The Federal Democratic Republic of Ethiopia
Ministry of Water, Irrigation and Electricity

THE PROJECT FOR GROUNDWATER RESOURCES ASSESSMENT IN THE MIDDLE AWASH RIVER BASIN IN THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA

FINAL REPORT
MAIN REPORT

December 2015

Japan International Cooperation Agency

Kokusai Kogyo Co., Ltd.

Composition of the Report

Executive Summary

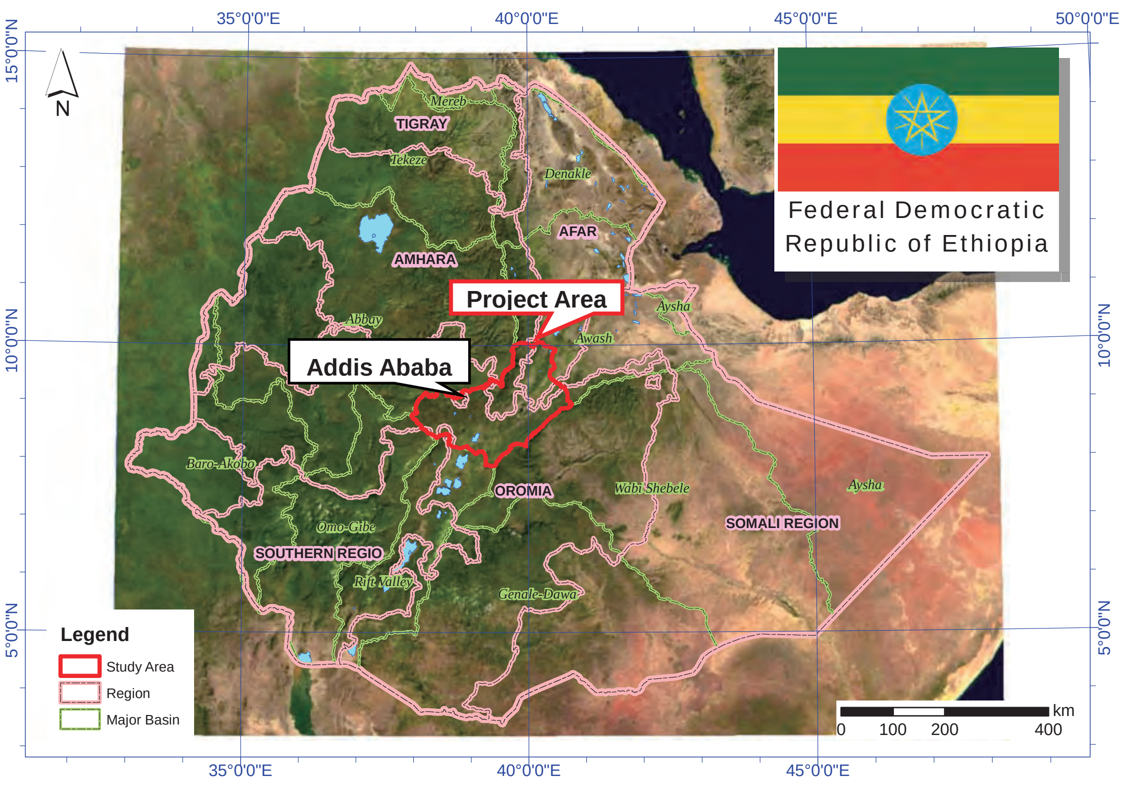
Main Report

Supporting Report

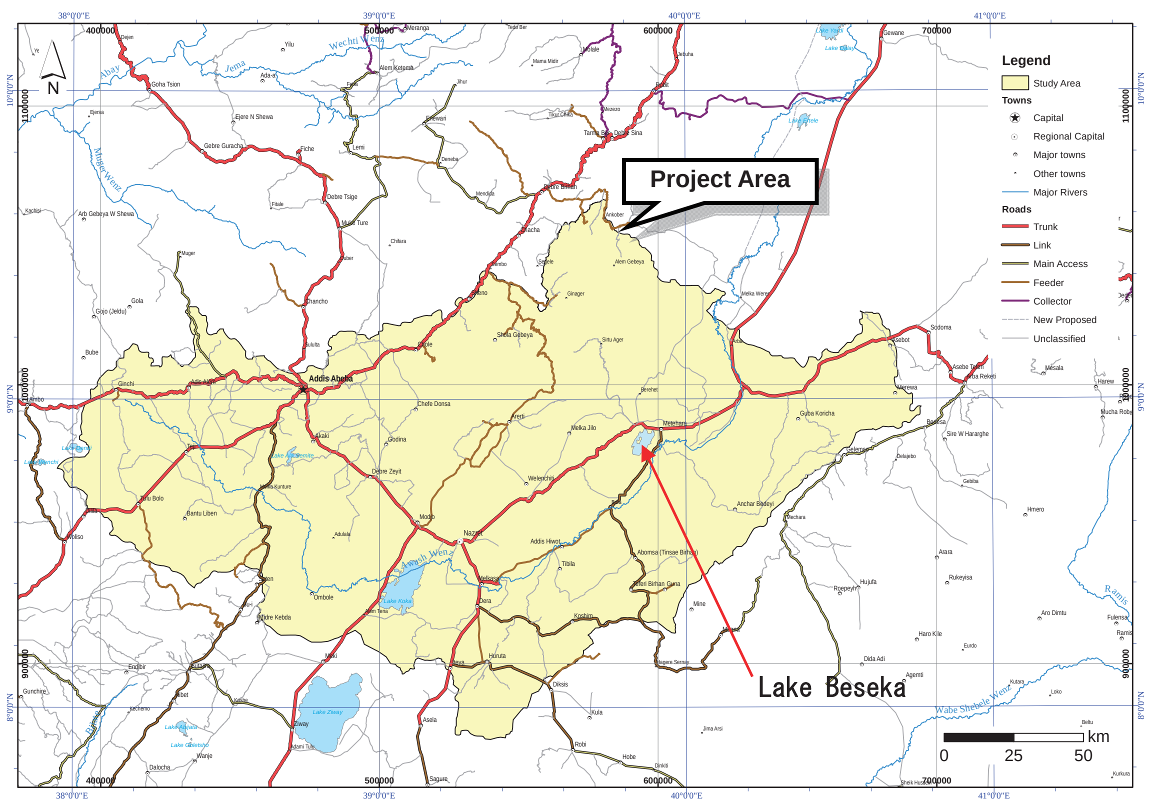
Data Book

Geological and Hydrogeological Maps

This Report is prepared based on the price level and exchange rate of July 2015.
The exchange rate is:
US$1.0 = ETB20.6298 = JPY123.80



Location of the Study Area



The Middle Awash River Basin

LOCATION MAP

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Abbreviations

AAU	Addis Ababa University
AGRAP	Alidge Groundwater Resources Assessment Project
AIDS	Acquired Immune Deficiency Syndrome
ALOS	Advanced Land Observing Satellite
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASTER-GDEM	ASTER-Global Digital Elevation Model
BFI	Base Flow Index
CAD	Computer Aided Design (System)
CDE	Center for Development and Environment, Ministry of Agriculture
CFC	Chloride Fluoride Carbon
CREC	China Railway Engineering Corporation
CSA	Central Statistical Agency
CSE	The Conservation Strategy of Ethiopia
C/P	Counterpart (organization or personnel)
DB	Datebase
DCI	Ductile Cast Iron
DEM	Digital Elevation Model
DF/R	Draft Final Report
DTH	Down-the-hole Hammer
DWL	Dynamic Water Level
EA	Environmental Assessment
EC	Electric Conductivity
EEPCO	Ethiopia Electric Power Corporation
EGRAP	Ethiopian Groundwater Resources Assessment Program
EIA	Environmental Impact Assessment
EIGS	Ethiopian Institute of Geological Survey, now renamed as Geological Survey of Ethiopia (GSE)
EL	Elevation
ELC	Elc electroconsult milano and Geotermica italiana pisa, Italia (an Italian Consultant)
ELSA	Equilibrium Lake Surface Area
EMA	Ethiopia Mapping Agency
ENGDA	Ethiopian National Groundwater Database
ENGWIS	Ethiopian National Groundwater Information System
EPA	Environmental Protection Agency, now renamed as Ministry of Environment and Forest (MEF)
EPC	Environmental Protection Council
ERA	Ethiopian Road Authority
ERC	Ethiopian Railway Corporation
ESA	Ethiopian Standard Agency
ESIA	Environmental and Social Impact Assessment
ET	Evapotranspiration
EWCA	Ethiopian Wildlife Conservation Authority
EWTEC	Ethiopia Water Technology Center, now renamed as Ethiopia Water Technology Institute (EWTI)
EWTI	Ethiopia Water Technology Institute, formerly known as Ethiopia Water Technology Center (EWTEC)
F/R	Final Report
FAO	Food and Agriculture Organization of the United Nations
FAO-AGLW	FAO Water Resource, Development and Management Services
FDM	Finite Difference Method
FEM	Finite Element Method
GD	Groundwater Directorate (of MoWIE)

GDP	Gross Domestic Product
GHB	General Head Boundary
GIS	Geographical Information System
GL	Ground Level
GNI	Gross National Income
GPS	Global Positioning System
GSE	Geological Survey of Ethiopia
GSP	Galvanized Steel Pipe
GTP	Growth and Transformation Plan
GWR	Groundwater Recharge
HIV	Human Immunodeficiency Virus
IAEA	International Atomic Energy Agency
IC/R	Inception Report
IEE	Initial Environmental Examination
IMF	International Monetary Fund
INGEIS	Instituto de Geocronología y Geología Isotópica (Institute of Geochronology and Geology, Argentine)
ISO	International Standard Organization
ISODATA	The Iterative Self-Organizing Data Analysis Technique
IT/R	Interim Report
ITCZ	Inter-tropical Convergence Zone
JICA	Japan International Cooperation Agency
LEL	Local Evaporation Line
LMWL	Local Meteoric Water Line
M&E	Monitoring and Evaluation
M/M	Minutes of Meeting
MCM	Million Cubic Meter
MDGs	Millennium Development Goals
MEF	Ministry of Environment and Forest, formerly known as Environmental Protection Agency (EPA)
MER	Main Ethiopian Rift
MOA	Ministry of Agriculture
MoWR	Ministry of Water Resources, now renamed as Ministry of Water, Irrigation and Electricity (MoWIE)
MoWE	Ministry of Water and Energy, now renamed as Ministry of Water, Irrigation and Electricity (MoWIE)
MoWIE	Ministry of Water, Irrigation and Electricity, formerly known as Ministry of Water, Irrigation and Energy(MoWIE), Ministry of Water and Energy (MoWE) or Ministry of Water Resources (MoWR)
MSE	Metehara Sugar Estate
MWL	Meteoric Water Line
NASA	National Aeronautics and Space Administration, USA
NGI	National Groundwater Institute
NGO	Non-Governmental Organization
NMA	National Meteorology Agency
OLEPB	Oromia Land and Environmental Protection Bureau
ORP	Oxidation and Reduction Potential
O(R)WMEB	Oromia (Regional) Water, Material and Energy Development Bureau
OWNP	One WASH National Program
OWWDSE	Oromia Water Works Design and Supervision Enterprise
P/R	Progress Report
PA	Preliminary (Environmental) Assessment
PASDEP	Plan for Accelerated and Sustained Development to End Poverty
PC	Personal Computer

PPP	Purchasing Power Parity
PRSP	Poverty Reduction Strategy Paper
PVC	Polyvinyl Chloride
R/D	Record of Discussions
REA	Regional Environmental Agencies
RESTEC	Remote Sensing Technology Center of Japan
RVLB	Rift Valley Lakes Basin
SC	Steering Committee
SCM	Steering Committee Member or Steering Committee Meeting
SDPRP	Sustainable Development and Poverty Reduction Program
SEA	Strategic Environmental Assessment
SFGS	Streamflow Gauging Station
SP	Spontaneous potential
SPOT	Satellite Pour l'Observation de la Terre (French Satellite for Earth Observation)
SRTM	Shuttle Radar Topography Mission
SS	Suspended Solids
TDS	Total Dissolved Solids
TEM	Transient (or Time-domain) Electromagnetic Method
TIR	Thermal Infrared
TM	Thematic Mapper
TOR	Terms of Reference
TU	Tritium Unit
TWSSO	Town Water Supply Service Office
TWSSSE	Town Water Supply and Sewerage Service Enterprise
UAP	Universal Access Program
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Children’s Fund
uPVC	Unplasticized Polyvinyl Chloride
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey
UTM	Universal Transversal Mercator
VES	Vertical Electrical Sounding
VIP	Ventilation Improved Pit
WASH	Water Supply, Sanitation and Hygiene Program
WB	World Bank
WC	Water Committee
WFB	Wonji Fault Belt
WHO	World Health Organization
WSDP	Water Sector Development Program
WSSM	Water Supply and Sanitation Master Plan
WWDSE	Water Works Design and Supervision Enterprise
WWMEO	Woreda Water, Mineral and Energy Office
ZWMEO	Zonal Water, Mineral and Energy Office

Project Photos (1/5)

Discussion of IC/R

The discussions held on 5 Nov. 2013 were participated by Ministry of Water, Irrigation and Electricity and Geological Survey of Ethiopia. The M/M was exchanged on 11 Nov

Project Introduction

Introducing the outline of the Project to the stakeholder when purchasing the hydrological information.

Site Visit (1)

Discussion between counterparts and experts regarding the construction period of the railway during the site visit to Lake Beseka.

Site Visit (2)

Currently, the water is being discharged to Awash River by a canal at the eastside of the lake as a countermeasure for water level rise.

Geophysical Survey (1)

The observation drilling sites were selected based on the resistivity information (200 m depth) of underground obtained from the geophysical survey (VES).

Geophysical Survey (2)

The observation drilling sites were selected based on the resistivity information (400 m depth) of underground obtained from the geophysical survey (TEM).

Project Photos (2/5)

Geological Survey (1)

The C/P from MoWIE has accompanied the experts in the geological survey for at least 3 months to finalize the geological map.

Geological Survey (2)

Megacha highly welded tuff that overlies Bofa Basalt to the west of Bofa.

Socio-Economic Survey

Focus Group discussions regarding water use status at Kinteri Town of Oromia Region.

Water Usage Inventory Survey (1)

Survey of existing water facilities at Geldiya Town in Oromia Region.

Water Usage Inventory Survey (2)

Situation at the public water tap of Areda Town of Oromia Region. Twenty litres of water cost around 2 Japanese Yen.

Sampling for IAEA Analysis

The tubing method of sampling Helium gas using copper pipe was instructed in order to facilitate IAEA stable isotope analysis.

Project Photos (3/5)

First C/P Meeting

Discussions on P/R1 held on 24 April 2014, with participants from the Ministry of Water, Irrigation and Electricity and Oromia Region. The M/M was exchanged later.

Site Visit by JICA (1)

Outcrops of rhyolite observed along the Arba River, a tributary of the Awash River. Discussions about geology were had with the C/Ps.

Site Visit by JICA (2)

The topographical and geological field survey was carried out in April 2014 at the Study area with Dr. Suzuki, Professor of Okayama University in Japan.

Wonji Sugar Plantation

This large-scale national sugar plantation is located about 10 km south of Adama Town. The photo shows an interview in regard to the general conditions of the plantation.

Metehara Sugar Plantation

This large-scale national sugar plantation is located about 5 km south of Metehara Town. Its area is more than 10,000 ha. The photo shows a well within the plantation.

Observation Well Drilling (1)

Clay balls made of mixed bentonite and straw are thrown into well AWBH-3 to prevent circulation loses and wall collapses between the surface and a depth of 30 m.

Project Photos (4/5)

Observation Well Drilling (2)

Well cleaning at AWBH-11: High-pressured air is sent into the well to discharge the remaining mud after the completion of the well.

Observation Well Drilling (3)

Pumping test at AWBH-1: The volume of pumped groundwater is measured by reading the water level (cm) which overflows the triangular notch tank.

Sampling for Water Quality Test (1)

Water for quality testing was sampled in existing wells, springs, river water, lake water, and so on. The water quality was classified by analysis. The photo shows the sampling of a deep well in East Shewa

Sampling for Water Quality Test (2)

The photo shows the sampling of spring water at the west side of Lake Beseka. The results of analysis of the spring flowing into Lake Besaka are different from that of other springs.

Sampling for Water Quality Test (3)

Water quality sampling was undertaken in the irrigation farm. The result shows the similar characteristic as south shore of Lake Beseka with high HCO_3 which caused by the vegetation.

Discussion of Progress Report 2

Discussion of P/R2 was held on 24th July 2014 attended by the C/P from Ministry of Water, Irrigation and Energy and Oromia Region. The M/M was exchanged later.

Project Photos (5/5)

GIS Workshop

GIS Workshop was held on 30th January 2015 at MoWIE. The theme was about the outline of GIS database for groundwater resources assessment.

Tone Spring

Tone spring is located at the southwest of Lake Beseka. The discharge volume could not be measured since it is submerged though the spring can be observed.

Environmental and Social Consideration

Situation during an interview at Department of Education at Woreda Office in Mojo. The information/data related to water fetching situation enrollment rate was collected.

Discussion of Interim Report

Discussion of IT/R was held on 11th July 2015. The contents have been discussed with the Deputy Minister of MoWIE. The M/M was exchanged later.

Technology Transfer Seminar

The Technology Transfer Seminar was held on 27th October 2015. The presentation includes the output, tasks and recommendations. The seminar was attended by C/Ps (MoWIE, EWTI, GSE, OWMEB and AAU) and NGOs.

Discussion of Draft Final Report

Discussion of DF/R was held on 27th October 2015 and the utilization method of this reports after the Project period have been discussed. The M/M was exchanged later.

Chapter 1

Project Summary

1 Project Summary

1.1 Introduction

This report was prepared to report the whole outputs of the Project for Groundwater Resources Assessment in the Middle Awash River Basin in the Federal Democratic Republic of Ethiopia (hereafter referred to as “the Project”) based on the results of the records of the discussions (hereafter referred to as “R/D”) agreed and signed by the Federal Democratic Republic of Ethiopia and the Japan International Cooperation Agency (hereafter referred to as “JICA”) on 27 May 2013. JICA organized a team of consultants (the Project Team) made up of 12 members to implement the Project. The Project started in October 2013 and completed in December 2015. The Project was executed through close collaboration between the Project Team and the counterpart personnel (hereafter referred to as “C/P”) of Ethiopia.

1.2 Background of the Project

The access ratio to improved drinking water sources in Ethiopia is 42% (96% in urban and 32% in rural areas) (UNICEF/WHO, 2008), which is far lower than the average coverage rate of 60% in Sub-Sahara Africa. Therefore, urgent action needs to be taken to secure safe water in Ethiopia. In 2011, the Government of Ethiopia (hereinafter referred to as “GoE”) formulated a national development plan called the Growth and Transformation Plan (GTP). The GTP set out four objectives with seven strategies. Improvement of access to safe water is mentioned in the strategy of “enhancing expansion and quality of social development”. In 2011, the GoE revised its Universal Access Program (UAP), which was originally issued in 2006 as a strategy for the water and sanitation sector. The updated UAP (UAP2) aims to improve the national average water supply access rate from 91.5% (estimation of UAP, 2010) to 100% in urban areas and from 65.8% (estimation of UAP, 2010) to 98% in rural areas by 2015 based on a water consumption per capita of 20 liters and 15 liters per day in urban and rural areas, respectively.

To achieve the aforementioned goal, it is important to develop groundwater sources that have a generally stable quantity with only slight seasonal fluctuations and relatively good quality. For better groundwater development in the Middle Awash River Basin, the plan shall be formulated based on the information of groundwater recharge and flow mechanisms and stored/developable amount (groundwater potential).

Under such circumstances, the GoE has requested the Government of Japan (hereinafter referred to as “GoJ”) to support a technical cooperation project for development of geological and hydrogeological maps on a scale of 1:250,000 in the Middle Awash River Basin and formulation of a provisional water supply scheme development plan in small towns in the Oromia Region. The area extends across three regions (the area of each region is: Oromia 55%, Afar 25% and Amhara 20%) and borders on the objective area of “the Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin” in 2012 (hereinafter referred to as “the Rift Valley Study 2012”) in the southwest. It is crossed by the Blue Nile River Basin, which also contains National Highway No.1 and runs in a northwesterly direction. The area faces the Shebelle River Basin in the southeast.

In response to the above request, JICA dispatched a Detailed Planning Survey Team in September 2012 and formulated the framework of the Project through discussions with the GoE side. The Project includes the following: production of geological and hydrogeological maps, evaluation of groundwater potential, formulation of a provisional water supply scheme development plan for the proposed 30 small towns (population of 15,000 or less) in the Oromia Region, selection of about 10 priority plans, etc. In addition, the project includes a study on the groundwater recharge and flow mechanism in Lake Beseka, which has caused severe inundation damage in the lakeside area due to its sudden and drastic surface water level rise since the 1960s.

1.3 Objectives of the Project

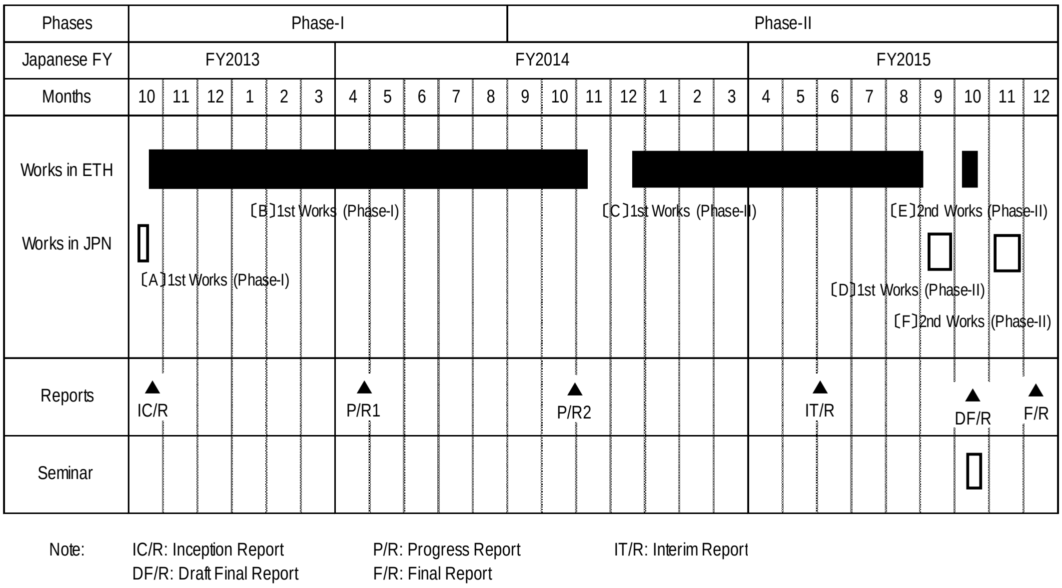
The objective of the Project is to enhance the capacities for the groundwater development planning and implementation of the Groundwater Directorate (hereafter referred to as “GD”) of Ministry of Water, Irrigation and Electricity (hereafter referred to as “MoWIE”) and Oromia Regional Water, Mineral and Energy Bureau (hereafter referred to as “OWMEB”) through the following activities: production of geological and hydrogeological maps, assessment of groundwater potential, formulation of provisional water supply facility scheme plans and selection of the priority plans therefrom.

1.4 Scope of the Project

The Project was implemented in accordance with the R/D, signed on May 27, 2013 and the Minutes of Meeting (hereafter referred to as “M/M”) relevant to the R/D. The Project Team undertaken the work items mentioned in the work schedule below to achieve the objectives mentioned above. The Project Team prepared the study reports as interim outputs and discussions thereon have been made among the Project Team, the GoE and JICA.

