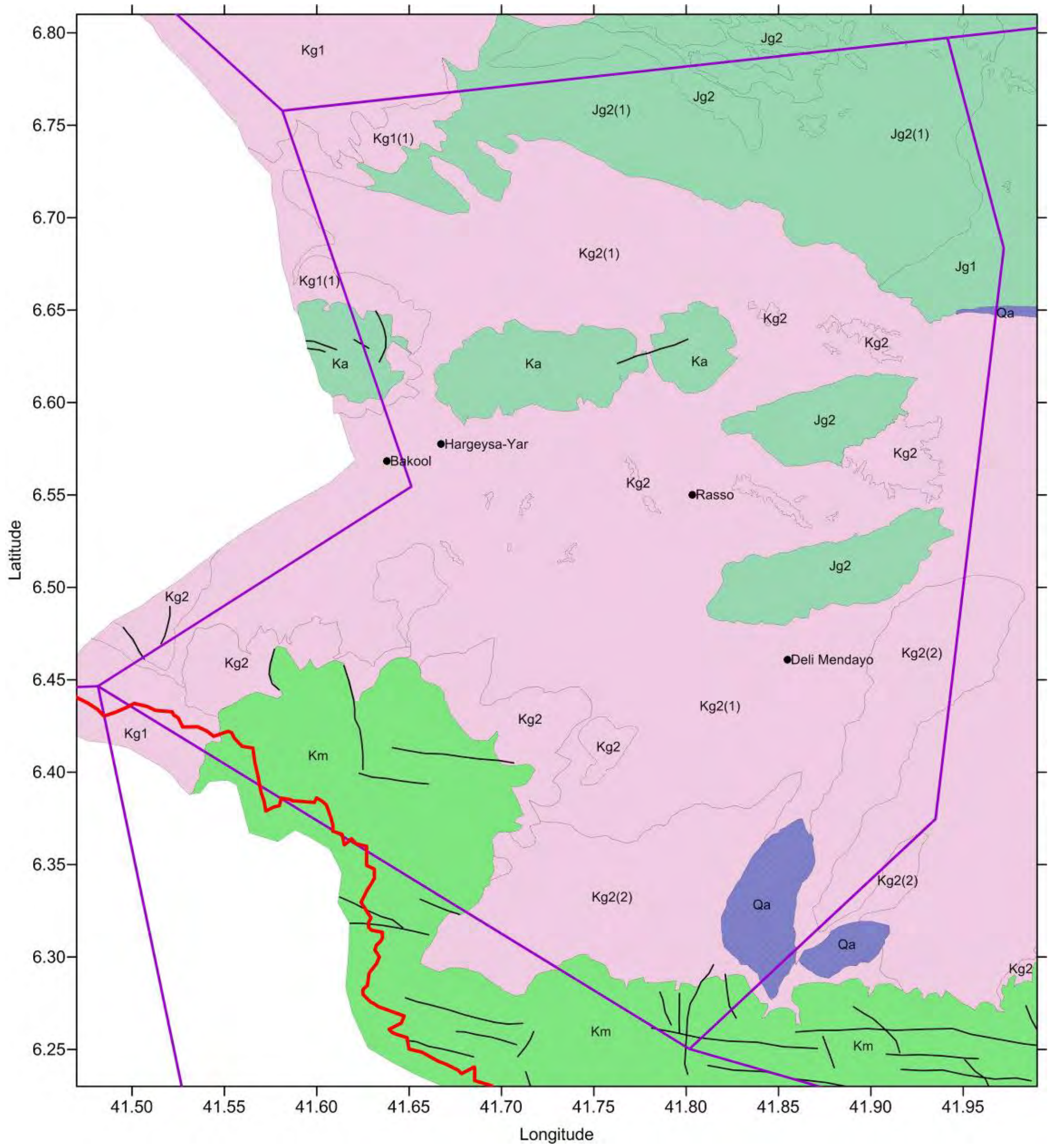


Figure 6.20: Groundwater Utilization Potential Evaluation Map of Rasso Woreda

Table 6.11: Record of Wells Constructed in Rasso Woreda

Temp. ID	Long. (°)	Lat. (°)	UTM-X (m)	UTM-Y (m)	Elev. (m)	Type	Depth (m)	SWL (GL-m)	DWL (GL-m)	Yield (L/sec.)	Date of Const.	Const. by	Status	Well log
Rasso BH	41.7924	6.5334	145190	723229	-	-	-	-	-	-	-	-	-	-

b.2 West Ime woreda

Groundwater utilization potential evaluation map of West Ime woreda, is shown in Figure 6.21. Well construction record for the area is shown in Table 6.12.

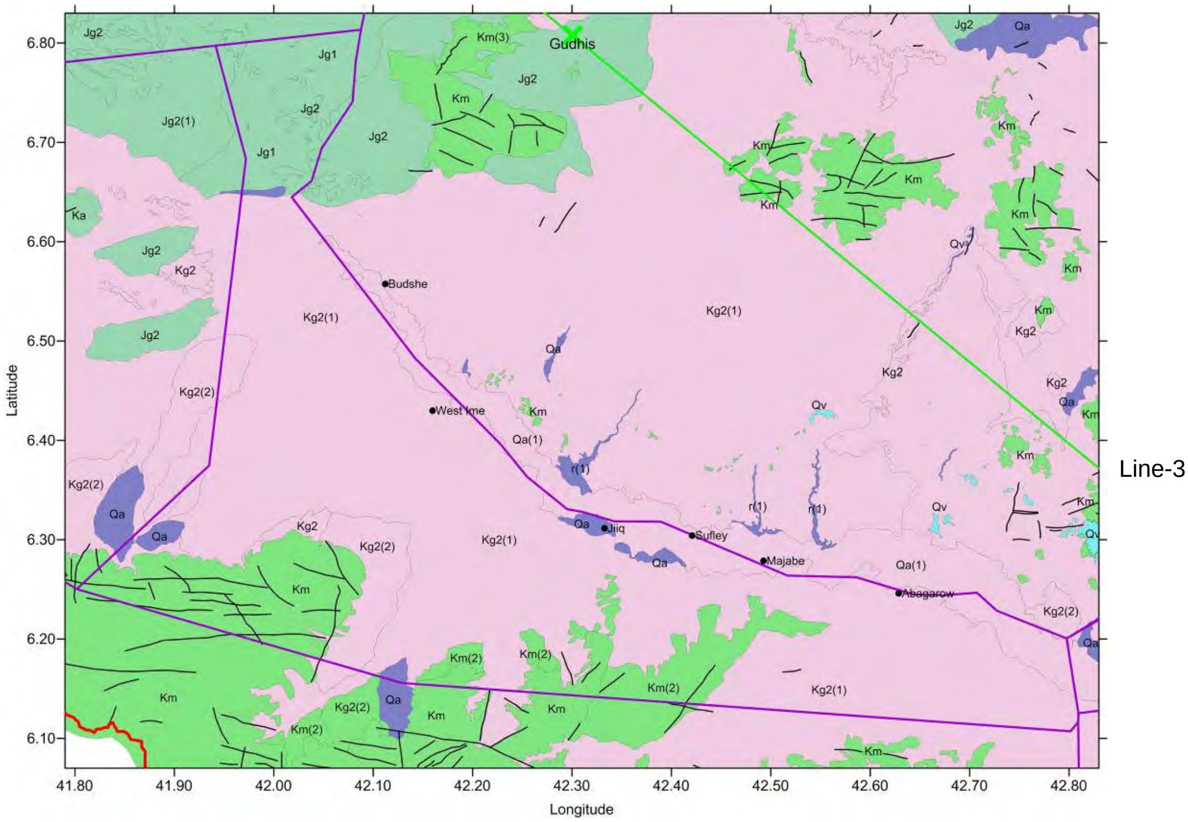


Figure 6.21: Groundwater Utilization Potential Evaluation Map of West Ime Woreda

Table 6.12: Record of Wells Constructed in West Ime Woreda

Temp. ID	Long. (°)	Lat. (°)	UTM-X (m)	UTM-Y (m)	Elev. (m)	Type	Depth (m)	SWL (GL-m)	DWL (GL-m)	Yield (L/sec.)	Date of Const.	Const. by	Status	Well log
Bula BH	41.9902	6.5325	167091	722998	-	-	-	-	-	-	-	-	-	-

b.3 East Ime woreda

Groundwater utilization potential evaluation map of Eest Ime woreda, is shown in Figure 6.22. Well construction record for the area is shown in Table 6.13.

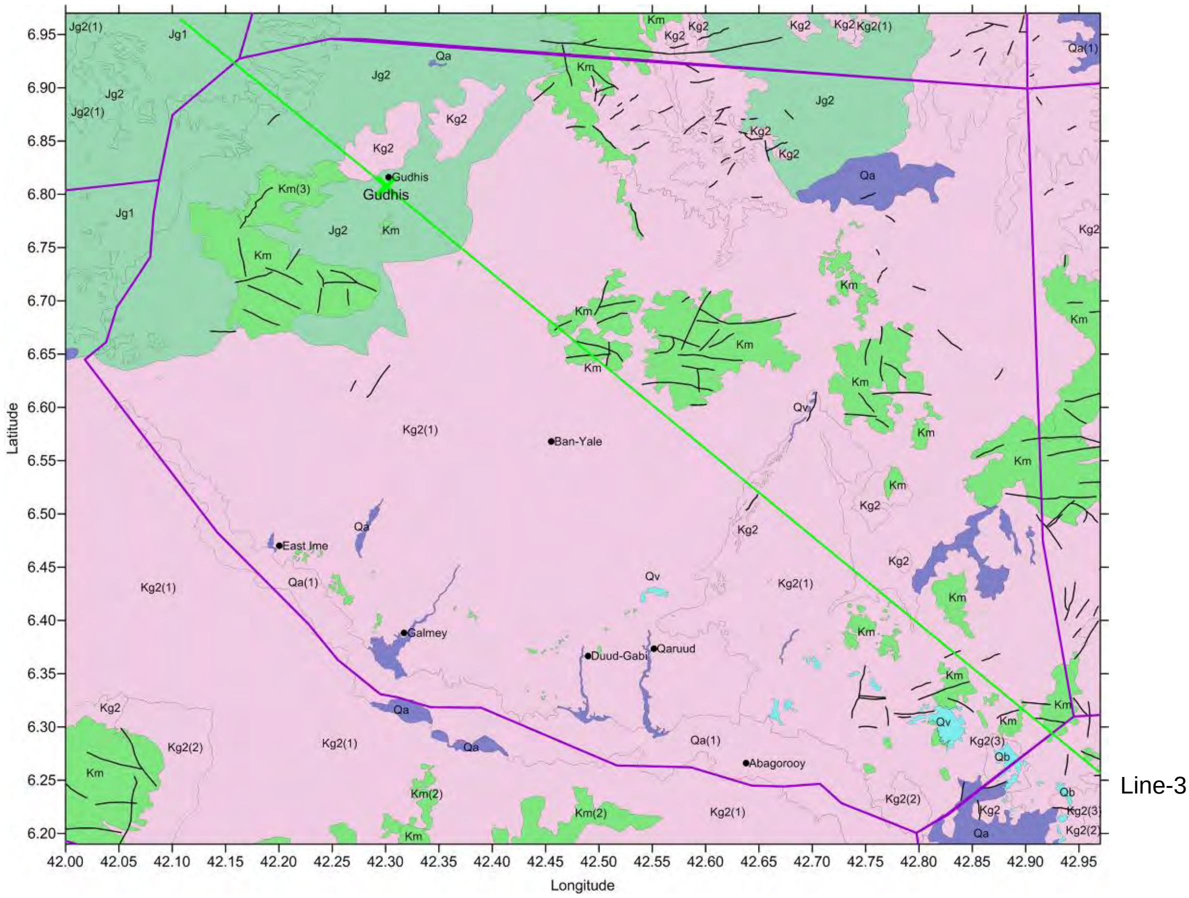


Figure 6.22: Groundwater Utilization Potential Evaluation Map of East Ime Woreda

Table 6.13: Record of Wells Constructed in East Ime Woreda

Temp. ID	Long. (°)	Lat. (°)	UTM-X (m)	UTM-Y (m)	Elev. (m)	Type	Depth (m)	SWL (GL-m)	DWL (GL-m)	Yield (L/sec.)	Date of Const.	Const. by	Status*	Well log
Gudhis	42.3006	6.8074	201614	753219	634	BH	145	-	-	-	-	-	A (BWQ)	○

* A: Abandoned, BWQ: Bad water quality

b.4 Adadle woreda

Groundwater utilization potential evaluation map of Adadle woreda, is shown in Figure 6.23. Well construction record for the area is shown in Table 6.14.

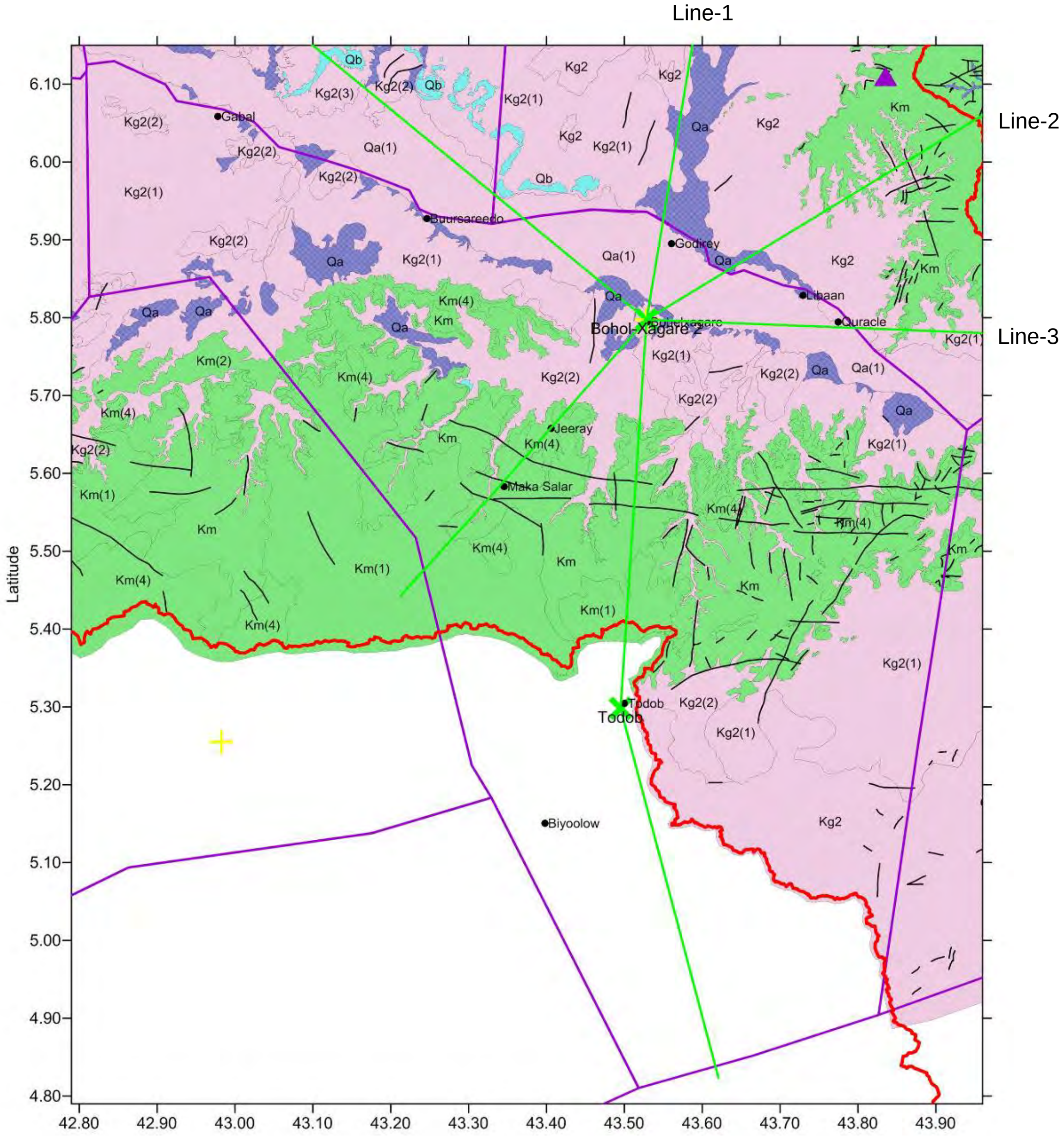


Figure 6.23: Groundwater Utilization Potential Evaluation Map of Adadle Woreda

Table 6.14: Record of Wells Constructed in Adadle Woreda

Temp. ID	Long. (°)	Lat. (°)	UTM-X (m)	UTM-Y (m)	Elev. (m)	Type	Depth (m)	SWL (GL-m)	DWL (GL-m)	Yield (L/sec.)	Date of Const.	Const. by	Status*	Well log
Bohol-Xaga	43.528	5.797	337070	640968	285	BH	150	-	-	-	-	-	A (BWQ)	○
Bohol-Xaga re 2	43.528	5.797	337070	640968	285	-	150	-	-	-	-	-	-	○
Todob	43.495	5.298	333231	585781	538	BH	150	-	-	-	2000	SCF/USA	A (BWQ)	○
Qobo well NO.1	43.330	5.572	315024	616179	453	-	280	-	-	-	2007	-	A (L.Y.)	○

* A: Abandoned, L.Y.: Low yield, BWQ: Bad water quality

b.5 Danan woreda

Groundwater utilization potential evaluation map of Danan woreda, is shown in Figure 6.24. Well construction record for the area is shown in Table 6.15.

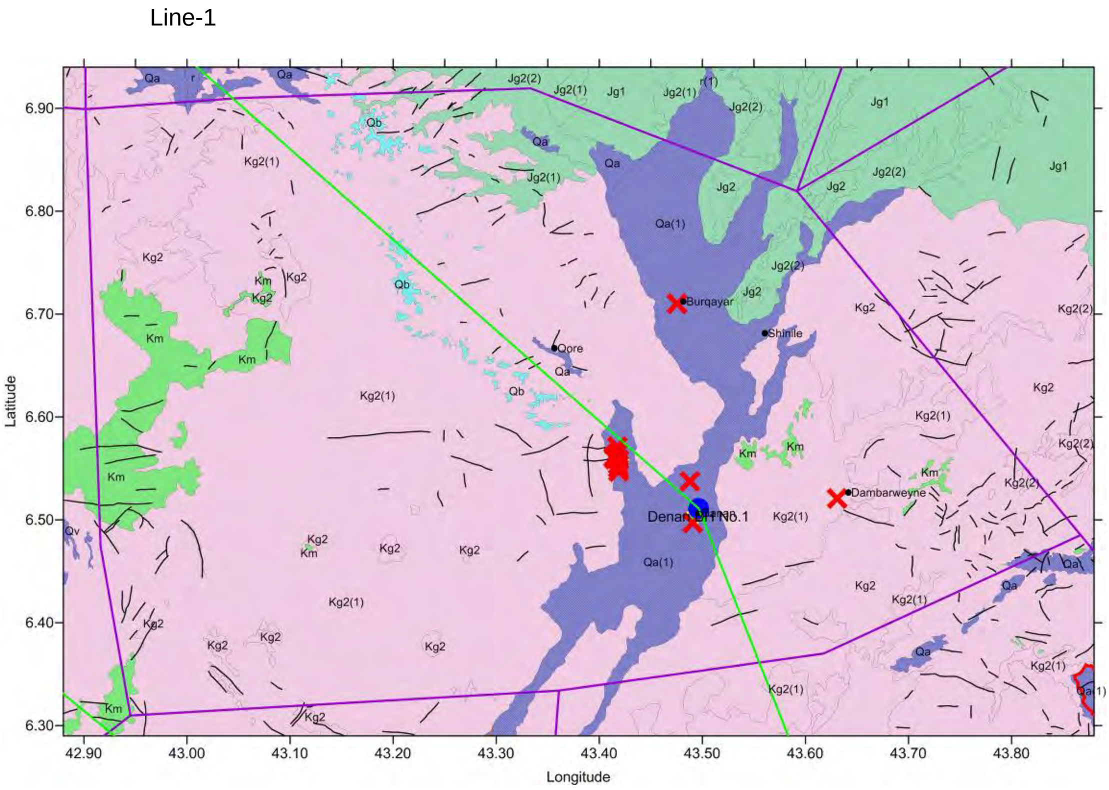


Figure 6.24: Groundwater Utilization Potential Evaluation Map of Danan Woreda

Table 6.15: Record of Wells Constructed in Danan Woreda

Temp. ID	Long. (°)	Lat. (°)	UTM-X (m)	UTM-Y (m)	Elev. (m)	Type	Depth (m)	SWL (GL-m)	DWL (GL-m)	Yield (L/sec.)	Date of Const.	Const. by	Status*	Well log
Burqayar	43.4754	6.7101	331482	741890	510	BH	151	93	-	-	2000	SCF/USA	A (L.Y.)	-
Danan	43.4951	6.5068	333592	719404	434	BH	90	-	-	-	2000	SCF/USA	(BWQ)	-
Danan 1	43.4951	6.5068	333592	719404	434	BH	111.25	-	-	-	2000	SCF/USA	A (BWQ)	○
Danan 2	43.4908	6.4972	333113	718346	428	BH	-	-			-	-	A (BWQ)	-
Danan 3	43.4878	6.5373	332795	722787	445	BH	-	-			-	-	A (BWQ)	-
Dhanbarwey	43.6307	6.5209	348593	720923	448	SW	60	23			2000	SCF/USA	A (L.Y.)	-
Koore	43.4189	6.5576	325182	725050	445	SW	25	6			2000	SCF/USA	S	-
Koore 2	43.4183	6.5535	325114	724598	444	SW	-	-			-	-	A (L.Y.)	-
Koore 3	43.4186	6.5503	325146	724241	440	SW	-	-			-	-	A (L.Y.)	-
Koore 4	43.4189	6.5468	325178	723854	440	SW	-	-			-	-	A (L.Y.)	-
Koore 5	43.4175	6.5645	325029	725821	447	SW	-	-			-	-	A (L.Y.)	-
Koore 6	43.4175	6.5713	325032	726566	452	SW	-	-			-	-	A (L.Y.)	-
Denan BH No.1	43.4964	6.5111	333736	719886	435	-	30	18	-	-	1984(EC)	-	S	○
Kore well	43.4147	6.5591	324715	725221	444	-	25	10.6	-	-	2010	-	(L.Y.)	○
Kore-1	43.4189	6.5582	325185	725117	444	-	28.3	12.5	-	-	2008	-	A (L.Y.)	○
Kore well	43.4142	6.5607	324665	725398	447	-	25	8.4	-	-	2010	-	(L.Y.)	○
Kore-2	43.4189	6.5582	325185	725117	444	-	28.3	12.5	-	-	2008	-	A (L.Y.)	○

* S: Successful, A: Abandoned, L.Y.: Low yield, BWQ: Bad water quality

b.6 Godey woreda

Groundwater utilization potential evaluation map of Godey woreda, is shown in Figure 6.25. Well construction record for the area is shown in Table 6.16.

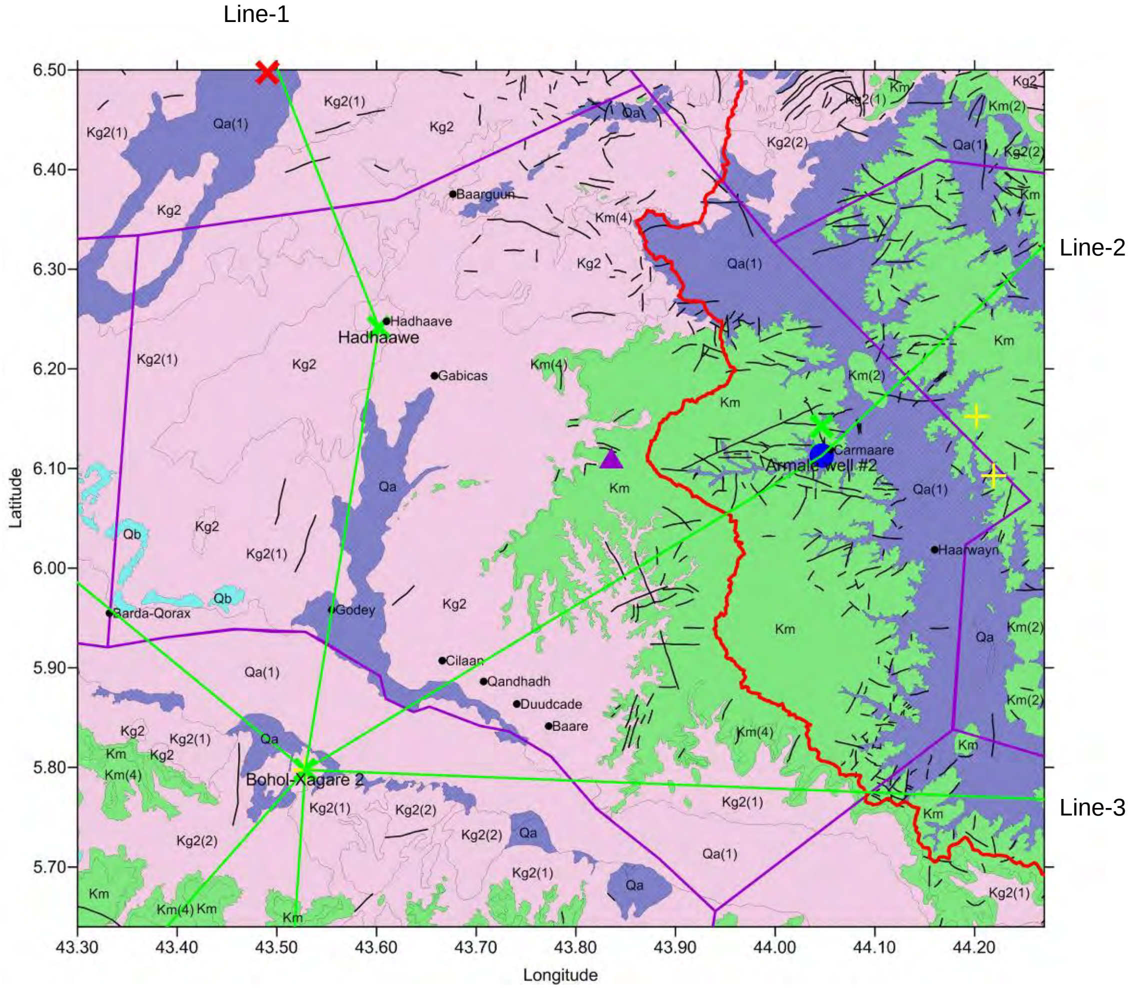


Figure 6.25: Groundwater Utilization Potential Evaluation Map of Godey Woreda

Table 6.16: Record of Wells Constructed in Godey Woreda

Temp. ID	Long. (°)	Lat. (°)	UTM-X (m)	UTM-Y (m)	Elev. (m)	Type	Depth (m)	SWL (GL-m)	DWL (GL-m)	Yield (L/sec.)	Date of Const.	Const. by	Status*	Well log
Carmale BH	44.0469	6.1423	394542	678970	532	BH	-	-	-	-	-	-	A (BWQ)	-
Carmale SW	44.0467	6.1129	394514	675712	490	SW	-	-	-	-	-	-	S	-
Hadhaawe	43.6025	6.2413	345391	690025	354	BH	65	-	-	-	2003	WRDB	A (BWQ)	○
Elele deep oil well	43.8355	6.1103	371144	675470	586	Oil Well	3590	-	-	-	-	-	-	○
Magan deep oil well	44.2192	6.0927	413596	673453	463	Oil Well	4056	-	-	-	-	-	-	○
Armale well #2	44.0467	6.1129	394513	675712	490	-	234	6	-	-	2007	-	A (BWQ)	○
Armale well #3	44.0467	6.1129	394513	675712	490	-	25	6	-	-	2007	-	S	○

* S: Successful, A: Abandoned, BWQ: Bad water quality

b.7 Beercaano woreda

Groundwater utilization potential evaluation map of Beercaano woreda, is shown in Figure 6.26. Well construction record for the area is shown in Table 6.17.