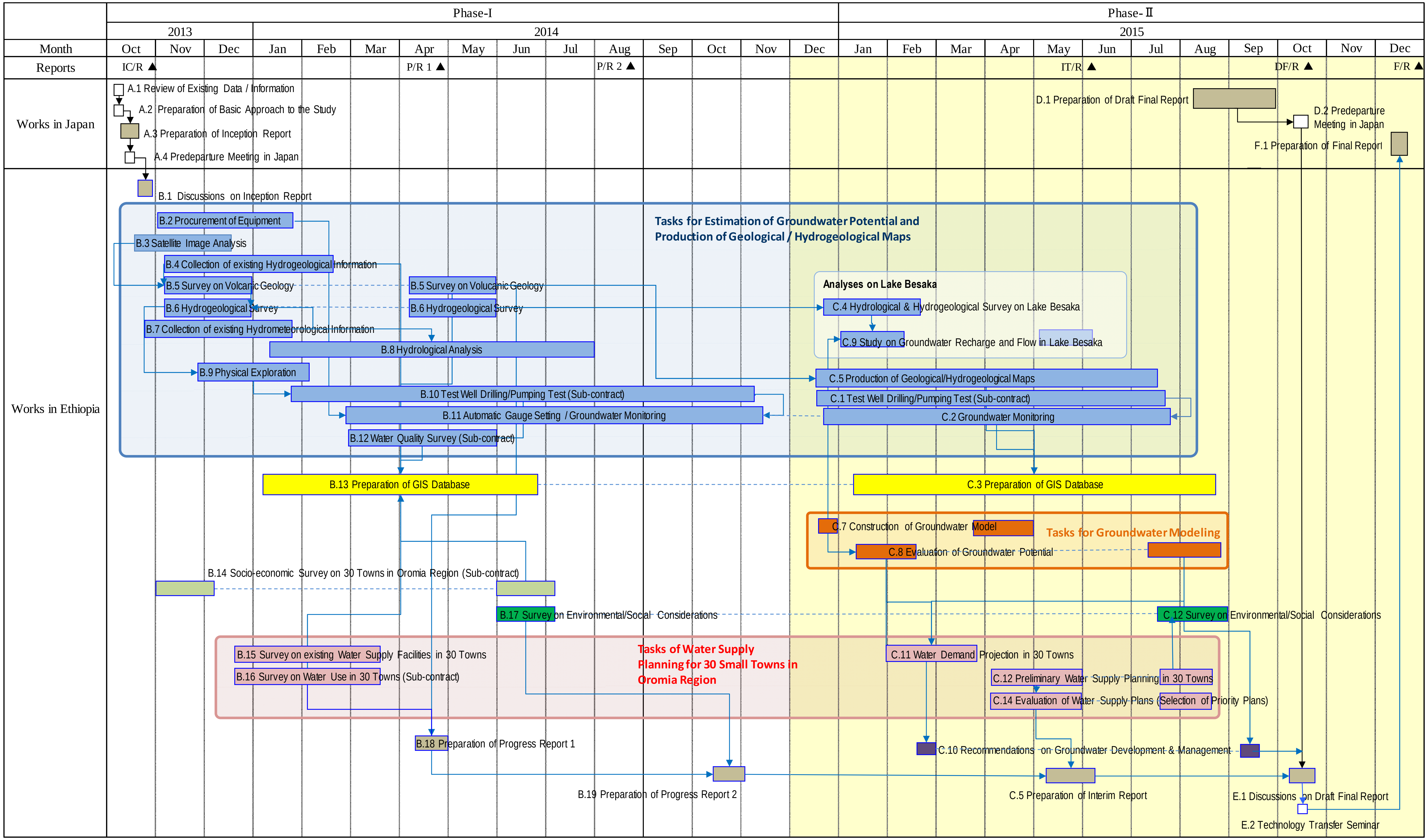
1.5 Work schedule

This Project, which commenced in October 2013, was completed in December 2015. The work plan of the Project is shown in Figure 1.5.1 and Figure 1.5.2 below:



Source: the Project Team, Data: JICA Instruction Document

Figure 1.5.1: Outline of the Project Schedule



Source: the Project Team, Data: JICA Instruction Document

Figure 1.5.2: Workflow of the Project

1.6 Project area and target areas

1.6.1 Project area

The Project area is the Middle Awash River Basin. Its coverage area is approx. 29,000 km^2, and the areas subject to the hydrogeological map production and the water supply planning are approx. 20,000 km^2 and 15,000 km^2, respectively. The Project area is shown in Figure 1.6.1.

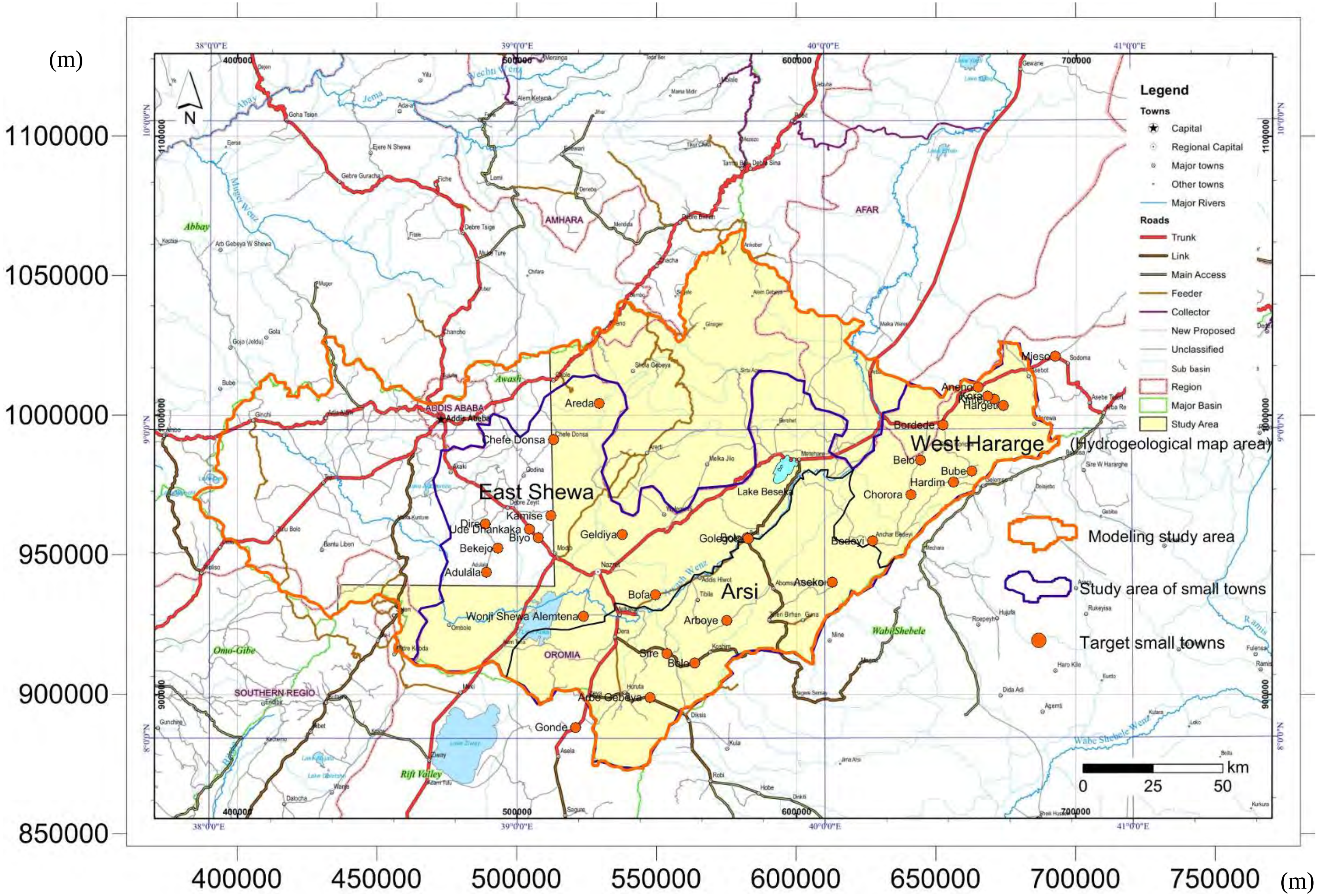
1.6.2 Target towns

Thirty (30) small towns, which are the target towns for the provisional water supply plan in the Oromia Region in the middle Awash River Basin, were selected with technical notes exchanged between the JICA Team and OWMEB. As a result of the field survey, Woredas and the small town names were confirmed. The target small towns are shown in Table 1.6.1.

Table 1.6.1: Target Small Town

Zone	Woreda	Town
East Shewa	Adama Zuriya	Wonji Shewa Alemtena Town
	Adama Zuriya	Geldiya Town
	Ada A	Dire Town
	Boset	Bofa Town
	Boset	Bole Town
	Ada A	Ude Dhankaka Town
	Ada A	Bekejo Town
	Lume	Kamise Town
	Gimbichu	Chefe Donsa Town
	Gimbichu	Areda Town
	Lume	Biyo Town
	Liben Chikuala	Adulala Town
Arsi	Sire	Sire Town
	Jeju	Bolo Town
	Jeju	Arboye Town
	Aseko	Aseko Town
	Merti	Golegota Town
	Tiyo	Gonde Town
	Lodehetosa	Arbe Gebeya Town
West Hararge	Anchar	Chorora Town
	Anchar	Bedeyi Town
	Guba Qoricha	Hardim Town
	Guba Qoricha	Bube
	Mieso	Mieso Town
	Mieso	Hargeti
	Mieso	Bordede Town
	Mieso	Kinteri
	Mieso	Aneno
	Mieso	Belo
	Mieso	Kora

Source: the Project Team, Data: OWMEB



Source: the Project Team, Data: OWMEB

Figure 1.6.1: Project Area

1.7 Project team and persons involved

1.7.1 Project team

The members of the Team are listed in Table 1.7.1 below.

Table 1.7.1: JICA Project Team

Position or Speciality	Name
Team Leader / Groundwater Resources Development and Management	Toshiyuki MATSUMOTO
Deputy Team Leader / Hydrometeorology/Project Evaluation	Kensuke SAKAI
Hydrogeology / Water Quality Analysis	Hisayuki UKISHIMA
Small Town Water Supply Scheme Development / Water Use Planning / O&M Planning	Satoshi ISHIDA
Groundwater Modelling	Peifeng LEI
Volcanic Geology	Masahiko IKEMOTO
Geophysical Exploration	Mitsuyoshi SAITO
Test Well Drilling	Masatoshi TANAKA
GIS/Database	Yoshimizu GONAI
Environmental & Social Consideration	Shingo ARAI
Socio-economic Analysis	Yosuke YAMAMOTO
Coordinator / Hydrometeorology	Makoto TOKUDA

Source: the Project Team, Data: JICA Instruction Document

1.7.2 Persons of the Ethiopian side involved

The main relevant organizations of the Ethiopian side are: the responsible agency, MoWIE and the implementation agency, GD in MoWIE. In particular, the State Minister is the Chairperson of the steering committee of the Project, and the director of GD is the Project director. And each C/P of GD is assigned to coordinate with the Project closely, and the Ethiopian Water Technology Institute (hereinafter referred to as "EWTI") members are also C/P personnel who are assigned to prepare the geophysical survey equipment and technical support. The steering committee members and C/P personnel of the Project are shown in Table 1.7.2 and Table 1.7.3, respectively.

Table 1.7.2: List of Steering Committee Members

Name	Position	Organization	Remarks
Ato. Kebede Gerba	State Minister	MoWIE	Chair Person
Ato. Tesfaye Tadesse	GD Director	MoWIE	C/P
Ato. Zebene Lakew		MoWIE	C/P
Ato. Hundie Melka	Chief Geologist	Geological Survey of Ethiopia (GSE)	Member
Ato.Muhuddin Abdela		GSE	Member
Ato. Demissie Alamirew		GSE	Member
Ato. Fekadu Lebecha		OWMEB	C/P
Prof.Tenalem Ayenew		Addis Ababa University (AAU)	Member
Mr. Itsuro Takahashi		JICA Ethiopia Office	Member
JICA Project Team members		JICA Project Team	Member

Source: the Project Team, Data: MoWIE、GSE, OWMEB、AAU、JICA Ethiopia office

Table 1.7.3: List of C/P Personnel

Name	Position	Organization	Remarks
Ato. Tesfaye Tadesse	GD Director	MoWIE	Project Director, SCM
Ato. Zebene Lakew		MoWIE	Project Coordinator, SCM
Ato. Ketema W/agegnehu		MoWIE	
Ato. Fekadu Lebecha		OWMEB	SCM
Ato. Tamiru Fekadu	Course Coordinator	EWTI	

Source: the Project Team, Data: MoWIE、OWMEB、EWTI

Chapter 2

Natural and Socio-Economic Conditions in the Middle Awash River Basin

2 Natural and Socio-Economic Conditions in the Middle Awash River Basin

2.1 Introduction

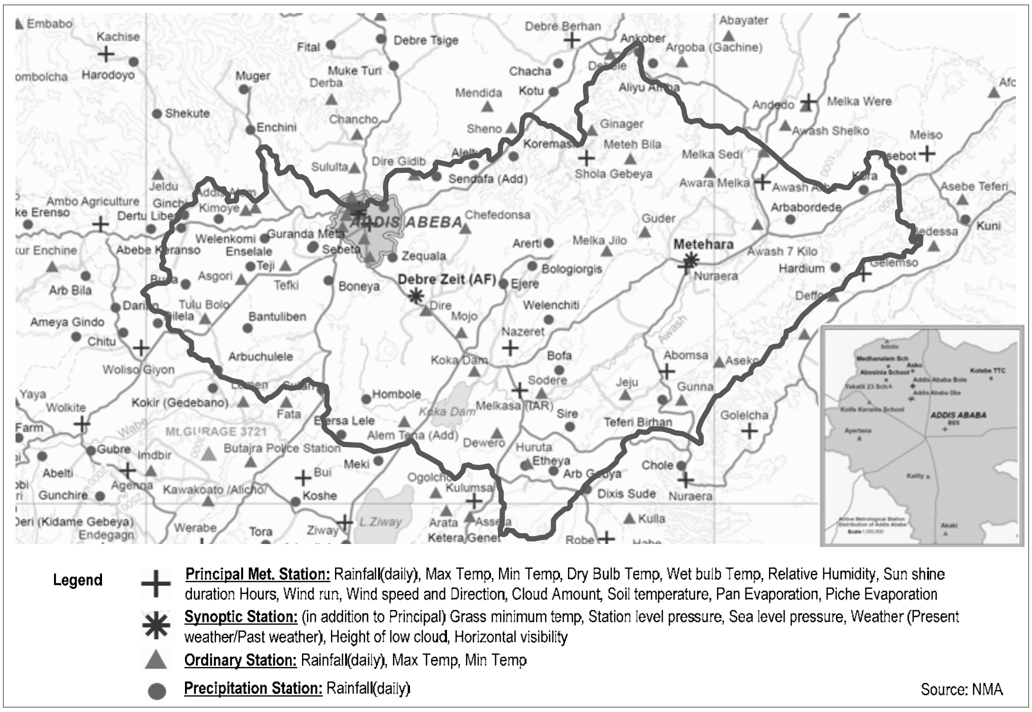
This chapter describes the general condition concerning the national and social situations in the study area. It is bounded by the limits of $38^0$00' – $40^0$00' east longitude and $8^0$00' – $9^0$30' north latitude, and its coverage area is approx. 29,000 km^2. The Adama, the provincial capital of Oromia Region, is located about 80 km southeast of the capital Addis Ababa. The area is topographically characterized by a depression zone with steep marginal faults along its edges and high land partly. The study area is a basin within the middle Awash River area called the middle Awash River Basin (which lies within the independent Awash River Basin). The middle Awash River Basin consists of three Regions (the area of each region is: Oromia 55%, Afar 25% and Amhara 20%) with a population of about 6.5 million (including 2.7 million in Addis Ababa) as of 2007. The main industries are agriculture, manufacturing, and services in middle Awash Basin.

2.2 Natural conditions

2.2.1 Meteorology and Hydrology

a. Review of meteorology data

Meteorological stations in Ethiopia are managed by the National Meteorological Agency (hereafter referred to as "NMA"). Location map of the NMA's meteorological stations in and around the Middle Awash River Basin is shown in Figure 2.2.1.



Source: NMA

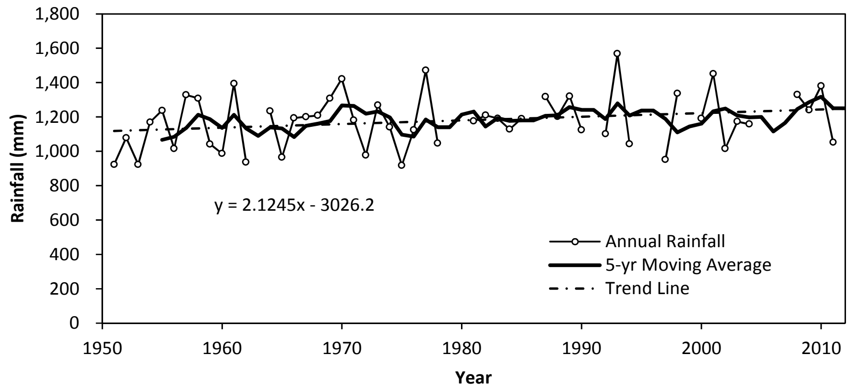
Figure 2.2.1: Meteorological Stations in and around the Middle Awash River Basin

Meteorological data collected from NMA were analyzed as described in the following subsections.

a.1 Rainfall

a.1.1 Long-term tendency of annual point rainfall

The historical trends of annual rainfall at Addis Ababa is analyzed as shown in Figure 2.2.2.



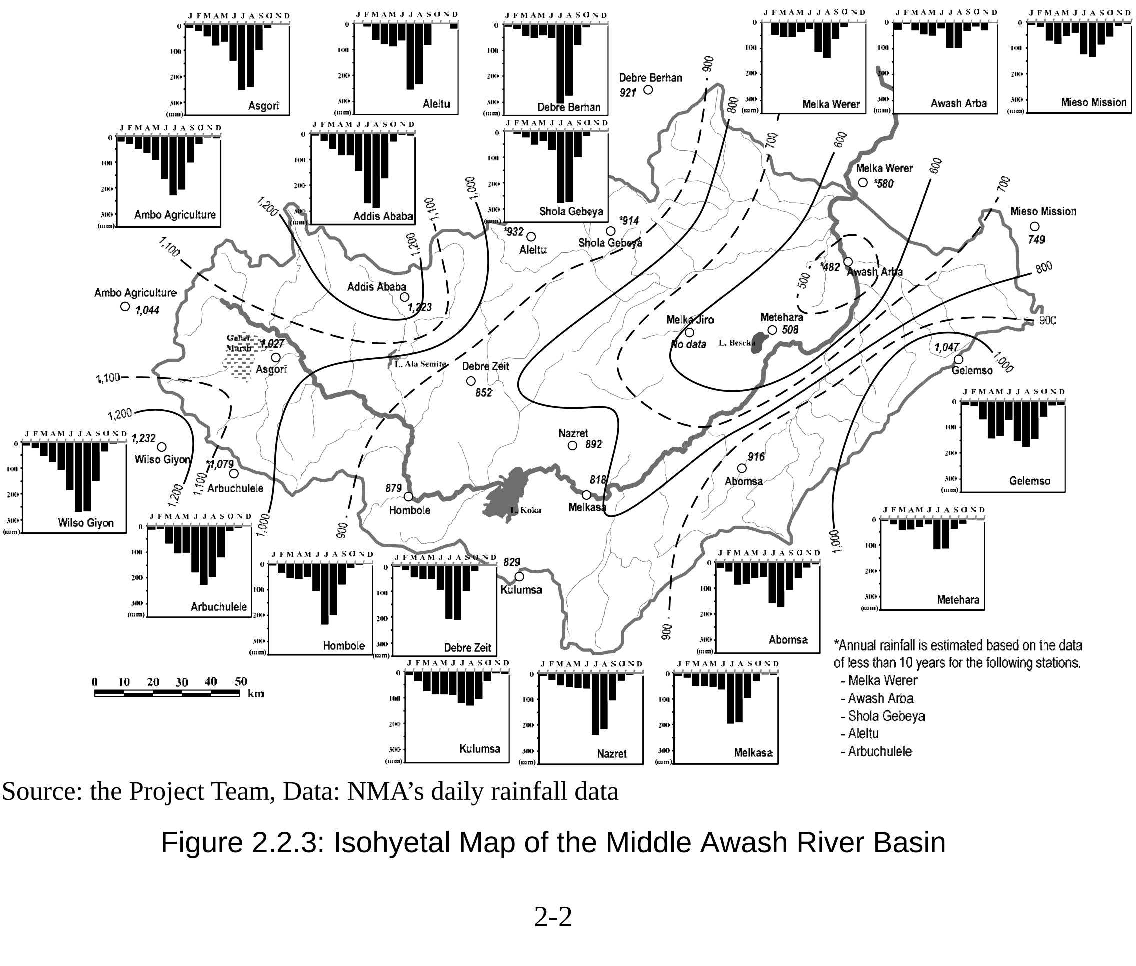
Source: the Project Team, Data: NMA's daily rainfall data

Figure 2.2.2: Historical Trend of Annual Rainfall at Addis Ababa (1951–2011)

Slight upward trend is observed at Addis Ababa. However, a downward trend is observed at another station. Therefore, no significant tendency in annual rainfall in the Middle Awash River Basin is indicated.

a.1.2 Spatial rainfall distribution

Isohyetal map of the Middle Awash River Basin is generated as shown in Figure 2.2.3.



Source: the Project Team, Data: NMA's daily rainfall data

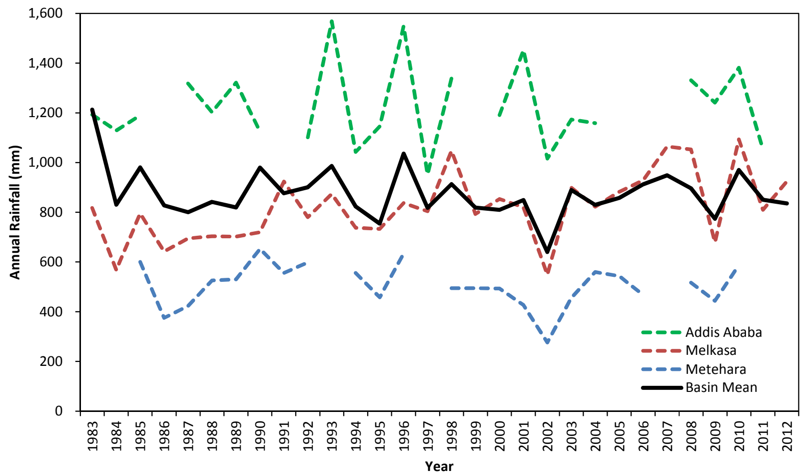
Figure 2.2.3: Isohyetal Map of the Middle Awash River Basin

The annual rainfall is larger in the northwestern (i.e., upstream) part of the basin. The areas with low annual rainfall are found in the downstream. Annual rainfall in the western and northwestern areas reaches more than 1,000 mm. The annual rainfall in the middle reaches of the Middle Awash around Lake Koka is 800–900 mm. Rainfall of 500 mm or less is observed in the downstream of the Middle Awash from Metehara.

According to Figure 2.2.3, prominent peaks of monthly rainfall can be seen in July and August. Small rainfall peaks are found in March and April in many observatories. The Middle Awash River Basin is located in the climate area characterized by three distinct seasons: Bega (dry season; October–January), Bleg (small rainy season; February–May), and Kiremt (main rainy season; June–September).

a.1.3 Basin mean rainfall over the Middle Awash River Basin

The annual mean rainfall over the Middle Awash River Basin was calculated by the Thiessen method. Historical trend of the annual mean rainfall over the Middle Awash River Basin for current 30 years (1983–2012) is depicted in Figure 2.2.4 together with the annual rainfall data at three representative rainfall stations, i.e., Addis Ababa, Melkasa, and Metehara, for upstream, middle-reaches, and downstream areas, respectively.



Source: the Project Team, Data: NMA's daily rainfall data

Figure 2.2.4: Historical Trend of Annual Rainfall in the Middle Awash River Basin

The average annual mean rainfall at the Middle Awash River Basin for the period of 1983–2012 is 876 mm, while the average annual point rainfall at Addis Ababa, Melkasa, and Metehara is 1,283 mm, 818 mm, and 508 mm, respectively.

a.2 Evaporation

Monthly evaporation amounts are estimated on the basis of the daily evaporation data through averaging the total evaporation for the months without missing data. For example, in an observatory, if the complete data for the month of January is available in 1998, 2000, and 2005, the monthly mean evaporation at this observatory is estimated as the simple average of the total evaporation in January for those 3 years.

The estimated monthly mean evaporation at the 11 observatories are shown in Table 2.2.1.

Table 2.2.1: Monthly Mean Evaporation at 11 Observatories

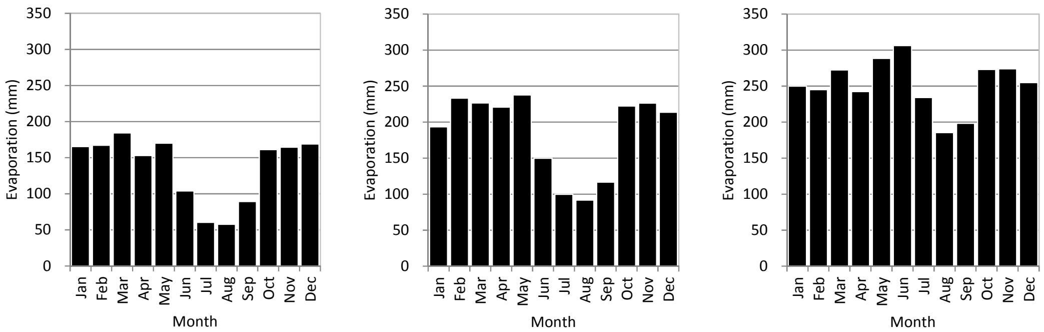
Unit: mm

	Abomsa	Addis Ababa	Ambo Agriculture	Debre Zeit	Debre Berhan	Gelemso	Kulumsa	Metehara	Mieso Mission	Shola Gebeya	Woliso Giyon
Elevation (m amsl)	1,630	2,386	2,068	1,900	2,750	1,739	2,211	944	1,332	2,500	2,058
Jan	190	165	217	193	153	244	200	250	204	152	260
Feb	203	167	229	233	173	288	195	245	215	202	290
Mar	226	184	229	227	163	242	207	272	222	192	259
Apr	232	153	195	221	147	180	192	242	222	194	245
May	303	170	185	238	193	150	197	288	289	253	177
Jun	298	104	83	150	163	139	147	306	309	174	80
Jul	224	61	50	100	68	131	115	234	267	78	51
Aug	163	58	47	92	56	116	96	185	222	64	51
Sep	144	89	62	117	85	108	93	198	176	104	76
Oct	184	161	161	222	127	162	203	273	242	159	178
Nov	205	165	193	226	143	237	217	274	228	164	265
Dec	210	169	216	214	151	244	207	255	197	160	306
Total	2,585	1,646	1,867	2,232	1,622	2,240	2,069	3,023	2,794	1,895	2,239

Note: Locations of the above observatories are shown in Figure 2.2.3.

Source: the Project Team, Data: NMA's daily evaporation data

The annual evaporation varies between 1,622 mm at Debre Berhan (outside the Awash but adjoining) and 3,023 mm at Metehara. Monthly evaporation at three observatories, i.e., Addis Ababa (EL 2,386 m), Debre Zeit (EL 1,900 m), and Metehara (EL 944 m), is graphically shown in Figure 2.2.5.



Addis Ababa Debre Zeit Metehara

Source: the Project Team, Data: NMA's daily evaporation data

Figure 2.2.5: Monthly Evaporation at Three Observatories

Evaporation shows its minimal value in the main rainy season, July to September. There is no dominant peak of monthly evaporation and the amount is constantly high during dry and minor rainy seasons.

a.3 Temperature

Maximum and minimum temperatures and relative humidity in and around the Middle Awash River Basin is summarized in Table 2.2.2 and Figure 2.2.6.

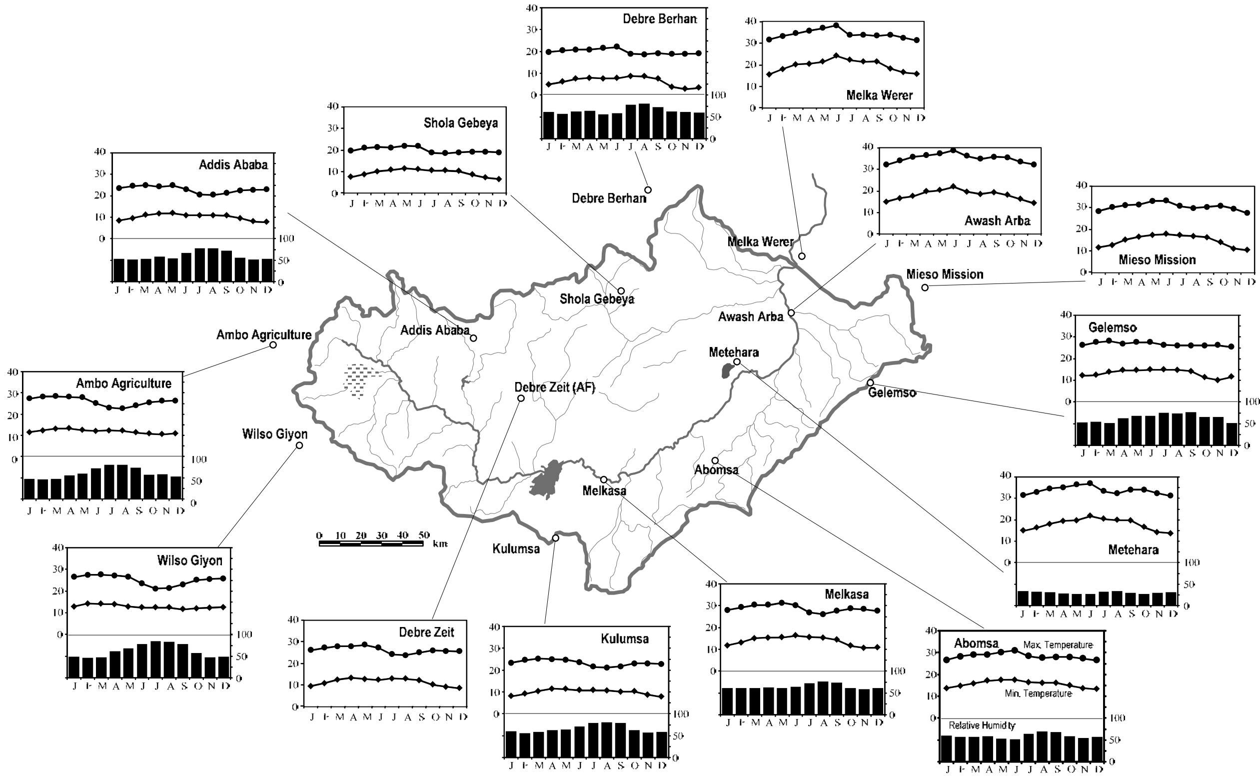
Table 2.2.2: Temperature, Relative Humidity, and Sunshine Hours at Several Stations in and around the Middle Awash River Basin

Station	Elevation (m a.m.s.l)	Max. Temperature (°C)	Min. Temperature (°C)	Annual Mean Temperature (°C)	Annual Mean Relative Humidity (%)	Annual Mean Sunshine Hours (hours/day)
Abomsa	1,630	31.0 (Jun.)	13.2 (Dec.)	21.9	59.3	7.5

Station	Elevation (m a.m.s.l)	Max. Temperature (°C)	Min. Temperature (°C)	Annual Mean Temperature (°C)	Annual Mean Relative Humidity (%)	Annual Mean Sunshine Hours (hours/day)
Addis Ababa Obs	2,386	24.9 (Mar.)	7.7 (Dec.)	16.5	60.4	6.6
Ambo Agriculture	2,068	28.4 (Mar.)	10.5 (Nov.)	18.9	61.2	6.4
Awash Arba	780	38.9 (Jun.)	14.3 (Dec.)	26.8	-	-
Debre Berhan	2,750	22.0 (Jun.)	2.8 (Nov.)	13.1	64.7	-
Debre Zeit	1,900	28.6 (May)	8.6 (Dec.)	18.9	-	-
Gelemso	1,739	28.1 (Mar.)	10.0 (Nov.)	20.0	64.0	6.7
Kulumsa	2,211	25.2 (Mar.)	7.8 (Dec.)	16.6	65.8	7.0
Melka Werer	740	38.1 (Jun.)	15.3 (Jan.)	26.7	-	-
Melkasa	1,540	31.2 (May)	10.6 (Nov.)	21.2	64.8	8.4
Metehara	944	36.9 (Jun.)	13.6 (Dec.)	25.8	30.4	8.5
Mieso Mission	1,332	33.3 (Jun.)	10.5 (Dec.)	22.7	-	-
Shola Gebeya	2,500	22.0 (May)	6.5 (Dec.)	14.7	-	-
Wilso Giyon	2,058	27.6 (Mar.)	11.7 (Sep.)	18.9	62.3	-

-: Data is not available or has not been collected.

Source: the Project Team, Data: NMA's climatic data



Source: the Project Team, Data: NMA's climatic data

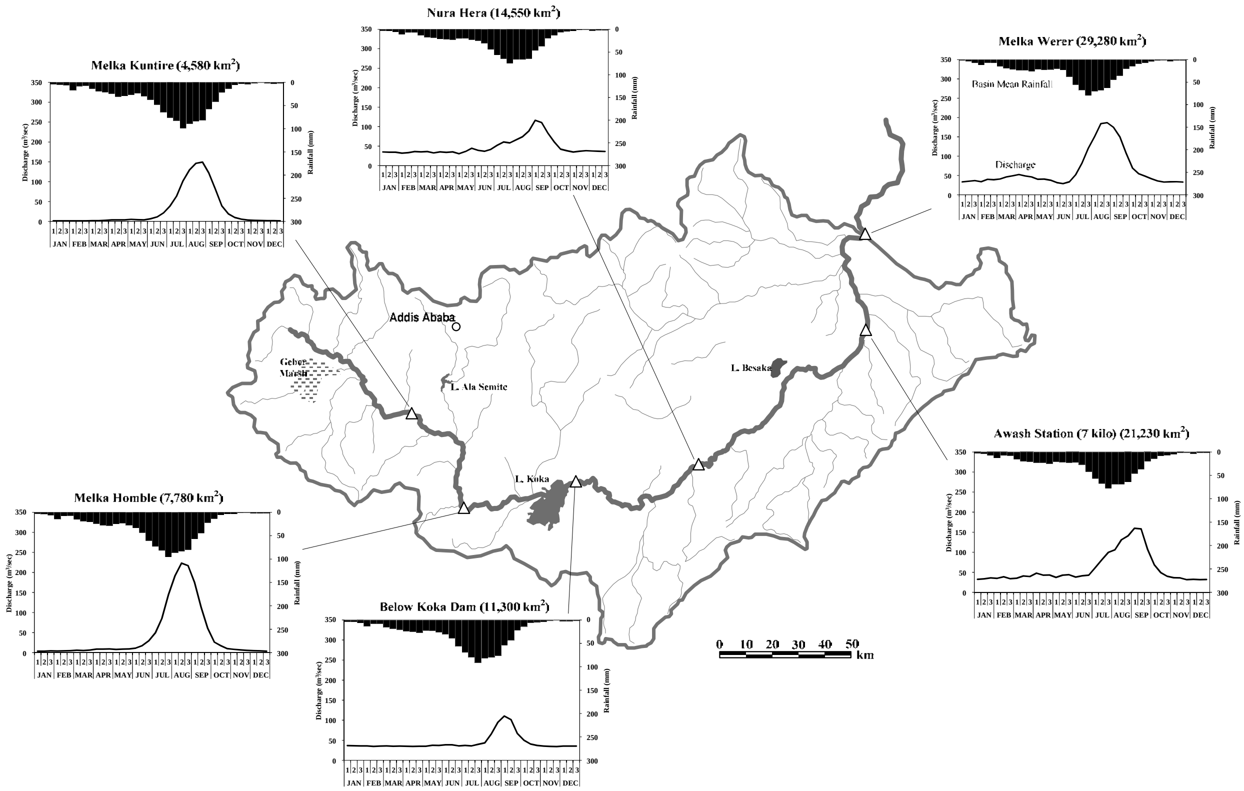
Figure 2.2.6: Monthly Temperature and Relative Humidity at Several Stations in and around the Middle Awash River Basin

Maximum temperature is observed in the late small rainy season or in the beginning of the main rainy season, i.e., from May to June, at every observatory. In the main rainy season, although the maximum temperature reduces, the minimum temperature is higher. The fluctuation of temperature is, therefore, small in the main rainy season. The maximum temperature reaches more than 36 °C at the stations of downstream regions such as Awash Arba, Melka Werer, and Metehara. The temperature drops less than 10 °C in the high lands such as Addis Ababa, Debre Zeit, Kulumsa, and Shola Gebeya.

In terms of relative humidity, the peak is observed in the main rainy season and annual mean value ranges 60–65% except for the points in dry regions such as Metehara, where annual mean relative humidity is only 30%.

b. Review of hydrological data

Mean 10-day runoff at several water level gauging stations on the Middle Awash is calculated based on the daily discharge data from 1980 to 2009 and presented in Figure 2.2.7 and Table 2.2.3 below:



Source: the Project Team, Data: MoWIE's hydrologic data and NMA's rainfall data

Figure 2.2.7: Mean 10-day Runoff Hydrograph at Major Stations on the Middle Awash

Table 2.2.3: Mean 10-day Runoff at Major Stations on the Middle Awash

			Melka Kuntire	Melka Homble	Below Koka Dam	Nura Hera	Awash Sta.	Melka Werer
Catchment (km^2)			4,580	7,780	11,300	14,550	21,230	29,280
Discharge (m^3/sec)	Jan	1	1.5	3.7	36.7	34.9	32.2	33.4
		2	1.6	3.9	36.3	34.4	33.6	35.2
		3	1.4	4.3	36.0	34.3	35.7	36.7
	Feb	1	1.4	4.0	36.1	31.9	34.9	33.9
		2	1.4	4.2	34.7	33.1	38.7	40.0
		3	1.4	4.7	35.4	36.2	33.7	39.1
	Mar	1	1.8	6.0	35.8	35.3	35.3	40.8
		2	2.0	5.1	34.9	36.1	40.8	46.2
		3	2.6	6.2	35.6	32.4	39.3	49.2
	Apr	1	4.0	8.9	35.1	35.2	47.8	52.4
		2	3.7	8.8	34.6	34.0	42.9	48.9
		3	4.0	9.1	35.1	35.1	43.1	46.3
	May	1	5.3	8.0	35.0	30.3	37.2	40.2
		2	4.1	8.9	37.7	36.0	42.6	40.8
		3	4.0	9.0	37.0	44.6	43.8	37.8

			Melka Kuntire	Melka Homble	Below Koka Dam	Nura Hera	Awash Sta.	Melka Werer
	Jun	1	6.9	11.4	38.7	39.2	38.1	31.6
		2	11.2	17.5	38.7	36.8	41.2	28.9
		3	21.7	29.6	36.2	41.6	42.6	33.7
	Jul	1	38.6	49.3	37.1	52.2	61.5	51.9
		2	63.5	85.7	36.2	60.6	81.0	81.9
		3	102.0	144.8	39.9	58.0	99.6	120.5
	Aug	1	129.8	191.7	43.6	66.3	106.1	150.7
		2	146.2	**223.2**	65.2	73.9	131.0	184.3
		3	**149.4**	216.9	94.7	88.9	140.8	**186.8**
	Sep	1	121.5	175.1	**110.2**	**116.2**	**159.7**	174.8
		2	80.9	113.2	101.6	110.8	158.2	150.5
		3	39.2	61.0	66.8	83.6	107.4	108.2
	Oct	1	19.0	26.4	49.9	60.6	69.2	69.6
		2	10.0	17.5	40.6	42.3	49.2	54.5
		3	5.8	9.9	36.9	38.0	40.0	48.2
	Nov	1	3.5	8.3	35.6	34.8	36.4	41.6
		2	2.7	6.6	34.7	36.6	35.8	36.0
		3	2.2	5.8	34.2	38.3	31.4	33.0
	Dec	1	1.9	4.9	35.5	37.5	32.3	33.6
		2	1.8	4.3	35.5	36.8	31.4	33.9
		3	1.6	3.9	35.7	36.4	31.8	33.0
Ann. Mean (m^3/sec)			27.8	41.7	44.0	47.6	58.5	64.1
Height (mm/yr)			191	169	123	103	87	69

Source: the Project Team, Data: MoWIE's hydrologic data

According to the information above:

- Peak runoffs are observed during the period from the middle of August to the beginning of September while peak of rainfall is observed in July and August;
- The Lake Koka releases constant discharge of approximately 35 m^3/sec in dry season;

Annual runoff height at Melka Werer, the downstream end of the Middle Awash, is 69 mm, and this is less than 8% of the annual basin mean rainfall of 876 mm (1983 – 2012).

c. Hydrological analysis

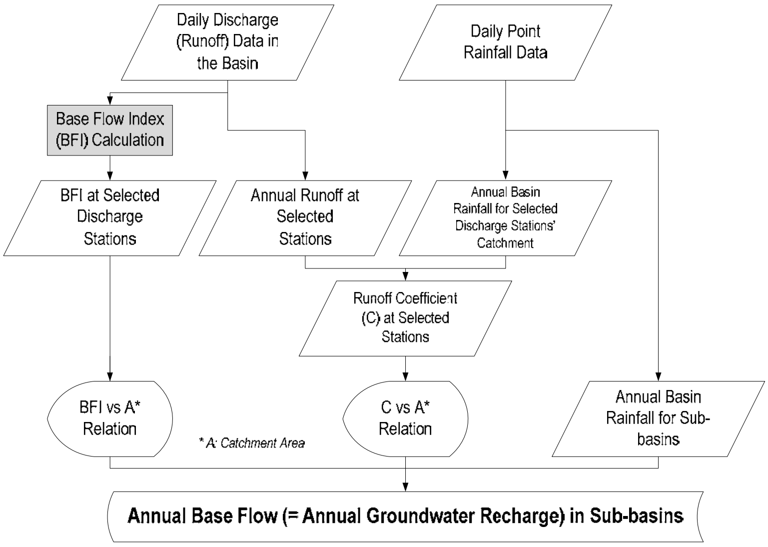
c.1 Introduction

c.1.1 Purpose of the hydrological analysis

One of the main purposes of the hydrological analysis in this Project is to evaluate the available groundwater resources in the Middle Awash River Basin and formulate a groundwater development plan based on the evaluation. The hydrological analysis is to estimate annual groundwater recharge in the Middle Awash River Basin. In this section, groundwater recharge, which is equivalent to available groundwater resources, is estimated using general relationship between river runoff and groundwater recharge, and other relevant data/information.

c.1.2 Procedure

The analysis is undertaken through the procedure shown in Figure 2.2.8.



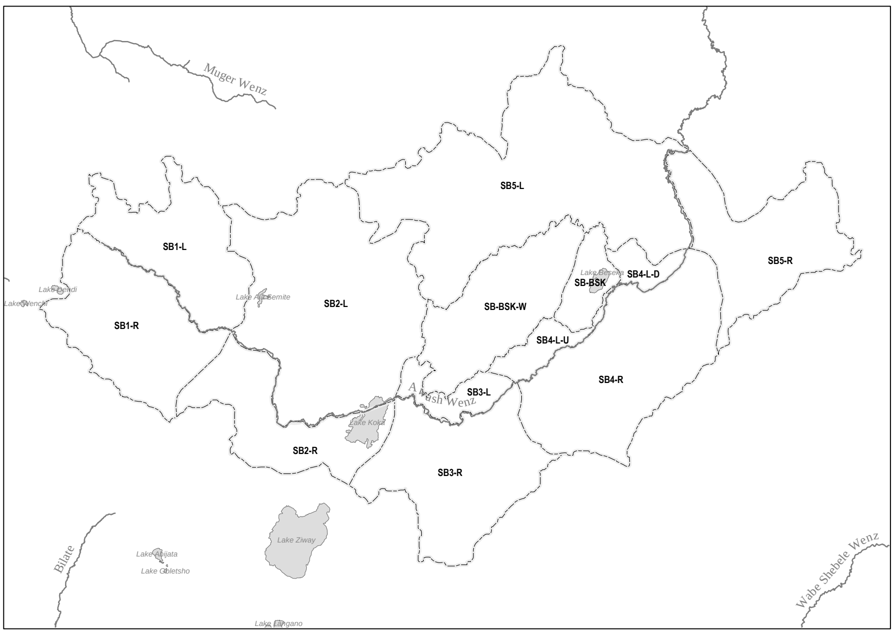
Source: the Project Team, Data: Result of hydrology survey in this Project

Figure 2.2.8: Procedure of the Hydrological Analysis

First, river flow at selected discharge stations in the Middle Awash River Basin is analyzed to obtain base flow amount (or index), which is considered to be equivalent to groundwater recharge. The relationship between base flow amount and catchment area is then analyzed. Second, total river runoff at the selected discharge stations is compared with the stations' basin mean rainfall amount to analyze the relationship between runoff coefficient and catchment area. Further, the groundwater recharge in the sub-basins is estimated by applying the relationships analyzed above.

c.1.3 Sub-basins

The Middle Awash River Basin is divided into 13 sub-basins as shown in Figure 2.2.9.



Source: the Project Team, Data: Result of hydrology survey in this Project

Figure 2.2.9: Basin Division for Groundwater Recharge Estimation

Outlines of the sub-basins are tabulated below. The catchment areas of sub-basins vary from 310 km^2 to 5,710 km^2:

Table 2.2.4: Summary of Sub-basins

No	Name	Outlet	Area [km^2]	Description
1	SB1-L	Awash	2,068	Catchment of the left bank side of the Awash upstream “Melka Kuntire” SFGS (stream flow gauging station).
2	SB1-R	Awash	2,508	Catchment of the right bank side of the Awash upstream “Melka Kuntire” SFGS.
3	SB2-L	Awash	4,860	Catchment of the left bank side of the Awash between “Below Koka Dam” and “Melka Kuntire” SFGSs
4	SB2-R	Awash	1,859	Catchment of the right bank side of the Awash between “Below Koka Dam” and “Melka Kuntire” SFGSs
5	SB3-L	Awash	508	Catchment of the left bank side of the Awash between “Nura Hera” and “Below Koka Dam” SFGSs
6	SB3-R	Awash	2,743	Catchment of the right bank side of the Awash between “Nura Hera” and “Below Koka Dam” SFGSs
7	SB4-L-U	Awash	435	Catchment of the left bank side of the Awash between the bridge on the Awash at the entrance of Metehara Sugar Plantation and “Nura Hera” SFGS
8	SB4-L-D	Awash	312	Catchment of the left bank side of the Awash between “Awash Station” SFGS and the bridge on the Awash at the entrance of Metehara Sugar Plantation
9	SB4-R	Awash	3,367	Catchment of the right bank side of the Awash between “Awash Station” and “Nura Hera” SFGSs
10	SB5-L	Awash	5,710	Catchment of the left bank side of the Awash between “Melka Werer” and “Awash Station” SFGSs
11	SB5-R	Awash	2,347	Catchment of the right bank side of the Awash between “Melka Werer” and “Awash Station” SFGSs
12	SB-BSK-W	Depression (no outlet is confirmed topographically)	2,041	Catchment in the western side of the Lake Beseka Catchment
13	SB-BSK	Lake Beseka, Awash (through a Drainage Channel)	532	Catchment of the Lake Beseka
Total			29,289	

Source: the Project Team, Data: Result of hydrology survey in this Project

c.2 River flow analysis

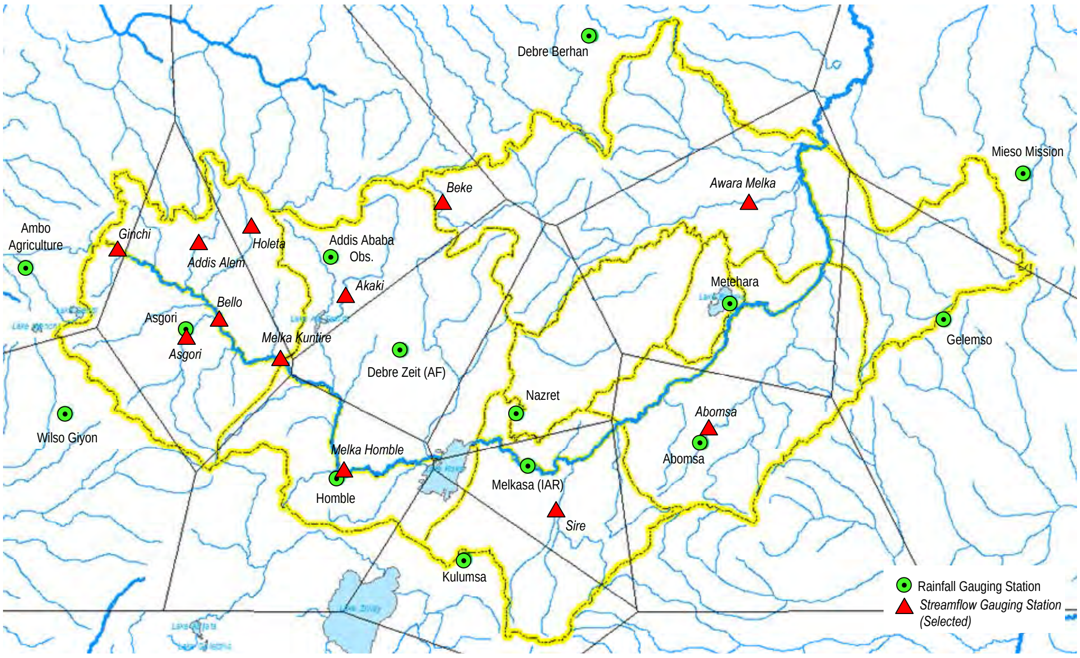
c.2.1 Separation of river flow components (BFI calculation)

The ratio of the groundwater component in a river flow is defined as base flow index (hereafter referred to as “BFI”). Many methods have been developed and used to separate the groundwater (base flow) component and direct runoff component from daily river flow data. However, the result will naturally differ depending on the method employed. In this analysis, two methods (programs) were selected since both are considered to be reliable. They are “PART” (United States Geological Survey: USGS, 2007)[1] and “BFI” (United States Bureau of Reclamation: USBR, 2013)[2].

c.2.2 Selection of streamflow gauging stations for BFI calculation

As hydrological stations subject to BFI calculation, following 12 stations are selected:

[1] http://water.usgs.gov/ogw/part/
[2] http://www.usbr.gov/pmts/hydraulics_lab/twahl/bfi/



Source: the Project Team, Data: Result of hydrology survey in this Project

Figure 2.2.10: Location Map of Selected Stations for BFI Calculation

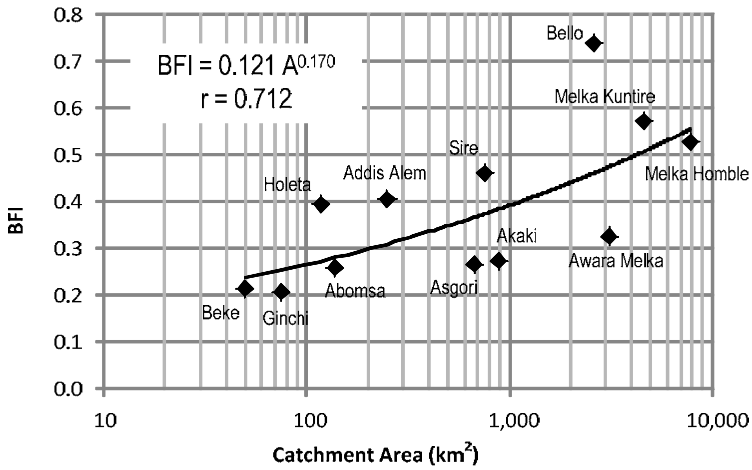
Table 2.2.5: Selected Stations for BFI Calculation

Station Name	River Name	Area (km^2)	Number of Years	Period
Abomsa	Arba	140	5	1995–1999
Addis Alem	Berga	248	18	1984, 1989–1991, 1993–2002, 2004–2007
Akaki	Akaki	884	14	1983–1984, 1986–1992, 2000–2004
Awara Melka	Kesem	3,113	20	1983–1984, 1986–2000, 2003–2004, 2006
Asgori	Teji	663	11	1983–1985, 1987–1991, 1996, 2001, 2007
Beke	Kesem	50	14	1986, 1988–1989, 1993, 1995–1997, 1999–2003, 2005–2006
Bello	Awash	2,569	11	1987–1990, 1992, 1994, 1996–1997, 2000, 2004, 2008
Ginchi	Awash	76	12	1994–1995, 1997, 1999–2007
Holeta	Holeta	119	16	1988, 1991, 1994–2002, 2004–2008
Melka Homble	Awash	7,780	27	1983–2009
Melka Kuntire	Awash	4,580	24	1983–1984, 1986–2005, 2007–2008
Sire	Keleta	747	13	1983–1984, 1985, 1987–1988, 1990–1993, 1995, 1997, 1999–2000

Source: the Project Team, Data: Result of hydrology survey in this Project

c.2.3 Selection of streamflow gauging stations for BFI calculation

The minimum (smaller) BFI value calculated by “PART” and “BFI” programs is considered as the BFI at a gauging station from the conservative view. Figure 2.2.11 shows the calculated BFIs plotted with the catchment area on the x-axis.