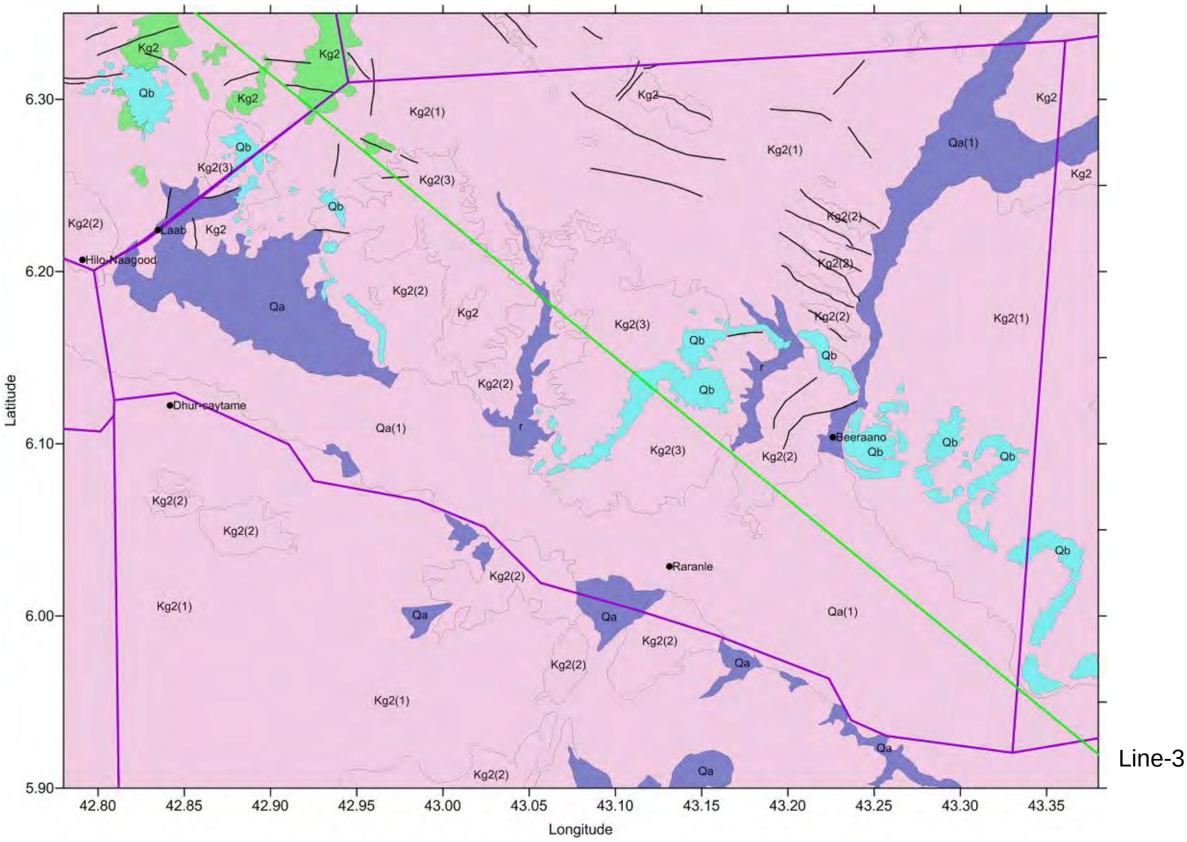


Figure 6.26: Groundwater Utilization Potential Evaluation Map of Beercaano Woreda

Table 6.17: Record of Wells Constructed in Beercaano Woreda

Temp. ID	Long. (°)	Lat. (°)	UTM-X (m)	UTM-Y (m)	Elev. (m)	Type	Depth (m)	SWL (GL-m)	DWL (GL-m)	Yield (L/sec.)	Date of Const.	Const. by	Status	Well log
No Construction														

b.8 Kalafo woreda

Groundwater utilization potential evaluation map of Kalafo woreda, is shown in Figure 6.27. Well construction record for the area is shown in Table 6.18.

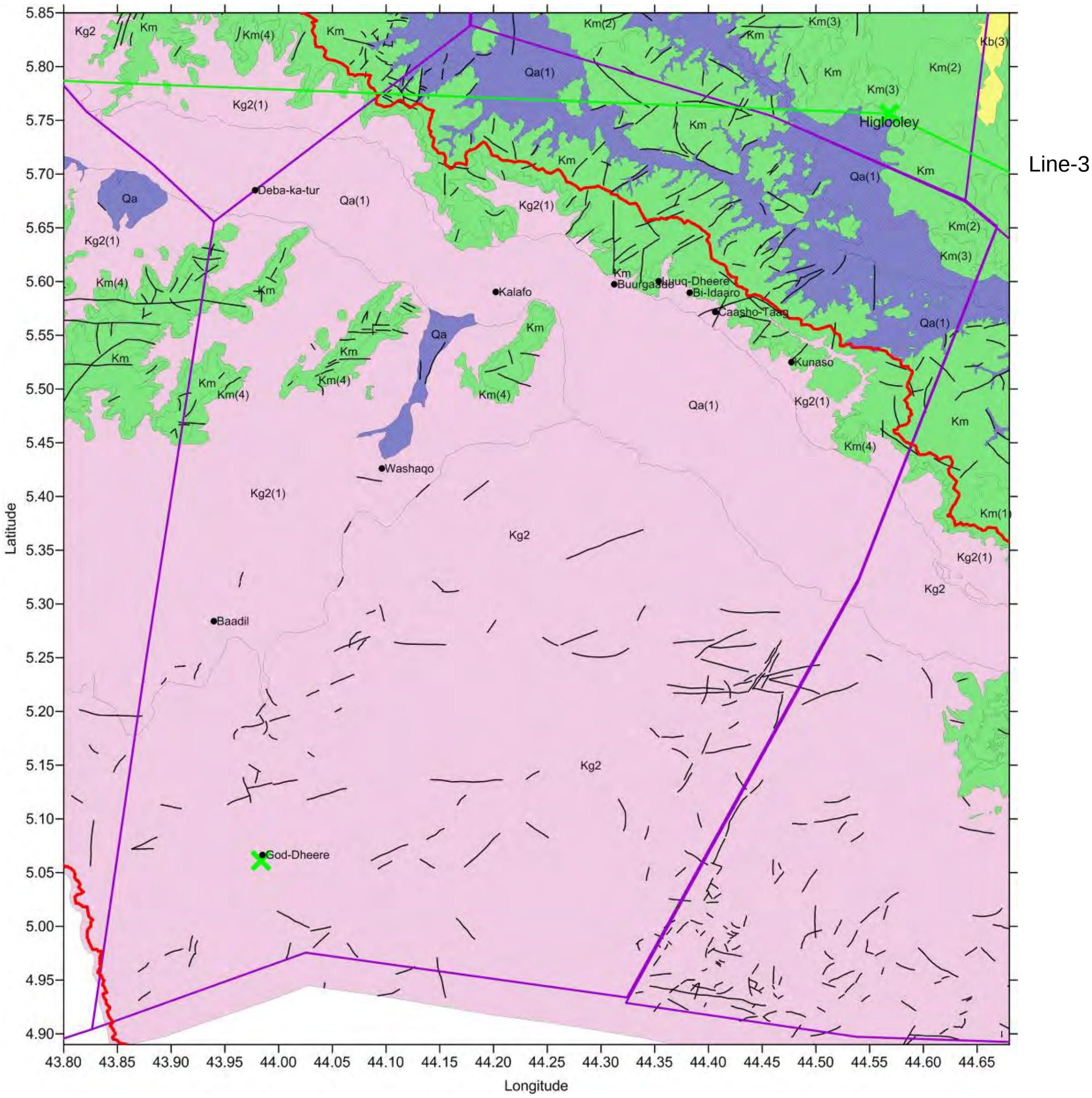


Figure 6.27: Groundwater Utilization Potential Evaluation Map of Kalafo Woreda

Table 6.18: Record of Wells Constructed in Kalafo Woreda

Temp. ID	Long. (°)	Lat. (°)	UTM -X (m)	UTM -Y (m)	Elev. (m)	Type	Depth (m)	SWL (GL-m)	DWL (GL-m)	Yield (L/sec.)	Date of Const.	Const. by	Status*	Well log
God-Dheere	43.9837	5.0611	387341	559452	419	BH	180	30	-	-	2003	Rabah	A (BWQ)	○

* A: Abandoned, BWQ: Bad water quality

b.9 Mustahil woreda

Groundwater utilization potential evaluation map of Mustahil woreda, is shown in Figure 6.28. Well construction record for the area is shown in Table 6.19.

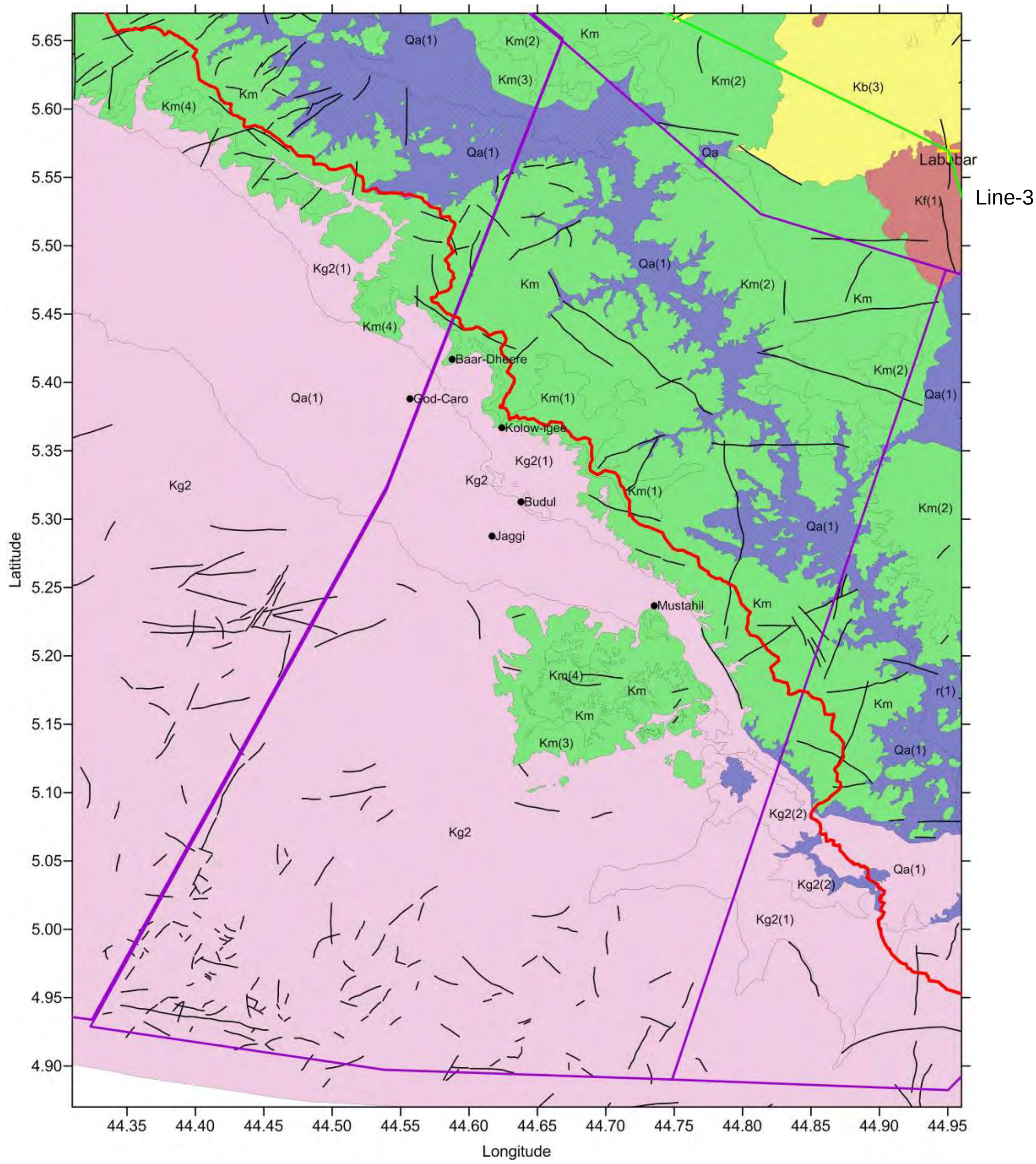


Figure 6.28: Groundwater Utilization Potential Evaluation Map of Mustahil Woreda

Table 6.19: Record of Wells Constructed in Mustahil Woreda

Temp. ID	Long. (°)	Lat. (°)	UTM-X (m)	UTM-Y (m)	Elev. (m)	Type	Depth (m)	SWL (GL-m)	DWL (GL-m)	Yield (L/sec.)	Date of Const.	Const. by	Status	Well log
No Construction														

b.10 Geological profile

Locations of three cross-sections in Shebele sub-basin for groundwater utilization potential evaluation profiles are shown in Figure 6.29. And the profiles of these cross-sections are shown in Figure 6.30, Figure 6.31 and Figure 6.32.

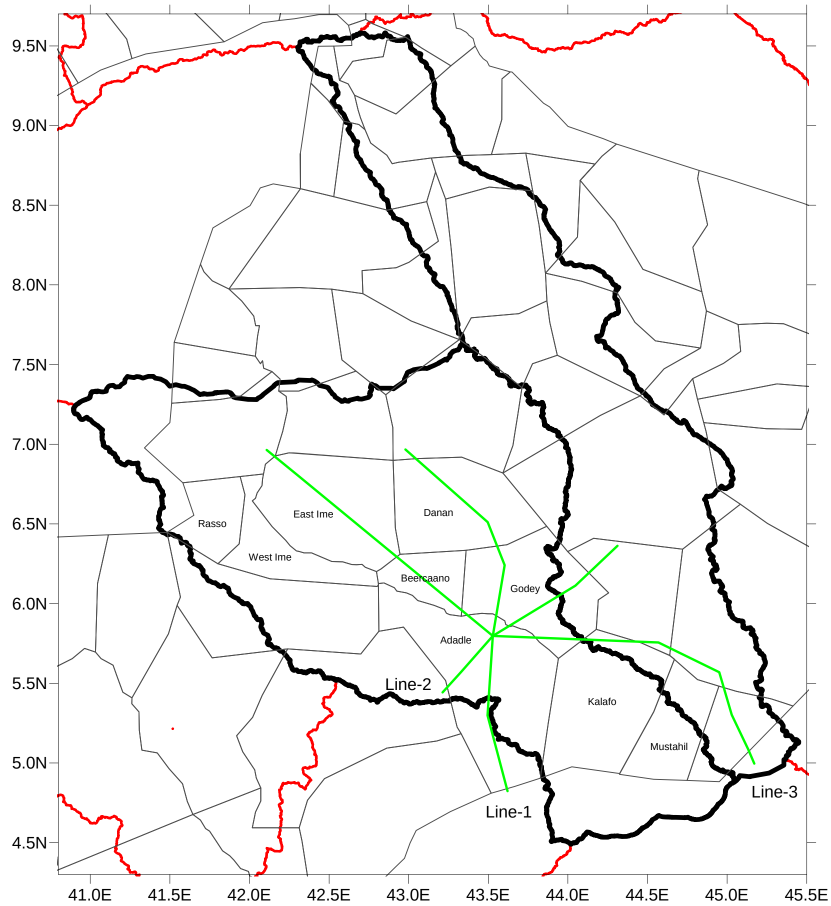


Figure 6.29: Groundwater Utilization Potential Evaluation Profiles in Shebele Sub-Basin

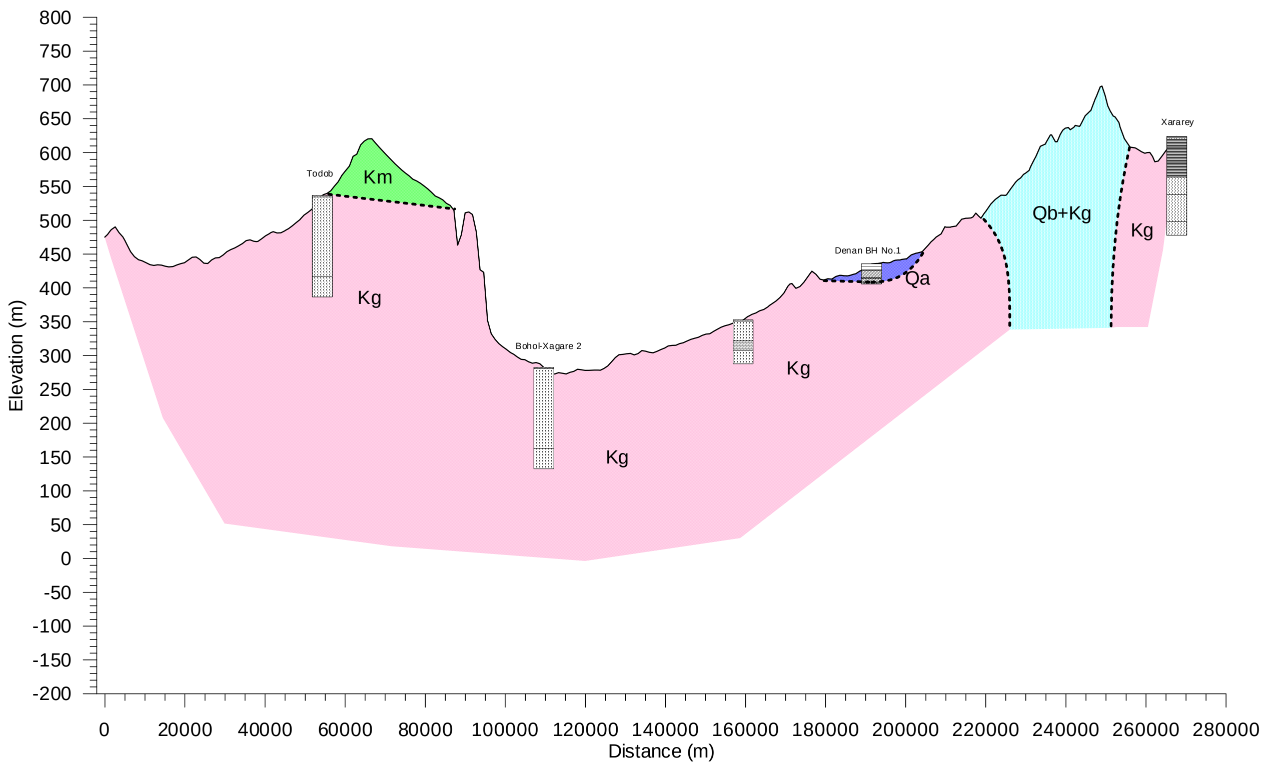


Figure 6.30: Groundwater Utilization Potential Evaluation Profile of Shebele Sub-Basin (line-1)

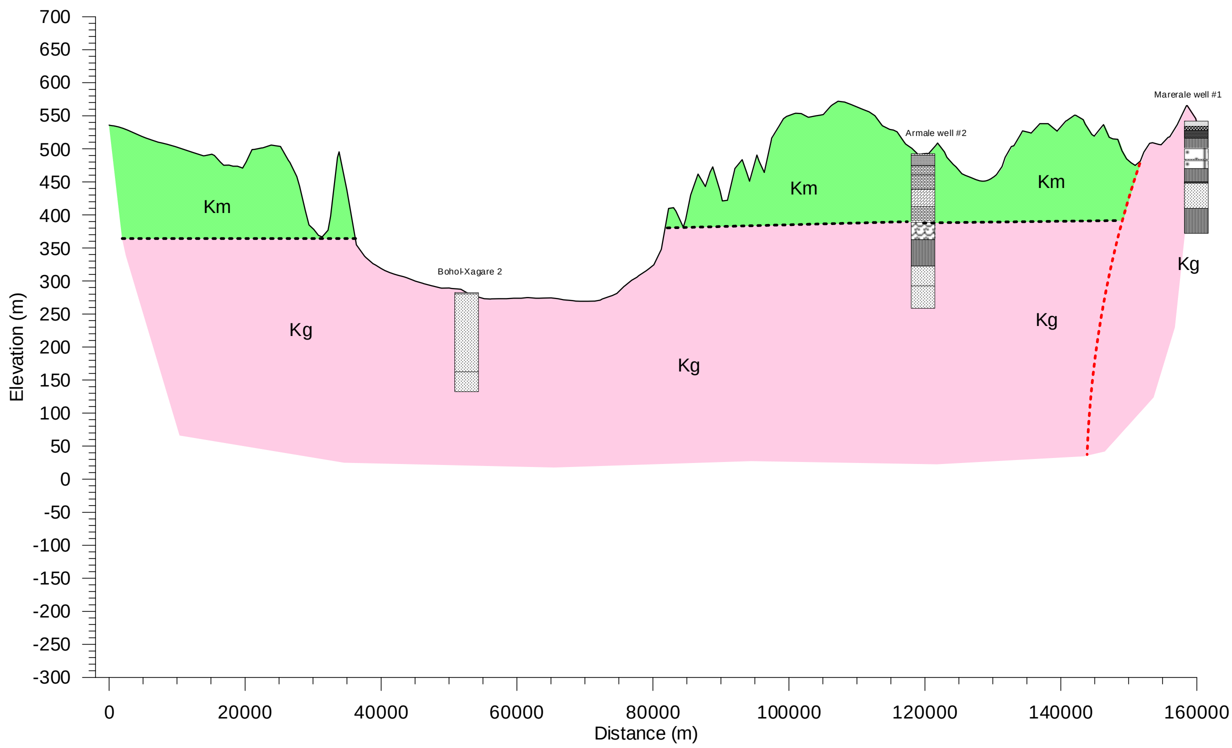


Figure 6.31: Groundwater Utilization Potential Evaluation Profile of Shebele Sub-Basin (line-2)

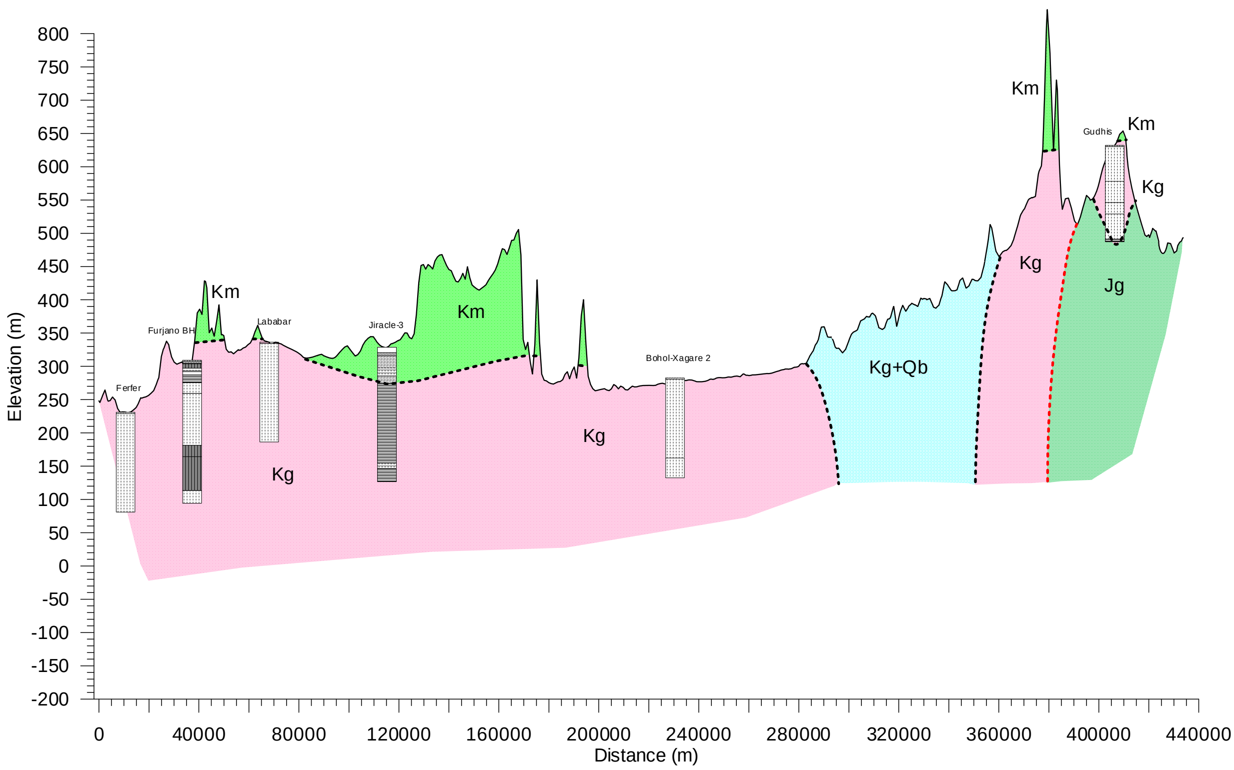


Figure 6.32: Groundwater Utilization Potential Evaluation Profile of Shebele Sub-Basin (line-3)

Chapter 7

Water Resources Information Map for Somali Region

7 Water Resources Information Map for Somali Region

7.1 Relevant data collection

The existence of the groundwater and available quantity depends on the following four main factors.

1) Groundwater recharge
2) Topography
3) Geology
4) Lineament
5) Water quality

Remote sensing can be used for the analysis of the two factors firstly: Groundwater recharge and topography. The third factor of geology is composed of two features: geology stratum and structure (lineament). The remote sensing can be used for lineament extraction but that is impossible for stratum analysis. The fourth factor of water quality is similar as the third one, the remote sensing cannot be analyzed by using water quality. Taken the availability of remote sensing into consideration, the necessary data have been collected as follows.

The first task of Water Resources Information Map (WRIM) by using remote sensing is to collect data relating to groundwater basin's formation. The data can be separated into two main types: primary data and secondary data.

Primary data means the images directly obtained from aerial survey such as Landsat from US NASA and PALSAR from JAXA. This kind of data directly reflects aspects on the ground surface to have higher reliability. But because of influence by many kinds of other natural conditions, the primary data also has a defect of many noises within it.

Secondary data means the analysis result by using the primary data combined with many other relative and indispensable data for modification of primary data, for example noise erasing. Because not only a lot of primary data but also numerous supporting data needs to be collected for the modification, these kind of analysis can only be conducted by a lot of experts in many agencies and organizations.

The most reliable and widely used secondary data can be considered as Mrsid and SRTM. Mrsid (Multiresolution Seamless Image Database) is a natural condition image database created by using Landsat bands. This database has been used as the background of Google earth and many other survey or analysis. SRTM (Shuttle Radar Topography Mission) is the analysis result using the images from Shuttle Imaging Radar and Synthetic Aperture Radar to show the topography for the whole world.

Plentiful secondary data have been released by those agencies and organizations in many countries. Those data provides basic information about precipitation, potential evapotranspiration, temperature and so on. Most of the secondary data are based on Landsat image together with other relative and indispensable observation results. Some well known secondary data can be simply summarized as the land cover data from World Resources Institute, Chiba University, Global Land Cover Facility and others; potential evapotranspiration data from FAO, EU_WATCH, UNEP and so on; soil moisture data from

FAO, ESA (European Space Agency), NOAA (National Oceanic and Atmospheric Administration, Department of Commerce, US)) and so on. All these secondary data are very important and useful for WRIM.

7.1.1 Recharge data collection

Amount of groundwater recharge is the essential factor for WRIM. Groundwater recharge in almost all area is determined by precipitation and evaporation. Therefore, both precipitation and evapotranspiration data need to be collected for groundwater recharge analysis.

Several secondary precipitation data has been collected from different organizations and survey groups, such as World Clim, a research group in California University. Same as the precipitation data, secondary evapotranspiration data was also collected from several organizations and survey groups, for example the potential evapotranspiration grid data released by FAO and USNASA.

7.1.2 Topography data collection

As shown in Figure 7.1 the effect of topography on groundwater, groundwater flows following the topography from high to low elevation area. Some groundwater flow get over the ground surface to become river's recharge of base flow, and other part flowing towards to the lowest location in the basin.

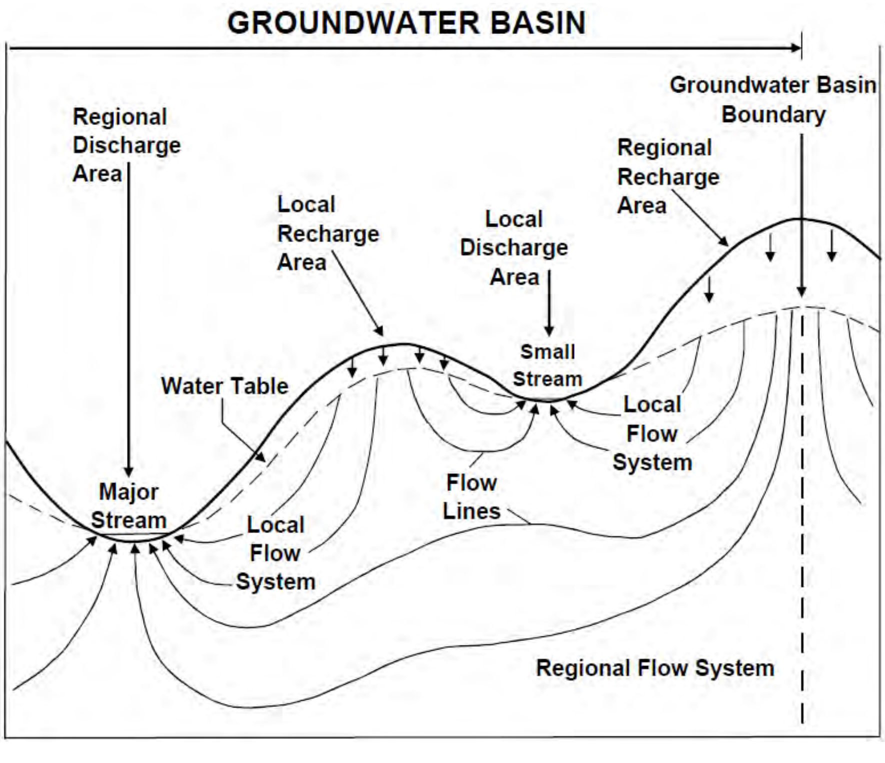


Figure 7.1: Two-dimensional Theoretical Potential Distributions and Flow Patterns (Modified conception map from Toth, 1983)

As the base for topography analysis the secondary data of SRTM from USNASA and Aster from USNASA & JSS are collected.

7.1.3 Geology data collection

As mentioned above, even though stratum data of geology is indispensible for groundwater analysis, but it is impossible to find the stratum data by remote sensing. Hence, the geology data from UNESCO is directly used. For analysis of geology data of lineament two kinds of primary data are collected. The first is Landsat that were collected to cover the whole study area, because Landsat is freely released from USNASA. Another one is PALSAR collected that has higher resolution and collected to cover main area in Somali region.

7.1.4 Water quality data collection

The same as the geology stratum, it's impossible to obtained data of groundwater quality from remote sensing. Hence, the water quality classification data from UNESCO (2012) was directly used.

7.1.5 Other data collection

The primary data and secondary data collected for this project are summarized in Table 7.1 and Table 7.2.

Table 7.1: Collected Primary Data

Landsat					
Path_162-55	Date	88_01_25	01_1_12	07_04_19	
Path_163-54	Date	86_02_19	00_02_02	01_11_03	05_12_16
Path_163-55	Date	86_02_19	01_11_13	06_05_09	
Path_163-56	Date	85_02_16	00_07_27	06_05_09	
Path_164-54	Date	86_03_30	00_05_15	05_11_05	
Path_164-55	Date	86_03_30	99_11_21	05_06_14	
Path_164-56	Date	86_01_09	99_11_21	05_12_07	
Path_164-57	Date	99_11_21	00_03_28	05_12_07	
Path_165-54	Date	86_02_01	05_10_27		
Path_165-55	Date	86_02_01	01_11_17	05_11_28	
Path_165-56	Date	86_02_01	01_11_17	05_11_28	
Path_165-57	Date	86_02_01	01_11_17	05_11_28	
Path_166-52	Date	85_06_13	00_05_13	05_04_09	
Path_166-53	Date	85_03_09	00_05_13	06_04_12	
Path_166-54	Date	86_01_23	00_12_23	06_11_06	
Path_166-55	Date	86_01_23	01_01_24	05_12_05	
Path_166-56	Date	86_01_23	01_01_24	05_12_05	
Path_166-57	Date	86_01_23			
Path_167-52	Date	01_03_20	03_09_02	06_03_02	
Path_167-53	Date	86_01_30	00_03_17	01_02_16	06_03_02
Path_167-54	Date	86_01_30	00_11_28	05_11_26	
Path_167-55	Date	86_01_30	00_11_28	05_11_26	
Path_167-56	Date	86_01_14	00_11_28	05_12_12	
Path_167-57	Date	86_01_14	05_12_12	00_11_28	01_01_31
Path_167-58	Date	86_01_14	00_12_14	05_01_10	
PALSAR					
PASL41010061519492812073100049			PASL41010072619424312073100077		
PASL41010061519493612073100050			PASL41010072619425112073100078		
PASL41010061519494412073100051			PASL41010072619430012073100079		
PASL41010061519495212073100052			PASL41010072619430812073100080		
PASL41010061519500012073100053			PASL41010072619431612073100081		
PASL41010061519500912073100054			PASL41010062019560712073100082		
PASL41010061519501712073100055			PASL41010062019561512073100083		
PASL41010061519502512073100056			PASL41010062019562412073100084		
PASL41010061519503312073100057			PASL41010062019563212073100085		
PASL41010061519504212073100058			PASL41010070219513412073100086		
PASL41010061519505012073100059			PASL41010070219514212073100087		
PASL41010062719450312073100060			PASL41010070219515012073100088		
PASL41010062719451112073100061			PASL41010070219515812073100089		
PASL41010062719451912073100062			PASL41010070219520612073100090		
PASL41010062719452712073100063			PASL41010070219522312073100091		
PASL41010062719453612073100064			PASL41010070219523112073100092		
PASL41010062719454412073100065			PASL41010070219523912073100093		
PASL41010062719455212073100066			PASL41010070219524812073100094		
PASL41010062719460012073100067			PASL41010070719581412073100095		
PASL41010071419470112073100068			PASL41010070719582212073100096		
PASL41010071419470912073100069			PASL41010070719583012073100097		
PASL41010071419471712073100070			PASL41010071919533212073100098		
PASL41010071419472612073100071			PASL41010071919534012073100099		
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PASL41010071419474212073100073			PASL41010071919535612073100101		
PASL41010071419475012073100074			PASL41010071919540512073100102		
PASL41010071419475812073100075			PASL41010072420002712073100103		
PASL41010071419480712073100076					

Table 7.2: Collected Secondary Data

Source & Data Name	Content
CGIAR	Aridity Index and Potential Evapotranspiration
Chiba University	Landcover and tree percent
ESA	Landcover and soil moisture
EU_WATCH	Evapotranspiration and soil moisture
FAO	Soil moisture, Landcover, Aridity index, surface water etc.
GEM (V5)	Landcover
GLG	Tree cover
ISCGM	Land cover and tree percent
MODIS	Landcover, bare land and tree percent
NOAA US	Normalized Difference Vegetation Index
NRCS US	Soil type classification
Postel	Land cover and soil moisture
SAGE	Evapotranspiration, Net Primary Productivity and soil moil moisture
SEDAC	Agricultural Land and Drought Hazard
UN	Population and water system
UNEP	Forest canopy, precipitation, evapotranspiration, land caver, tree percent etc.
University of California (World Clim)	Temperature, precipitation and Isothermally
University of Maryland	Landcover, bare land and tree percent
USDA(Global soil)	Soil type classification
USGS	Geological map and hydrological data
USNASA & JSS (Aster)	Topography
USNASA （SRTM）	Topography
WMO	Precipitation and temperature

Note: Name of data source
CGIAR: Consultative Group on International Agricultural Research
ESA: European Space Agency
EU_WATCH: Project of Water and Global Change (WATCH, 2007-2011), funded under the EU.
GEM: Global Environment monitoring, EU
GLG: Grass Land GIS
ISCGM: International Steering Committee for Global Mapping
MODIS: MODerate resolution Imaging Spectroradiometer, a sensor of earth observation satellite TERRA/AQUA
NOAA: National Oceanic and Atmospheric Administration.
NRCS: Natural Resources Conservation Service, United States Department of Agriculture.
Postel: Pole d'Observation des Surfaces confaces continenetales par Teledetection
SAGE: Sustainability and the Global Environment at the University of Wisconsin Madison
SEDAC: Socioeconomic Data and Applications Center, USNASA
USDA: United States Department of Agriculture
USGS: United States Geological Survey
JSS: JAXA Supercomputer System
WMO: World Meteorological Organization

7.2 Method of WRIM preparation

The water resources information map (WRIM) is affected by many factors. Most of them can be directly or indirectly analyzed by remote sensing except the classification of geological strata. The procedure of remote sensing analysis to create WRIM can be summarized as follows.

1) Necessary data collection
2) Collected data's merge, compiling, and adjustment.
3) Set the classification criteria for each factor, and create the classed map or table
4) Following the dimensions of the affect to WRIM from different factors, set the weigh to each of them.
5) Compile all the factors with different weight setting to complete the WRIM.

Before compiling the data, the weights should be set to different factors that affect the result. This procedure is indispensible for WRIM compiling, but there is no officially established methods in both hydrogeology and remote sensing fields. Therefore, several different sets of weight were prepared at first and several WRIM maps were created based on the weights. Then the maps were compared with each other and also with the Groundwater Utilization Potential Evaluation Maps (GUPE maps) to determine the weights. Finally the most appropriate maps have been chosen as the final outcome.

7.3 Results of analysis of major items

7.3.1 Natural condition of Somali Region and Ethiopia

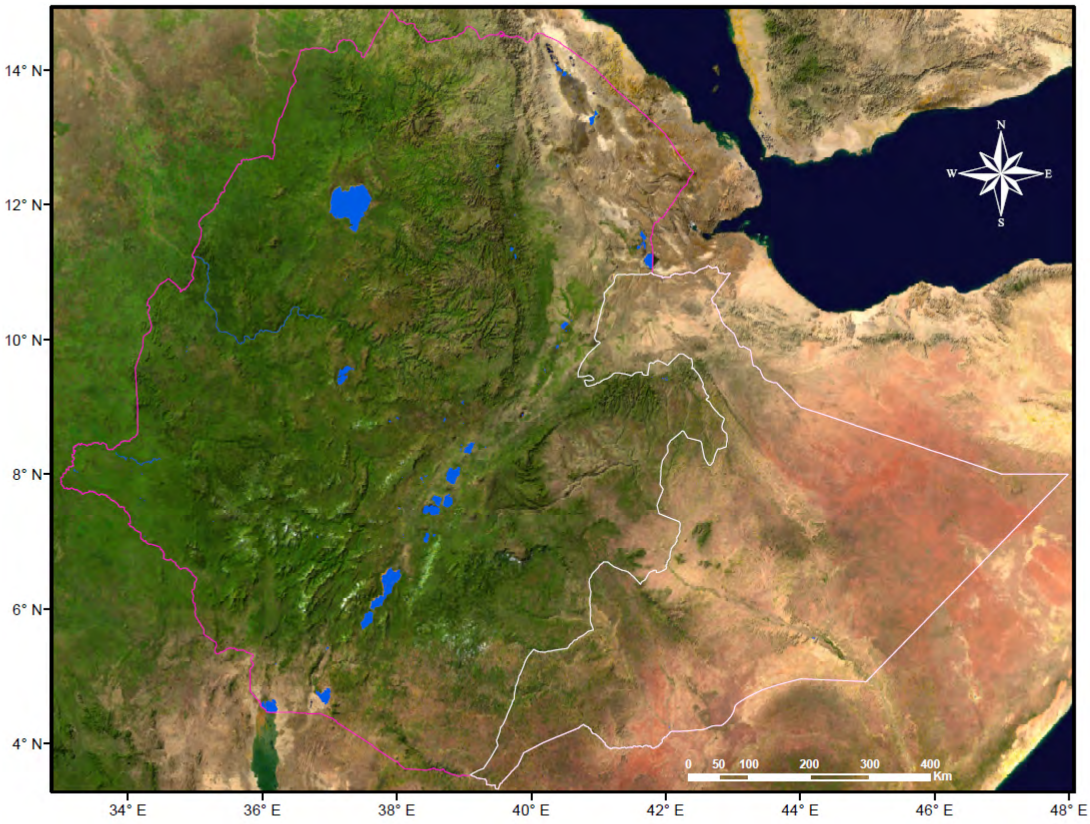


Figure 7.2: Natural Condition of Somali Region and Vicinity Area

As the first step in creation of WRIM, Figure 7.2 was created to show the natural condition of Somali Region and its surrounding areas. The map creation is based on the secondary data of Mrsid, which is an image database using visual bands from Landsat. The Landsat visual bands have resolution of 30m. To increase the precision of the database the only 15m resolution band of Panchromatic in Landsat is used for visual bands of adjustment for resolution.

As shown in the figure, in most areas of Ethiopia the ground surface is covered by green color, showing a lot of vegetations there. As mentioned above, the distribution of vegetations concerns with available groundwater. Therefore, it can be estimated that in majority area of Ethiopia there is groundwater table near the ground surface. But in the study area of Somali Region, the color is mainly sepia, meaning bare land with less vegetation except southwest part. It is clear that under natural conditions, the study area is not available for vegetation because of the shortage of water resources.

7.3.2 Precipitation

Figure 7.3 shows the distribution of annual average precipitation in Somali Region and its adjacent area. The map's creation uses the secondary data from World Clim, a research group in California University. The precipitation distribution is quite similar to the Figure 7.2. In contrast to west area of Ethiopia, precipitation amount in Somali Region is small. The abundance or available groundwater amount for a groundwater basin is based on the amount of recharge, and the recharge mainly depends on precipitation. Therefore, the small precipitation in Somali Region becomes an essential factor to make the WRIM in the study area less than other areas in Ethiopia.

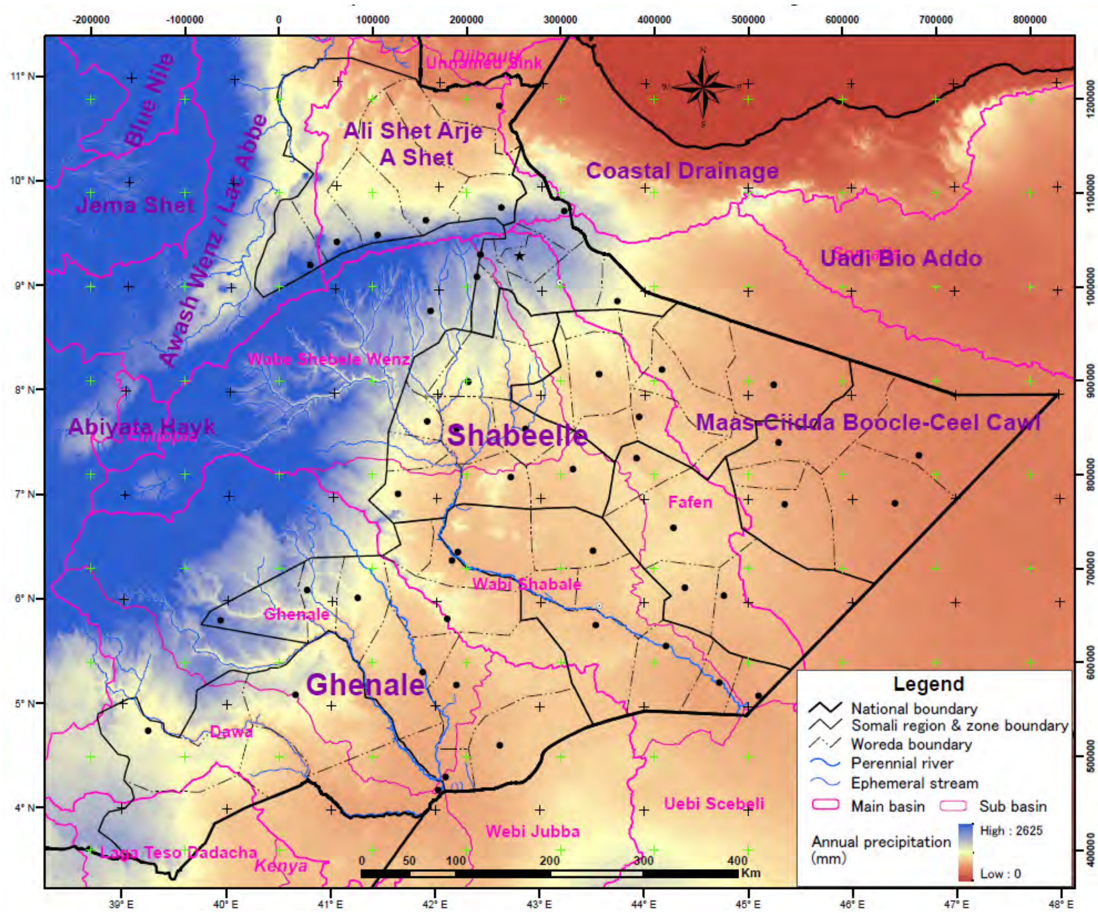


Figure 7.3: Annual Precipitation Distribution in and around Somali Region, Ethiopia

The annual precipitation in Somali Region is only 1/3 of the other areas in Ethiopia. This difference in precipitation surely is a decisive factor of lower water resources potential in

Somali Region (refer to Table 7.3).

Table 7.3: Precipitation Distribution in Main Areas

Name	Area(km^2)	Max	Min	Average
Ghenale	195,408	1,890	238	513
Shabelle	251,756	1,376	244	492
Ali Shet Arje A Shet	52,908	1,187	160	456
Lagh Dera	55,168	737	306	420
Maas-Ciidda Boocle-Ceel Cawl	232,171	793	141	240

As shown in Figure 7.3, the precipitation of main basins in Somali Region, Shabelle and Ghenale are only about 500mm. There are several basins in Somali Region but their water resources environments are different depending on the topography and climatic condition. Also the areas located upstream of a basin has relatively higher precipitation, and if compared with the downstream side, the difference can be nearly double. The difference in precipitation in upper and lower stream of a basin indicates that the groundwater recharge occur in the upstream.

7.3.3 Potential evapotranspiration

The distribution of potential evapotranspiration in and Somali Region and its surrounding area is shown in Figure 7.4. The map was created based on the secondary data of potential evapotranspiration grid released by FAO and USNASA.

The most important factor for WRIM is groundwater recharge as mentioned above. However, the amount of groundwater recharge does not only depend on precipitation, but also affected by evapotranspiration. As a general consideration, groundwater would be become relatively more if the ratio of precipitation is relatively large compared to the amount of potential evapotranspiration.

As shown in the map of precipitation distribution, precipitation in the study area of Somali Region is smaller than other area in Ethiopia. Opposite to it, potential evapotranspiration in Somali Region is larger than other areas as shown in Figure 7.4.

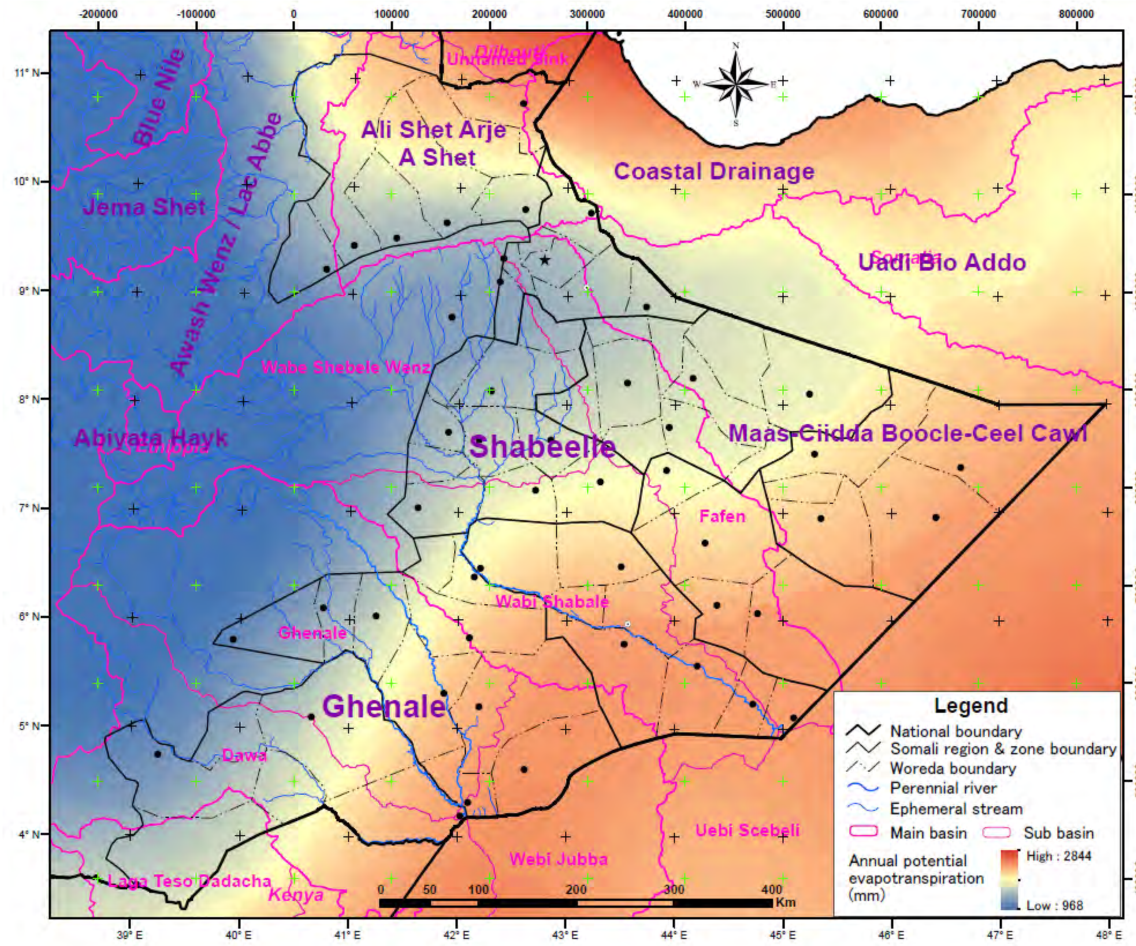


Figure 7.4: Annual Potential Evapotranspiration Distribution in and around Somali Region

It is difficult to estimate the groundwater recharge by comparison of potential evapotranspiration and precipitation directly. Therefore, it is important points to consider the result of balance between precipitation and evaporation. Thus, the one of the method is to compare potential evapotranspiration and precipitations values in different areas. The potential evapotranspiration is higher than the precipitation, the area has smaller water resources potential. The potential evapotranspiration in the major area of Somali Region is summarized in Table 7.4.

Table 7.4: Potential Evapotranspiration of Main Areas

Name	Area (km^2)	Max	Min	Average
Ghenale	195,408	2,590	1,101	1,941
Shabeelle	251,756	2,440	1,103	1,978
Ali Shet Arje A Shet	52,908	2,772	1,522	2,126
Lagh Dera	55,168	2,745	1,594	2,189
Maas-Ciidda Boocle-Ceel Cawl	232,171	2,665	1,702	2,302

Precipitation is generally affected by topography. In a groundwater basin, areas of high elevation ordinarily have higher precipitation than other areas. Topography also affects potential evapotranspiration. The potential evapotranspiration takes the reverse tendency against precipitation in high elevation area. The difference of potential evapotranspiration for branch basins of Shebele and Ghenale basins can be found clearly in Table 7.5. The difference of potential evapotranspiration will be indicated 1.5 times with comparing low land and high land.

Since potential evapotranspiration is not the true value of evapotranspiration, groundwater recharge cannot be calculated from precipitation and potential evapotranspiration. High precipitation area is larger than other areas, the amount of groundwater recharge in such area can be also considered larger than the other basins.

Table 7.5: Comparison of Precipitation and Potential Evapotranspiration

Basin Name	R_mean	E_mean	R/E(%)	Rank
Ghenale	513	1,941	26.4%	5
Shebele	492	1,978	24.9%	6
Ali Shet Arje A Shet	456	2,126	21.4%	7
Lagh Dera	420	2,189	19.2%	8
Maas-Ciidda Boocle-Ceel Cawl	240	2,302	10.4%	9

R_mean: Annual average precipitation
E_mean: Annual average potential evapotranspiration
R/E (%): Percent of ration for precipitation and potential evapotranspiration

In the same basin, groundwater recharge is variable depending on the climate and topography of the site. The data on the average precipitation, evapotranspiration, and the ratio of precipitation to potential evapotranspiration is shown in Table 7.4. Classification of recharge areas was done based on this data. The map of natural condition, precipitation and potential evapotranspiration, it can be found the correlation with each map.

Table 7.6 was summarized the ratios result of precipitation to potential evapotranspiration in smaller areas of the 4 main basins in Somali Region.

Table 7.6: Comparison of Precipitation and Potential Evapotranspiration in Smaller Areas

Main Basin Name	Name	R_mean	E_mean	R/E(%)	Rank
Shabeelle	Wabe Shabeelle Wenz	730	1,489	49	1
	Fafen	396	2,074	19	2
	Uebi Scebeli	402	2,348	17	3
	Wabi Shabale	356	2,183	16	4
Ghenale	Ghenale	630	1,685	37	1
	Dawa	474	1,846	26	2
	Webi Jubba	373	2,447	15	3
Lagh Dera	Laga Teso Dadacha	450	1,968	23	–––
Ali Shet Arje A Shet	Ali Shet Arje A Shet	456	2,014	23	–––

R_mean: Average precipitation
E_mean: Average evapotranspiration
R/E (%): Percent of ration for precipitation and potential evapotranspiration

The result of groundwater recharge classification in groundwater basins of Somali Region is shown in Figure 7.5. The rank classification result shown in the map was done based on the ratio of precipitation to potential evapotranspiration. The final WRIM was further processed through weighing the factors.

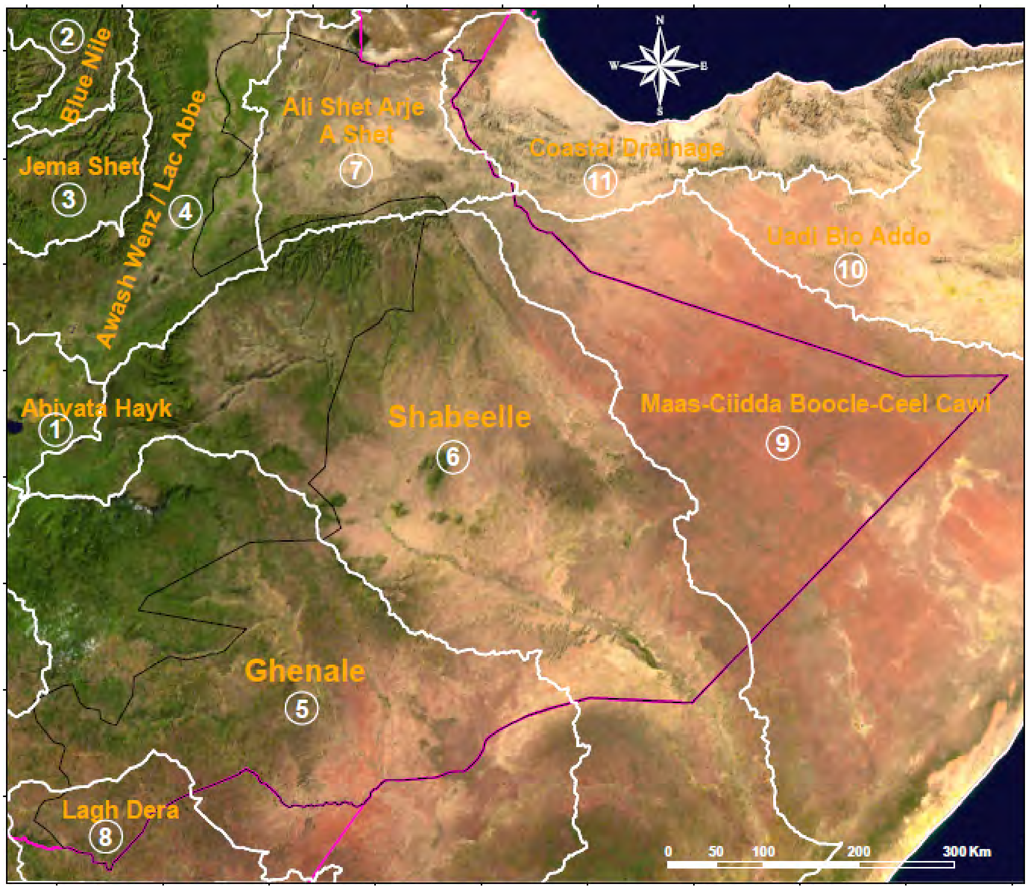


Figure 7.5: Result of Groundwater Recharge Classification

7.3.4 Vegetation

Water in root zone is always available for vegetation's absorption, the root zone is thought to have some connection with groundwater table. Thus, the water can reach to root zone by capillary operation. That is, areas with vegetation surely has soil water recharged from precipitation or from groundwater. Therefore, even though distribution of vegetation cannot be used directly for WRIM, it can be used as reference information for indirectly estimation of groundwater information.