Source: the Project Team, Data: Result of hydrology survey in this Project

Figure 2.2.11: Relationship between Catchment Area and BFI Values

The graph shows high correlation (r > 0.70) between catchment area and BFI. According to the figure, the larger the catchment area, the larger is the BFI.

c.3 Water balance analysis

c.3.1 Runoff coefficient at selected 12 gauging stations

BFI is the percentage of base flow to the total river runoff. Therefore, the groundwater recharge amount can be quantitatively estimated if the river runoff amount is available.

Runoff coefficient at 12 stations is calculated as the percentage of annual river runoff to annual basin mean rainfall. Annual river runoff can be obtained from the daily discharge record. Annual basin mean rainfall is estimated on the basis of the point rainfall data by applying the Thiessen method (see Figure 2.2.10 for the Thiessen polygons).

Calculated mean annual rainfall and runoff are shown in Table 2.2.6.

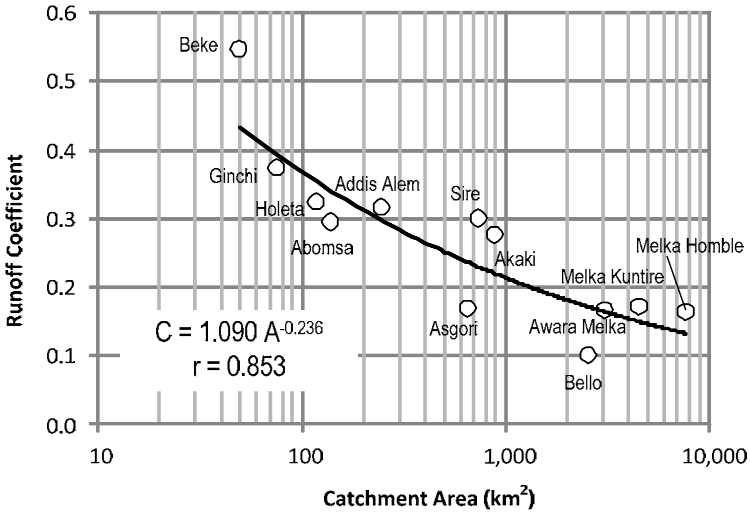
Table 2.2.6: Mean Annual Runoff and Rainfall for Selected Stations

Station Name	River Name	Area (km^2)	Runoff (mm/yr)	Rainfall (mm/yr)	Runoff Coefficient	Period
Abomsa	Arba	140	301	1,018	0.295	1995–1999
Addis Alem	Berga	248	357	1,136	0.315	1984, 1989–1991, 1993–2002, 2004–2007
Akaki	Akaki	884	331	1,198	0.276	1983–1984, 1986–1992, 2000–2004
Awara Melka	Kesem	3,113	135	824	0.164	1983–1984, 1986–2000, 2003–2004, 2006
Asgori	Teji	663	189	1,115	0.169	1983–1985, 1987–1991, 1996, 2001, 2007
Beke	Kesem	50	682	1,249	0.546	1986, 1988–1989, 1993, 1995–1997, 1999–2003, 2005–2006
Bello	Awash	2,569	111	1,098	0.101	1987–1990, 1992, 1994, 1996–1997, 2000, 2004, 2008
Ginchi	Awash	76	364	979	0.372	1994–1995, 1997, 1999–2007
Holeta	Holeta	119	393	1,220	0.322	1988, 1991, 1994–2002, 2004–2008
Melka Homble	Awash	7,780	172	1,066	0.162	1983–2009
Melka Kuntire	Awash	4,580	188	1,103	0.171	1983–1984, 1986–2005, 2007–2008

Station Name	River Name	Area (km^2)	Runoff (mm/yr)	Rainfall (mm/yr)	Runoff Coefficient	Period
Sire	Keleta	747	242	806	0.300	1983–1984, 1985, 1987–1988, 1990–1993, 1995, 1997, 1999–2000

Source: the Project Team, Data: Result of hydrology survey in this Project

In general, the larger the catchment area, the smaller is the runoff coefficient. This can be said for the Middle Awash River Basin. The relationship between catchment area and runoff coefficient is depicted in Figure 2.2.12.



Source: the Project Team, Data: Result of hydrology survey in this Project

Figure 2.2.12: Relationship between Catchment Area and Runoff Coefficient

c.3.2 Annual Groundwater Recharge in the Selected 12 Gauging Station's Catchments

Based on the above, annual groundwater recharge (hereafter referred to as "GWR") can be expressed as follows:

$$GWR = R \cdot C \cdot BFI$$

where, *GWR*: Annual groundwater recharge (mm/year)
R: Annual basin mean rainfall (mm/year)
C: Runoff coefficient (-)
BFI: Base flow index (-)

The annual groundwater recharge at selected 12 gauging stations' catchments is estimated as shown in Table 2.2.7.

Table 2.2.7: Annual Groundwater Recharge in 12 Station's Catchments

Station Name	River Name	Area [km^2]	Rainfall (R) [mm/yr]	Runoff Coefficient (C)	Base Flow Index (BFI)	Groundwater Recharge (GWR) [mm/yr]	GWR/R
Abomsa	Arba	140	1,018	0.295	0.26	77	7.6%
Addis Alem	Berga	248	1,136	0.315	0.40	144	12.7%
Akaki	Akaki	884	1,198	0.276	0.28	91	7.6%
Awara Melka	Kesem	3,113	824	0.164	0.33	44	5.4%
Asgori	Teji	663	1,115	0.169	0.27	50	4.5%

Station Name	River Name	Area [km^2]	Rainfall (R) [mm/yr]	Runoff Coefficient (C)	Base Flow Index (BFI)	Groundwater Recharge (GWR) [mm/yr]	GWR/R
Beke	Kesem	50	1,249	0.546	0.21	145	11.6%
Bello	Awash	2,569	1,098	0.101	0.74	82	7.4%
Ginchi	Awash	76	979	0.372	0.21	76	7.8%
Holeta	Holeta	119	1,220	0.322	0.39	154	12.6%
Melka Homble	Awash	7,780	1,066	0.162	0.52	90	8.5%
Melka Kuntire	Awash	4,580	1,103	0.171	0.57	108	9.8%
Sire	Keleta	747	806	0.300	0.46	111	13.8%

Source: the Project Team, Data: Result of hydrology survey in this Project

c.4 Water balance analysis

The annual groundwater recharge in the divided 13 sub-basins (see Figure 2.2.9 and Table 2.2.4) is estimated in the same procedure as that in 12 stations' catchments. In this estimation, both BFI and runoff coefficient (C) are assumed to be the function of catchment area as shown below (see Figure 2.2.11 and Figure 2.2.12 also):

$$GWR = R \cdot C \cdot BFI$$
$$BFI = 0.121A^{0.170}$$
$$C = 1.090A^{-0.236}$$

where, *GWR*: Annual groundwater recharge (mm/year)
R: Annual basin mean rainfall (mm/year)
C: Runoff coefficient (-)
BFI: Base flow index (-)
A: Catchment area (km^2)

The annual rainfall over sub-basins is calculated on the basis of the point rainfall data by applying the Thiessen polygon method (see Figure 2.2.10 for the Thiessen polygons).

Then, annual basin mean rainfall is multiplied by the runoff coefficient and BFI, which are estimated using the equations stated above. The annual groundwater recharge is estimated as in Table 2.2.8.

Table 2.2.8: Result of Groundwater Recharge Estimation by Sub-basins

SL No.	Sub-basin	Area (A) [km^2]	Annual Rainfall (R) [mm/yr]	Runoff Coefficient (C) [-]	Base Flow Index (BFI) [-]	Annual Groundwater Recharge (GWR)		GWR/R [%]
						[mm/yr]	[10^6 m^3/yr]	
1	SB1-L	2,068	1,097	0.18	0.44	87.2	180.3	7.9%
2	SB1-R	2,508	1,075	0.17	0.46	84.4	211.6	7.8%
3	SB2-L	4,860	982	0.15	0.51	73.7	358.4	7.5%
4	SB2-R	1,859	867	0.18	0.43	69.4	129.0	8.0%
5	SB3-L	508	853	0.25	0.35	74.4	37.8	8.7%
6	SB3-R	2,743	832	0.17	0.46	64.9	178.1	7.8%
7	SB4-L-U	435	824	0.26	0.34	72.5	31.6	8.8%
8	SB4-L-D	312	548	0.28	0.32	49.3	15.4	9.0%
9	SB4-R	3,367	806	0.16	0.48	62.0	208.8	7.7%
10	SB5-L	5,710	779	0.14	0.53	57.9	330.8	7.4%
11	SB5-R	2,347	870	0.17	0.45	68.6	161.0	7.9%
12	SB-BSK-W	2,041	740	0.18	0.44	58.9	120.2	8.0%
13	SB-BSK	532	548	0.25	0.35	47.6	25.3	8.7%
All Basin		29,290	876	-	-	67.9	1,988.3	7.7%

Source: the Project Team, Data: Result of hydrology survey in this Project

The estimated groundwater recharge ranges between 47 mm/year and 87 mm/year and is equivalent to 7.4%–9.0% of the annual rainfall.

The water balance in each sub-basin is estimated as in Table 2.2.9 by assuming that all losses are incorporated in the form of evapotranspiration.

Table 2.2.9: Water Balance in Sub-basins

SL. No.	Sub-basin	Area (A) [km^2]	Incoming	Outgoing		
			Annual Rainfall (R) [mm/yr]	Direct Runoff [mm/yr]	Base Flow (Groundwater Recharge) [mm/yr]	Evapotranspiration [mm/yr]
1	SB1-L	2,068	1,097	110	87	900
2	SB1-R	2,508	1,075	100	84	891
3	SB2-L	4,860	982	71	74	837
4	SB2-R	1,859	867	90	69	707
5	SB3-L	508	853	139	74	639
6	SB3-R	2,743	832	75	65	692
7	SB4-L-U	435	824	141	73	610
8	SB4-L-D	312	548	105	49	394
9	SB4-R	3,367	806	67	62	677
10	SB5-L	5,710	779	52	58	669
11	SB5-R	2,347	870	83	69	719
12	SB-BSK-W	2,041	740	75	59	607
13	SB-BSK	532	548	88	48	412
All Basin		29,290	876	78	68	730

Source: the Project Team, Data: Result of hydrology survey in this Project

2.2.2 Location, access and physiography

a. Location and access

The study area is located about 180 km east of the capital Addis Ababa. It is bounded by the limits of $38^0$00’ – $40^0$00’ east longitude and $8^0$00’ – $9^0$30’ north latitude. The area is topographically characterized by the depression zone with steep marginal faults along its edges. The study area is an independent basin, therefore it is called middle Awash River Basin.

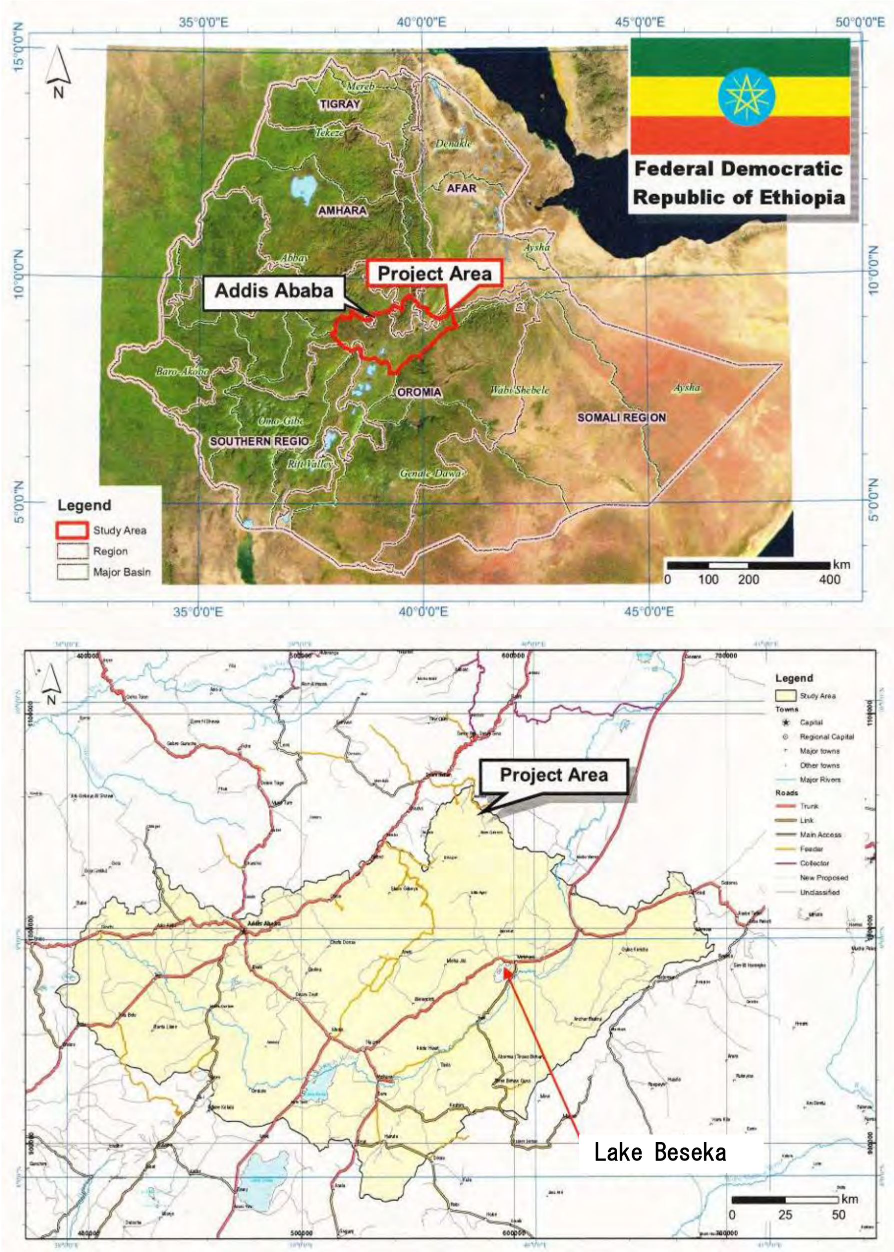


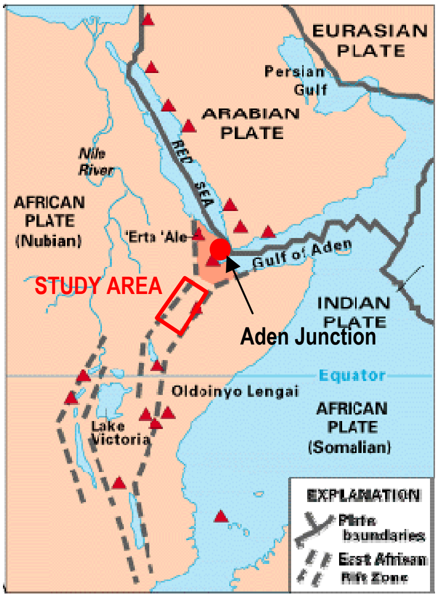
Figure 2.2.13: Location of the Study Area

b. Physiography

The study area belongs to African Rift. The African Rift originates from the Aden Junction (see Figure 2.2.14) and continues in the direction of SW- SSW traverse longitudinally through the eastern African countries such as Djibouti, Eritrea, Ethiopia, Kenya, Uganda, and Tanzania.

Generally the valley is characterized by the geological occurrence of active faults, active volcanoes and hot springs, which indicates it is a geothermal area. Geophysical and petrological data show that lithosphere is thinning by intrusion of hot mantle below the valley.

The valley is considered to be a separation boundary of the African Plate. The eastern plate is called the Somalian Plate and the western is the Nubian Plate. The two plates are separating at a speed of 5 mm/year (Stamps et. al, 2008).



Source: http://people.dbq.edu/faculty/deasley/Essays/EastAfricanRift.html

Figure 2.2.14: Distribution of African Rift Valley

2.2.3 Geology

a. Outline

a.1 Adama town, Mt. Boseti and its surrounding areas

Adama town–Mt. Boseti and its surrounding areas are located in the central MER. The rift floor is widely covered by Pleistocene to Holocene volcanic deposits. The lowest unit, named Alaji basalts, is observed at the scarps of the eastern margin and the NE-SW trending faults. Alaji basalts is distributed widely in the survey area and has a chronological age of 24-23Ma according to Chernet et. al, 1998, 14.4Ma according to Kuntz et al., 1975, 28-15Ma according to Morbideli et al., 1975, and 21.06±1.5Ma, 14.94±1.5Ma, 17.4±1.-0Ma according to Kazumin, et al., 1978. Chefeco rhyolites and Pliocene rhyolites overlie Alaji basalts and have formed hilly topography. Nazret pyroclastic deposits are mainly observed at the scarps of the rift margin. Chilalo trachybasalts is observed at the northern foot of Mt. Chilalo. Bofa basalts from Late Pliocene to Pleistocene is well observed at the area, and has a chronological age of 1.21Ma by Kazmin et.al, 1978, and 6.1-4.4 Ma by Morton et al., 1979. Pleistocene, Dino ignimbrite, Quaternary rhyolites, Chefe Donsa pyroclastic deposits and Pleistocene basalts are widely observed on the rift floor. In the Late Pleistocene period, pumice fall from Mt. Boseti, and Fentale ignimbrite are widely distributed on the rift floor and fault scarps. In Holocene, rift floor basalts from volcanic activities in the eastern side of Mt. Boseti.

a.2 Kone – Mt. Fentale and its surrounding areas

Kone-Mt. Fentale and its surrounding areas are located in the central MER. The basin floor is widely covered by volcanic deposits from the Pleistocene to Holocene periods. WFB (Wonji Fault Belt) is well developed on the floor and margin of the MER in the area. Therefore, Pliocene – Pleistocene strata are generally observed at the scarps of these faults. The lowest unit, named Birenti-Hada rhyolites, is observed at the foot of Mount Bosena. Bofa basalts overlies Birenti-Hada rhyolites at the southern foot of Mt. Bosena, and is widely observed at a gentle slope at the lava plateau. Dino ignimbrite is observed at the northern foot of Kone caldera, the western foot of Mt. Fentale, and is widely distributed at the flat plain of the southeastern plateau. Dino ignimbrite has a chronological age of 1.5 Ma according to Mobidelli et. al, 1975, and 1.51 Ma according to Kazmin, et al, 1978. Tuff ring, Pleistocene basalts, Kone ignimbrite, Kone pumice fall, Fentale volcanic rocks and Fentale ignimbrite are observed in the surroundings of Kone caldera and Mt. Fentale. In Holocene, rift floor basalts and recent obsidian flows from volcanic activity are observed in the southwest of Lake Besaka.

A more detailed geological survey was carried out around Lake Besaka. The details are described in Chapter 3.

a.3 Mojo town – Ararti town – Debre Birhan town and its surrounding areas

Mojo town-Ararti town, Debre Birhan town and its surrounding areas are located in the central Ethiopian plateau and the central MER. The plateau area is mainly covered by Miocene volcanic deposits and the basin floor is widely covered by Pleistocene deposits. The lowest unit, named Kesem basalts, is observed at the Kesem River. In Debre Birhan, ignimbrite, which consists of ignimbrite and conglomerated stone that is cemented by white ash, overlies Kesem basalts and is widely observed at the northern plateau of the Kesem River. Tarmaber-Megezeze basalts forms a high mountain range, and has a chronological age of 13 Ma according to Zanettin, et al, 1974, and 10.4 Ma according to Chernet et al, 1998. In Pliocene, Bokan rhyolites, Nazret pyroclastic deposits, and Tulu Rie basalts are observed on the basin floor. Nazret pyroclastic deposits are widely observed at the southern flat plain of the Kesem River. Tulu Rie basalts, contrasted as a part of the Bofa Basalt, is observed at the surrounding Mojo area, and has a chronological age of 2.7±0.1 Ma according to INGEIS-Buenos Aires, and 1.44±0.03 Ma according to Chernet et. al, 1998. In Pleistocene, Dino ignimbrite, Chefe Donsa pyroclastic deposits, Zkikala trachyte, Maar deposits, Boseti Pumice Fall, and Fentale ignimbrite are observed at the basin floor.

a.4 Awash town – Asebe Teferi town and its surrounding areas

Awash town-Asebe Teferi town and its surrounding areas are located in the central MER. The basin floor is widely covered by Holocene deposits. WFB is well developed on the floor and margin of the MER in the area. Therefore Pliocene – Pleistocene strata are generally observed at the scarps of these faults. The lowest unit, named Alaji basalts, is observed at the southern mountain chain. Huse Ridge rhyolites and Anchar basalts overlie Alaji basalts, and are observed at the southern mountain chain with a NE-SW trend. Anchar basalts has a chronological age of 12.4 Ma, according to Kazmin et.al, 1978. Gara Gumbi rhyolites is observed on the basin floor of the remaining hills. Also, Adele rhyolitic tuffs and Bofa basalts are widely observed at the basin floor. In Pleistocene, Dino ignimbrite, Dofan basalts, Asebot welded tuff, Awash acidic volcano-sedimentary rocks and Fentale ignimbrite are widely distributed on the basin floor.

Stratigraphy in each area are shown in Table 2.2.10, Table 2.2.11, Table 2.2.12 and Table 2.2.13, and correlation chart of each stratigraphy is shown in Table 2.2.14.

In addition, location map of each outcrop number mentioned in this chapter is shown in Figure 2.2.15.