Vegetation distribution map (Figure 7.6) was created by using secondary grid data from Chiba University. Main river basin boundaries in and around Somali Region are included in the map. The statistical results of vegetation distribution in these basins are summarized in Table 7.7. It can be found from the table that in the two main areas in the study area, Ghenale and Shebele, the vegetation density is relatively higher than the other areas.

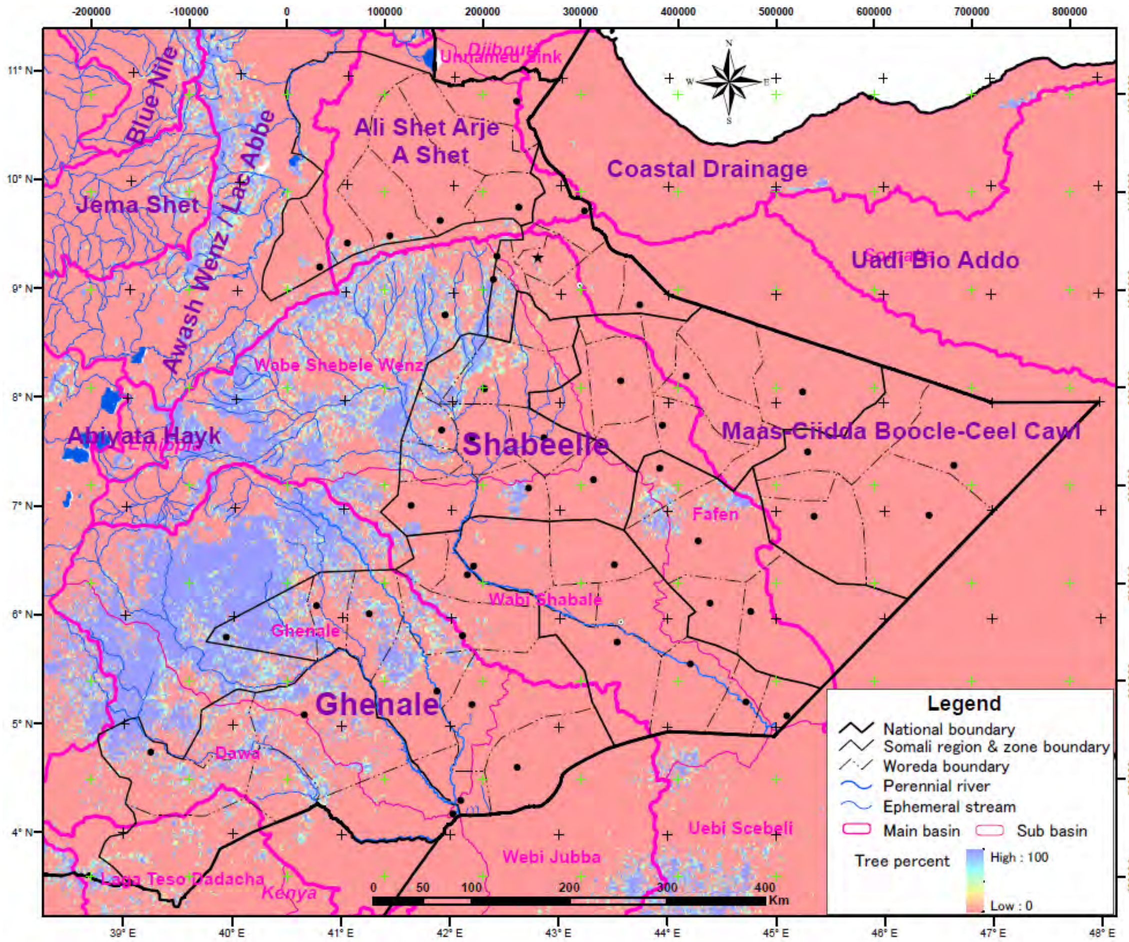


Figure 7.6: Vegetation Coverage in and around Somali Region

Table 7.7: Vegetation Coverage of Main Areas in Somali Region

Name	Area(km^2)	Max (%)	Min (%)	Average (%)
Ghenale	195,408	100	0	12.74
Shabeelle	251,756	100	0	6.14
Lagh Dera	55,168	84	0	1.84
Ali Shet Arje A Shet	52,908	77	0	1.68
Maas-Ciidda Boocle-Ceel Cawl	232,171	82	0	0.05

Vegetation distribution for further divided areas of Somali Region is summarized in Table 7.8.

Table 7.8: Vegetation Coverage of Sub-areas in Somali Region

Sub-area Name	Name	Max (%)	Min (%)	Average (%)	Max (%)
Shabeelle	Wabe Shabeelle Wenz	79,622	100	0	13.92
	Uebi Scebeli	55,539	100	0	4.23
	Fafen	49,190	100	0	0.91
	Wabi Shabeelle	67,406	100	0	2.34
Ghenale	Ghenale	82,139	100	0	21.43
	Dawa	60,301	100	0	10.83
	Webi Jubba	52,968	96	0	1.42
Lagh Dera	Laga Teso Dadacha	33,137	59	0	0.57
Ali Shet Arje A Shet	Ali Shet Arje A Shet	42,064	77	0	0.66

In comparison with the other maps and data, the vegetation coverage pattern is similar to the precipitation map, potential evapotranspiration map, and to the result of comparison of ratio of precipitation to potential evapotranspiration. The vegetation coverage is the differences of 10 times higher in the upper branch areas and lower in the downstream areas.

7.3.5 Topography

Groundwater formation, storage and flow are based on groundwater basin. And groundwater basin is defined by topography. A groundwater basin has different recharge and groundwater flow system from other basins. Figure 7.7 shows the characters of topography in Somali Region and its surrounding area. The map is created by using the secondary data of SRTM from USNASA.

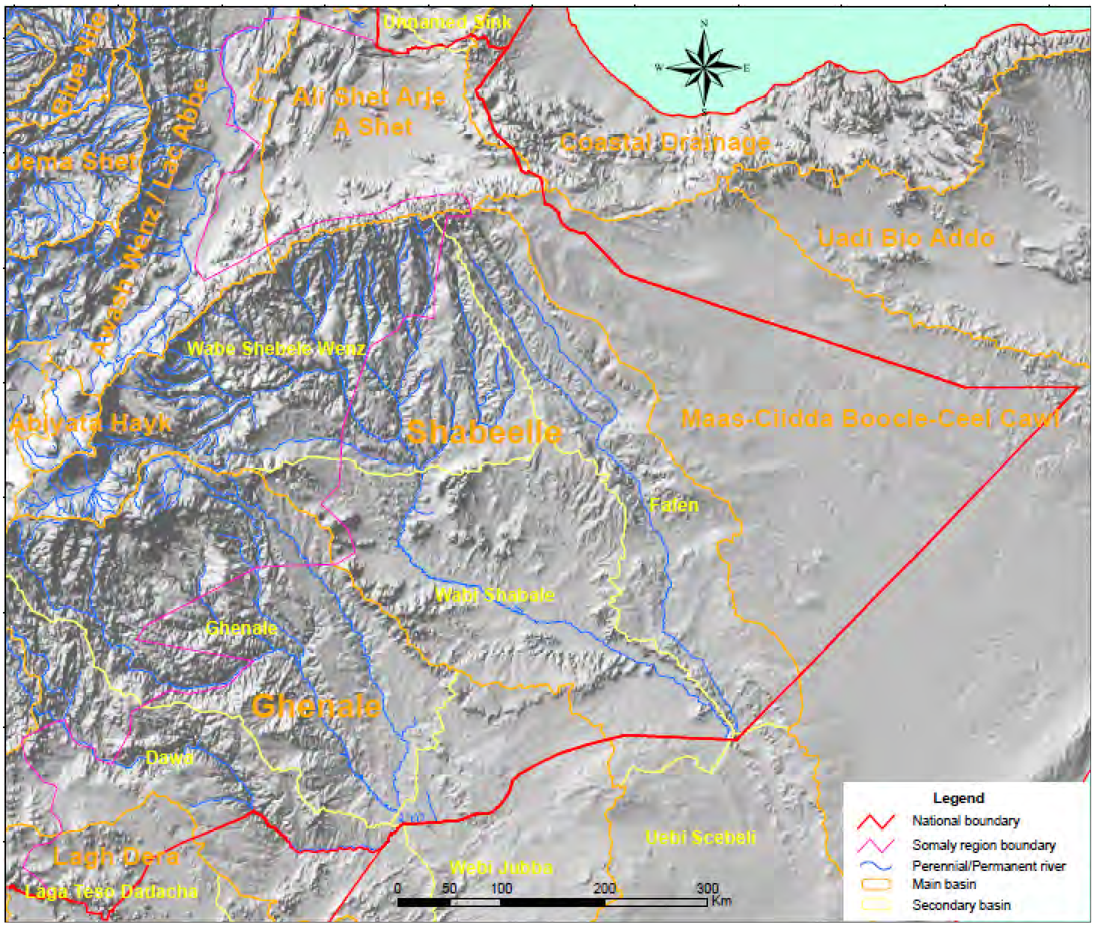


Figure 7.7: Topography and Groundwater Basins in Somali Region

As showing in the Figure 7.7, the main mountain exists in Somali Region and surrounding area from west to east direction. Following this range's strike direction, main groundwater basins stretches in north-southern direction. Most area in Somali area located in the southern part of the range.

The elevation is getting lower towards southern or south-eastern direction. But the topography's change is not gentle, a lot of sub range or watershed and valleys stretch different from the main mountains range, stretches in north-southern direction. Comparing to the main mountain range, these sub range have to be divided as the secondary classes, the main groundwater basin's classification is based on them.

Within the 7 main areas in Somali Region, the Ali Shet Arje A Shet area in northern area and Maas-Diidda Boocle-Ceel Gawl area in eastern area have extremely low precipitation as shown in precipitation map. Therefore, these two areas can be divided into a dry area without perennial river flowing. It is clearly that these two areas have low comparing to other basins. The groundwater basins of Shebele located in central area and Ghenale in western part is also classified as dry area. Rivers flowing throughout a year can sustain their flows because of recharge from the base flow (groundwater).

7.3.6 Geology

Geology analysis of stratum is difficult by using remote sensing as mentioned above. But the stratum information is indispensible for WRIM. The surface geology map is shown in Figure 7.8. The map is based on the compiled result from geology maps of UNESCO (2012) and

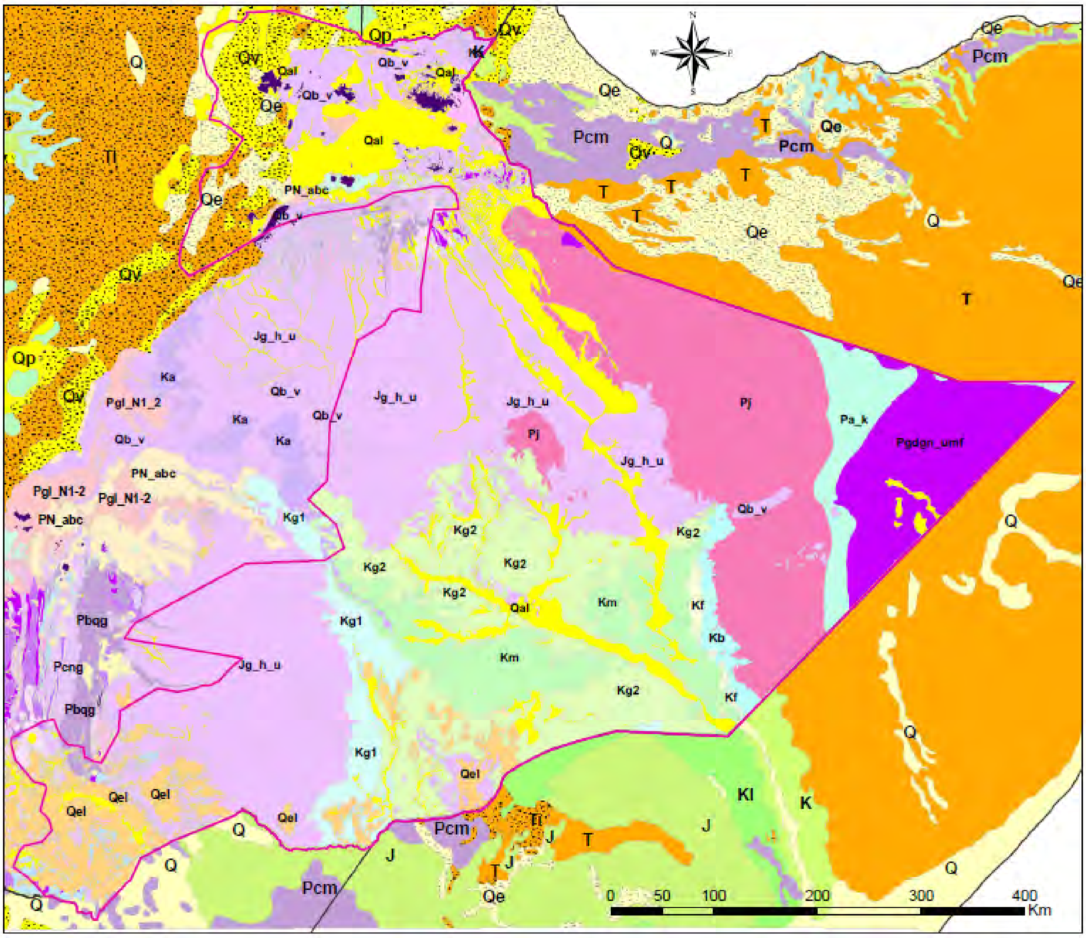
USGS.

The scale of UNESCO Geology map is 1:500,000, having relatively detailed geology classification. But the map is created around the central area in Somali Region, some area in and around Somali Region is not covered by it. For those uncovered area, geology map is created by using USGS geological map with scale of 1: 2,500,000.

As shown in the map, in northern part of Somali Region, the sedimentary layer of Quaternary distributes mainly, and majority area in central and southern part, strata of Tertiary and Mesozoic distributes. Except south-western area, Quaternary sedimentary layer can be found in Somali Region alone the groundwater basin of Shebele and its branches.

The sand and gravel layers formed in Quaternary can be classified as aquifer because their higher hydraulic conductivity. Contrast to them, groundwater can only storage in secondary porosity of bed rocks. Rather than characteristics of those rocks, amount and connection of those secondary porosities are mainly affected by geological tectonic movement. Therefore, even though generally those bed rocks is hardly considered as a good aquifer, but in case of a relative large fault can be found within the rock, the area near the fault can be classified as a good aquifer, because many secondary fissures occurs near the fault.

Although for aquifer classification or WRIM, rather than surface geology, strata below the groundwater table is more important. On the other hand, in case of surface geology is Quaternary layer, it is hardly to known how depth the layer would extend. But if the surface geology is bed rock before Tertiary, it is sure that there is no sedimentary layers under the bed rock. Hence, in WRIM analysis, if the surface geology is bed rock, the potential of the rock as an aquifer can be assessed based on the geological map.



Legend

UBESCO gelogg map

- Qal: Aluvium
- Qalg: Gravel
- Qtr:Travertine
- Qel: Eluvium
- Qcal: Calceret
- Qls:Lake sediment
- Qb_v: Basalt
- Tv: Ahs and lava flows
- Qv_N1-2gg_n: Recent vocanics
- Tsy: Graite
- Pgl_N1-2: Basalt
- Pa_k: Limestone
- PE2b_M: Marble
- PN_abc: Basalt
- Pj: Sandstone
- PE2b_P: Sandstone and conglomerate
- Pamp_psva: Amphibolite
- Pgt1_H: Hornbolite
- Pumf: Gabbro
- Pgb: Gabbros and amphibolite
- PE2b_C: Chlorite
- Pgt1_D: Diorite
- Pgdgn_umf: Gneiss
- Ptts_cgn_eb: Schist
- PE1_bqg: Gneiss and schist
- Pmgt_G: Geneiss and migmatite
- Pcsc_gtng_fqg:Geneiss and granite
- Ptts: Serpentinite
- PE2b_S: Phyllite
- Pmgt_M: Migmatite
- Pgt_cdt_cgn: Granite
- Pgt2: Granite and quartz
- PE2b_G: Granite and schist
- Pmdt_Q: Quart and diorite
- Pfqg_cng: Quartz and gneiss
- Pcng: Quartz and schist
- N2ab: Basalt
- Pdtgn: Gneiss_T
- Ja: Sandstone and shale_T
- PE_b_bqg_tts:Schist_T
- Kb: Limestone_K
- Ka: Sandstone_K
- Km: Sandstone and limestone_K
- Kg1: Shale and limestone_K
- Kf: Shale_K
- Kg2: Shale gypsum dolomite_K
- Ja_Mlsst_pzt: Standstone_J
- Jg_h_u: Limestone_J
- L&S: Lakes and swamp

USGS geology map

- Q: Quaternary
- Qe: Holocene
- Qp: Plestocene
- Qv: Quaternaty extrusive rocks
- T: Tertiary
- Ti: Tertiary extrusive rocks
- K: Cretaceous
- Kl: Lower Cretaceous
- Kj: Cretaceous and Jurassic
- J: Jurassic
- Jl: Lower Jurassic
- Pcm: Precambrian
- Lake and swaps

Figure 7.8: Surface Geology Map in Somali Region

Aquifer classification depends on hydraulic conductivity of different strata. But for the same strata or layer, the difference of hydraulic conductivity would be as large as several times or several powers. For diverse layers, it is not unusual to find the difference as big as more than 10 powers. The exact hydrological conductivity value can only be obtained from laboratory experiment or test well. Therefore, a lot of data from laboratory experiment and wells have been collected from groundwater experts all over the world to summarize the hydrological conductivity values. Based on those summarized results, it can be known that gravel layer has relative large hydraulic conductivity for 10^{-3} to 3 cm/sec. the middle level hydraulic conductivity layer can be considered as basalt that is much distributed in Somali Region, various in a range from 10^{-7}～10^{-3} cm/sec. The representative lower hydraulic conductivity layer in the study area might be granite with a range of 10^{-18}～10^{-2}. Because of the large fluctuation range, it is necessary to laboratory experiment or test well to estimate hydraulic conductivity.

On the other hand, from the above mentioned 3 types of strata, it is clear that a large difference exists in the average values of hydrological conductivity for different strata. Hence, the hydrological conductivity classification for different type strata in the study area of Somali Region are conducted following the average values from many groundwater experts. The result is shown in Table 7.9.

Table 7.9: The Hydraulic Conductivity Rank Classification for Different Strata

Lithology	Min	Max	Average	Rank
Gravel 1) 3)	0.03	3	0.1	1
Eluvium4)	0.01	1	0.09	2
Ash and lava flows4)	0.0001	3.3	0.036	3
Dolomite 4)	0.0007	0.29	0.0097	4
Lake sediments4)	0.00001	0.001	0.004	5
Alluvium 1)	E-8	1	0.0021	6
Limestone1) 2)	E-21	0.75	0.0016	7
Travertine1)	0.0002	0.00036	0.00028	8
Calceret1)	0.0002	0.00036	0.00028	9
Phyllite4)	---	---	0.00011	10
Gabbro1)	---	---	0.0001	11
Basalt1) 2)	1.5E-10	0.01	0.000089	12
Sandstone1)	3.7E-8	0.0001	0.000088	13
Serpentinite 1)	7E-6	0.0015	0.000082	14
Conglomerate1) 4)	E-6	0.0063	0.000079	15
Marble4)	8E-7	5.00E-03	0.000063	16
Recent vacancies1) 3)	1.3E-7	0.3	0.000053	17
Chlorite1)	5E-6	0.0002	0.000047	18
Granite1) 2) 3)	E-18	0.02	0.000043	19
Diorite1)	5E-6	0.0005	0.000042	20
Amphibolite1)	5E-6	0.00059	0.000036	21
Quartz 1) 4)	E-10	0.00026	2.9E-6	22
Schist1) 2)	E-10	0.00001	1.3E-6	23
Shale1) 2) 4)	E-21	0.004	5.4E-7	24
Gypsum_dolomite4)	E-8	E-6	E-7	25
Gneiss1)	E-14	0.00001	3.16E-10	26
Migmatite1) 2)	5E-13	6E-10	1.73E-11	27

1) From Yanagisawa, Furuya et al, Study on the permeability of rock mass in Japan, 1992.
2) From Sato, Watanabe, Groundwater handbook, 1978.
3) From Domenico ＆ Schwarz, Physical and Chemical Hydrology, 1990.
4) From other reference.

Within these reference materials, the most reliable document can be considered as the first one of "Study on the permeability of rock mass in Japan" from Yanagisawa, Furuya et al. Most of the 522 well's data for the compilation are from the survey result for tunnel or dam construction, not concerning with groundwater use. If a well is drilled for groundwater use, the well's screen location generally being selected following two features of hydrological conductivity and strata's thickness. And then the screen is generally set in the location with higher hydraulic conductivity in the well. For example, when a well is drilled in a granite stratum, it is no way to set the screen in the location with hydraulic conductivity less than 10^{-10} cm/sec. The hydrological conductivity value from a test well for purpose of water supply is generally higher than other layer or stratum within the well. Therefore, the result by using a test well for water supply might be higher than real average value of target strata hydrological conductivity.

The same as groundwater recharge rank classification, ranks in the table is based on the average hydraulic conductivity's value, but dose not show the real difference between those strata. For example, between rank 5 of Lake sediments and rank 6 of Alluvium, the difference of average hydrological conductivity is nearly twice, but between rank 21 of Amphibolite and rank22 of Quartz the difference is more than 12 times. Therefore, when compiling this geology data into WRIM, the real value of hydrological conductivity will be used, rather than the rank classification result shown in the Table 7.9. To clearly showing the difference of hydrological conductivity, the log distribution of average values for all kinds of strata in and around Somali Region is summarized in Figure 7.9.

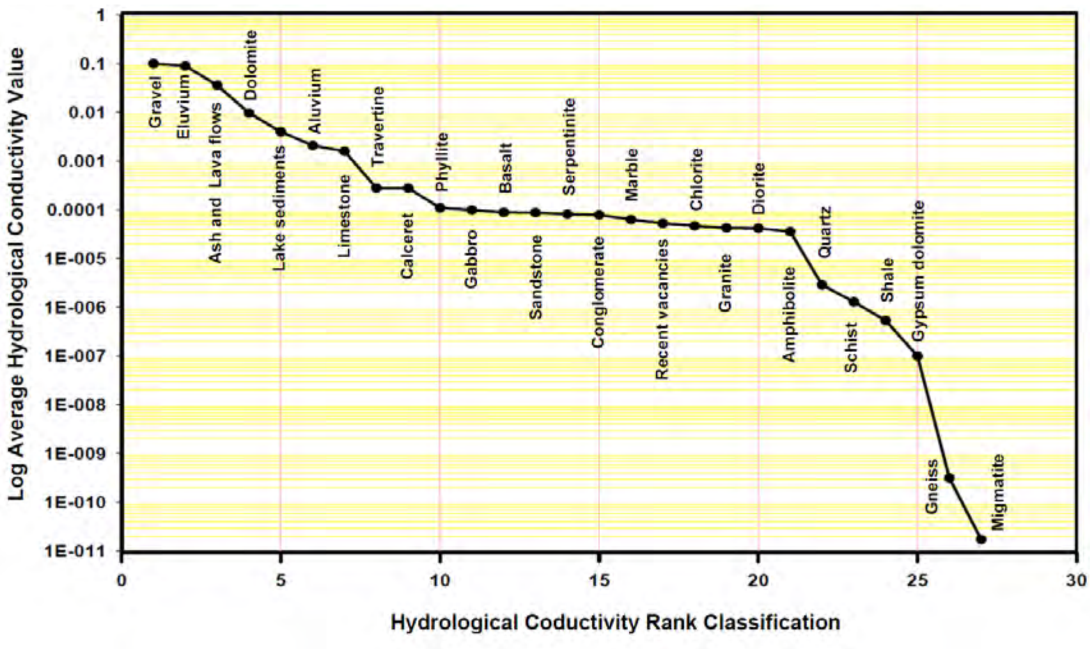


Figure 7.9: Log Classification of Hydraulic Conductivity's Average Value

7.3.7 Lineament

Lineament cannot be obtained from any secondary data, its extraction can only be done by primary data analysis. Two types of primary data of Landsat and PALSAR have been collected as shown in Table 7.1. Therefore, 55 PALSAR images were collected to cover the major part of the study area. The coverage of collected Landsat and PALSAR data is shown is Figure 7.10.

To use primary data for lineament extraction, several procedures have to be conducted like image extraction and combination, lineament extraction, noise erasing, data format changing, extraction result checking, modification, and so on. Thus, it takes much longer time to extract lineaments from the primary data than the usage of the secondary data. This process of lineament extraction by the remote sensing data do not considers the geological information.

The resolutions of PALSAR images is 12.5m as compared to the 30 m for Landsat and thus, more detailed lineament analysis can be done by using PALSAR. On the other hand, quite long time is needed for the analysis, because of huge amount of data and complex analysis procedure. One PALSAR image from the collected 55 data sets covers an area of 4,800km^2. After 2 months of extraction work, 93,193 lineament having been extracted from PALSAR, with total length of 227,286km.

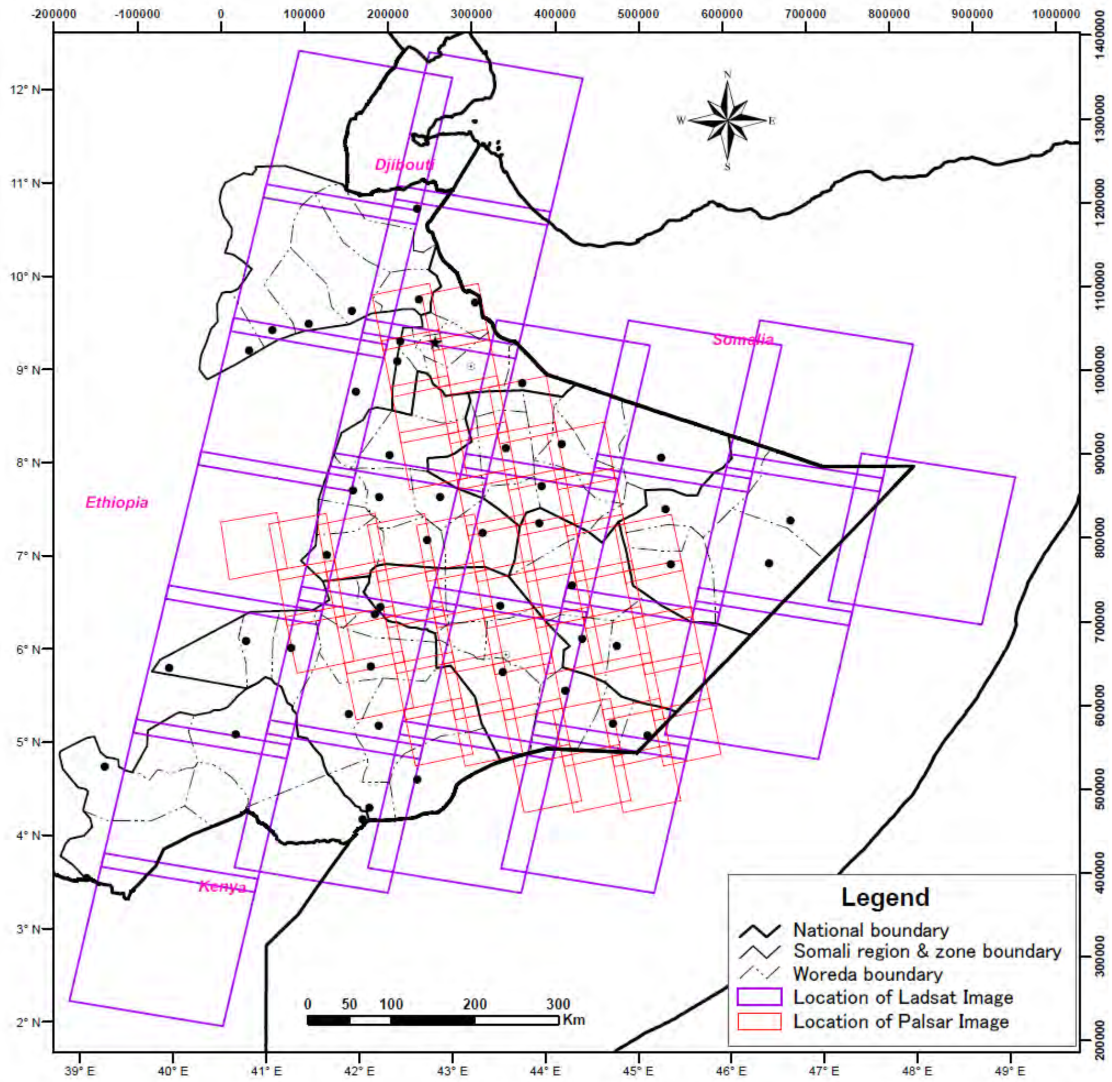


Figure 7.10: Location of Collected Landsat and PALSAR Images

Total length of the lineaments in each direction in and around the study area of Somali Region is shown in Figure 7.11 and Figure 7.12.

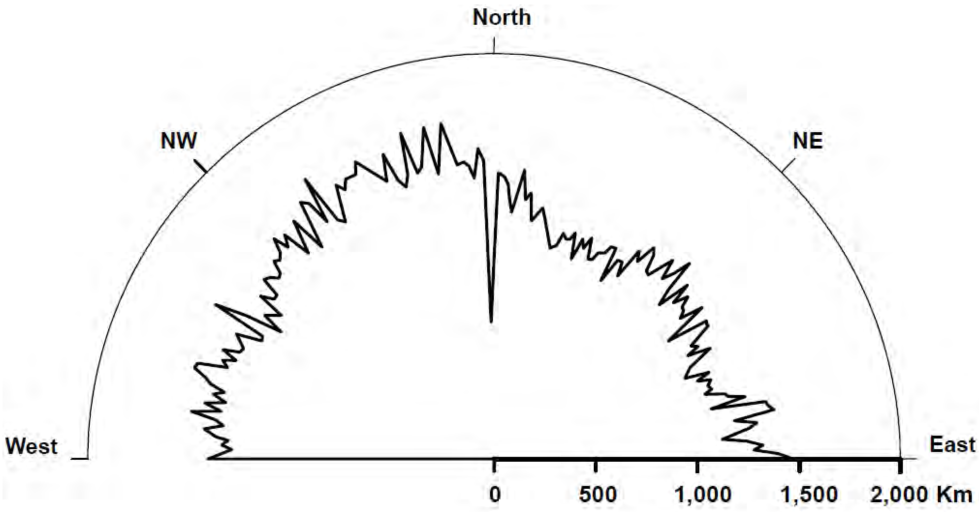


Figure 7.11: Rose (azimuth-frequency) Diagram with Total Length of Lineaments Orientations in Somali region.

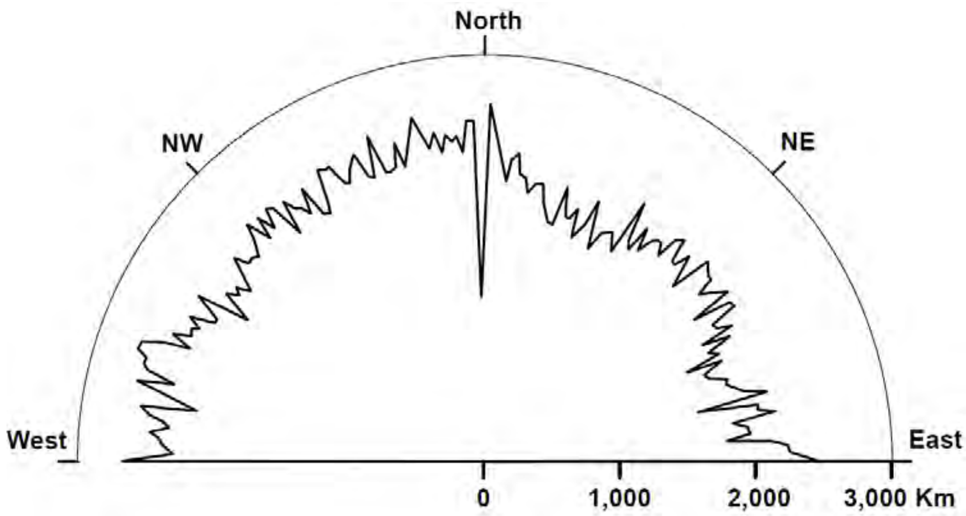
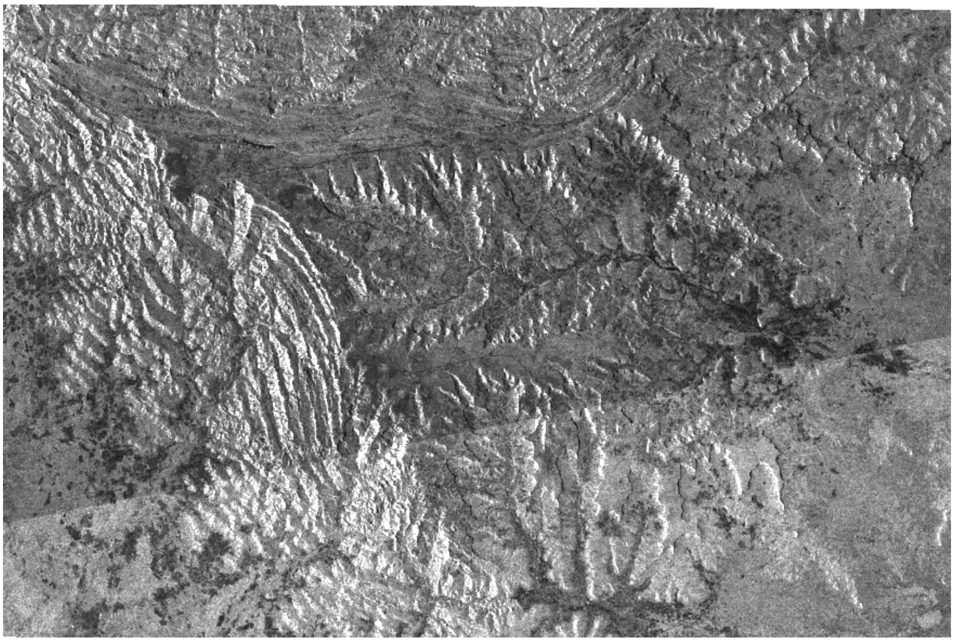


Figure 7.12: Rose (azimuth-frequency) Diagram with Total Length of Lineaments Orientations in and around Somali region.

As an example, Figure 7.13 shows combined result of two PALSAR images PASL4101006201956071207310082 and PASL4101006201956151207310083. It is clear that a lot of lineament can be extracted from the image.

To extract lineament from aerial survey data, many methods have been tried such as Laplacian, Sobel and so on. However, up to now, no reliable method has been officially recognized. On the other hand, the basic principle for lineament extraction from aerial survey data is to compare the value between the adjacent cells. Methods of Laplacian and Sobel are also based on this principle. Because the methods of Laplacian and Sobel have been confirmed not being suitable for lineament extraction by using PALSAR, some other method has to be selected for this task.



（PASL4101006201956071207310082 and PASL4101006201956151207310083）

Figure 7.13: Combined Image of PALSAR

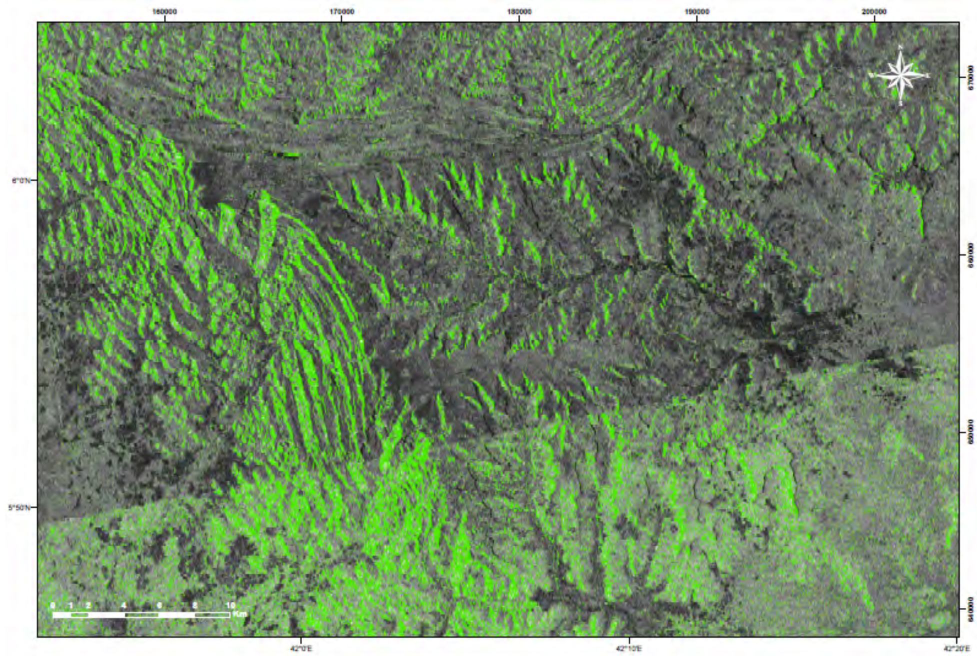


Figure 7.14: Result of Lineament Extraction with a lot of Noise

The method of Percent Rise was chosen as a relatively better method for this task. By this method, the difference of values between adjacent cells will be extracted and expressed in absolute value of percentage. Then it is easy to find places with higher percentage there in Palsar image. Figure 7.14 shows the lineament extraction result based on combined PALSAR images by using percent rise method.

As shown in Figure 7.14, main lineament seems to have been successfully extracted. However, the extraction result contains lot of noise.

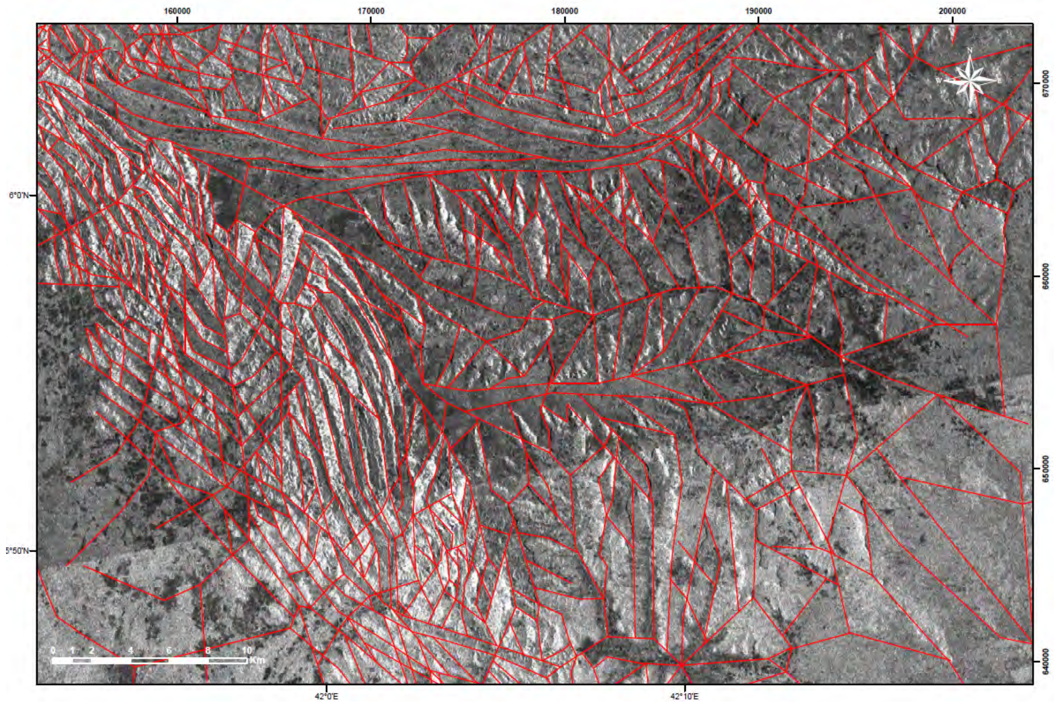


Figure 7.15: Result of Lineament Extraction from PALSAR

For noise erasing in this study, the method of Neighborhood was employed as a better method than the others, which is included in the GIS software program.

After noise erasing, all lineament with relatively lengthy lineament can be extracted from the satellite image. However, lineaments affected by noises, and many linked lineaments have been separated. There is no method can be used for automatic modification to solve this problem. The only way is visual inspection to see if the extracted lineament can be extended following its direction. And if the visual inspections find the possibility of lineament extension, the operation of the extension can only be done manually. Figure 7.15 shows the final result of lineament extraction.

7.3.8 Topography for main groundwater basin

In some casa, the evaluation of groundwater potential for narrow area is more effective than that of large area because groundwater's storage and flow is based on area.

Table 7.10 shows the main topographic features of Somali region.

Table 7.10: Topography and Area of Groundwater Basins in Somali Region

Groundwater Basin	Ethiopia			
	Max	Min	Mean	Area
Shebelle	4,179	188	1,043	191,675
Ghenale	4,383	165	1,079	139,935
Maas-Ciidda Boocle -Ceel Cawl	2,046	337	741	86,053
Ali Shet Arje A Shet	3,001	215	899	64,279

The groundwater basins of Somali Region were classified in Table 7.10 following the area extent of each groundwater basin. Main two areas have the maximum elevation over 4,000 m, and these basins are classified in upper or middle classes, another areas with maximum elevation around 2000 - 3,000 meters are classified as middle or lower rank, one basin with maximum elevation less than 2000m is classified as the lowest rank.

7.3.9 Groundwater table and topography

For WRIM, an important factor is the depth of groundwater table. As shown in schematic maps and profile map, the depth of groundwater table is largely affected by topography. Basically, groundwater table is following, but gentle than topography. Therefore, the groundwater table is deep from ground surface in high elevation area and shallow in low elevation area. In lower part of steep sloped area, groundwater flows out of ground surface to recharge river.

Therefore, topography had better be considered as an important factor for WRIM. In the following section, a different analysis was executed for evaluation of shallow groundwater potential by using the factor of topography in order to the analysis of WRIM.

1. <u>Topography of the lowland:</u> Groundwater mainly flows from high elevation area to low elevation area. In relatively lower area in each basin, the groundwater recharged directly from precipitation would be quite few, However this area can get recharge from mountain area by groundwater flow. In this area, groundwater can be preserved and groundwater table might be relatively shallow from ground surface. Therefore, in lowland, the groundwater potential might be considered high compare to mountain side.
2. <u>Gentle slope area in mountain side:</u> It is important to extract the gentle slope area, such as small river from steep slope area. Not only perennial river, but also non-perennial river can be used for WRIM. In non-perennial river, it can be only got groundwater recharge in rainy season, groundwater table is sometimes higher than ground surface in the rainy season. In dry season, groundwater can not flow out of ground surface, but the groundwater table might be considered as relatively higher than other areas. However, in steeped slope area, both of river water and groundwater is not easy to use there. On the other hand, some gentle slope area also might be found in mountain or hill area with a river. This gentle slope area may not useful for river's formation, but might be able to get recharge from both surrounding mountain area and river. Therefore, there area can easily be defined with higher potential.
3. <u>Plain area close to mountain or hill area:</u> As the principle of groundwater table's

slope is gentler than topography, in the plain side close to the boundary between mountain and plain, groundwater might be shallow from ground surface relatively, even though groundwater cannot flow out to river. However, groundwater potential can be defined as higher because of the following 2 points: 1) In the relative steeped slope, the hydraulic gradient become large and then the groundwater in plain area is easy to be recharged by mountain area; 2) Groundwater table is relatively higher than other plain area.

Analysis of water potential was conducted the procedures above.

For the first point, the analysis is to extract the data of topographic fluctuation for each area, to set the highest rank to the area on the bottom of the basin, and to set the lowest rank to the area with high elevation. Other area was classified between these highest and lowest ranks. Then, the weight for different ranks was set for WRIM.

For the second point, the analysis is similar to the shallow groundwater potential, to extract areas with steeped slope, and to compare the extracted result of rivers. If there are some flat areas near the river, those areas can be considered to be recharged by both mountain or hill area and the river. Following this recharge amount and characteristic of flat topography, groundwater table is easy to be estimated as shallow relatively from the ground surface. Then it can be confirmed to have high potential. Moreover, the rank1 will be set to the area with a perennial river, because the groundwater will be stable for using in any season in there. If a perennial river flows in there, at least groundwater can be perennially used with groundwater table relatively shallow from surface in those areas near the river. Hence those areas can be set as rank 2. For other flat area with only non-perennial river, groundwater table is shallow in rainy season when the water flows in the river. In the dry season, groundwater table would get low down, but there are not so many areas have natural groundwater table 10 meters below, so this area can be set as rank 3. In other flat area without any river, the rank can only be set as 0.

Analysis for the third point is to check the topography’s change for the extracted steeped slope area. If the difference of elevation is not so large near the boundary of mountain or hill area and plain area, the groundwater table might be affected by deeper groundwater table in mountain area. So the potential has to be considered relatively low. Opposite to it, in case of big difference between the mountain or hill area and plain area, groundwater in plain area would be relatively high. As groundwater table is gentle than topography, then the potential would be considered high in plain area close to the mountain or hill area.

a. Analysis of the first point

Based on the above mentioned procedure, the topography extraction result is summarized in Figure 7.16 together with maximum and minimum evaluations.

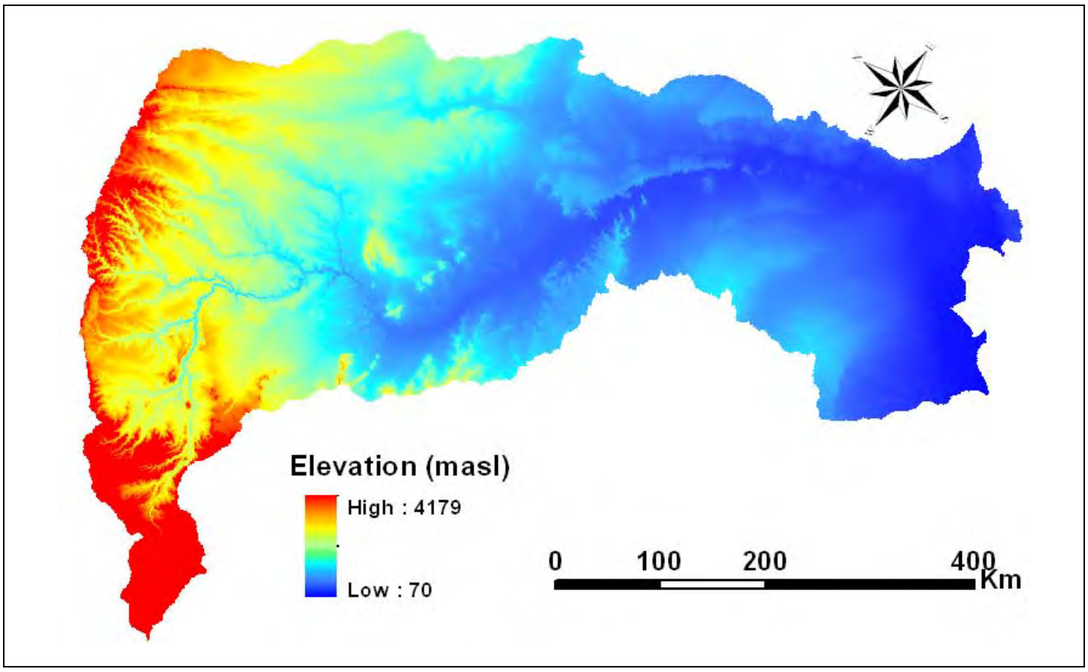


Figure 7.16: Topography Classification for Groundwater Sub-basin of Shebele

b. Analysis of the second point

The first step for analysis of the second point is to extract the steep slope area by using the tool of Slope contained in GIS program.

As shown is Figure 7.17, in the study area of Somali Region, the most of perennial rivers are formed in relatively steeped areas relatively with greater than 13 degree. In contrast, the steeped slope cannot be found in the eastern part area of Maas-Ciidda Boocle Ceel Cawl. In these areas the perennial river does not exist. and it means that groundwater recharge is low.

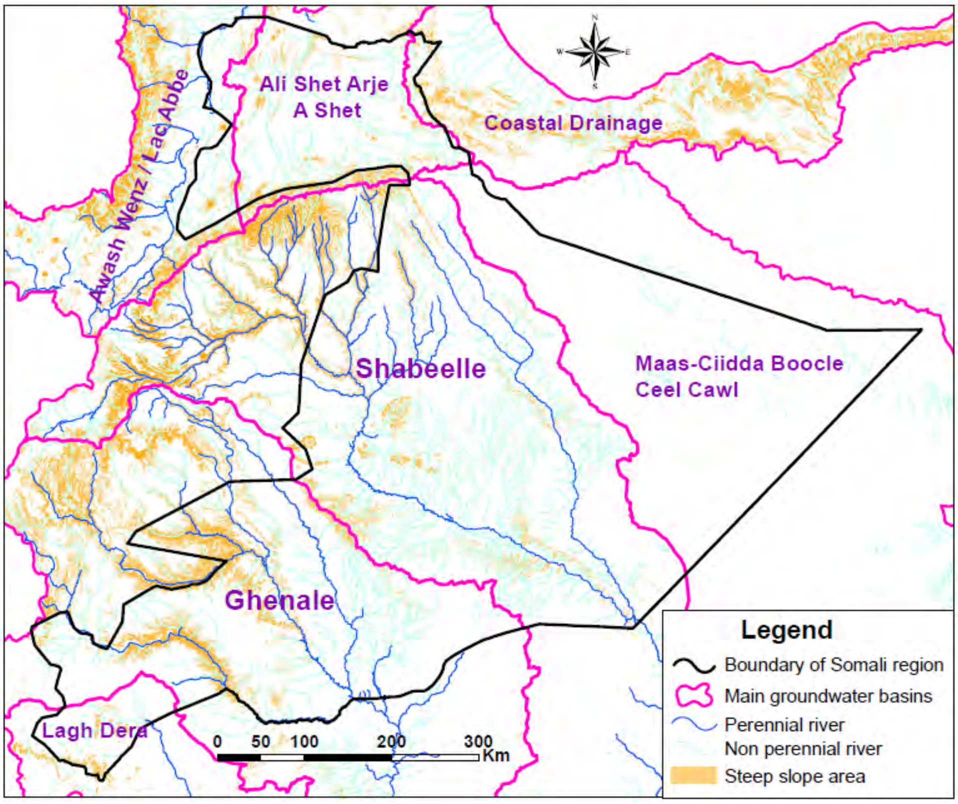


Figure 7.17: Steep Slope Area in Groundwater Basins

The steeped slope makes big fluctuation of topography to form mountains or hills. However, in mountain area the steeped slope dose not distribute any where. Some flat area can also be found within mountain area. If a river flows in this flat area, the area would be able to get the recharge from both of river and surrounding mountains. Therefore, high potential can be considered in these areas. Then depending on the analysis procedure mentioned above, the flat area with the slope of less than 2 degree was extracted in mountain area together with a river. The extraction result is shown in Figure 7.18

As shown in Figure 7.18, the flat slope can be found in mountain area and the steeped slope can also be found in plain area. It is difficult to classify the flat area into mountain area or plain area. On the other hand, the purpose of this analysis is to find the flat area around a river within mountain side. In any event, the area can get recharge from river and surrounding mountains.

The basic principle in hydrogeology is that the amount of groundwater recharge depends on precipitation. No matter where distributes a flat area, it can only be considered as a groundwater consumption area, if the precipitation in the area is small. Therefore the precipitation is used to examine as the reference, in case that it is possible to get recharge from both of river and surrounding mountains.

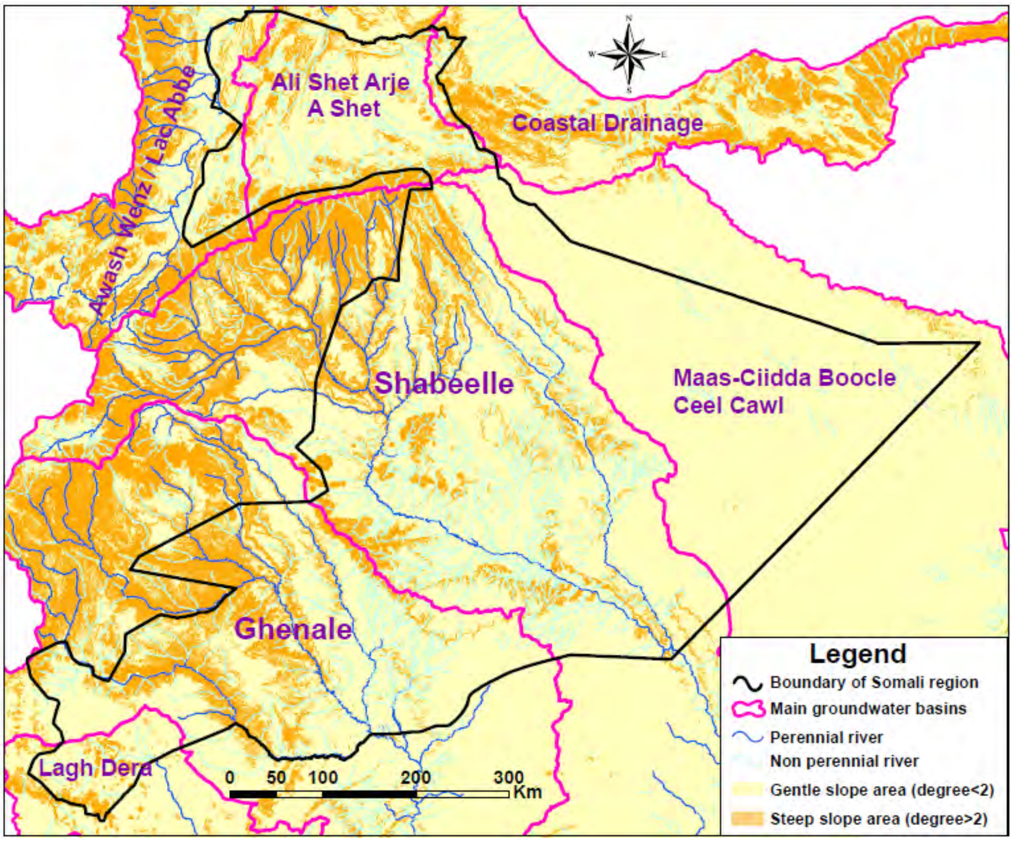


Figure 7.18: Extraction Result of Flat Area around Rivers

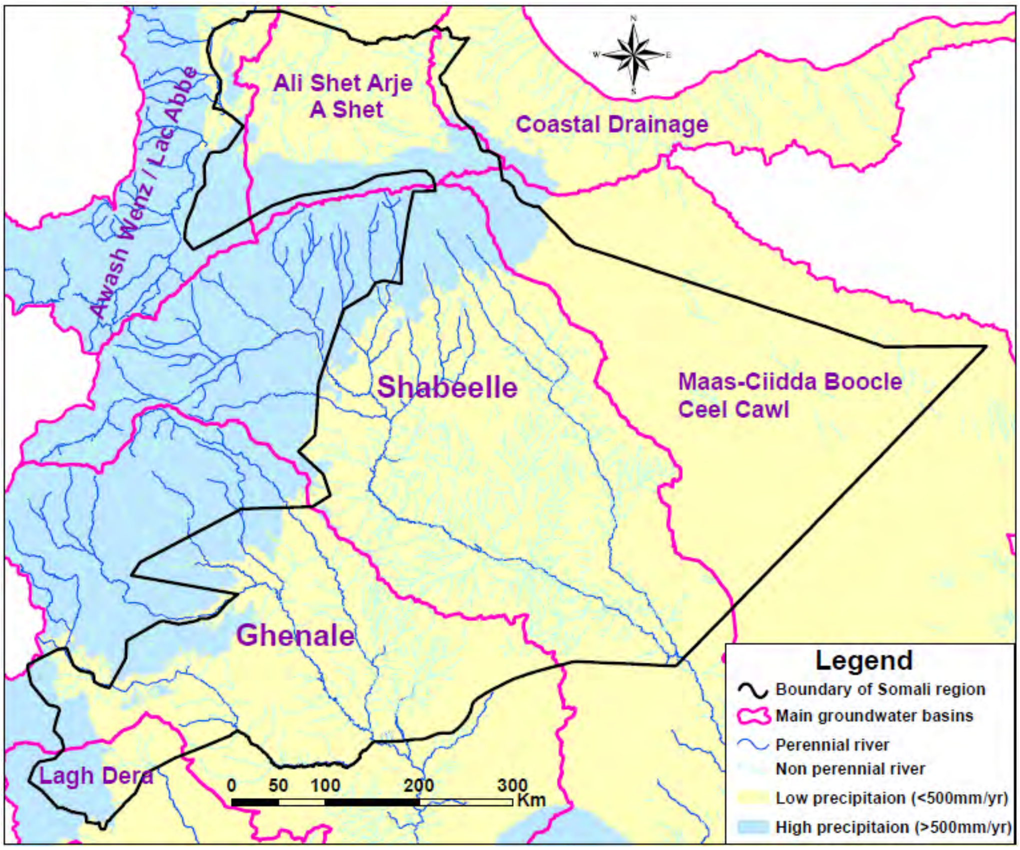


Figure 7.19: Annual Precipitation Classification by a Criterion of 500mm

Precipitation in the study area ranges from 0 to 2,625mm, as shown in precipitation map. The annual precipitation is lower than 500mm, the area would be classed as a dry area. Therefore, 500mm of precipitation is taken as criteria for groundwater recharge classification. The classification uses the secondary grid data for precipitation map creation from "World Clim", and the result is shown in Figure 7.19.