Table 2.2.10: Stratigraphy in Adama Town-Mt. Boseti

Age			Stratigraphy	Major Lithology		Age
Cainozoic	Quarternary	Holocene	Qal	Alluvium	sand, clay, lucstrin	
Cainozoic	Quarternary	Holocene	Qr2	Recent rhyolitic domes & lava flows	rhyolitic domes with obsidian lava flows	
Cainozoic	Quarternary	Holocene	Qb2	Recent basalts	glassy basalt	
Cainozoic	Quarternary	Holocene	Qb2	Recent basalts	aphyric basalt and scoria cone	
Cainozoic	Quarternary	Pleistocene	Qi3	Fantale ignimbrite	pare green strongly welded tuff with fiamme	168,000±38,000 y (OWWDSE ,2013)
Cainozoic	Quarternary	Pleistocene	Qp2	Boseti pumice falls	pumice fall (Mt. Boseti)	
Cainozoic	Quarternary	Pleistocene	Qb1	Pleistocene basalts	aphyric basalt	
Cainozoic	Quarternary	Pleistocene	Qp1	Chefe Donsa pyroclastic deposits	Pumice and tuff with intercalated with poorly welded tuff	Chefe Donsa pyroclastic deposits : 1.71±0.04 Ma(Morrton et al.,1979), 2.24±0.3 Ma(IGGI-Pisa)
Cainozoic	Quarternary	Pleistocene	Qr1	Pleistocene rhyolites	rhyolite	
Cainozoic	Quarternary	Pleistocene	Qi1	Dino ignimbrite	Greenish grey welded tuff with fiamme	Dino : 1.5my (Mobidelli et al., 1975), 1.51 Ma (Kazmun, et al.,1978)
Cainozoic	Tertiary	Pliocene	Tb3	Bofa basalts	aphyric basalt	Tulu Rie basalt: 2.7±0.1 Ma(INGEIS-Buenos Aires), 1.44±0.03 Ma(Chernet et al., 1998) Bofa : 1.21 Ma (Kazumin, et al., 1978), 6.1-4.4 Ma(Morton et al.,1979)
Cainozoic	Tertiary	Pliocene	Tt	Chilalo Trachybasalts	Trachytes and Trachybasalts	
Cainozoic	Tertiary	Pliocene	Ti3	Nazret pyroclastic deposits	light to dark grey welded tuff with fiamme	Nwp : 3.5±0.1 Ma, 3.2±0.1 Ma(IGGI-Pisa), 4.7±0.7 Ma, 5.4±0.2 Ma(INGEIS-Buenos Aires), 3.32±0.06 Ma, 3.11±0.06 Ma(Morton et al., 1979)
Cainozoic	Tertiary	Pliocene	Ti2	Nazret pyroclastic deposits	pumice and tuff	
Cainozoic	Tertiary	Pliocene	Tr2	Chefeko rhyolites	rhyolite with pumiceous tuff	
Cainozoic	Tertiary	Miocene	Tb1	Alaji basalts	plagioclase phyric basalt	24-23Ma (Chernet et al., 1998), 14.4 Ma (Kuntz et al., 1975), 28-15 Ma (Morbidelli et al., 1975), 21.06±1.5 Ma, 14.94±1.5 Ma, 17.4±1.0 Ma (Kazumin, et al., 1978)

Table 2.2.11: Stratigraphy in Kone-Mt. Fentale and its Surrounding Areas

Age			Stratigraphy	Major Lithology		Age
Cainozoic	Quarternary	Holocene	Qal	Alluvium	sand, clay, lucstrin	
Cainozoic	Quarternary	Holocene	Qr2	Recent rhyolitic dome & lava flows	rhyolitic domes with obsidian lava flows	
Cainozoic	Quarternary	Holocene	Qb2	Holocene basalts	aphyric basalt and scoria cone	
Cainozoic	Quarternary	Pleistocene	Qi3	Fantale ignimbrite	pare green strongly welded tuff with fiamme	168,000±38,000 y (OWWDSE ,2013)
Cainozoic	Quarternary	Pleistocene	Qf	Fanrale volcanic rocks	greenish grey welded tuff, tuff, trachyte	
Cainozoic	Quarternary	Pleistocene	Qp2	Kone pumice falls	pumice fall , tuff	
Cainozoic	Quarternary	Pleistocene	Qi2	Kone ignimbrite	greenish consolidated to welded fine tuff	
Cainozoic	Quarternary	Pleistocene	Qb1	Pleistocene basalts	aphyric basalt	
Cainozoic	Quarternary	Pleistocene	Qs	Sobebor volcanic sand beds	sand, tuff, alternation	
Cainozoic	Quarternary	Pleistocene	Qi1	Dino ignimbrite	Greenish grey welded tuff with fiamme	Dino : 1.5my (Mobidelli et al., 1975), 1.51 Ma (Kazmun, et al.,1978)
Cainozoic	Tertiary	Pliocene	Tb3	Bofa basalts	aphyric basalt	Tulu Rie basalt: 2.7±0.1 Ma(INGEIS-Buenos Aires), 1.44±0.03 Ma(Chernet et al., 1998) Bofa : 1.21 Ma (Kazumin, et al., 1978), 6.1-4.4 Ma(Morton et al.,1979)
Cainozoic	Tertiary	Pliocene	Tr2	Birenti-Hada rhyolites	rhyolite with pumiceous tuff	

Table 2.2.12: Stratigraphy in Mojo Town-Arerti Town-Debre Birhan Town and Surrounding Areas

Age			Stratigraphy	Major Lithology		Age
Cainozoic	Quarternary	Holocene	Qal	Alluvium	sand, clay, lucstrin	
Cainozoic	Quarternary	Pleistocene	Qi3	Fantale ignimbrite	pare green strongly welded tuff with fiamme	168,000±38,000 y (OWWDSE ,2013)
Cainozoic	Quarternary	Pleistocene	Qp2	Boseti pumice falls	pumice fall and ash	
Cainozoic	Quarternary	Pleistocene	Qb1	Pleistocene basalts	aphyric basalt	Zikwala olivine basalt : 0.61±0.03Ma (Morton et.al.,1979)
Cainozoic	Quarternary	Pleistocene	Qs	Maar deposits	sand, tuff, alternation	
Cainozoic	Quarternary	Pleistocene	Qt	Zikwala Trachytes	dark gray, porphyritic trachytes with intercalation of pyroclastic material	0.85±0.05Ma, 0.92±0.04Ma, 1.28±0.15Ma (Morton et al.,1979)
Cainozoic	Quarternary	Pleistocene	Qp1	Chefe Donsa pyroclastic deposits	Pumice and tuff with intercalated with poorly welded tuff	Chefe Donsa pyroclastic deposits : 1.71±0.04 Ma(Morrton et al.,1979), 2.24±0.3 Ma(IGGI-Pisa)
Cainozoic	Quarternary	Pleistocene	Qi1	Dino ignimbrite	Greenish grey welded tuff with fiamme	Dino : 1.5my (Mobidelli et al., 1975), 1.51 Ma (Kazmun, et al.,1978)
Cainozoic	Tertiary	Pliocene	Tb3	Tulu Rie basalts	aphyric basalt	Tulu Rie basalt: 2.7±0.1 Ma(INGEIS-Buenos Aires), 1.44±0.03 Ma(Chernet et al., 1998) Bofa : 1.21 Ma (Kazumin, et al., 1978), 6.1-4.4 Ma(Morton et al.,1979)
Cainozoic	Tertiary	Pliocene	Ti2, Ti3	Nazret pyroclastic deposits	light to dark grey welded tuff with fiamme	Nwp : 3.5±0.1 Ma, 3.2±0.1 Ma(IGGI-Pisa), 4.7±0.7 Ma, 5.4±0.2 Ma(INGEIS-Buenos Aires), 3.32±0.06 Ma, 3.11±0.06 Ma(Morton et al., 1979)
					pumice and tuff	
Cainozoic	Tertiary	Pliocene	Tr2	Bokan rhyolites	rhyolite with pumiceous tuff	
Cainozoic	Tertiary	Miocene	Tb2	Tamaber-Megezeze basalts	aphyric basalt	Anchar : 12.4 Ma (Kazumin et.al., 1978) Mt. Megezeze: 13Ma, (Zanettin et al., 1974), 10.4Ma, (Chernet et al., 1998)
Cainozoic	Tertiary	Miocene	Ti1	Debre Birhan ignimbrite	Upper Conglomerate(inc. greenish welded tuff fragments, cemented by white ash), tuff. Sand, alternation	
					greenish consolidated to welded fine tuff	
					Lower Conglomerate(inc. basalt fragments, cemented by white ash)	
Cainozoic	Tertiary	Miocene	Tb1	Kesem basalts	plagioclase phyric basalt	24-23Ma (Chernet et al., 1998), 14.4 Ma (Kuntz et al., 1975), 28-15 Ma (Morbidelli et al., 1975), 21.06±1.5 Ma, 14.94±1.5 Ma, 17.4±1.0 Ma (Kazumin, et al., 1978)
					rhyolite with pumiceous tuff (Balchi rhyolite)	

Table 2.2.13: Stratigraphy in Awash Town-Asebe Teferi Town

Age			Stratigraphy	Major Lithology		Age
Cainozoic	Quarternary	Holocene	Qal	Alluvium	sand, clay, lucstrin	
Cainozoic	Quarternary	Pleistocene	Qi3	Fantale ignimbrite	pare green strongly welded tuff with fiamme	168,000±38,000 y (OWWDSE ,2013)
Cainozoic	Quarternary	Pleistocene	Qi2	Asebot welded tuffs	yellowish brown pumiceous tuff with hornblend & plagioclase	
Cainozoic	Quarternary	Pleistocene	Qb1	Dofan basalts	dark grey porhyritic plagioclase basalt	
Cainozoic	Quarternary	Pleistocene	Qp1	Awash Arba Volcano-sedimentary rocks	Pumice and tuff with intercalated with poorly welded tuff	Chefe Donsa pyroclastic deposits : 1.71±0.04 Ma(Morrton et al.,1979), 2.24±0.3 Ma(IGGI-Pisa)
Cainozoic	Quarternary	Pleistocene	Qi1	Dino ignimbrite	Greenish grey welded tuff with fiamme	Dino : 1.5my (Mobidelli et al., 1975), 1.51 Ma (Kazmun, et al.,1978)
Cainozoic	Tertiary	Pliocene	Tb3	Bofa basalts	aphyric basalt	Tulu Rie basalt: 2.7±0.1 Ma(INGEIS-Buenos Aires), 1.44±0.03 Ma(Chernet et al., 1998) Bofa : 1.21 Ma (Kazumin, et al., 1978), 6.1-4.4 Ma(Morton et al.,1979)
Cainozoic	Tertiary	Pliocene	Ti2	Adele rhyolitic tuffs	pumice and tuff with minor welded tuff	Nwp : 3.5±0.1 Ma, 3.2±0.1 Ma(IGGI-Pisa), 4.7±0.7 Ma, 5.4±0.2 Ma(INGEIS-Buenos Aires), 3.32±0.06 Ma, 3.11 ±0.06 Ma(Morton et al., 1979)
Cainozoic	Tertiary	Pliocene	Tr2	Gara Gumbi rhyolites	rhyolite with pumiceous tuff	
Cainozoic	Tertiary	Miocene	Tb2	Anchar basalts	black fine ol-basalt	Anchar : 12.4 Ma (Kazumin et.al., 1978) Mt. Megezeze: 13Ma, (Zanettin et al., 1974), 10.4Ma, (Chernet et al., 1998)
Cainozoic	Tertiary	Miocene	Tr1	Huse Ridge rhyolites	light grey to pare pink rhyolitic fine slightly welded tuff	
Cainozoic	Tertiary	Miocene	Tb1	Alaji basalts	plagioclase phyric basalt	24-23Ma (Chernet et al., 1998), 14.4 Ma (Kuntz et al., 1975), 28-15 Ma (Morbidelli et al., 1975), 21.06±1.5 Ma, 14.94±1.5 Ma, 17.4±1.0 Ma (Kazumin, et al., 1978)

Table 2.2.14: Correlation of Stratigraphy in the Study Area

Age			Areas: Nazret-Mt.Boseti	Areas: Kone-Mt.Fantale	Areas: Mojo-Arerti-Debre Birhan	Areas: Awash-Asebe Teferi	Areas: Lake Besaka (1:100,000)	Stratigraphy of the whole study area	Age
Cainozoic	Quarternary	Holocene	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium (Qa)	**Alluvium (Qal)**	
Cainozoic	Quarternary	Holocene	Recent rhyolitic domes & lava flows	Recent rhyolitic domes & lava flows				**Recent rhyolitic domes & lava flows (Qr2)**	
Cainozoic	Quarternary	Holocene	Holocene basalts	Holocene basalts			Holocene basalts (Qb2)	**Holocene basalts (Qb2)**	
Cainozoic	Quarternary	Pleistocene basalt	Fantale ignimbrite	Fantale ignimbrite	Fantale ignimbrite	Fantale ignimbrite	Fentale ignimbrite (Qi3)	**Fentale ignimbrite (Qi3)**	168,000±38,000 y (OWWDSE ,2013)
Cainozoic	Quarternary	Pleistocene basalt		Fantale volcanic rocks			Fentale volcanic rocks (Qf)	**Fentale volcanic rocks (Qf)**	
Cainozoic	Quarternary	Pleistocene basalt	Boseti pumice falls	Kone pumice falls	Boseti pumice falls			**Boseti-Kone pumice fall deposits (Qp2)**	
Cainozoic	Quarternary	Pleistocene basalt		Kone ignimbrite		Asebot welded tuffs	Kone ignimbrite (Qi2)	**Kone ignimbrite (Qi2)**	
Cainozoic	Quarternary	Pleistocene basalt	Pleistocene basalts	Pleistocene basalts	Pleistocene basalt	Dofan basalt	Pleistocene basalts (Qb1)	**Pleistocene basalts (Qb1)**	Zikwala olivine basalt : 0.61±0.03Ma (Morton et.al.,1979)
Cainozoic	Quarternary	Pleistocene basalt		Tuff ring deposits	Maar deposits		Sobebor volcanic sand beds (Qs)	**Sobebor volcanic sand beds (Qs)**	
Cainozoic	Quarternary	Pleistocene basalt			Zikwala Trachytes			**Zikwala Trachytes (Qt)**	0.85±0.05Ma, 0.92±0.04Ma, 1.28±0.15Ma (Morton et al.,1979)
Cainozoic	Quarternary	Pleistocene basalt	Chefe Donsa pyroclastic deposits		Chefe Donsa pyroclastic deposits	Awash Arba Volcano-sedimentary rocks		**Chefe Donsa pyroclastic deposits (Qp1)**	Chefe Donsa pyroclastic deposits : 1.71±0.04 Ma(Morrton et al.,1979), 2.24±0.3 Ma(IGGI-Pisa)
Cainozoic	Quarternary	Pleistocene basalt	Pleistocene rhyolites					**Pleistocene rhyolites (Qr1)**	
Cainozoic	Quarternary	Pleistocene basalt	Dino ignimbrite	Dino ignimbrite	Dino ignimbrite	Dino ignimbrite	Dino ignimbrite (Qi1)	**Dino ignimbrite (Qi1)**	Dino ignimbrite: 1.5my (Mobidelli et al., 1975), 1.51 Ma (Kazmun, et al.,1978)
Cainozoic	Tertiary	Pliocene	Bofa basalt	Bofa basalts	Tulu Rie basalts	Bofa basalt	Nura Hira basalts (Tb)	**Bofa basalts (Tb3)**	Tulu Rie basalt: 2.7±0.1 Ma(INGEIS-Buenos Aires), 1.44±0.03 Ma(Chernet et al., 1998) Bofa : 1.21 Ma (Kazumin, et al., 1978), 6.1-4.4 Ma(Morton et al.,1979)
Cainozoic	Tertiary	Pliocene	Chilalo Trachybasalts					**Chilalo Trachybasalts (Tt)**	
Cainozoic	Tertiary	Pliocene	Nazret pyroclastic deposits: Upper		Nazret pyroclastic deposits: Upper		Old ignimbrite (Ti)	**Upper Nazret pyroclastic deposit (Ti3)**	Nwp : 3.5±0.1 Ma, 3.2±0.1 Ma(IGGI-Pisa), 4.7±0.7 Ma, 5.4±0.2 Ma(INGEIS-Buenos Aires), 3.32±0.06 Ma, 3.11±0.06 Ma(Morton et al., 1979)
Cainozoic	Tertiary	Pliocene	Nazret pyroclastic deposits: Lower		Nazret pyroclastic deposits: Lower	Adele rhyolitic tuffs		**Lower Nazret pyroclastic deposits (Ti2)**	
Cainozoic	Tertiary	Pliocene	Chefeko rhyolites	Birenti-Hada rhyolites	Mt. Bokan rhyolites	Gara Gumbi rhyolites	Birenti-Hada rhyolites (Tr)	**Pliocene rhyolites (Tr2)**	
Cainozoic	Tertiary	Miocene			Tarmaber-Megezeze basalts	Anchar basalts		**Anchar basalts (Tb2)**	Anchar : 12.4 Ma (Kazumin et.al., 1978) Mt. Megezeze: 13Ma, (Zanettin et al., 1974), 10.4Ma, (Chernet et al., 1998)
Cainozoic	Tertiary	Miocene			Debre Birhan ignimbrite			**Debre Birhan ignimbrite (Ti1)**	
Cainozoic	Tertiary	Miocene				Huse Ridge rhyolites		**Huse Ridge rhyolites (Tr1)**	
Cainozoic	Tertiary	Miocene	Alaji basalts		Kesem basalts	Alaji basalts		**Alaji basalts (Tb1)**	24-23Ma (Chernet et al., 1998), 14.4 Ma (Kuntz et al., 1975), 28-15 Ma (Morbidelli et al., 1975), 21.06±1.5 Ma, 14.94±1.5 Ma, 17.4±1.0 Ma (Kazumin, et al., 1978)

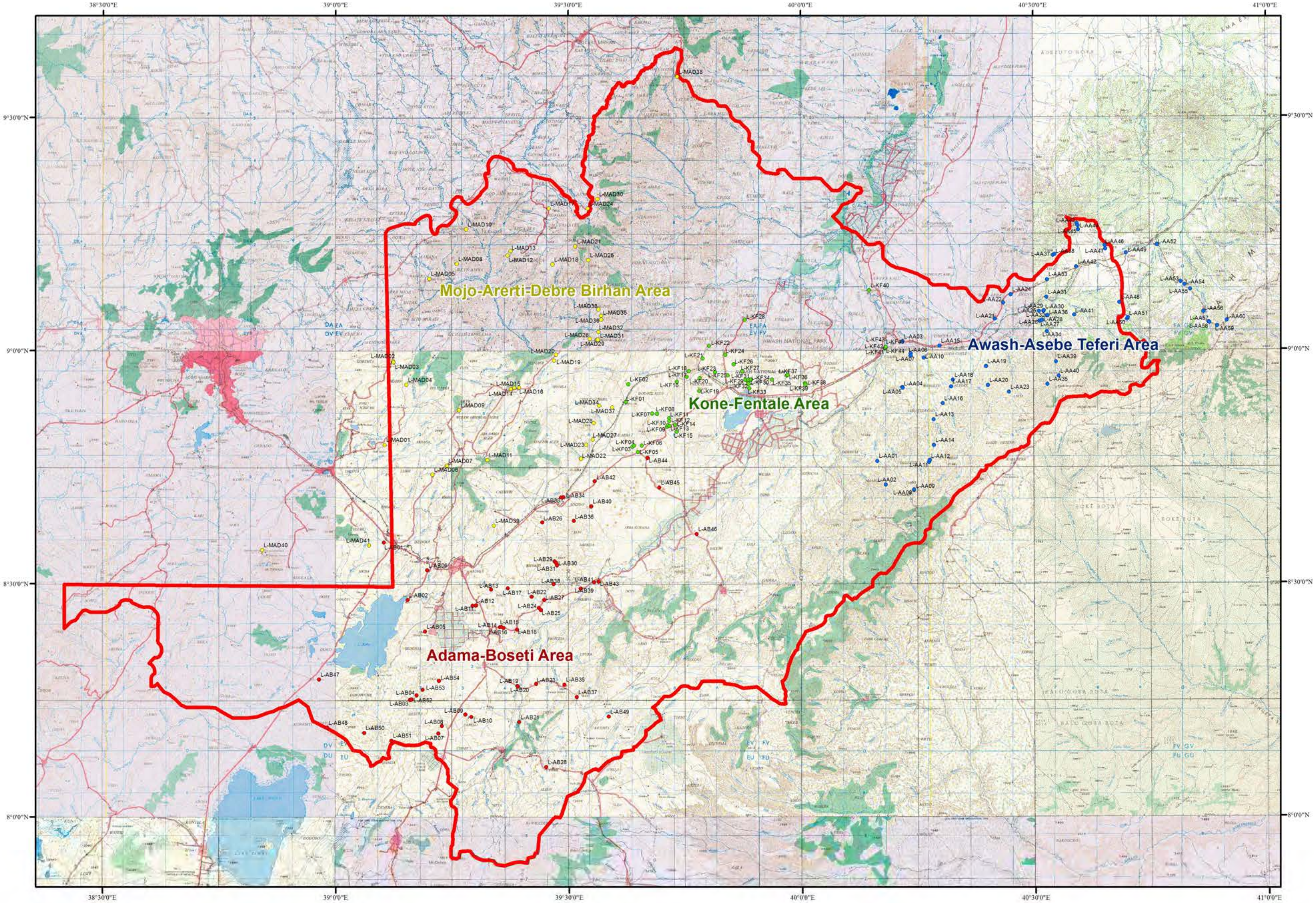


Figure 2.2.15: Location Map of Outcrops

b. Characteristics of geological units

b.1 Miocene-Pliocene

b.1.1 **Alaji Basalts**: porphyritic to aphyric basalt lavas: Tb1

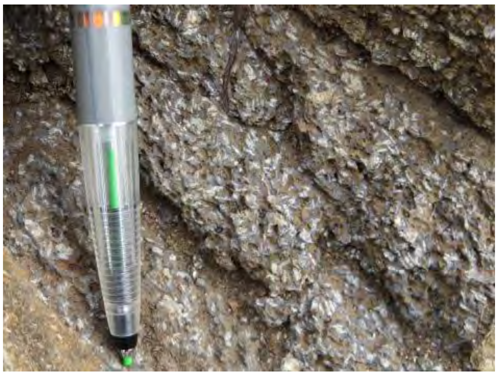
Lithology: Consists of porphyritic basalt lavas with large plagioclase and aphyric basalt lavas. At Arba Rekete (L-AA59), the unit is divided by two flow units: from the lowest, dark grey porphyritic basalt lava (more than 10 m in thickness), light gray to dark grey porphyritic plagioclase basalt lava with columnar joints (more than 10 m in thickness). At Komena (L-AA35), the unit is divided in lower porphyritic plagioclase-basalt and upper aphyric basalt. This unit is unconformably overlain by Huse ridge rhyolites at Huse ridge (L-AA53), 10 km northwest of Asebe Teferi town. At Balchi (L-MAD14), the unit is divided by three lithological facies; from the lowest, pale blue to light grey rhyolite (more than 40 m in thickness, Balchi rhyolite), light gray to pale blue tuff containing white pumice (2 m in thickness), and bluish-grey porphyritic plagioclase basalt lava (more than 20m in thickness). At Tigre Ridge in northeast Welenchiti town (L-MAD22), the unit is divided by three lithological facies; from the lowest, reddish-brown tuff breccia (more than 2m in thickness), black fine plagioclase-basalt lava with columnar joint (17m in thickness), and black massive fine basalt (17m in thickness).This unit is overlain by the lower conglomerate of Debre Birhan ignimbrite along the Arerti town – Kesem river route (L-MAD29).

Distribution: Around Arba Rekete town, Huse ridge in northwest of Asebe Teferi town, and around Cheleleka town. Western cliff of Sire town, Hula near Arboye town, and Kelefa river near Huruta town. Widely distributed in the Kesem river basin, around Balchi town, NE-SW direction cliff of western Melka Jilo town.

Thickness: More than 20m at Arba Rekete, 5km southwest of Asebe Teferi town (L-AA59). More than 30m at Kelefa river (L-AB21). More than 62m at Balchi (L-MAD14). More than 200m along the Kesem valley.


Dark grey porphyritic to plagioclase phyric basalt. Kelefa River (L-AB21)


The unit is divided into two flow units, dark grey porphyritic basalt lava and light gray to dark grey porphyritic plagioclase basalt lava. Arba Rekete (L-AA59)



Plagioclase-basalt. Komena (L-AA35)

Plagioclase-basalt. Cheleleka (L-AA09)

Bluish-grey porphyritic to plagioclase phyric basalt. Balchi (L-MAD14)

Balchi rhyolite which is distributed at the lowest part. Balchi（L-MAD15）

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.16: Outcrop Photos of Alaji Basalts

b.1.2 Huse Ridge Rhyolites: Rhyolite, rhyolitic tuff: Tr1

Lithology: Consists mainly of white to bluish-grey, rarely pale pink rhyolite and tuff. The unit is unconformably overlain by Anchar basalts at the query of Asebe Teferi town (L-AA55). At Huse Ridge (L-AA53), the unit forms NE-SW ridge (more than 50 m high).

Distribution: Beka town to NE-SW distribution at Huse Ridge in 10km southeast of Mieso town.

Thickness: More than 50m at Huse Ridge, 10km southeast of Mieso town (L-AA53)

Rhyolitic Tuff at Huse Ridge (L-AA53)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.17: Outcrop Photos of Huse Ridge Rhyolites

b.1.3 Debre Birhan Ignimbrite: ignimbrite, conglomerates, and tuff: Ti1

This unit is divided by three lithological facies; the lower part consists of conglomerate, alternation of sands, tuff and minor pumice (lower conglomerate), the widely distributed middle part consists of consolidated to highly welded finer to medium tuff and unwelded to slightly welded pumiceous tuff (ignimbrite) and the upper part consists of conglomerate included pebble of Debre Birhan ignimbrite, alternation of sands, tuff and minor pumices (upper conglomerate). The lower conglomerate is distributed only in the Arerti town – Kesem river route.