Using the result of Figure 7.19 (Precipitation classification) and analysis procedure for point 2, the higher potential areas within the mountain area around rivers were extracted and shown in Figure 7.20.

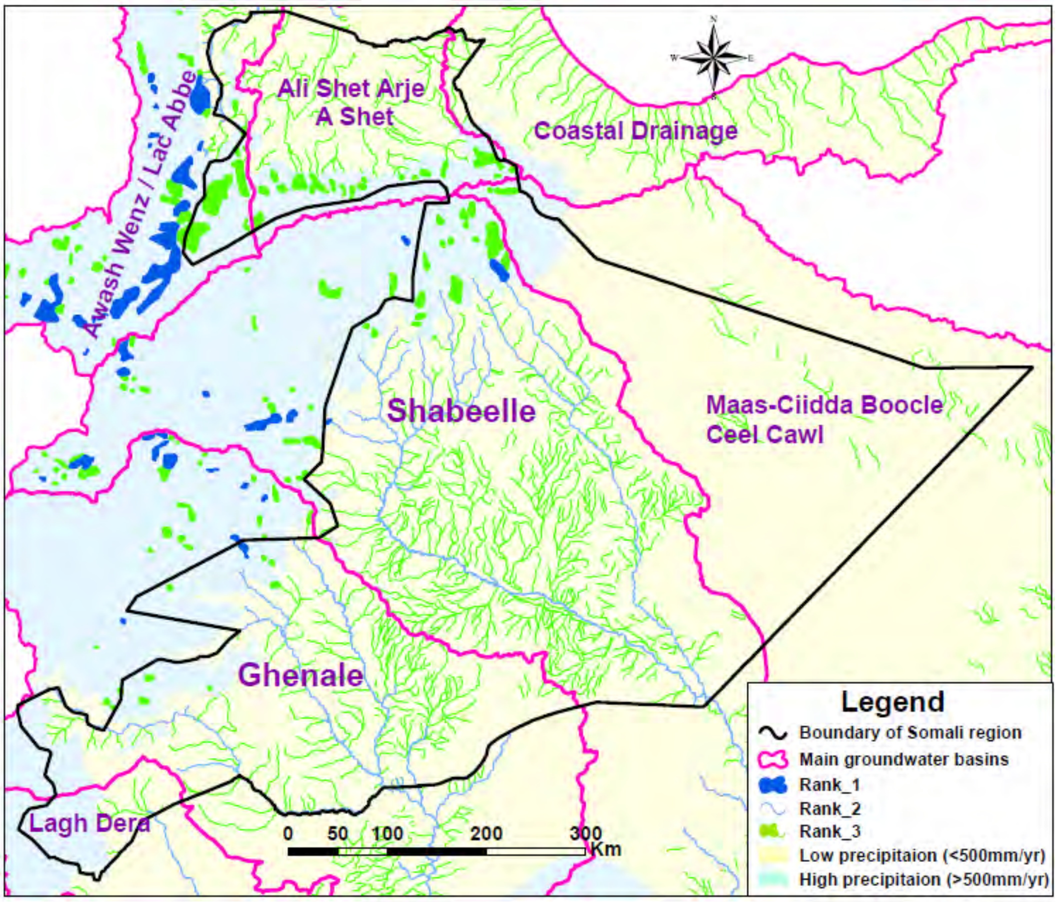


Figure 7.20: Rank Classification for Areas around Rives

In the figure, some large area found in mountain area with much precipitation relatively is classified as rank1 and rank 3, because those area are not only flat but also have a river in there. In contract, the plain area and a part of hill area with insufficiency precipitation are classified as rank 2 and rank 3. It is difficult to find the difference of these rank2 and 3 classified area with rivers because the scale of map is small. Groundwater table can be considered as shallow from ground surface in these areas, so these areas indicated the high potential relatively. But, the shallow groundwater table can only be recharged from rivers. On the other hand, the recharge amount from river is quite limited, because the river would not be able flow to the downstream area. The river water will be lost be recharge groundwater and then the river become dry. Thus, classification area of rank 2 and rank 3 are extracted by the distance of 100m from the river.

c. Analysis of the Third Point

Most perennial rivers are formed from steeped mountain area with slope of more than 13 degree as mentioned above. The clear boundary between mountain or hill area and plain area are examined for identifying the boundaries' slope tentatively. In Figure 7.21, a clear boundary between hill and plain areas can be found from the profile in lower part of Shebele basin. After extracting this part and showing it to upper right site of the figure, it can be found that the hill side was shown as pink color of grids and the slope ranges from 3 to 9 degree.

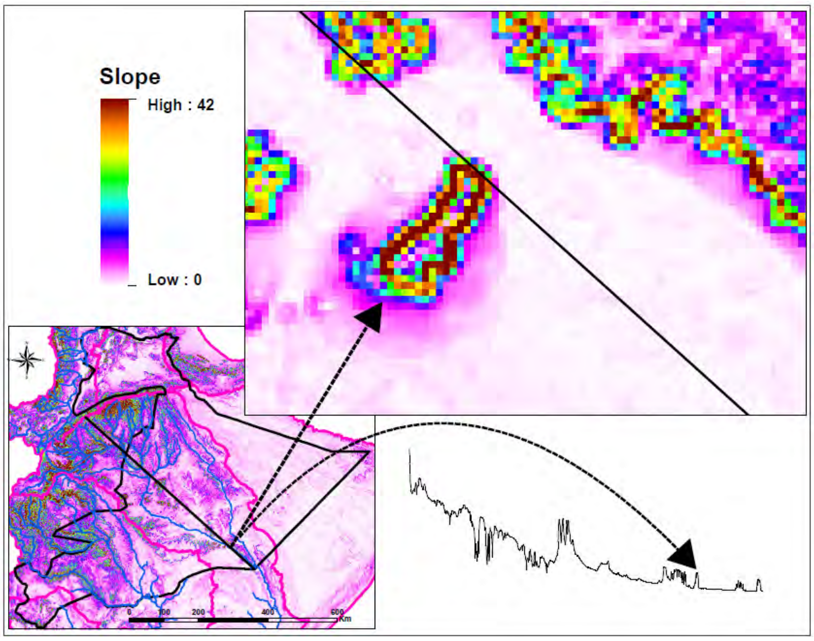


Figure 7.21: Base Map for Hill and Plain Boundary Classification

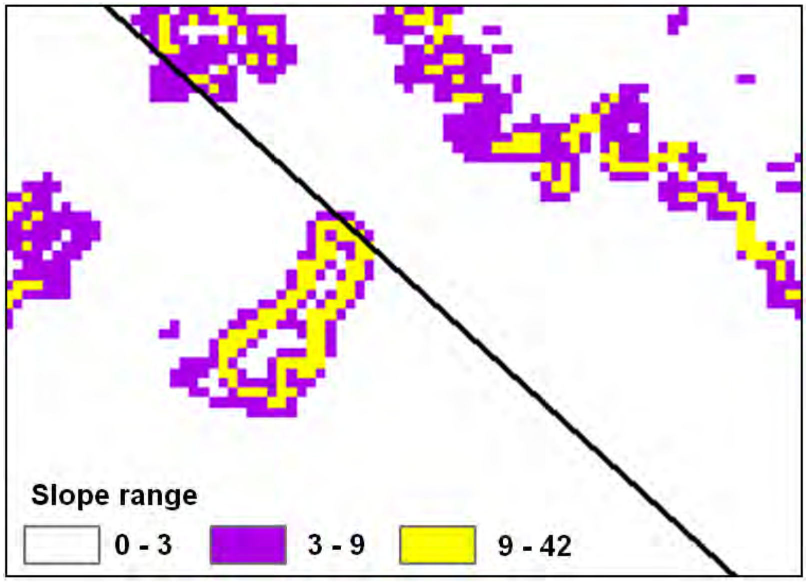


Figure 7.22: Hill and Plain Boundary Classification

This examination result is used as the standard of point 3 analysis for slope classification in the study area. The result is shown in Figure 7.22. As a result of this examination result, the area with slope of more than 9 degree was extracted. If the flat areas with a slope less than 3 degree can be found close to extracted area within 1km, the flat area can be considered to have shallow groundwater table relatively from ground surface. Then the result was shown together with a background of the hill shade in the study area (refer to Figure 7.23).

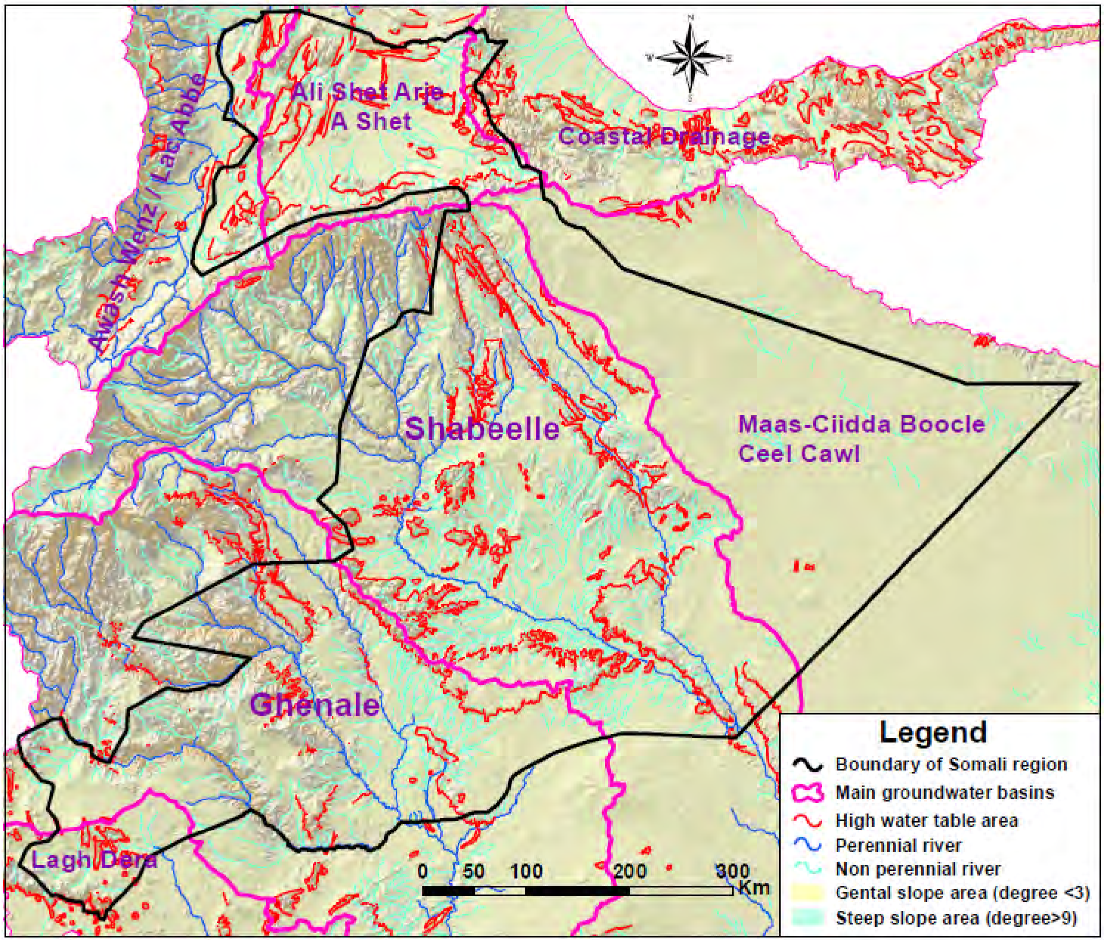


Figure 7.23: Predicted Shallow Groundwater Table Area

Groundwater table would be relatively high in slope from steep to gentle, but the influence to groundwater table is not only the slope, but also the extent of area in backland. If area is in the backland, a lot of groundwater storage would be there. Therefore, the area shown in the map of hill and plain boundary classification will not be used in WRIM uniformly; ranks for those areas will be set based on the extent of backland.

7.4 Drawings and explanation

Based on the basic principle for groundwater formation, all available and necessary factors have been analyzed. The procedure by using analyzed result of those factors for WRIM is to compile the comprehensive values from each factor in each point of the study area.

7.4.1 Grid specification in the study area

The analyzed result from each factor changes at each point in the study area, so it has to be considered how to take in detail as the compilation standard. The whole analyzed area covers 919,000km^2, with 361,493km^2 located in Somali Region. This study of WRIM is mainly concentrated in Somali Region, the grid size of base file is set as 1km^2. Centroid point of this grid base will be used for extraction and compiling of analyzed result from each factor to create the base of WRIM. The maximum and minimum values of the compiling result were set as highest and lowest rank in WRIM and all other values between them were set to different rank following the value's size and by using straight line division method.

7.4.2 Each factor's maximum weight specification

The influence of WRIM from each factor of groundwater recharge, topography, geology strata and lineament is not the same. A weight classification must be done before the compilation, in consideration of the bigness of influence from each factor to WRIM. Even though the weight classification is indispensable issue for WRIM, there is no suitable classification result at present moment. The potential analysis has been conducted by using remote sensing in many places all over the world. The most important factor for groundwater basin's formation is recharge from precipitation, but the potential analysis is not merely following the precipitation amount at each point in a groundwater basin. The mountain area generally has plenty precipitation to become groundwater recharge area, but groundwater table is deep from ground surface in many area. In contrast, even though the recharge from precipitation is very few, in plane area, groundwater can get recharge from mountain side by groundwater flow, so, it is not uncommon to find high potential in plain area. However, in some potential analysis, the remote sensing experts directly using the precipitation amount for each point in a groundwater basin because they forget the principle for groundwater formation. If this kind of classification together with higher weight set to recharge from precipitation, the potential in mountain area surely being much greater than plain area.

In this analysis, the influence of each factor is taken as the base for weight specification and the primary classification result is as follows:

The highest influence to groundwater basin's formation is recharge, so the result of recharge rank classification is set with the weight of 40%.

The second important factor is considered to be topography, which affects both of groundwater flow and groundwater table's depth. Therefore, the second weight of 30% was set to this factor of topography.

For the other two factors of geology strata (hydraulic conductivity) and lineament, the former one can be considered as relatively larger than the later one, and then the weight for them are set as 20% and 10% respectively.

7.4.3 Each factor's minimum weight specification

After the weight specification for maximum value of each factor as mentioned above, it has to be devised how to specify the weight for the lowest value. For example, the main groundwater basin Ghenale has the highest ratio of precipitation to potential evapotranspiration of 26.4%. In contrast, another groundwater basin Coastal Drainage has the lowest ratio of 6.3%. Even if 40% of the former value is taken in the potential analysis, there is no standard for the lowest value's specification. Therefore, no other method can be considered better than executing several kinds of specification for the lowest value of 6.3%. And then following the maximum specification of 40% for Ghenale groundwater basin, the percent for the Coastal Drainage groundwater basin are specified into 3 types of 30, 20 and 10%. The recharge specification for other groundwater basins is conducted by calculation between the maximum and minimum values using straight line analysis method.

The topographical altitude in the study area fluctuates between elevations of 2,460m~171m. Because as the groundwater flows depend on the topography, the lowest area can be considered to easy relatively to gather groundwater from surrounding area, therefore it can be specified as high rank of 30%. But in the highest elevation area there is no standard for rank's specification. Therefore, as well as the recharge specification, the highest elevation point is set into 3 ranks of 20%, 15% and 10%. The topography specification for other area is also conducted by calculation between the maximum and minimum values using straight line analysis method.

The maximum specification for geology (hydraulic conductivity) is set as 20%, as well as the weight of recharge and topography. Therefore, two types of weight specification for the lowest value are specified as 10% and 5% (refer to Table 7.11).

The weight of lineament is has been set as the smallest value of 10%, therefore there is no need to separate the lineament into different types. If there is no lineament in a grid, the weight is 0, and for all other grids with some lineament in it, the weight is calculated between 0 and maximum value of 8,146m by using straight line analysis method.

Table 7.11: Weight (%) Specification of Each Factors for WRIM

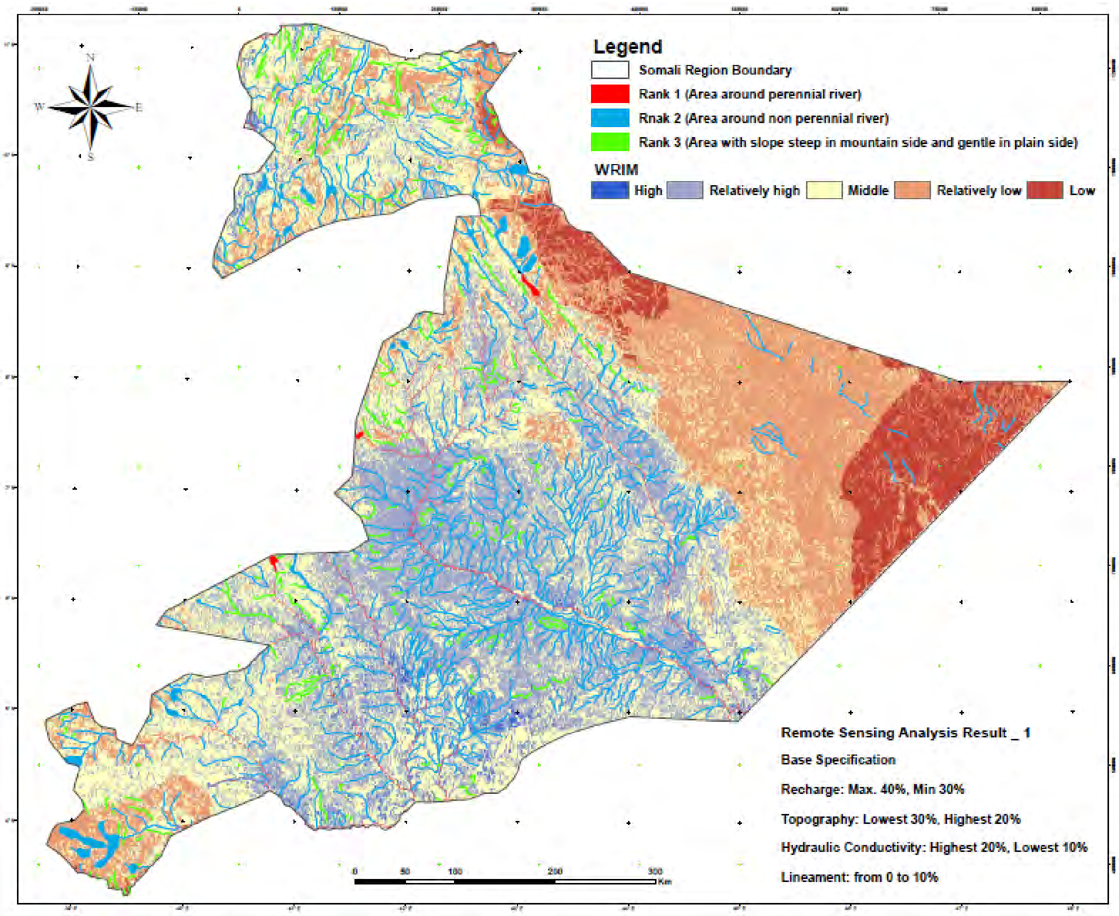
Recharge	Topography	HC*	Expression
40/30	30/20	20/10	1
		20/5	2
	30/15	20/10	3
		20/5	4
	30/10	20/10	5
		20/5	6
40/20	30/20	20/10	7
		20/5	8
	30/15	20/10	9
		20/5	10
	30/10	20/10	11
		20/5	12
40/10	30/20	20/10	13
		20/5	14
	30/15	20/10	15
		20/5	16
	30/10	20/10	17
		20/5	18

HC: Hydraulic Conductivity
Expression: Number of the figures below.

7.4.4 Method for WRIM rank division

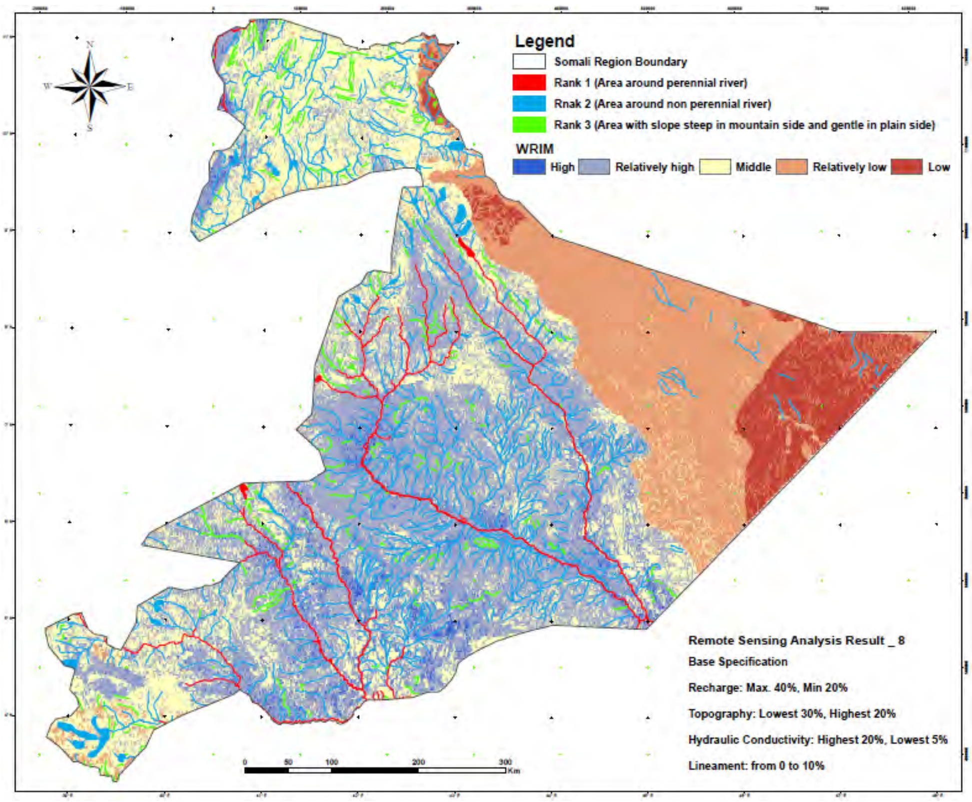
As mentioned above procedure, 18 WRIMs were created as Figure 7.24 to Figure 7.41 and shown in the following.

Within these 18 sheets of WRIM, the maximum value ranges 99.6%～99.8% in a very narrow area. In contrast, as shown in the Table 7.11, the minimum value fluctuates from 34%～69.5%. The high value is surely being taken as high rank for WRIM, but it has to be considered how to separate them into 5 different ranks. The most simple method would be equally separate them. However, from map's of natural condition, and precipitation it can be known that the available groundwater in the study area is lower than that of other area in Ethiopia. So in Somali region, the area with low groundwater potential would be more than the area with high potential. Therefore, the equally separation method is not used for the rank's division. The rank's division is specified from the highest values to lowest value as 12 is high, 16 is relatively high, 20 is middle, 24 is relatively low, and 28 is low.



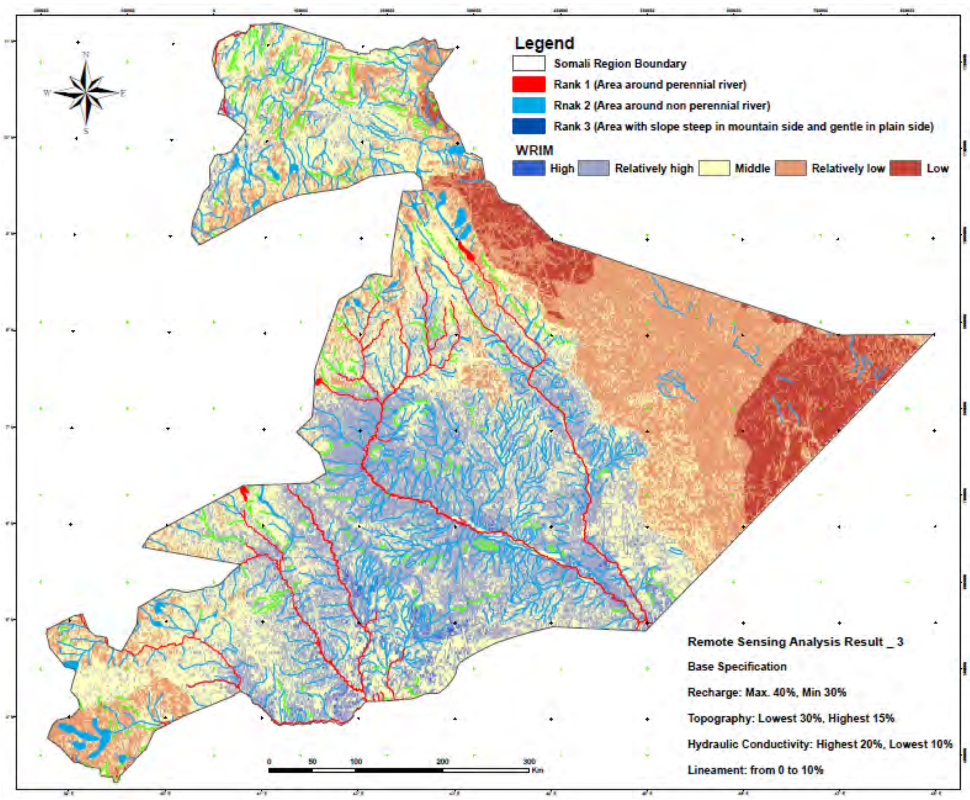
Recharge 4/3, Topography 3/2, HC.2/1, Lineament 0-10

Figure 7.24: WRIM Result 1



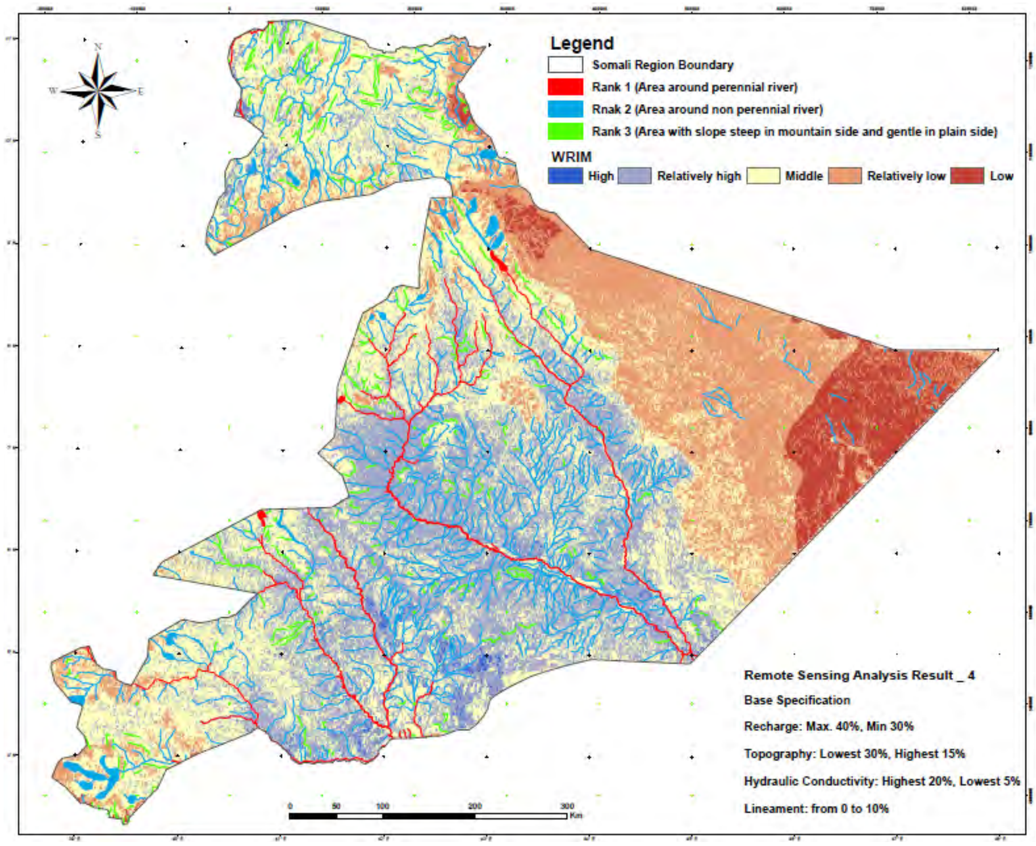
Recharge 4/3, Topography 3/2, HC. 2/0.5, Lineament 0-10

Figure 7.25: WRIM Result 2



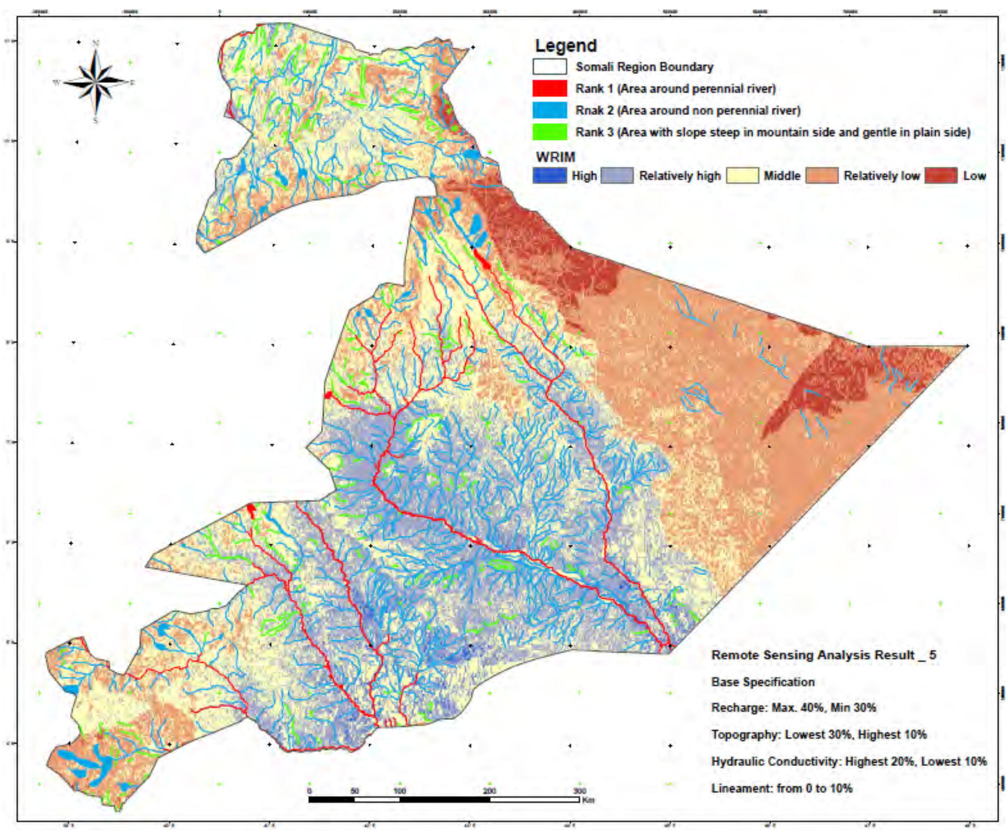
Recharge 4/3, Topography 3/1.5, HC. 2/1, Lineament 0-10

Figure 7.26: WRIM Result 3



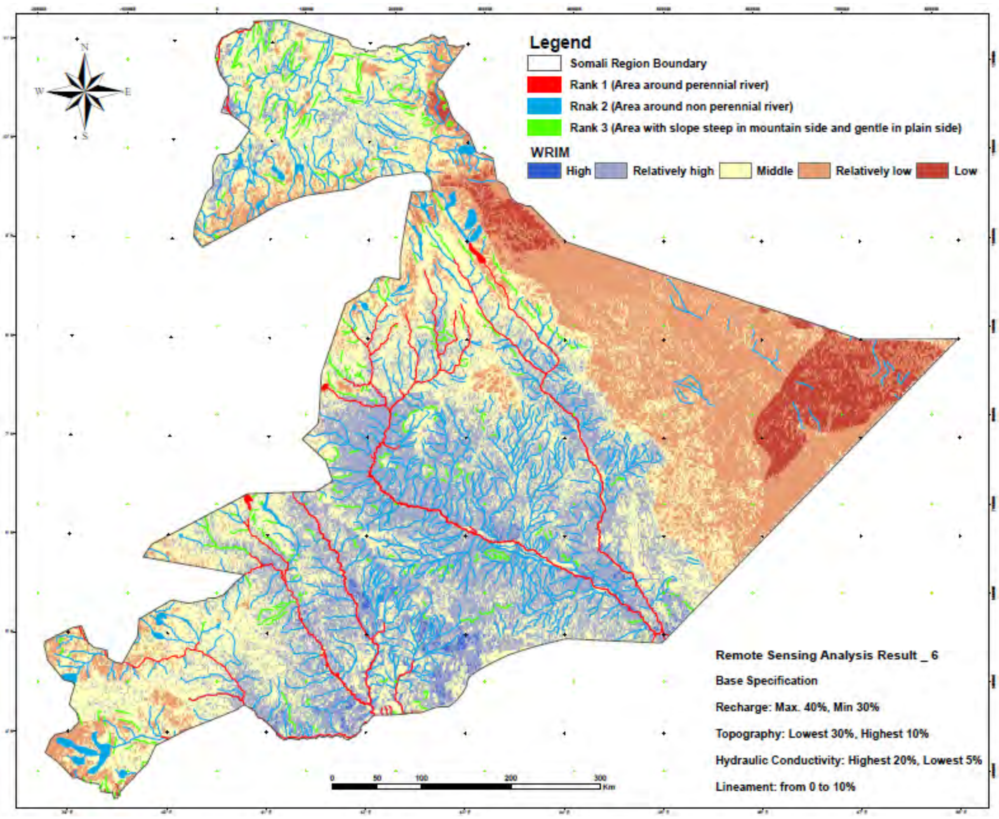
Recharge 4/3, Topography 3/1.5, HC. 2/0.5, Lineament 0-10

Figure 7.27: WRIM Result 4



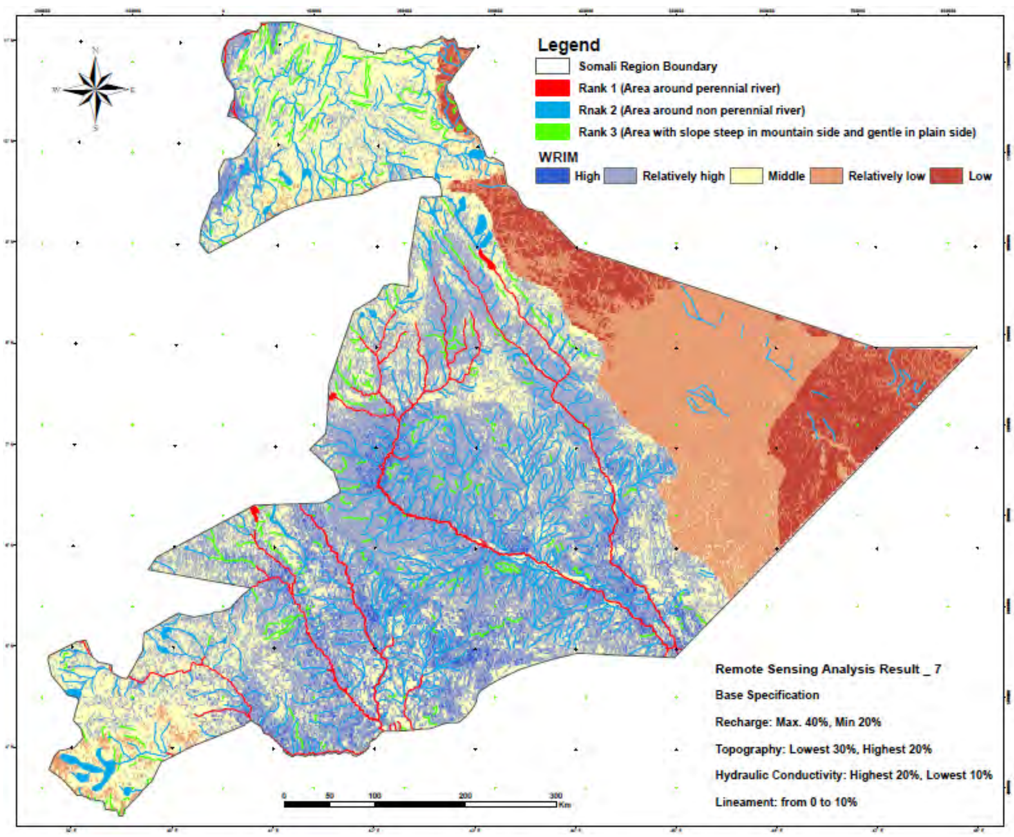
Recharge 4/3, Topography 3/1, HC. 2/1, Lineament 0-10

Figure 7.28: WRIM Result 5



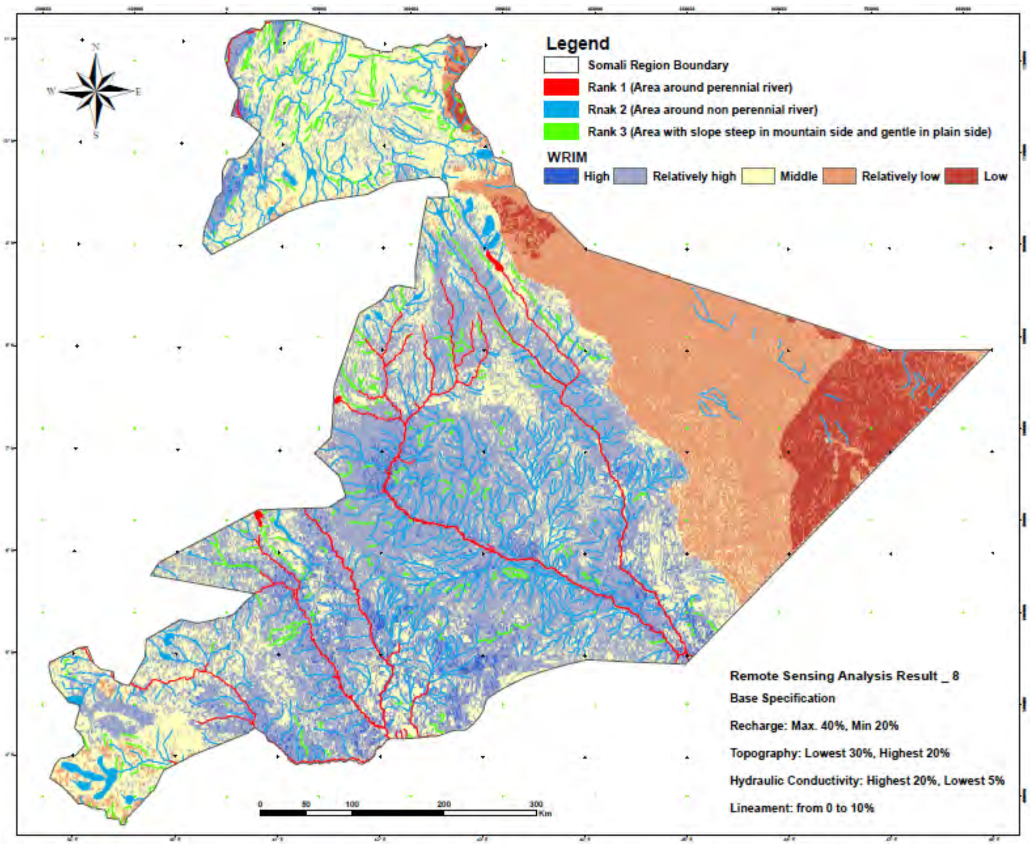
Recharge 4/3, Topography 3/1, HC. 2/0.5, Lineament 0-10

Figure 7.29: WRIM Result 6



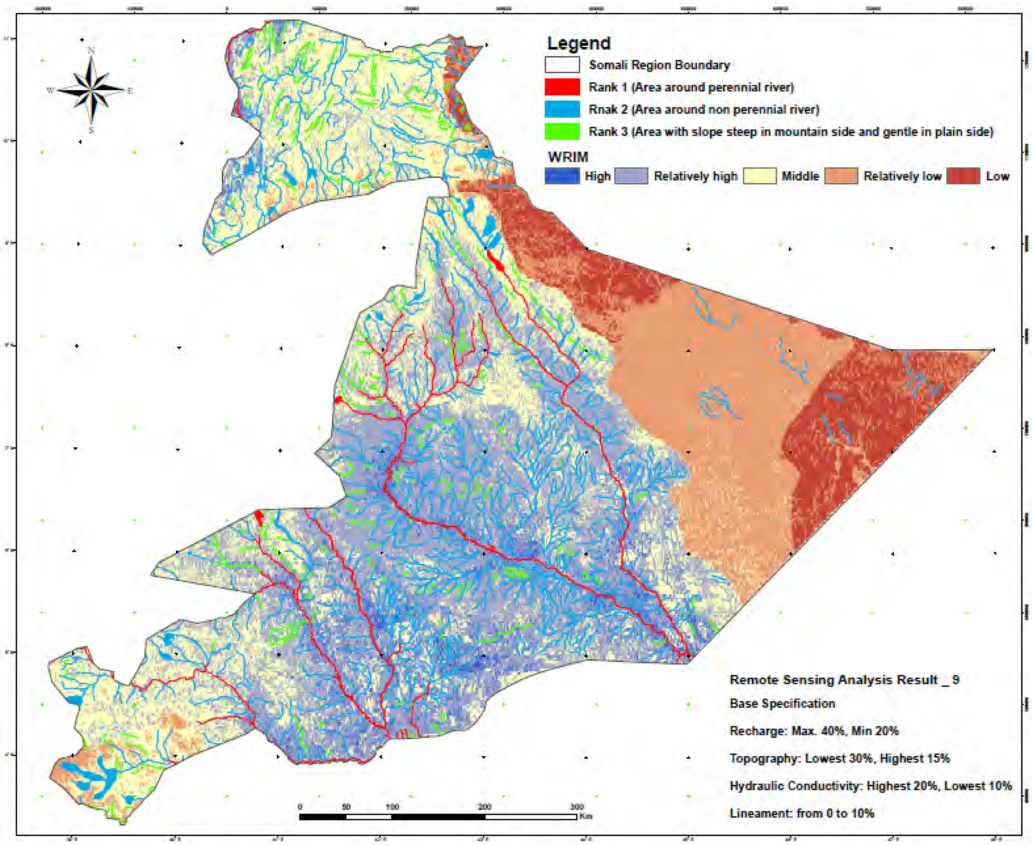
Recharge 4/2, Topography 3/2, HC. 2/1, Lineament 0-10.

Figure 7.30: WRIM Result 7



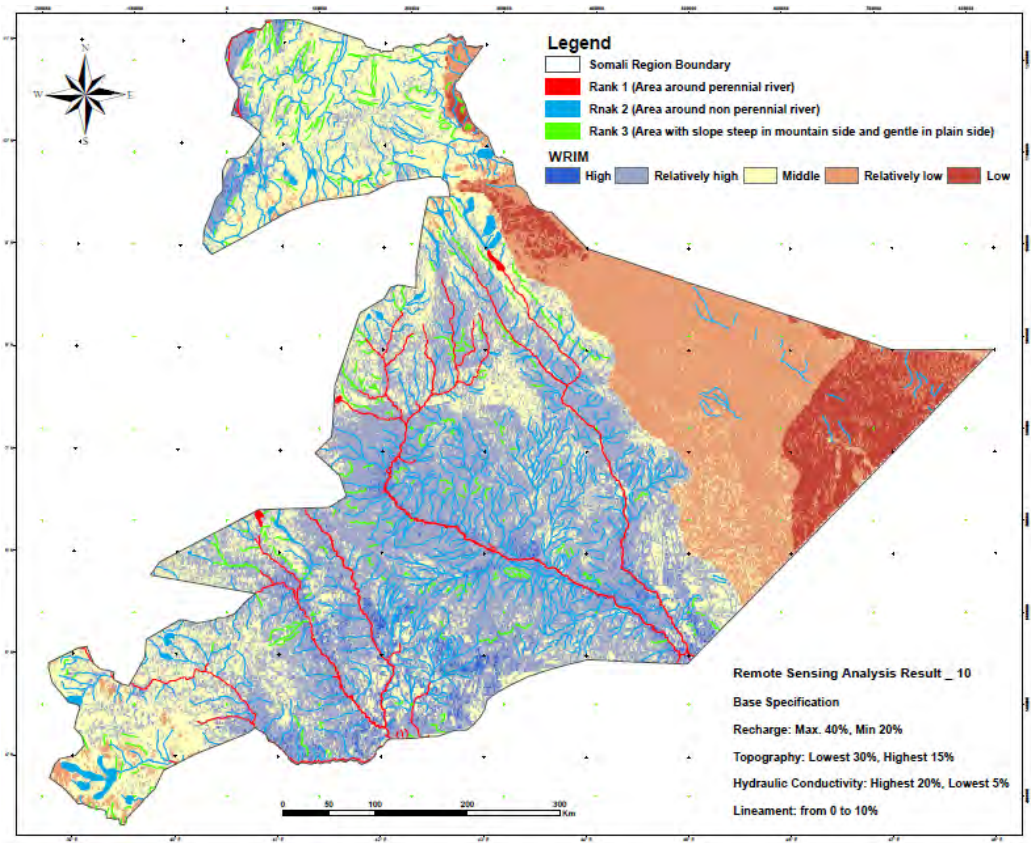
Recharge 4/2, Topography 3/2, HC. 2/0.5, Lineament 0-10

Figure 7.31: WRIM Result 8



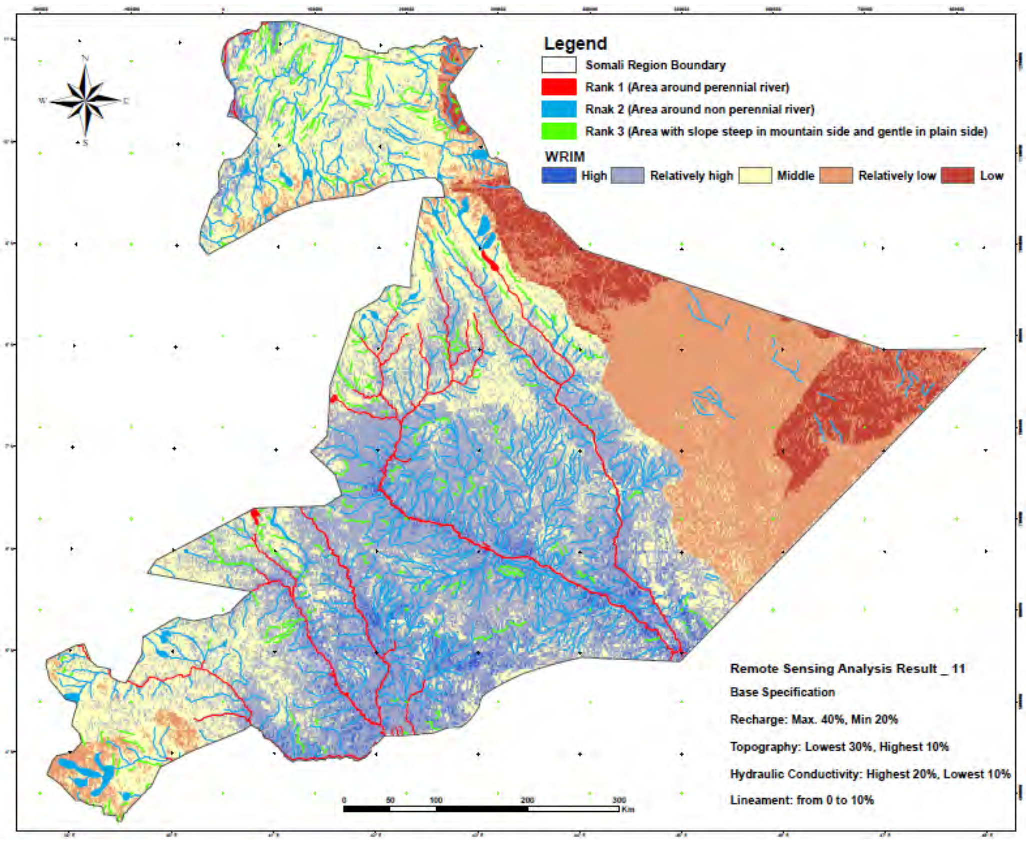
Recharge 4/2, Topography 3/1.5, HC. 2/1, Lineament 0-10.

Figure 7.32: WRIM Result 9



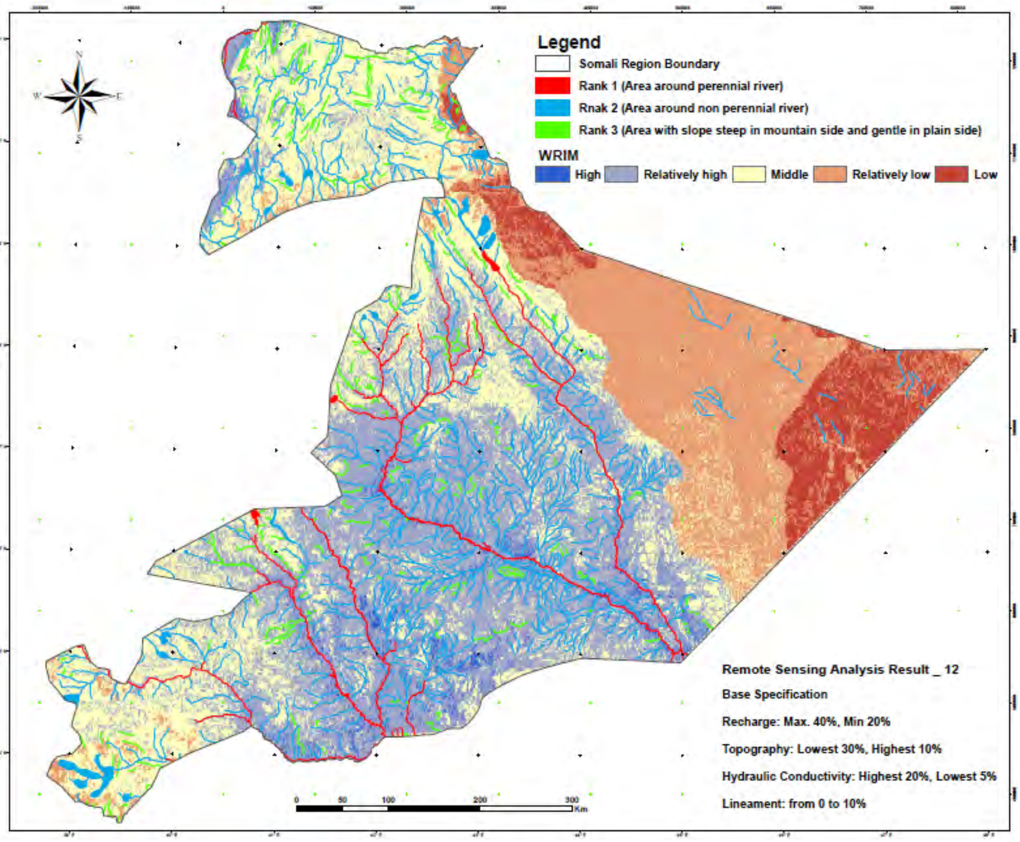
Recharge4/2, Topography3/1.5, HC. 2/0.5, Lineament 0-10

Figure 7.33: WRIM Result 10



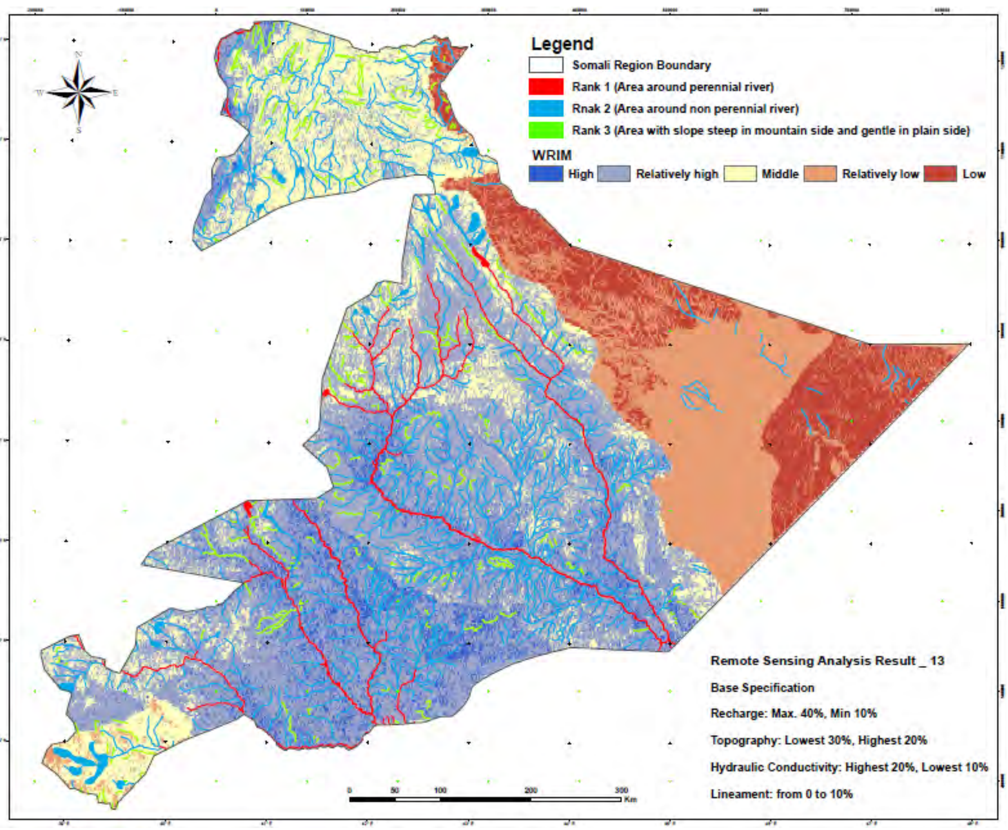
Recharge4/2, Topography3/1, HC. 2/1, Lineament 0-10

Figure 7.34: WRIM Result 11



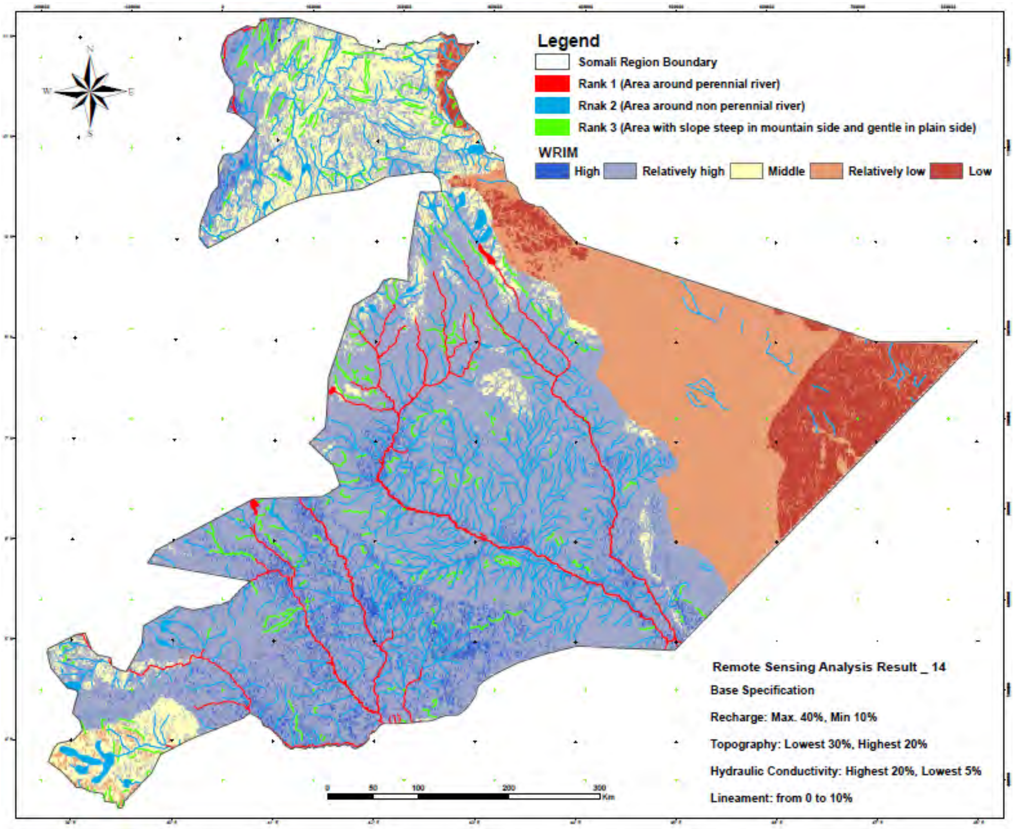
Recharge 4/2, Topography 3/1, HC. 2/0.5, Lineament 0-10