Lithology: Consists of greenish-blue to light green consolidated to welded fine to medium tuff. At Aroge Minjar (L-MAD29), the unit is unconformably overlain by Nazret pyroclastic deposits, and is unconformably overlain by Tarmaber-Megezeze basalts at Balchi (L-MAD14).

Distribution: Widely distributed in the plains surrounding the Kesem river and the Kebena river, form the flat plain along Sendefa town to Seno town route.

Thickness: More than 25m at Kosfe (L-MAD33, L-MAD35) for ignimbrite layers. More than 8m of the lower conglomerate, and more than 7.5m of the upper conglomerate at Aroge Minjar, along the Arerti town – Kesem river route (L-MAD29).


The unit unconformably overlies Kesem basalts
Aroge Minjar (L-MAD29)


The unit is unconformably overlain by
Tarmaber-Megezez basalt. Balchi (L-MAD14)


The unit is unconformably overlain by
Tarmaber-Megezez basalt. Gobemsa (L-MAD25)


Conglomarates and ignimbrite layers. Aroge Minjar (L-MAD29)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.18: Outcrop Photos of Debre Birhan Ignimbrite

b.1.4 Anchar Basalts: massive basalt lavas and tuff breccia: Tb2

Lithology: Consists of massive aphyric basalt lavas and tuff breccia. At Asebe Teferi

(L-AA59), the unit is divided by three lithological facies; from the lowest, dark grey to black olivine-basalt with columnar joint (more than 40 m in thickness), reddish-brown auto-brecciated olivine-basalt (6m in thickness), reddish brown to grey auto-brecciated basalt (6m in thickness), and reddish-brown basaltic tuff breccia (6m in thickness). At the Awash river (L-KF45), the unit is overlain by a Bofa basalt unconformity. At Gidm Asfa (L-MAD21), the unit unconformably overlies Debre Birhan ignimbrite. At Balchi (L-MAD14), the unit unconformably overlies Debre Birhan ignimbrite and is unconformably overlain by Nazret pyroclastic deposits.

Distribution: NE-SW distribution at the southern mountain chain, around Awash town, Asebot town, Debala town and Chelelka town and widely distributed in the Kesem river basin.

Thickness: More than 58m at Asebe Teferi town (L-AA59). More than 20m at around Gidm Asfa (L-MAD21).


The unit unconformably overlies Huse ridge rhyolites. Asebe Teferi (L-AA57)


Outcrop of dark grey aphyric basalt. Agemti (L-AA20)


The unit unconformably overlies Debre Birhan ignimbrite. Gidm Asfa (L-MAD21)


The unit unconformably overlies Debre Birhan ignimbrite. Zongo (L-MAD10)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.19: Outcrop Photos of Anchar Basalts

b.2 Pliocene

b.2.1 Pliocene Rhyolites: Rhyolite: rhyolitic tuff, pumice tuff: Tr2

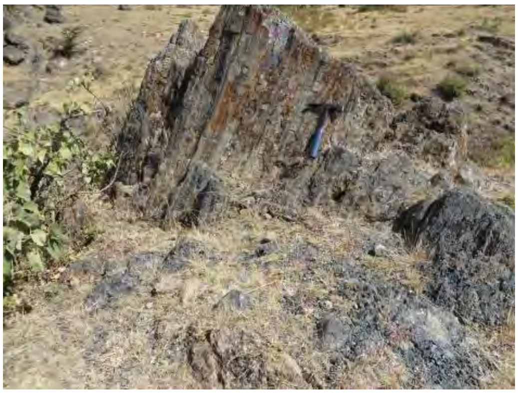
b.2.1.1 Chefeko Rhyolites: Rhyolite: rhyolitic tuff, pumice tuff

Lithology: Consists mainly of white to bluish grey rhyolite lava flows and tuff, white pumice and hard tuff including obsidians. This unit is unconformably overlain by Dino ignimbrite at Tulu near Itaya town (L-AB10). At Chefeko, (L-AB08) the rhyolite lava is observed to have developed platy joints and obsidians forming along chilled margin.

Distribution: Mt. Debeso, Chefeko, Lugo, forms a hill at Dera, Sodere, and Sara, and NE-SW distribution at Korkada Ridge.

Thickness: Around 150m at Chefeko, 5km northwest of Iteya town (L-AB08)


This unit is overlain unconformably by Dino ignimbrite (L-AB07r)


Hard tuff including obsidians at Chefeko (L-AB08)



Rhyolitic tuff, obsidian distributed at Mt. Debeso outcrop (L-AB09)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.20: Outcrop Photos of Chefeko Rhyolites

b.2.1.2 Birenti-Hada Rhyolites: Rhyolite, rhyolitic tuff, pumice tuff

Lithology: Consists mainly of white to bluish gray rhyolite lava flows and tuff, white pumice, pitchstone and hard tuff including obsidians. At Mt. Birenti (L-KF15), the unit is divided by six lithological facies; from the lowest, bluish-white rhyolitic fine tuff (more than 20m in thickness), bluish-grey pumice fall deposits (more than 5m in thickness), bluish-white rhyolitic pumice-tuff (more than 25m in thickness), white pumice-tuff (more than 3m in thickness), pitchstone (5m in thickness), and bluish- white rhyolitic tuff (more than 10m in thickness). At the southwestern part and northeastern part of the Kone caldera wall, the unit is observed more than 200 m from the bottom.

Distribution: Forms a NE-SW distribution hill at Bosena, Abadir Shero at Abadir Farm, Mt. Birenti and Dimtu Ridge south of Metehara Sugar Plantation.

Thickness: More than 80m at Bosena, northwest of Melka Jilo town (L-KF02).

Rhyolitic tuff. Bosena (L-KF02)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.21: Outcrop Photos of Birenti-Hada Rhyolites

b.2.1.3 Bokan Rhyolites: rhyolite with pumiceous tuff

Lithology: Consists mainly of white to bluish-gray rhyolite lava flows, tuff, white pumice, pitchstone and hard tuff including obsidians.

Distribution: This rhyolites form a hill at Mt. Bokan west of Balchi town, Mt. Gebre Arada east of Arerti town, NE-SW distribution at Adadi Ridge and Dikub, Yilas Ager.

Thickness: More than 100 m at Mt. Bokan, west of Balchi town (L-MAD09).

Rhyolitic tuff, with obsidian distributed (L-MAD09)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.22: Outcrop Photos of Bokan Rhyolites

b.2.2 Gara Gumbi Rhyolites: Rhyolite, rhyolitic tuff, pumice tuff

Lithology: Consists mainly of white to bluish-gray rhyolite, welded tuff, tuff, white pumice, pitchstone and hard tuff including obsidians. At Gara Gumbi Shinshit (L-AA06), the unit is bluish-grey rhyolite interbedded with white rhyolitic tuff and pumiceous tuff. At Dalecha (L-AA46), the unit is divided by five lithological facies; from the lowest, bluish-grey to white rhyolitic fine tuff (more than 10m in thickness), bluish-grey to greenish-grey welded tuff (th.5m), grayish-brown to white rhyolitic pumice-tuff (3m in thickness), grayish-white to dark grey rhyolite with pitchstone (10m in thickness), and bluish-white to grey rhyolitic tuff (more than 20m in thickness).

Distribution: Gara Gumbi, Dalecha Mountain Asebot town, forms a hill at northern part of Mieso town.

Thickness: More than 65 m at Gara Gumbi Shinshit (L-AA06), more than 50 m at Dalecha (L-AA46)

Rhyolitic tuff and pumiceous tuff at Gara Gumbi Shinshit. (L-AA06)

Rhyolitic Tuff including Obsidians. (L-AA46)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.23: Outcrop Photos of Gara Gumbi Rhyolites

b.2.3 Nazret Pyroclastic Deposits: Welded tuff, rhyolitic slightly welded tuff and tuff breccia, pumice, tuff, and crystal tuff

This unit is divided by two lithological facies; the lower part consists of yellowish white pumice fall deposits, tuff, crystal tuff, alternation of fine volcanic sands and pumiceous tuff (Ti2), and the upper part consists of white to bluish-gray welded tuff, rhyolitic consolidated tuff and tuff breccia which contain white pumice, rhyolitic lava fragments, crushed and/or slightly weathered obsidian fragments and sometimes reddish-brown basaltic lava fragments (Ti3).

b.2.3.1 Lower Nazret pyroclastic deposits: Ti2

Lithology: Consists of yellowish white pumice fall deposits, tuff, crystal tuff, alternation of fine volcanic sands and pumiceous tuff. At Boko (L-AB11), alternation of dark grey medium tuff, reddish-brown fine tuff, white pumiceous tuff, dark grey lapilli tuff and bluish-grey fine tuff are observed. The strike is N150W and the dip is 22 0W. This unit is overlain unconformably by Bofa basalts at the Wakleso river in Doni town (L-AB43).

Distribution: Boru river, Sire, Huruta town, Ufura Ridge. Samasembet in eastern Ejere town, NE-SW directional cliff of western Melka Jilo town. Around Adele, Kora town, Jejeba to Wangeyu southeastern foot of Gara Gumbi, northern part of Debala town.

Thickness: More than 15m at Boko (L-AB11). More than 85m at Samasembet (L-MAD11). More than 20m at Adele (L-AA30)

Tuff breccia of lower part. Sire (L-AB35)

The unit consists of pumice tuff and alternated tuff. Boko (L-AB11)

The unit consists of pumice tuff and alternated tuff. Samasembet (L-MAD11)

The unit consists of pumice tuff and alternated tuff. Adele (L-AA30)

The basaltic dyke is encountered in this unit. (L-AA29)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.24: Outcrop Photos of Lower Nazret Pyroclastic Deposits

b.2.3.2 **Upper Nazret pyroclastic deposits**: Ti3

Lithology: Consists of white to bluish-gray rhyolitic compacted tuff, grayish green welded tuff with fiamme and tuff breccia which contain white pumice, rhyolitic lava fragments, crushed and/or slightly weathered obsidian fragments and rare reddish brown basaltic lava fragments.

Distribution: Boru river, Huruta town, and the northeastern shore of Lake Koka. Widely distributed in the plains surrounding Ejere town to Arerti town forms a gentle slope along the Kesem river basin.

Thickness: More than 2m Koka Dam (L-AB02), more than 30m at Rukecha (L-MAD40)

The unit unconformably overlies the lower part of Nazret pyroclastic deposits. Koka Dam (L-AB02)

The unit consists of welded tuff and pumice tuff. Rukecha (L-MAD40)

The unit unconformably overlies conglomerate of Debre Birhan ignimbrite. Aroge Minjar (L-MAD29)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.25: Outcrop Photos of Upper Nazret Pyroclastic Deposits

b.2.4 Chilalo Trachybasalts: trachybasalt lavas and basaltic tuff breccia: Tt

Lithology:	Consists of dark grey to black massive trachybasalt lavas and basaltic tuff breccia. At River Robi (L-AB28), this unit is unconformably overlain by Chefe Donsa pyroclastic deposits.
Distribution:	Widely distributed in the northern mountain foot of Mt. Chilalo.
Thickness:	More than 30m at River Robi, north of Hamda Disks town (River Robi).

The unit is unconformably overlain by Chefe Donsa pyroclastic deposits. (L-AB28)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.26: Outcrop photos of Chilalo Trachybasalts

b.2.5 Bofa Basalts: Massive aphyric basalt lava and tuff breccia: Tb3

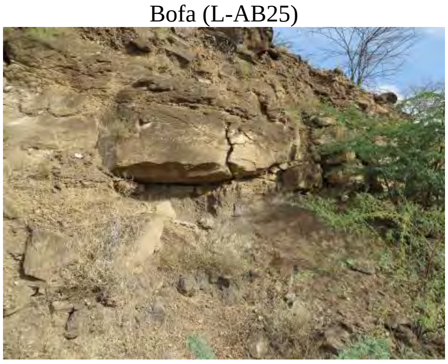
Lithology: Consists of dark grey to black massive aphyric basalt lavas and basaltic tuff breccia. At Bofa (L-AB25), the unit forms NE-SW ridge (30m high cliff) and is divided into two flow units. At the Awash river in Doni town, an approximately 20m high waterfall is formed by basaltic lava (L-AB41). At Holly spring in Doni town, southeastern foot of Mt. Boseti Guda (L-AB39), and the Wakleso river in Doni town (L-AB43), dark grey to black basaltic tuff breccia which contains fine to medium volcanic sand, black basaltic breccia, and rare hyaloclastites is observed. This unit is unconformably overlain by Dino ignimbrite west of Bofa town (L-AB22).

Distribution: Widely distributed in the plains surrounding the southern part of Mt. Boseti Guda, Bofa town, and Cheleko near Sire town. Awash river, Gara Gumbi Rasa. NE-SW distribution hill north of Mojo town to Ejere town.

Thickness: More than 30m at Bofa (L-AB25), around 700m at the center of Mt. Aluto (from borehole data by GSE, 1986). More than 15m at Kunche (L-MAD06, L-MAD07).

The unit forms NE-SW ridge (30m high cliff). Bofa (L-AB25)

The unit shows basaltic tuff breccia. Holly spring (L-AB39)



The unit is unconformably overlain by Dino ignimbrite. Awash river (L-KF43)

Basaltic tuff breccia. Gara Gumbi Rasa (L-AA10)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.27: Outcrop Photos of Bofa Basalts

b.3 Pleistocene

b.3.1 **Dino Ignimbrite**: rhyolitic to andesitic welded tuff: Qi1

Lithology: Consists of greenish-yellow to light gray rhyolitic to andesitic welded tuff which typically contains elongated obsidian lenses (fiamme). Generally, most fiamme is horizontal and concordant with the unit, but some fiamme shows irregular and/or ripple structure. At Awash river (L-KF42), the unit is divided into two flow units. The lower unit appears grayish-yellow in color, medium to coarse grained welded tuff with maximum 40cm-long fiamme, accompanied by 50cm-thick unwelded part at the bottom and contains rhyolite, green welded tuff, and white pumice. Rarely basaltic fragments and reverse grading of lithic fragments are observed. The upper part indicates normal grading of fiamme (large elongated obsidian clasta), and reverse grading of large litic clasts (rhyolite, white pumice, and rare green welded tuff) is observed. At Debela town (L-AA39), and Komena town (L-AA40), south of Bordede town, the perpendicular layer phases change of welding was observed. At West of Bofa town (L-AB22), the unit unconformably overlies Bofa basalts, and is overlain by Chefe Donsa pyroclastic deposits and Pleistocene basalts. The unit is highly to moderately welded medium tuff with maximum 30cm-long fiamme, rhyolite, pumice and rarely basaltic fragments.

Distribution: Around Megacha, west of Bofa town, east of Awash Melkasa town, east of Sire town , around Mojo town, and Jogo, Koka Dam. Forms a flat plain surrounding Dodose Kelo at the northern foot of Kone caldera and the southeastern foot of Mt. Fentale.

Thickness: More than 8 m west of Bofa town (L-AB22). More than 8m at Joro (L-AB47). Around 20m along Awash river (L-KF42).

Fiamme shows irregular and/or ripple structure. Jogo (L-AB06)

The unit unconformably overlies Bofa basalts. westward of Bofa town (L-AB22)

Rhyolitic to andesitic Welded Tuff. (L-KF39)

The unit unconformably overlies Tulu Rie basalts. Jolo (L-AB47)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.28: Outcrop Photos of Dino Ignimbrite

b.3.2 Pleistocene Rhyolites: Rhyolite, rhyolitic tuff, pumice tuff: Qr1

Lithology: Consists mainly of white to bluish-gray rhyolite lava flows and tuff, white pumice, pitchstone and hard tuff including obsidians. At the northeastern part of the Gademsa caldera wall, the unit is observed more than 100m from the bottom.

Distribution: Caldera wall of Gademsa.

Thickness: More than 100 m at northeastern cliff of Gademsa caldera.

The unit consists of rhyolitic tuff, obsidian. (L-AB05)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.29: Outcrop Photos of Pleistocene Rhyolites

b.3.3 Chefe Donsa Pyroclastic Deposits: pumice flow, pumice tuff: Qp1

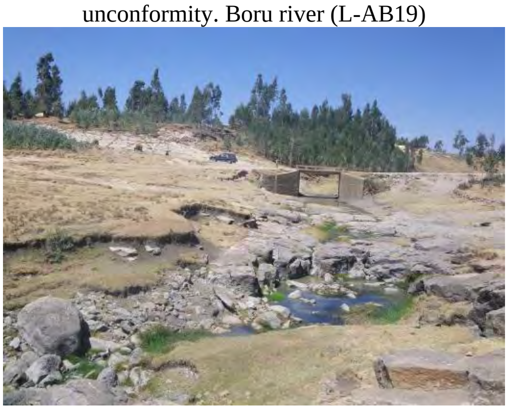
Lithology: Consists mainly of pumice flow, white pumice tuff, bluish white pumice and white tuff. At Boru river (L-AB19), the unit consists of at least three layers with a paleosoil unconformity. The lower part contains a lot of lapilli and the upper part contains a lot of pumice, indicating normal grading in the unit. The unit, which consists of pumice tuff, tuff and paleosoil, unconformably overlies Dino ignimbrite east of Sire town (L-AB37).

Distribution: Around Mojo town, Dire town, Sire town and northeast of Adama town, Debra Zeyt town, Chefe Donsa town. Widely distributed, forms a flat plain which is located around Awash Arba town.

Thickness: More than 70m at Boru river about 10km east of Dera town (L-AB19). More than 20m at Chefe Donsa town (L-MAD02). More than 6m at Jejeba (L-AA03).

The unit consists of pumice tuff with a paleosoil unconformity. Boru river (L-AB19)

The unit unconformably overlies Dino ignimbrite. Sire (L-AB37)



The unit unconformably overlies Nazret pyroclastic deposits. (L-MAD02)

Pumiceous tuff. Jejeba (L-AA03)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.30: Outcrop Photos of Chefe Donsa Pyroclastic Deposits

b.3.4 **Zikwala Trachytes**: Trachytes: Qt

Lithology: The unit consists of dark gray, porphyritic trachytes with intercalation of pyroclastic material.

Distribution: Around Mt. Zikwala (L-MAD41).

Thickness: More than 130m at Mt. Zikwala (L-MAD41).

The unit consists of dark gray, porphyritic trachytes. Mt. Zikwala (L-MAD41)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.31: Outcrop Photos of Zikwala Trachytes

b.3.5 **Sobebor Volcanic sand Beds:** volcanic sand and tuff alteration beds:

Lithology: The unit consists of yellowish brown-basaltic lapilli tuff to tuff breccia, containing basaltic sub-angular fragments. Boru Alore and Sobebor form craters and have relatively steep rims which dip equally both inwards and outwards. At Dinbiba, the southern foot of Mt. Fentale (L-KF30), the unit is unconformably overlain by Fentale welded tuff. The unit unconformably overlies Nazret pyroclastic deposits at Lake Haro Kilole (L-MAD01).

Distribution: A volcanic crater is formed. Boru Alore, the northeastern foot of Kone caldera, Sobebor, the western foot of Mt. Fentale, and Dinbiba, the southern foot of Mt. Fentale. In addition, around Argoba, Lake Haro Kilole, Lake Haro Meja, Bebeli.

Thickness: More than 15m at Dinbiba, more than 240m at Boru Alore, and more than 82m at Sobebor. More than 10 m at Argoba (L-MAD04).

Tuff ring in western foot of Mt. Fentale. Sobebor (L-KF23)

Basaltic tuff distributed in northeastern foot of Kone caldera. Boru Alore (L-KF18)

Approximately 25°dipping toward mountain (northeast) and unconformably overlaid by Fentale ignimbrite. Dinbiba (L-KF30)

The unit consists of alteration of yellowish-brown tuff and white tuff. Argoba (L-MAD04)

Lake Haro Meja (L-MAD01)

Lake Haro Kilole (L-MAD01)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.32: Outcrop Photos of Sobebor Volcanic Sand Beds

b.3.6 **Pleistocene Basalts:** olivine basalt and scoria: Qb1

Lithology: Consists of grayish-black aphyric basalt, dark grey to dark bluish-grey olivine basalt lavas, plagioclase basalt lavas and scoria cones. At Gambedra (L-AB38), the units unconformably overlie Chefe Donsa pyroclastic deposits. Plagioclase-basalt is widely distributed from Awash Arba town to Adami Hara town, and black fine olivine basalt is distributed from Deka Duku to Asebot town. At Adami Hara town (L-AA33), the unit is unconformably overlain by Asebot welded tuff.

Distribution: Southeastern shore of Lake Koka, around Awash Melkasa town to Bofa town and the Mt. Boseti surroundings, Kone caldera, the northern to western foot of Kone caldera, the southwestern and southeastern foot of Mt. Fentale. Around Mojo town, Debra Zeyt town, along the Kersa river northeast of Arerti town. Around Awash Arba town, Buri Arba to Aneno town, Adami Hara town and Asebot town.

Thickness: More than 15m at Gambedra, northeast of Bofa town (L-AB38). More than 38m at Dodose Use (L-KF20). More than 5m at Wubit Ager (L-MAD19). About 12 to 16m at Adami Hara town (L-AA33).

The unit unconformably overlies Chefe Donsa pyroclastic deposits. Gambedra (L-AB38)

The unit unconformably overlies Nazret pyroclastic deposits. Wubit Ager (L-MAD19)

Northeastern foot of Kone caldera . Dodote Use (L-KF20)

Southwestern foot of Mt. Fentale. The unit is overlain by a Fentale ignimbrite unconformity. Bogda (L-KF25)

The unit is unconformably overlain by Asebot welded tuff. Adami Hara (L-AA33)

The unit unconformably overlies Adele rhyolitic tuff. Buri Korkoda Ridge (L-AA22)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.33: Outcrop Photos of Pleistocene Basalts

b.3.7 **Kone Ignimbrite**: greenish consolidated to welded fine tuff: Qi2

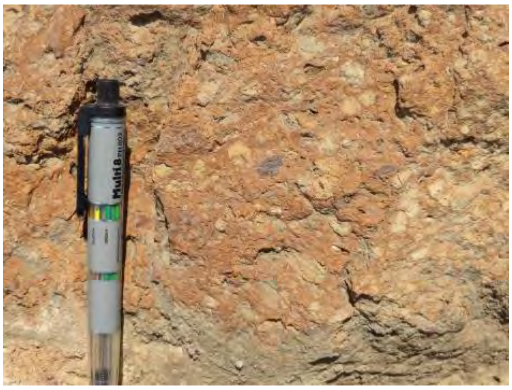
Lithology: Consists of greenish-blue to light green rhyolitic to andesitic consolidated to welded tuff. At Kone (L-KF13), the unit is unconformably overlain by Kone pumice fall deposits. At Mt. Asebot (L-AA44), the unit is divided into four lithological phases; from lower, dark grey to light grey moderately welded tuff (6m in thickness), yellowish-brown pumiceous tuff (0.8m in thickness), grayish-brown slightly welded tuff with elongated obsidian lenses (fiamme, 0.8m in thickness), and grayish-purple moderately welded tuff (more than 5m in thickness). At Kulbas, southwestern foot of Mt. Asebot (L-AA38), dark grey to light grey moderately welded tuff of this unit is observed to increase with higher altitudes in the northeast (Mt. Asebot).

Distribution: Kone caldera and the caldera wall of Korke surroundings. Widely distributed in the plains surrounding Buri Arba town to Aneno town, Adami Hara, and Asebot town.

Thickness: More than 20m at the Kersa Alore plain (L-KF08). More than 36m at Mt. Asebot (L-AA44), more than 60 m at Kulbas (L-AA37).

The unit is unconformably overlain by Kone pumice fall deposits. Kone (L-KF13)

Southwestern foot of Kone caldera. Ofe (L-KF03)



Yellowish brown pumiceous tuff. Mt. Asebot (L-AA44)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.34: Outcrop Photos of Kone Ignimbrite

b.3.8 Boseti-Kone Pumice Fall Deposits: pumice fall deposits, pumice tuff and tuff: Qp2

Lithology: Consists mainly of pale grey pumice fall deposits, light grey fine ash, white pumice tuff, bluish-white pumice and white tuff. The unit unconformably overlies Pleistocene basalts at Welensu (L-AB17) and Kone ignimbrite at Kone (L-KF13).

Distribution: Southwest of Mt. Boseti, Lake Koka and Adama town surroundings. NE-SW trending cliff of western Melka Jilo town. Kone caldera surroundings, and Mt. Fentale.

Thickness: More than 8 m at Mt. Boseti (L-AB30). More than 8m at Borchota (L-MAD23). More than 10m at Korke (L-KF10).