Figure 7.35: WRIM Result 12



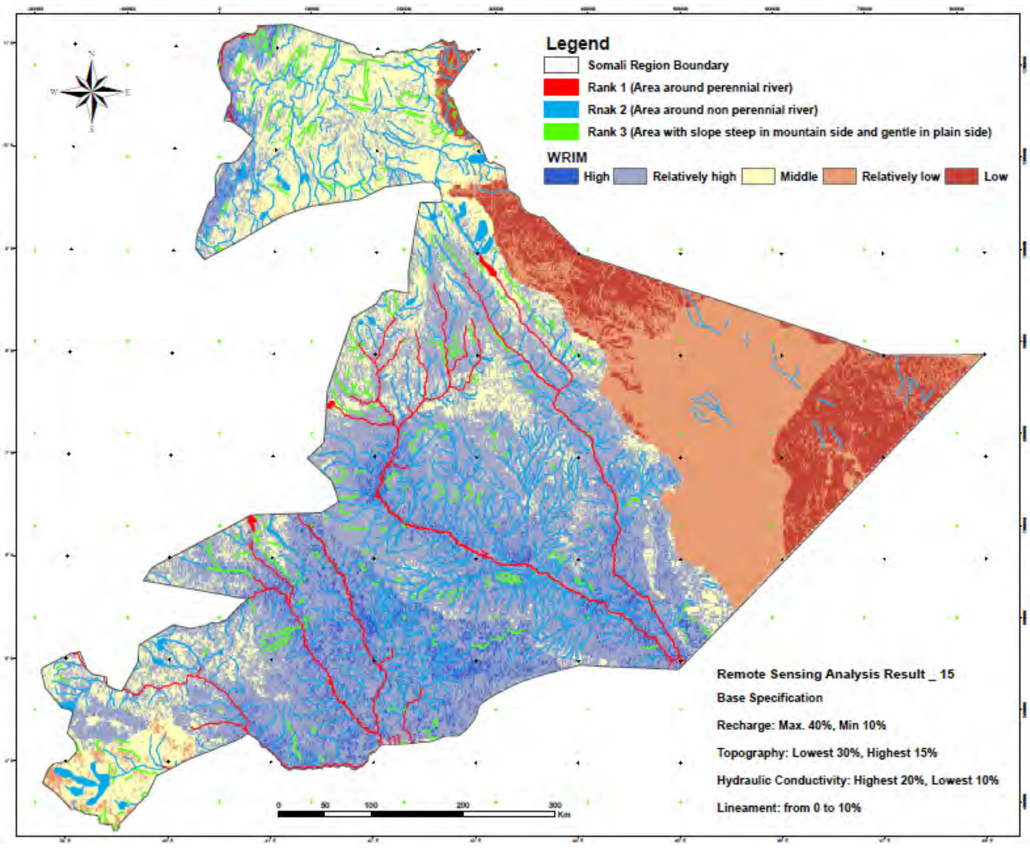
Recharge 4/1, Topography 3/2, HC. 2/1, Lineament 0-10

Figure 7.36: WRIM Result 13



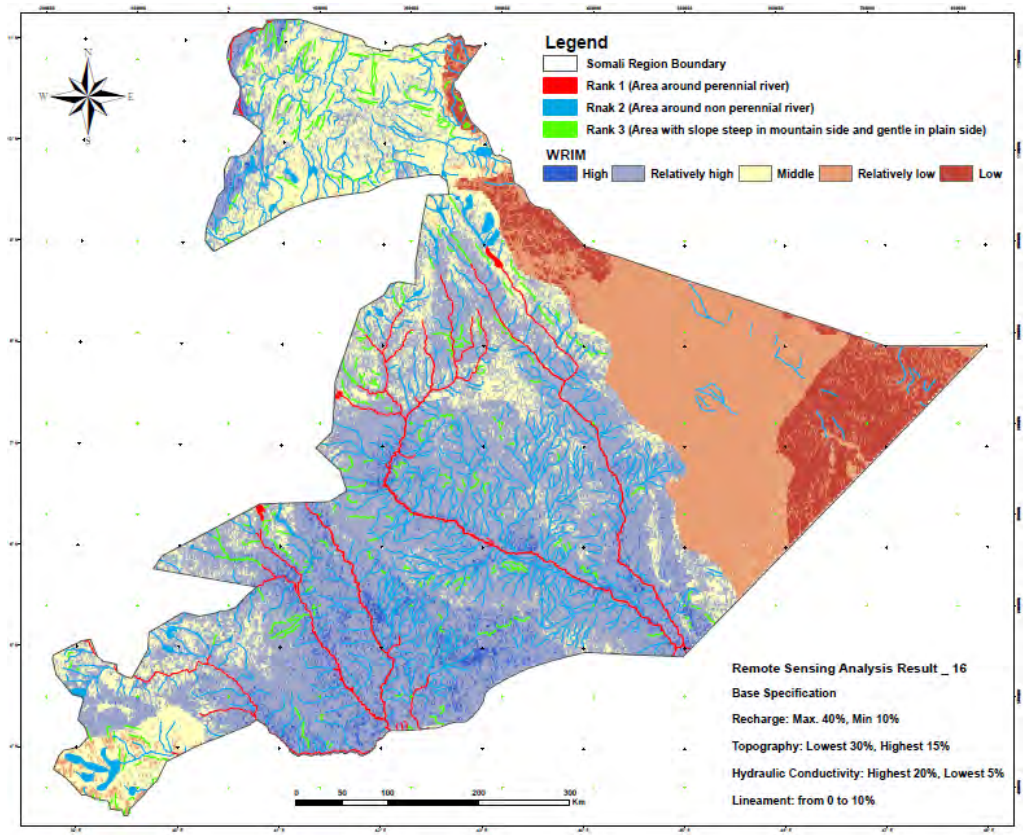
Recharge4/1, Topography3/2, HC. 2/0.5, Lineament 0-10.

Figure 7.37: WRIM Result 14



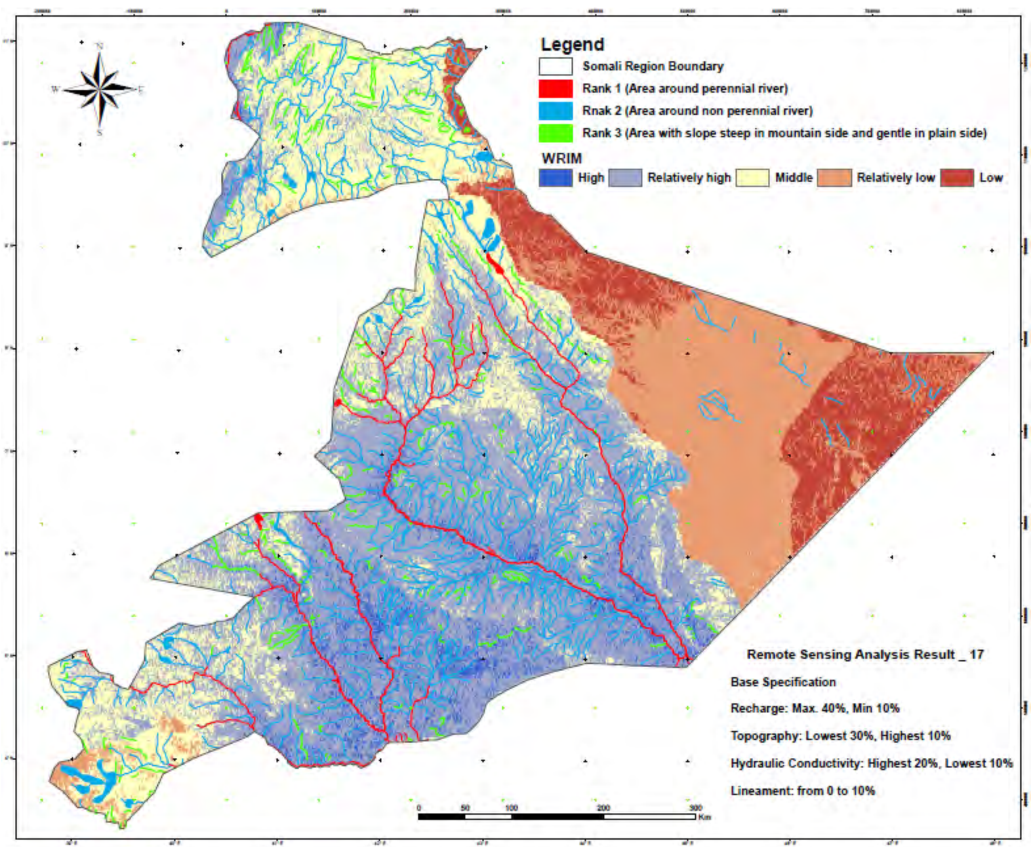
Recharge 4/1, Topography 3/1.5, HC. 2/1, Lineament 0-10

Figure 7.38: WRIM Result 15



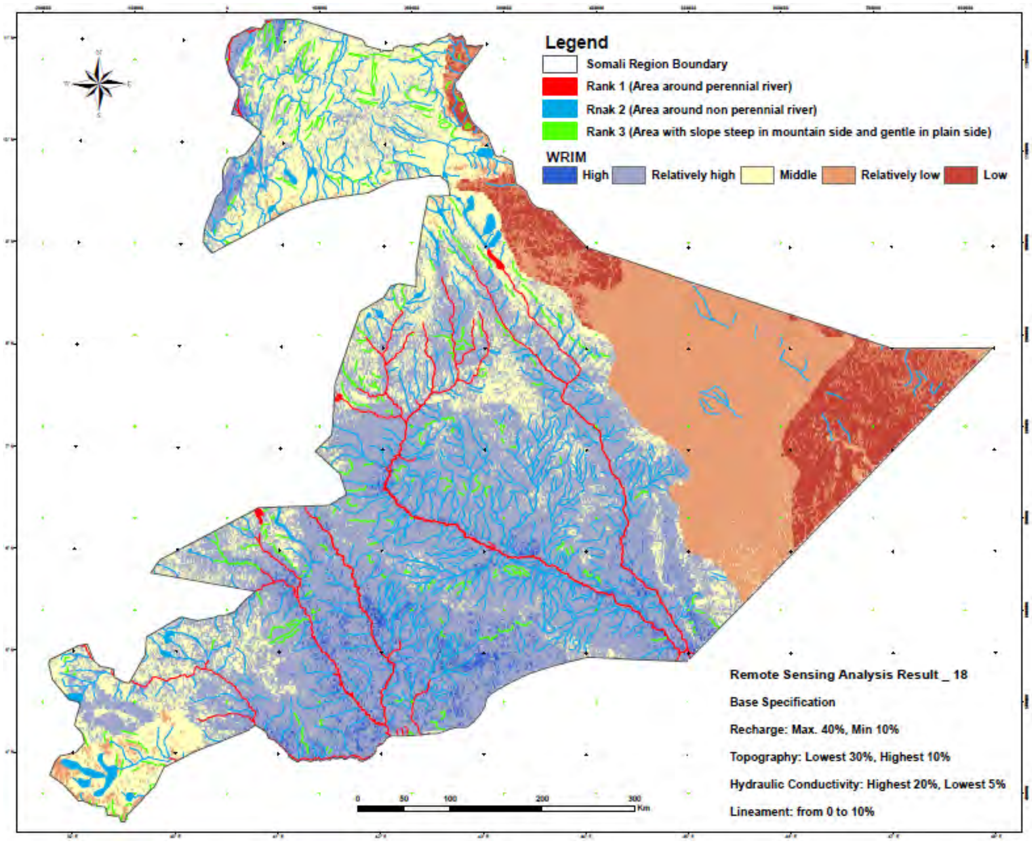
Recharge 4/1, Topography 3/1.5, HC. 2/0.5, Lineament 0-10.

Figure 7.39: WRIM Result 16



Recharge 4/1, Topography3/1, HC. 2/1, Lineament 0-10.

Figure 7.40: WRIM Result 17



Recharge 4/1, Topography 3/1, HC. 2/0.5, Lineament 0-10

Figure 7.41: WRIM Result 18

7.4.5 Water quality ranking

As being mentioned above, it is impossible to get the water quality's information by using remote sensing. Therefore, regarding the water quality classification UNESCO (2012) has been obtained for water quality's rank classification. The information was used to create the water quality map and the map is shown in Figure 7.42.

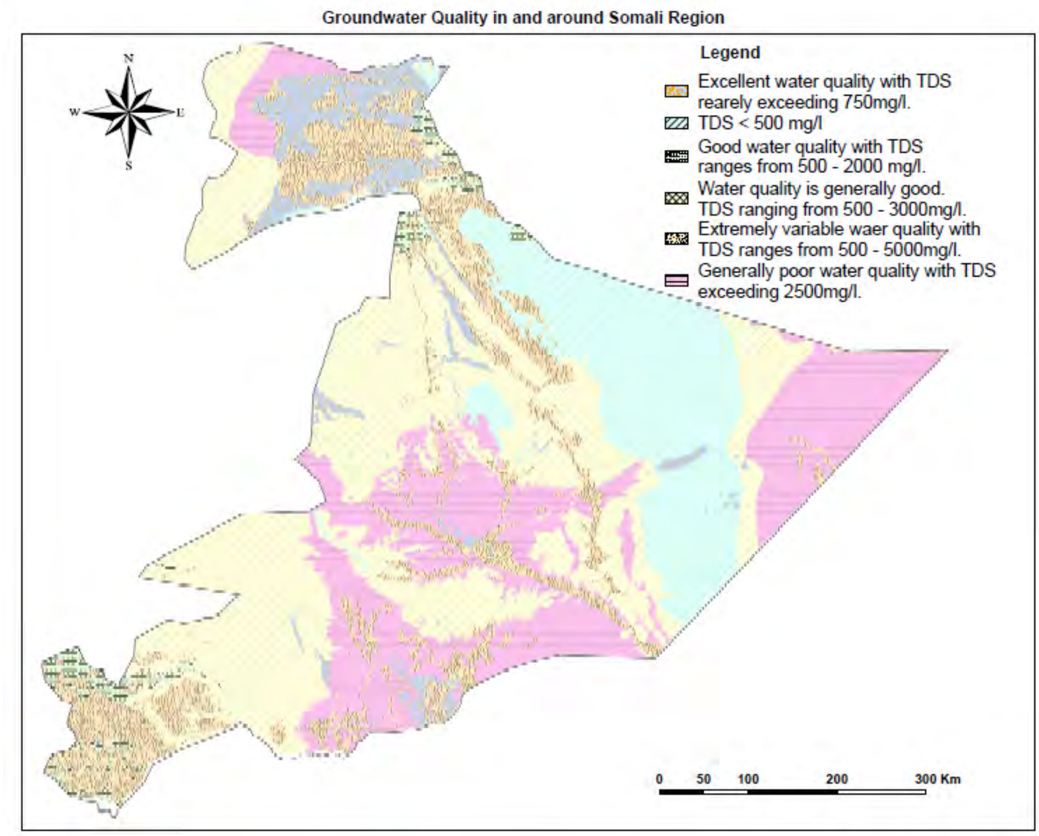
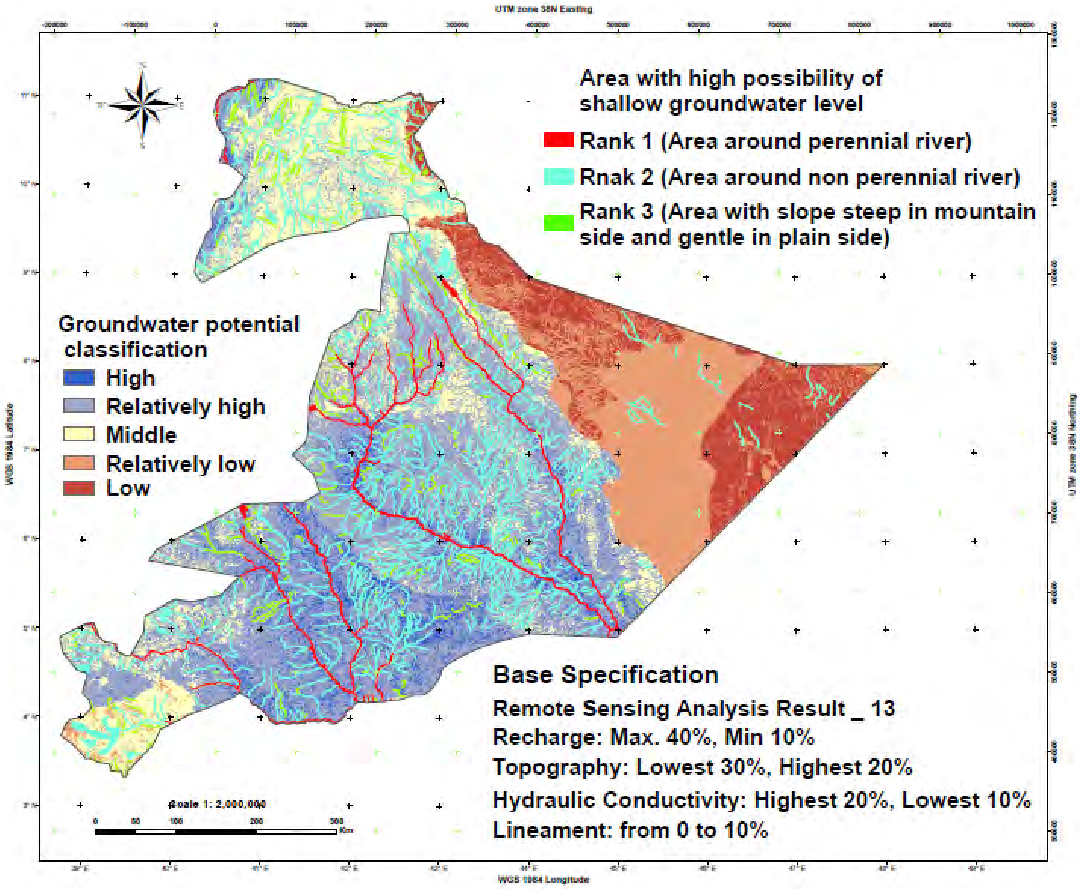


Figure 7.42: Water Quality Classification Map (UNESCO 2012)

Different results (WRIMs) have been created as a result of specifying different the sets of weights for all the relative factors. On the other hand, the groundwater analysis was conducted by using well information, the analysis of groundwater potential, and then GUPE map was created. The WRIMs of eighteen (18) were compared with GUPE map and the most appropriate WRIM was selected as the final output of number 13. The weight specifications of WRIM selected is shown below:

- Recharge: Maximum 40%, Minimum10%
- Topography: Maximum 30%, Minimum 20%
- HC. : Maximum 20%, Minimum 10%
- Lineament: Maximum 10%, Minimum 0%

Also for the purpose of comparing both WRIM and water quality classification map, Figure 7.43 was presented below. Finally, the two maps of Figure 7.43 were integrated by overlaying with each other to create a comprehensive map in scale of 1:2,000,000.



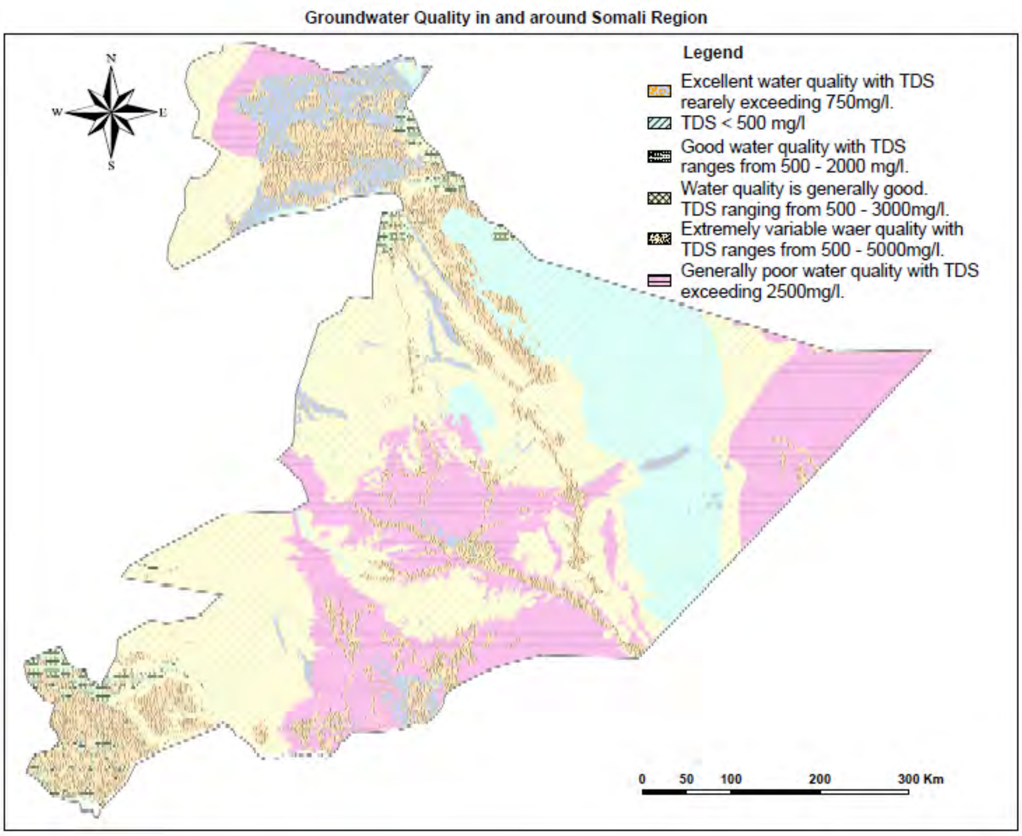


Figure 7.43: Comparison of WRIM and Water Quality Classification Map

7.4.6 Explanation of legend and methodology of usage for WRIM

All the 18 sheets of WRIM use the same legend and it consists of two categories of classicization and they are in concrete as follows:

Legend Category_1

Rank1 (Area around perennial river): Flat area around perennial rivers (refer to Figure 7.20)

Rank2 (Area around non-perennial river): Flat area around non perennial rivers (the same as Rank1 the base is the analysis result of the second point of topography as shown in Figure 7.20)

Rank3 (Area with steep slope in mountain side and gentle in plain side): Based on Figure 7.23 showing predicted shallow groundwater table area

Legend Category_2

High potential: The highest rank area covering 12% from the highest value to whole analysis result range.

Relatively High potential: The second higher rank area covering (12＋)16％ from the highest value to whole analysis result range.

Middle potential: The middle rank area covering (12＋16+)20％ from the highest value to whole analysis result range.

Relatively low potential: The second lower rank area covering (12＋16＋20＋)24％from the highest value to whole analysis result range.

Low potential: The lowest rank area covering 28% from the lowest value to whole analysis result range.

Legend Category_1 is mainly based on the result of rivers and topography gradient analysis to show the area with high possibility of shallow groundwater level.

Legend Category_2 is the groundwater potential analysis results based on different kinds of factor's weight specification shown in Table 7.11.

The rank divisions were contained in the WRIM relatively based on the four factors above in regard to the water resources potential in Somali Region at first. And also as the water quality map was overlapped on potential map, it is possible to discuss regarding the possibility of water usage. Therefore, the methodology of usage for WRIM is as follows below;

- The WRIM differ from GUPE map in relation to the method of evaluation for the water resources potential. However the relative evaluation about the water resources potential is reviewed in regard to the area in Somali Region except the Jarar valley and Shebele River sub basin. Moreover, the WRIM is useful for the discussion of methodology of water usage in reference to the information of water quality.

- The potential information is expressed by the accuracy of 1km mesh. But as the map scale is 1 to 2,000,000, WRIM is useful for the relative possibility of potential and information of water quality.

- The potential is relatively divided in regard to the information of shallow groundwater in consideration of the factor of topography mainly. Therefore WRIM is useful to obtain the primary data with water quality for some areas which are difficult to drill the deep well and are far from the perennial river.

Chapter 8

Conclusions

8 Conclusions

The conclusions are shown based on the results of water resources (groundwater) utilization potential survey.

8.1 Summary of the survey results

The average value of annual rainfall in the data collected was ranged from 220mm to 570mm per year in meteorological and hydrological data of Somali Region. The value of rainfall is lower than the other region of Ethiopia; meanwhile, the evaporation is high. The Shebele River is perennial river, and there is a strong correlation between the drainage area of the Shebele River and annual depth of runoff. As the results of water balance analysis, the average annual values of groundwater recharge was estimated range from 9.3mm to 47.95mm per year.

The geological formations of Somali Region range in age from Precambrian to Quaternary deposits. The oldest geological formations are undifferentiated Precambrian crystalline rocks, which include granite. The basement rocks are overlain by Mesozoic sediment, which are in turn overlain by Tertiary to Recent volcanic and alluvial deposits. Especially, the Quaternary deposits distribute along the river and in low land. The major and potential aquifers that have been identified as a result of existing and JICA wells are those of the Quaternary sediments, Quaternary to Tertiary basalts, a part of Tertiary and Cretaceous formations, Jurassic sediments, and Jurassic to Triassic (?) sandstone formations. As the results of the water quality analysis, the water resources types correspond to hot spring water, mine spring water, or fossil water, or the other types probably correspond to groundwater or river water that are locally in circulation. In turbidity, TDS, Chloride and total hardness, many samples exceeded the standard values of Ethiopia in the analysis of laboratory.

8.2 Conclusions

The groundwater utilization potential evaluation map in the area of Jarar valley and Shebele River sub-basins was created in accordance with the classification of aquifer evaluated by using the yield of wells, groundwater level and water quality. Map scale is 1:250,000. The map was illustrated relatively because there is quite few quantitative data. The following items were inferred from map;

- The high water quality aquifer with middle to high productivity distribute along the Jarar valley and the highland of left side of Jarar valley from Kabribeyah woreda to Kabridahar woreda. Meanwhile, in the right side of Jarar valley, the low quality and productivity aquifer or the middle quality and productivity area distribute as the elongated area. The southern area from Kabridahar woreda, The low productivity and high water quality aquifer distribute along the left side of Jarar valley in the the southern area from Kabridahar woreda. Also the same areas were dotted with low productivity and water quality.

- The gypsum layer distributes along the Shebele River area widely. The area shows the middle productivity of water resources, but since the water quality is very poor, it is not suitable to drink water. The groundwater potential is low along the Shebele River, but the potential of surface water has a meddle productivity.

On the other hand, the water resources potential and water quality were discussed by using water resources information map (WRIM) in the entire Somali Region in reference to the evaluation map above. The items assumed are as follows below;

- The topography , in particular the plane lowlands were noticed in regard to the shallow groundwater potential, and the shallow groundwater points was selected in terms of the existence of perennial river and plane land which exists at the boundary area changing from steep slopes to low land. Consequently, the areas of the high potential of shallow groundwater relatively were dotted along the Jarar valley and the small size valley in the highland and hill area.

- The water resources of high or relative high potential area distribute widely in the south west area of the Shebele River sub-basin except Ogaden area in relation to the potential evaluation of water resources in Somali Region according to the WRIM. However, the water quality in these areas is quite poor. In Jarar valley area, the water resources potential is expected from meddle to relative high condition. The water quality is good condition or the some area has a large fluctuation of water quality.

- Since WRIM and the water resources utilization potential evaluation map have similar information in Jarar valley and Shebele River sub-basin, WRIM has a high probability to be utilized in the entire Somali Region.