The unit unconformably overlies Pleistocene basalts. Welensu (L-AB17).

The unit consists of pumice fall deposits and ash. Mt. Boseti (L-AB29)

The unit consists of pumice fall deposits and ash. Borchota (L-MAD23)

Pumice fall deposits and ash. Korke (L-KF10)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.35: Outcrop Photos of Boseti-Kone Pumice Fall Deposits

b.3.9 Fentale Volcanic Rocks: rhyolite to trachyte lavas: Qf

Lithology: This unit is acidic volcanic rocks which form the main body of Mt. Fentale. The volcanic rocks are composed of rhyolite and trachyte lavas in which phenocrysts of alkali feldspar and hornblende are scattered. The lava surface is block type with a diameter from several dozen cm to about 1 m. The lavas are generally very glassy and are black to deep green in color.

Distribution: Mt. Fentale body and mountain foot.

Thickness: More than 100m at the foot of Mt. Fentale.

View of Mt. Fentale from the southern foot.

Trachyte lava distributed in the southern foot of Mt. Fentale.

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.36: Outcrop Photos of Fentale Volcanic Rocks

b.3.10 Fentale Ignimbrite: rhyolitic to andesitic welded tuff: Qi3

Lithology: Consists of greenish-blue to light yellow rhyolitic to andesitic welded tuff which typically contains elongated obsidian lenses (fiamme). Generally, fiamme is horizontal and concordant with the unit. At Dinbiba, the southern foot of Mt. Fentale (L-KF31), the unit is divided into three lithological facies; from lowest, greenish-blue highly welded tuff with fiamme, pumice fall deposits, and light yellow highly welded tuff with fiamme. At Dinbiba (L-KF30), the unit unconformably overlies Sobebor volcanic sand beds and is overlain by Holocene basalts. The unit is highly to moderately welded medium tuff with maximum 20cm-long fiamme, rhyolite, pumice and strongly welded tuff fragments.

Distribution: All around the foot of Mt. Fentale. NE-SW directional cliff of western Melka Jilo town. Widely distributed, forms a flat plain which is located around Awash town and Awash Arba town.

Thickness: More than 12m at Bogda, western foot of Mt. Fentale (L-KF24). More than 5m at Borchota (L-MAD23). More than 15m at Awash Arba (L-KF40).

The unit overlies a Mt. Boseti pumice fall deposit unconformity. (L-MAD37)

The unit consists of rhyolitic to andesitic welded tuff. Lake Koka (L-AB10)

The fiamme is horizontal and concordant with the unit. (southern foot of Mt. Fentale). Dinbiba (L-KF31)

The unit unconformably overlies Sobebor volcanic sand beds. Southern foot of Mt. Fentale (L-KF30)

The unit is unconformably overlain by Holocene basalts. Southern foot of Mt. Fentale (L-KF34)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.37: Outcrop Photos of Fentale Ignimbrite

b.4 Holocene

b.4.1 **Holocene Basalts**: vesicular basalt, scoria falls and scoria cones: Qb2

Lithology: Consists of dark gray to dark bluish-gray vesicular basalt lava and dark brown to reddish-brown scoria falls and scoria cones. Scoria cones of this unit are observed around Kone caldera and the western foot of Mt. Fentale.

Distribution: Widely distributed in the southwestern to northeastern foot of Kone caldera and Mt. Fentale surroundings. Around Mt. Boseti and southwestern shore of Lake Koka.

Thickness: 18m at Kera Feda, western foot of Kone caldera (L-KF21). More than 12m at Harorecha ,southern foot of Mt. Boseti (L-AB32).

Northeastern foot of Kone caldera. The unit unconformably overlies Sobebor volcanic sand beds. Boru Alore (L-KF21).

Dark gray to dark bluish-gray vesicular basalt. (L-AB32)

The unit unconformably overlies Chefeko rhyolites. Haribona (L-AB42)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.38: Outcrop Photos of Holocene Basalts

b.4.2 **Recent Rhyolitic Domes & Lava Flows**: obsidian lavas and domes: Qr2

Lithology: Consists of obsidian lavas, pumice fall deposits with obsidian and obsidian domes. At Waka Bute (L-AB04), the unit unconformably overlies Dino ignimbrites.

Distribution: Obsidian lava is observed at southeastern foot of Mt. Boseti and obsidian domes are situated at the southeastern Lake Koka area

Thickness: More than 20m at Waka Bute, southeastern part of Lake Koka (L-AB04).

The unit overlies unconformably Dino ignimbrite.
Waka Bute (L-AB04)

The unit unconformably overlies Holocene basalts.
Miesa (L-AB03)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.39: Outcrop Photos of Recent Rhyolitic Domes & Lava Flows

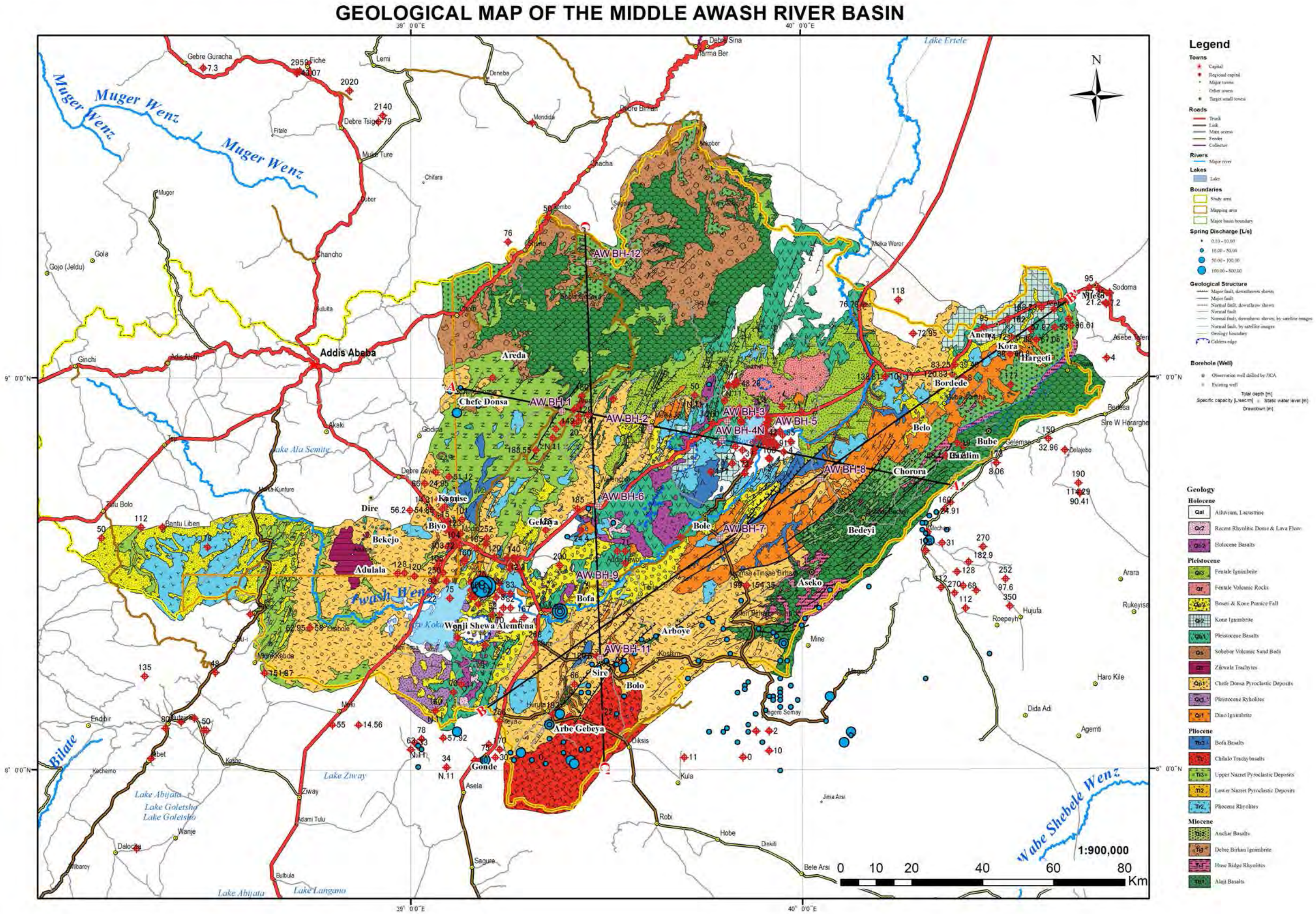
b.4.3 **Alluvium**: Qal

Lithology: Fine sand and mud

Distribution: Along Awash river and Mojo river.

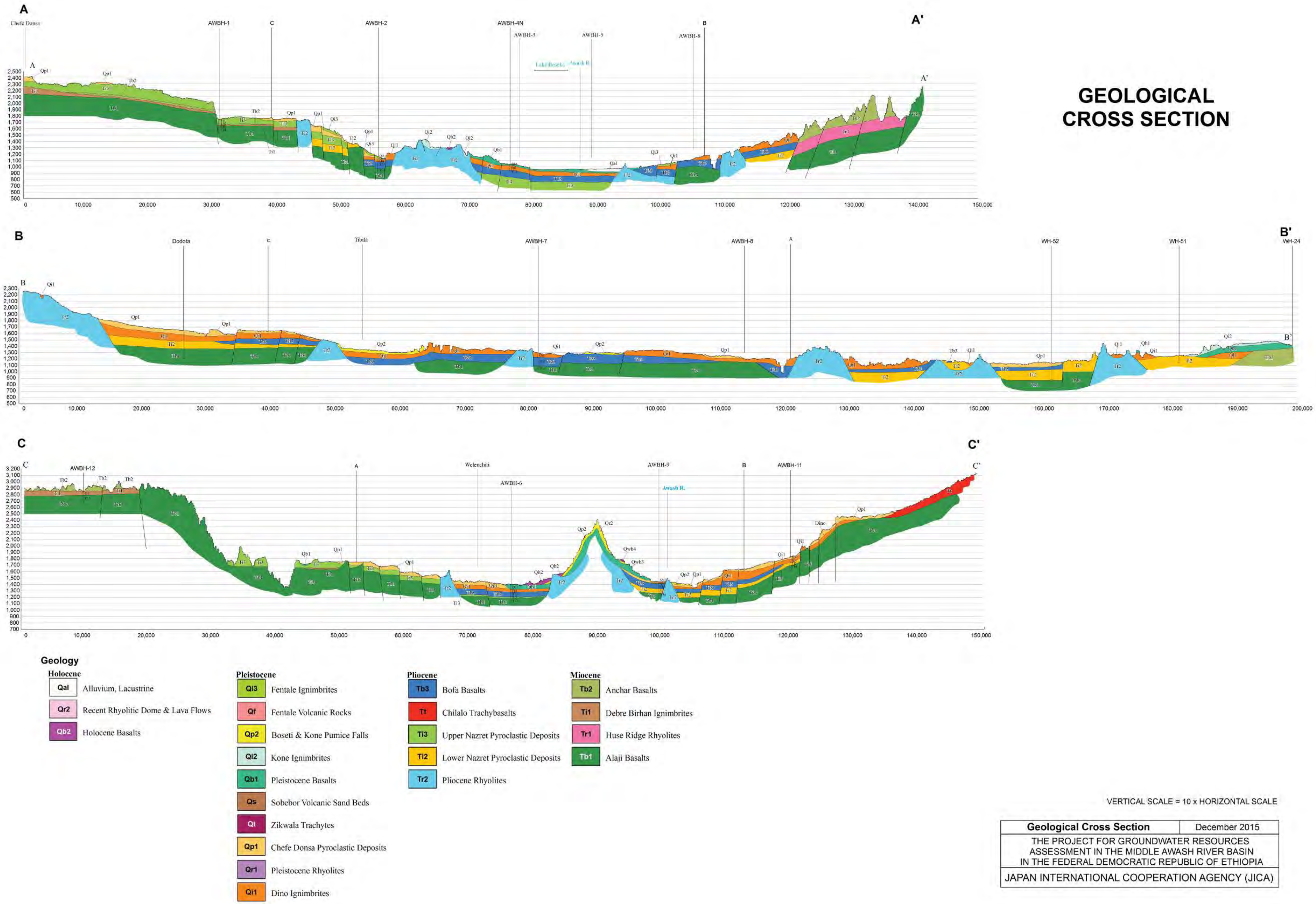
Thickness: 1 to 5 m

The geological map of study area is shown in Figure 2.2.40 and the geological cross section is shown in Figure 2.2.41.



Source: the Project Team, Data: Result of survey in this Project

Figure 2.2.40: Geological Map of Study Area



Source: the Project Team, Data: Result of survey in this Project

Figure 2.2.41: Geological Cross-Section of Study Area

2.2.4 Correlation of stratigraphy with previous studies

Results of correlation of stratigraphy established in this study and the previous documents listed below which cover the same area are shown in Table 2.2.15.

Documents and maps	Study area
Kazmin & Berhe (1978)	Nazret area
Alidge Groundwater Resources Assessment Project (2009)	Alidge, Awash area
Oromia Water Works Design & Supervision Enterprise (2013)	Beseka area
GSE (1985)	Dire Dawa area
GSE (2010)	Debre Birhan area
GSE (2010)	Akaki-Beseka area
F. Mazzarini et al (1999)	Debre Zeyt area
JICA (2012)	Rift valley lake zone

Table 2.2.15: Correlation of Stratigraphy with Existing Documents and Maps

Age			This study	Kazmin et al.(1978), GSE (1978) Nazret area	AGRAP (2009) Alidge-Awash area	OWWDSE (2013) Beseka area	GSE (1985) Dire-Dawa area	GSE (2010) Debre Birhan area	GSE (2010) Akaki-Beseka area	F. Mazzarini, et al.(1999) Debre Zeyt area	JICA (2012) Rift Valley lake zone	Geological Age
Cainozoic	Quarternary	Holocene	Alluvium (Qal)		Qed, Elluvial deposit Qsd, Slope deposits Qaf, Alluvial fan Qgf, Gravel outwash		Qtr, Travertine	Qal, Alluvial with minor agglomerate Qel, Eluvial	Qus, Alluvium	Alluvium Cover	Al, Alluvium Q, Unclassified fluvial deposits	
			Recent rhyolitic domes & lava flows (Qr2)	Qwra, Alkali and paralkali rhyolites, trachytes, domes and flows of Boset Weldoyi and Hada mountains (Wanji group) Qwpu, Unwelded rhyolitic pumice and unwelded tuffs (Wanji group)								
			Holocene basalts (Qb2)	Qwb3, Recent aphyric basalt (Wanji group)	Qb2, Aa lava	Holocene basalt Scoria cone	Qwbh, Recent and subrecent basaltic flows and caves		Qub, Basaltic lava flows Quc, Scoria cones and fall out deposits		rb, Butajira recent basalt	
		Pleistocene basalt	Fantale ignimbrite (Qi3)	Qwi2, Young ignimbrites of Fantale (Wanji group) Nn, Ash flow tuffs, pantelleritic ignimbrites and unwelded tuffs (Nazret group)	Qed, Elluvial deposit	Fantale ignimbrite	Fantale ignimbrite	Qfig, Fentale-Alay dege ignimbrite			G, Gonde strongly green welded tuff ob, Kulmusa highly welded tuff	168,000±38,000 y (OWWDSE ,2013)
			Fantale volcanic rocks (Qf)	Qwt, Trachytic flows and domes associated with Fantale, Tinish Fantale and Kone (Wanji group) Qwp, Pitchstone flows and domes (Wanji group) Qwpo, Pantelleritic volcanics of Fantale rhyolites, trachytes, tuffs and agglomerates (Wanji group)		diverse Fantale volcanics		Qft, Fentale trachyte				
			Boseti & Kone pumice falls (Qp2)	Qwpu, Unwelded rhyolitic pumice and unwelded tuffs (Wanji group) Nn, Ash flow tuffs, pantelleritic ignimbrites and unwelded tuffs (Nazret group) Qwb3, Recent aphyric basalt (Wanji group)							Y, Langano poorly welded pumiceous pyroclastics	
			Kone ignimbrite (Qi2)	Nn, Ash flow tuffs, pantelleritic ignimbrites and unwelded tuffs (Nazret group)	N2ab, Afar stratoid basalt upper		N1_2n, Stratoid silicics	Qdb, Dofan basalt			G, Gonde strongly green welded tuff	
			Pleistocene basalts (Qb1)	Qwb1, Pleistocene-subrecent basalts (Wanji group) Qwb2, Porphyritic feldspar basalts of Tulu Moye (Wanji group)	Qb1, Basic lava flow and caves	Pleistocene Basalt		Qdb, Dofan basalt		Bishoftu Volcanic unit	ba, Ogolche pleistocene basalt	Zikwala olivine basalt : 0.61±0.03Ma (Morton et.al.,1979)
			Sobebor volcanic sand beds (Qs)	Qwh, Basaltic hyaloclastites (Wanji group) Qwe, Bedded explosion tuffs (Wanji group)		Tuff Cone			Qup, Phreatomagmatic deposits			
			Zikwala Trachytes (Qt)						Qtz, Zikwala trachytes	Zikwala Volcanic unit		0.85±0.05Ma, 0.92±0.04Ma, 1.28±0.15Ma (Morton et al.,1979)
			Chefe Donsa pyroclastic deposits (Qp1)	Qwpu, Unwelded rhyolitic pumice and unwelded tuffs (Wanji group) Nn, Ash flow tuffs, pantelleritic ignimbrites and unwelded tuffs (Nazret group) Qwb3, Recent aphyric basalt (Wanji group)	N2ab, Afar stratoid basalt upper	older ignimbrite of the Fantale area	N1_2n, Stratoid silicics		Ncp, Chefe donsa pyroclastic deposits	Chefe Donsa unit	W, Ketar river acidic volcanic sedimentary rocks	Chefe Donsa pyroclastic deposits : 1.71±0.04 Ma(Morrton et al.,1979), 2.24±0.3 Ma(IGGI-Pisa)
			Pleistocene rhyolites (Qr1)	Nn, Ash flow tuffs, pantelleritic ignimbrites and unwelded tuffs (Nazret group) Qwp, Pitchstone flows and domes (Wanji group)							rh, Gademotta rhyolite	
			Dino ignimbrite (Qi1)	Qwi, Dino ignimbrites (Wanji group) Nn, Ash flow tuffs, pantelleritic ignimbrites and unwelded tuffs (Nazret group)	Nig, Dino ignimbrite	Dino Tuff					G, Gonde strongly green welded tuff	Dino ignimbrite: 1.5my (Mobidelli et al., 1975), 1.51 Ma (Kazmun, et al.,1978)
	Tertiary	Pliocene	Bofa basalts (Tb3)	N2Qb, Bofa basalts	N1ab, Afar stratoid basalt lower	Bofa basalt	N1_2ab, Stratoid basalts of Afar (lower part)			Tulu Rie Basalts unit	N2b, Basalt	Tulu Rie basalt: 2.7±0.1 Ma(INGEIS-Buenos Aires), 1.44±0.03 Ma(Chernet et al., 1998) Bofa : 1.21 Ma (Kazumin, et al., 1978), 6.1-4.4 Ma(Morton et al.,1979)
			Chilalo Trachybasalts (Tt)	N2c, Chilalo and Badda trachytes and trachybasalts								
			Upper Nazret pyroclastic deposit (Ti3)	Nn, Ash flow tuffs, pantelleritic ignimbrites and unwelded tuffs (Nazret group) Ql, Lacustrine sediments	N1ab, Afar stratoid basalt lower	older ignimbrite of the Fantale area			Nwp, Welded pyroclastic flows	Nazret unit	rht, Rhyolitic tuff Nqs, Rhyolite	Nwp : 3.5±0.1 Ma, 3.2±0.1 Ma(IGGI-Pisa), 4.7±0.7 Ma, 5.4±0.2 Ma(INGEIS-Buenos Aires), 3.32±0.06 Ma, 3.11±0.06 Ma(Morton et al., 1979)
			Lower Nazret pyroclastic deposits (Ti2)	Nn, Ash flow tuffs, pantelleritic ignimbrites and unwelded tuffs (Nazret group) Ql, Lacustrine sediments			N1_2ab, Stratoid basalts of Afar (lower part)		Npp, Welded to partially welded pyroclastic flows			
			Pliocene rhyolites (Tr2)	N2r, Older alkaline and paralkaline rhyolite domes and flows Qwt, Trachytic flows and domes associated with Fantale, Tinish Fantale and Kone (Wanji group) Qwra, Alkali and paralkali rhyolites, trachytes, domes and flows of Boset Weldoyi and Hada mountains (Wanji group)	Nry, Rhyolitic volcanic centres	rhyolite domes, flows and pumice N2r	N1_2gg, Peralkaline rhyolitic and trachytic domes and flows		Nrd, Rhyolitic and trachytic lava domes		N1_2n, Rhyolitic volcanics	
		Miocene	Anchar basalts (Tb2)	N1n, Anchar basalts	N1n, Anchor basalt		N1n, Anchar basalts	Ttb, Tarmaber-Megezeze basalt	E3tm, Tarmaber megezez formation Ega, Guraghe-Anchor basalts		Ngs, Sharenga rhyolite	Anchar : 12.4 Ma (Kazumin et.al., 1978) Mt. Megezeze: 13Ma, (Zanettin et al., 1974), 10.4Ma, (Chernet et al., 1998)
			Debre Birhan ignimbrite (Ti1)					Tdig, Sela dengay-Debre birhan-Gorgo ignimbrite			Ngu, Upper basalt	
			Huse Ridge rhyolites (Tr1)	N1r, Arba Guracha silicics	N1r, Arba guracha silicics		N1r, Arba guracha silicics				Ngu, Upper basalt	
			Alaji basalts (Tb1)	N1a, Alaji basalts	PNa1, Alajae formation		P3N1a, Alaji basalts	Tkb, Kesem basalt	E2aa, Aiba-Alaje basalts		Ngb, Beyana tuff, Ngm, Middle basalt	24-23Ma (Chernet et al., 1998), 14.4 Ma (Kuntz et al., 1975), 28-15 Ma (Morbidelli et al., 1975), 21.06±1.5 Ma, 14.94±1.5 Ma, 17.4±1.0 Ma (Kazumin, et al., 1978)

Source: the Project Team, Data: Result of survey in this Project

2.2.5 Geological structure and volcanic activity

a. Fault system

The MER (Main Ethiopian Rift) is an area of graben showing intense tensional tectonism and the related emplacement of volcanic products. The study area is located in a very complex junction of three important rift structures, two oceanic, the Red Sea and the Gulf of Aden and one continental, the East African Rift (Elc Electroconsult and Geotermica Italiana, 1987).

Generally, there are two main hypotheses of kinematic evolution of the Ethiopian Rift (ER). Some authors believe that the ER evolution has been mostly dominated by nearly pure extension (Mohr, 1983; Ebinger et al., 1993) with also a dextral component of displacement along the rift structure (Chorowicz et al., 1994), while the other authors suggest the occurrence of a left-lateral component of displacement along the rift axis during Quaternary (Boccaletti et al., 1999).

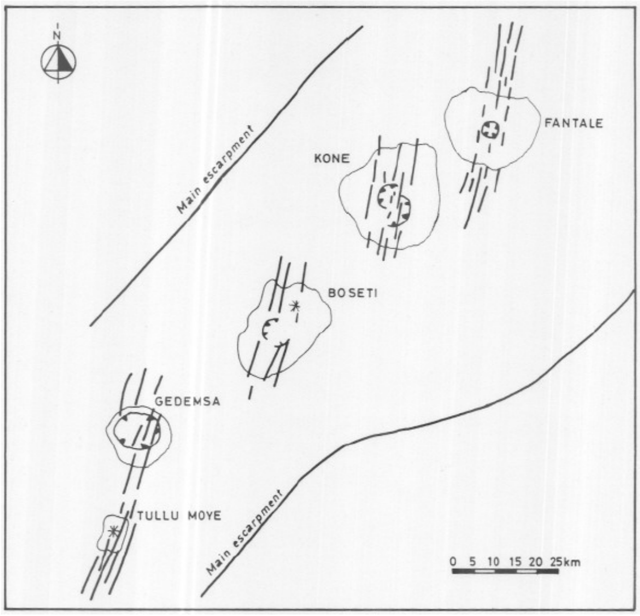
Boccaletti et al. (1999) summarized the previous study of structural setting of the MER as follows. The occurrence of two distinct fault systems in the MER is recognized; i) a mainly NE to NNE-trending border fault system that defines the rift margins and ii) a N to NNE-trending fault system that is mainly composed of right-stepping en-echelon faults constituting the so-called “Wonji Fault Belt (WFB)” (Mohr, 1960).

b. Active structures

The Wonji Fault Belt (WFB) is formed by several segments of Quaternary volcano-tectonic activity and these segments are disposed en-echelon left laterally (Gibson and Tazieff, 1970). They most probably represent incipient spreading center (Kazmin and Berhe, 1978).

The general structural pattern of the whole MER suggests the occurrence of a recent sinistral component of displacement along the rift axis. Nearly NNE-trending right-stepping en-echelon segments of the WFB located within the rift zone are arranged obliquely to the Rift margins. This setting is interpreted as evidence of the occurrence of some left-lateral shearing along the Rift (Boccaletti et al., 1999).

These segments of high activity can be recognized as shown in Figure 2.2.42. Kazmin and Barhe (1978) describe the characteristics of the WFB in the study area as follows. The southernmost segment, about 10km wide, extends along the eastern shore of Lake Ziway up to Gedemsa Caldera. It consists of numerous faults and open fractures situated 500 to 1,000m apart. This segment is marked by extensive eruptions of basalts, mainly from the Tulu Moye center and by the large silicic center of Gedemsa. There is no visible continuation of this axial segment in the north of Gademsa. It is substituted by the next segment, which is displaced about 10km to the east. This segment widens to 20km to the north and is marked by the two large silicic centers of Boseti and Kone as well as extensive fissure basalt eruptions. In the north of Kone Caldera, it is substituted by the third segment, which starts from the Fentale.



Source: Elc Electroconsult and Geotermica Italiana, 1987

Figure 2.2.42: En Echelon" Arrangement of the Active Volcano-tectonic Axis within the Northern Part of the Ethiopian Rift

2.2.6 Hydrogeology

a. Hydrogeological data collection

a.1 List of references

The geological map, hydrogeological map in relation to the hydrogeology and main reports have been collected for the references of the Study (refer to Table 2.2.16). Those reports and maps are collected mainly from Geological Survey of Ethiopia (hereafter referred to as "GSE"), Ministry of Water Irrigation and Electricity (hereafter referred to as "MoWIE"), and Water Works Design and Supervision Enterprise (hereafter referred to as "WWDSE") and so on.

Table 2.2.16: List of References

i)	Geological maps and explanation reports
	• Geological map of Nazret, Ethiopian Institute of Geological Surveys (EIGS), 1978 • Geology and Developing of the Nazret area, northern Ethiopia rift, Kazmin etc. EIGS 1978 • Geological map of Dire Dawa, EIGS, 1985 • Geological map of Debre Birhan, Geological Survey of Ethiopia (GSE), 1993 • Geology of Debre Birhan area, Daniel Mesheha etc. compiled, GSE, 2010 • Geological map of Akaki Beseka area, GSE, 1997 • Geology of Akaki Beseka, Efrem Beshawered compiled, GSE, 2010 • Geology of Addis Ababa map sheet, GSE, 1997 • Geology of Addis Ababa city, Getahun assigned, GSE, 2007
ii)	Hydrogeological maps and reports
	• Hydrogeology (Map) of the Nazret, EIGS, 1985 • Hydrogeology (Report) of the Nazret area (NC37-15), Gtahun Kebede, EICS, 1987 • Hydrogeological map of Ethiopia (1:2,000,000) compiled by Tesfaye Chernet and the Regional Geology Department, EIGS, 1988 • Hydrogeological map of Addis Ababa sheet (NC37-10), GSE, 2010 • Hydrochemical map of Addis Ababa sheet (NC37-10), GSE, 2010 • Hydrogeological report of Addis Ababa sheet (NC37-10), GSE, 2010

iii)	Project reports
	• Geothermal reconnaissance study of selected sites of the Ethiopian rift system, EIGS, 1987 • Fentale irrigation based interated development project, Oromia Water Works Design and Supervision Enterprise (OWWDSE), 2007 • Evaluation of water resources of the Ada'a and Becho plans groundwater basin for irrigation development project, Water Works Design and Supervision Enterprise (WWDSE), planned by Ministry of Water Resources (MoWR), 2009 • Allaidege plain groundwater resources assessment project, WWDSE planned by MoWR, 2009
ⅳ)	Drilling reports
	• Well completion report for well drilling Funyan Ajo, 2003 • Well completion report for Asebot town, 2008 • Technical well completion report on Bakiko water supply project, 2005 • Well completion report for well drilling at Oda Keneni,2003 • Technical well completion report on Geneda Ta'a water supply project, 2005 • Well completion report for well drilling at Hunde Missona, 2004 • Completion report of deep water well drilling in Kurfa Wachu village, 2008 • Well completion report for well drilling at Wolda Jajela, 2004 • Technical well completion report on Calalaka Ta'a water supply project, 2005 • Report on physical & Chemical analysis of water at Baka, Sararoo, and Caroraa, • Drilling report at Milinoztuftuewde, Fayo, Burka Misra, and Tu, 2002-2003 • Completion report of Abomsa deep well, 2008 • Watcha Dole well completion report, 2013 • Completion report of Abasa-Goroba deep wel, 2008 • Well completion report for Marfe Village, 2009 • Well completion report for Shamp Godo Kebele, 2009 • Technical report on water well drilling and completion works undertaken at Cheffe Mishoma, 2007 • Water well drilling completion report in Bote#1 site, 2013 • Water well drilling completion report in Bote#2 site, 2013 • Completion report for Mojo well, 2008 • Well completion report of Ilmo Chukela Borehole, 2012 • Waber Chukala well completion report, 2013 • Well completion report at Fatole & Kurma Fatole, 2013 • Well completion report at Kachachule Guja & Daglagala Jida, 2013 • Six boreholes drilling, construction and testing project, 2013 -Well completion report of well 01 Kuntlshile hama district - Well completion report of well 02 Manjikso waji district - Well completion report of well 03 Dhinque Cheleba district - Well completion report of well 04 Wara Jarsa district • Well completion report at Kallo Kabite, Adada Dambala and Giche Garbabo, 2013 • Well completion report at Tulu Ree, Foche, Wabor Cale amd Cheleleka, 2007 • Well completion report of Agemso Rogicha borehole, 2012 • Well completion report of Bishan Tino borehole, 2012 • North Showa zone Minjar Shenkora Woreda in Agirat kebele test /production wells drilling supervision report, 2011 • Water well drilling report format; Agirat water well, Agirat-2 and Mstw#2, 2011-2012 • Groundwater investigation report for rural kebeles in Minijar-Shenkora, 2007 • Study review to locate borehole sites and drilling supervision report for Ararti town, 2006 • Well drilling supervision report for Samsenbet area community water supply, 2008
ⅴ)	References and reports in relation to the Lake Beseka
	• The study of Beseka Lake levels, Sir William Halcrow and partners, 1978 • Study of Lake Beseka, MoWR, 1999 • Growing lake with growing problems: integrated hydrogeological investigation on Lake Beseka, Eleni Ayalew Belay, 2009 • National lakes of Ethiopia, Tenalem Ayenew, 2009, AAU Press. • Study and design of Lake Besaka level rise project Ⅱ, WWDSE, planned by Ministry of Water and Energy (MoWE), 2011 • Assessment and evaluation of cause for growth of Lake Besaka and design mitigation measures, OWWDSE, planned by MoWE, 2013
ⅵ)	References and reports in relation to the Study as a whole

- F. Mazzarini et al. (1999) Geology of Debre Zeyt area (Ethiopia)(with a geological map at scale:100,000), Acta Volcanologica-11, 131-141
- W. George Darling, et al. (1996) Lake-groundwater relationships and fluid-rock interaction in the East African Rift Valley: isotopic evidence, Journal African Earth Sciences 22, 423-431
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- Seifu Kebede et al. (2008) Groundwater origin and flow along selected transects in Ethiopian rift volcanic aquifers, Hydrogeology Journal 16, 55-73
- Caroline Le Turdu et al. (1999) The Ziway-Shala lake basin system, Main Ethiopian Rift: Influence of volcanism, tectonics, and climatic forcing on basin formation and sedimentation, Palaeogeography, Palaeoclimatology, Palaeoecology 150, 135-177
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- P. Mohr et al. (1980) Quaternary Volcanism and Faulting at O' A Caldera, Central Ethiopian Rift, Bull. Volcanol, 43-1, 173-188
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- Giday Woldegabriel et al. (1990) Geology, geochronology, and rift basin development in the central sector of the Main Ethiopia Rift, Geological Society of America Bulletin 102, 439-458
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- W.M. Edmunds (2010) Conceptual models for recharge sequences in arid and semi-arid regions using isotopic and geochemical methods, Cambridge University Press
- Halcrow Group Limited and Generation Integrated Rural Development Consultants (2008) Rift Valley Lakes Basin Integrated Resources Development Master Plan Study Project, MoWR

a.2 Existing well data

The collected existing well data are: i) Ethiopia National Groundwater Information System (hereafter referred to as "ENGWIS") inventories managed by Ministry of Water, Irrigation and Electricity (hereafter referred to as "MoWIE"); ii) Well records mentioned in existing reports, and iii) Well drilling records including well columnar sections and pumping test records.

The total data extracted from those files are 1,524 points. However, items included in the data are not filled out, and some coordinates of wells are missing in the inventory. Therefore, excluding data that has no coordinates, the total number of considered point well sources is 1,365. In the Study area, 763 new points of data have been included in the ENGWIS inventory; however the items regarding the groundwater data have not been filled out. From now, the C/P of MoWIE needs to fill in the ENGWIS inventory.

The number of basic data in groundwater has been arranged in the Table 2.2.17 below.

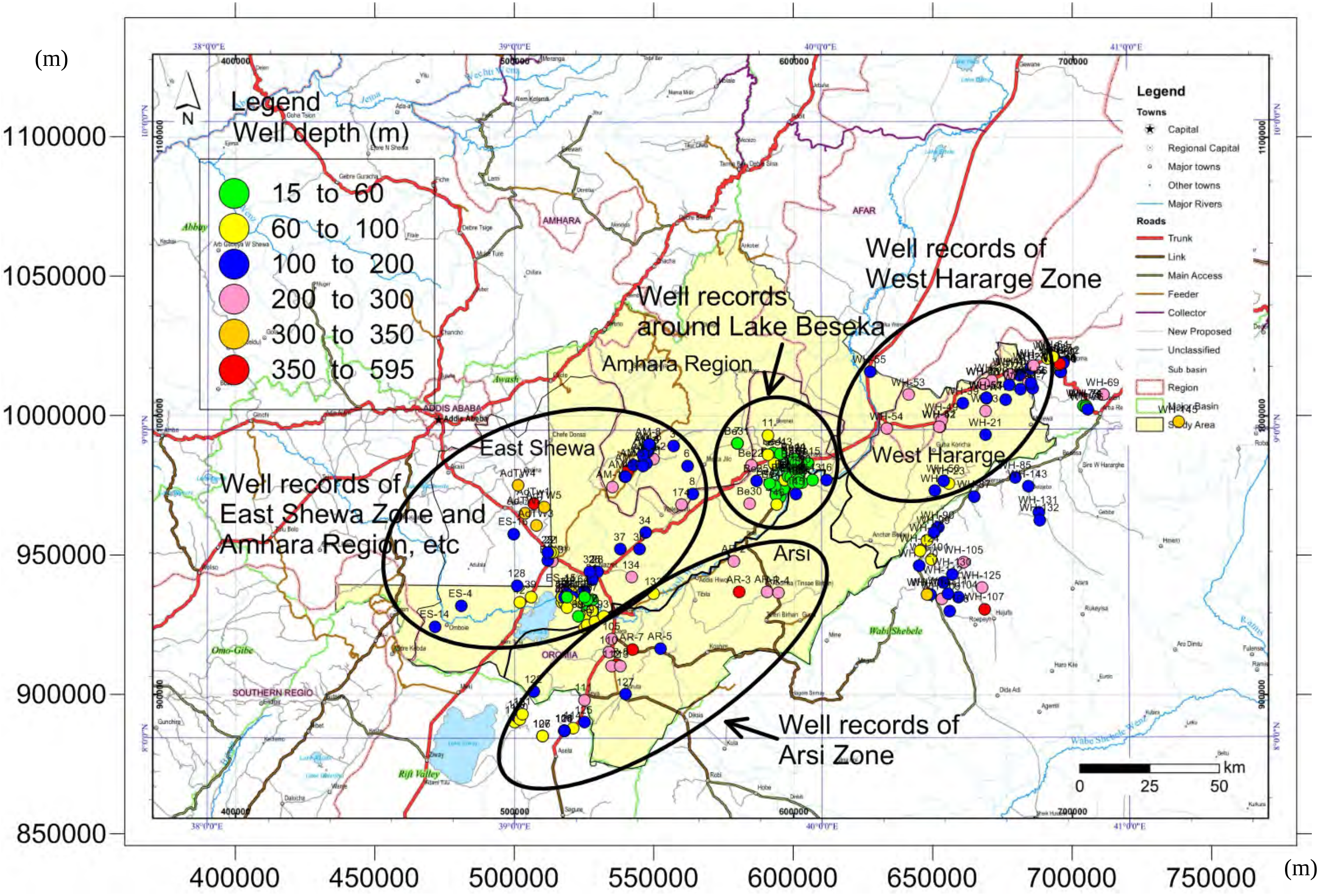
Table 2.2.17: Number of Data by Parameter in Well Database (with coordinates)

Parameter	Number of information
Static Water Level (SWL)	339
Dynamic Water Level (DWL) or Draw down (m)	154
Yield	305
Transmissivity (T)	55
Specific Capacity (Sc)	150
Water Quality Data	128
Geological Columnar Section	87

Source: the Project Team, Data: reference①, ②

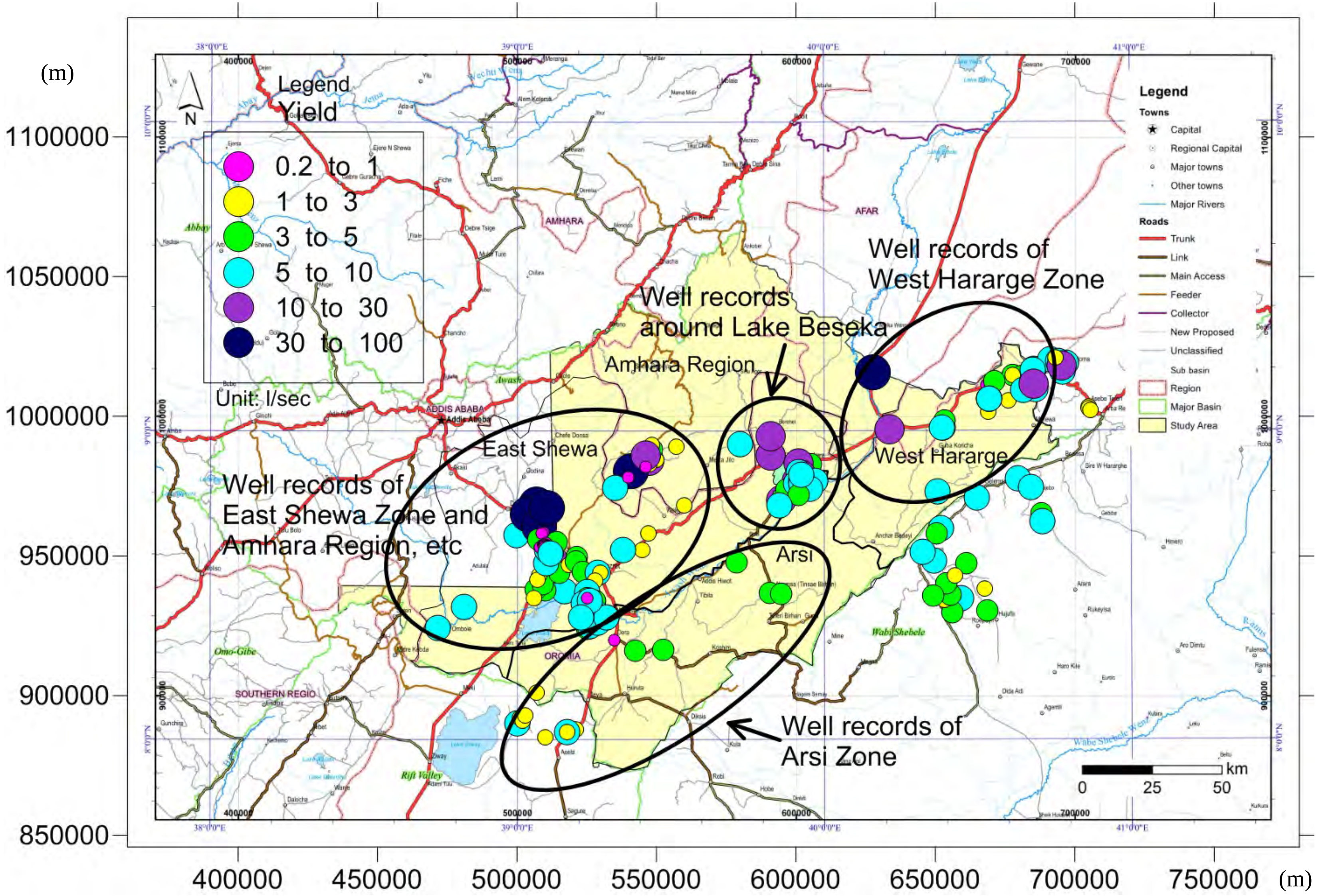
The location map of the existing wells for the well inventory in each Study area is shown in Figure 2.2.43. The yield data of each existing well is also shown in Figure 2.2.44.

The relationship between well depth and yield is shown in Figure 2.2.45 in West Hararge Zone and Figure 2.2.46 in East Shew zone and Amhara Region respectively.



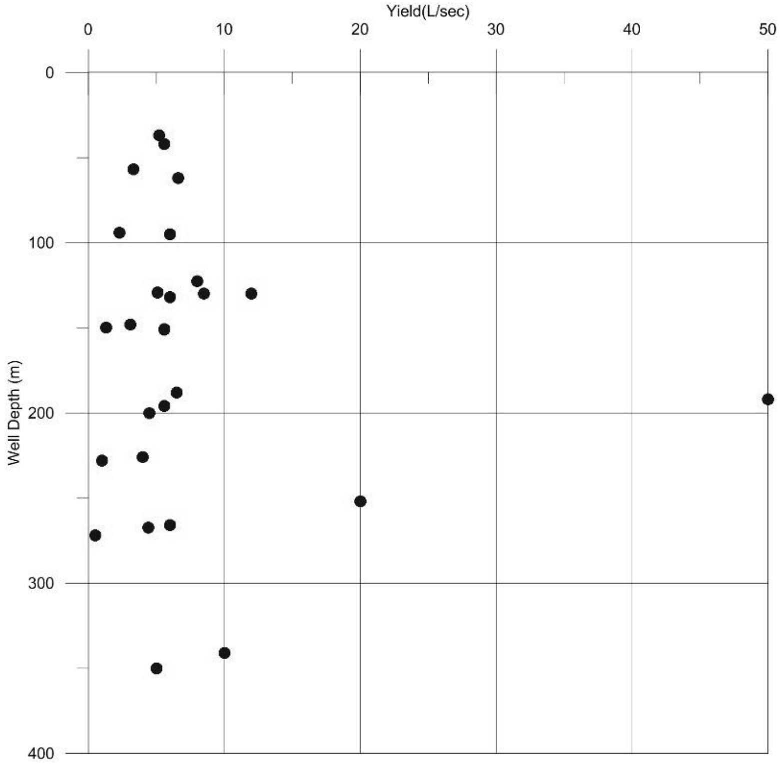
Source: the Project Team,
Data: reference ①, ②

Figure 2.2.43: Location Map of Existing Wells



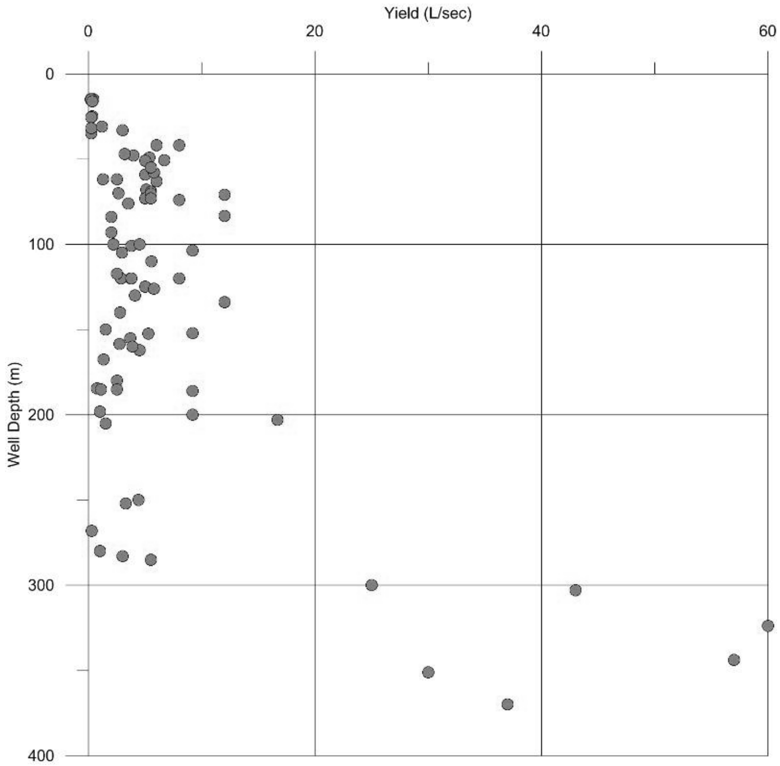
Source: the Project Team,
Data: reference ①, ②

Figure 2.2.44: Yield of Existing Wells



Source: the Project Team, Data: reference 1) of ②

Figure 2.2.45: Yield and Drilling Depth in West Hararge Zone



Source: the Project Team, Data: reference 1) of ① and 3), 4) of ②

Figure 2.2.46: Yield and Drilling Depth in East Shewa Zone, Amhara Region and Others

b. Aquifer by existing well

The columnar sections were described based on the lithological data of existing wells. The sample of columnar section includes the screen position and static water level. The existing columnar sections were utilized by themselves. The layers were assumed to be aquifers (depth of screens, grey bars next to column) and their assumed composition ratios and geological units are shown in Table 2.2.18. The results between those columnar sections and the geological map and the results of drilling data on JICA wells were all taken into account.

Table 2.2.18: Aquifer Lithology and Composition Ratio of Existing Wells

ID	Lithology	Main description in lithology	No.	Composition ratio	Main geological units (existing data)
1	Basalt	Trachytic basalt, Vesicular basalt, Highly weathered and fractured basalt, Massive basalt, Scoriacious basalt	40	29	Miocene Basalts (Anchar, Alaji basalts), Bofa basalts. Pleistocene basalts, Holocene basalts
2	Scoria	Black scoria, Fine gravel with sand	9	7	Distribute with basalt
3	Ignimbrite	Weathered ignimbrite, Fresh ignimbrite, Massive ignimbrite, Boulder ignimbrite	26	19	Nazret pyroclastic deposits, Pliocene rhyolits, Dino ignimbrite.
4	Rhyolite	Highly fractured rhyolite, Weathered rhyolite	6	4	Debre Birhan ignimbrite and Huse Ridge rhyorites, Dino ignimbrite
5	Tuff	Tuff, Indurated tuff, Unwelded tuff, Pumiceous tuff	9	7	Nazret pyroclastic deposits, Dino ignimbrite
6	Phonolite	Fractured phonolite,	4	3	Nazret pyroclastic deposits, Anchar basalts.
7	Welded tuff	Welded tuff	8	6	Kone ignimbrite, Fentale ignimbrite,
8	Pumice	Moderately weathered pumice	7	5	Nazret pyroclastic deposits, Chefe Donsa pyroclastic deposits.
9	Ash	Ash, Volcanic ash	10	7	Nazret pyroclastic deposits, Chefe Donsa pyroclastic deposits.
10	Pyroclastics	Highly weathered Pyroclastics, Pumicious pyroclastics, Volcanic	4	3	Nazret pyroclastic deposits

		breccia			
11	Trachyte	Trachyte	2	1	Chilalo Trachy basalts.
12	Sand, gravel (lower part)	Pumiceous sand, agglomerate, Silica rich sand, Fine to coarse sand with pebble	8	6	Nazret pyroclastic deposits.
13	Lacustrine, Alluvium	Sand and gravel	5	4	Alluvium, Lacustrine deposits

Source: the Project Team, Data: reference ①, ②

The layer of the longest screen is selected as main aquifer in the screen positions and is correlated with aquifer coefficient. The discharge (yield), Specific capacity (Sc) and Transmissivity (T) of each aquifer are shown in Table 2.2.19.

Table 2.2.19: Main Aquifer Information of Existing Wells

Described layer name	Collected data													
	Yield(ℓ/sec)				Specific Capacity(ℓ/sec/m)				Transmissivity(m^2/day)				Depth(m)	
	No	Maxmum	Minimum	Mean	No	Maxmum	Minimum	Mean	No	Maxmum	Minimum	Mean	No	Mean
Basalt	23	60	0.76	12.9	22	56.7	0.067	4.9	18	40800	0.0032	4689	27	190.7
Scoria	1	5.3	5.3	5.3	1	4.53	4.53	4.53	2	14758	378	7568	2	136.5
Ignimbrite (Pumice Flow Deposits, Welded Tuff etc.)	20	25	0.51	7.3	18	89.2	0.0054	8.24	14	6947	0.071	924	20	188.9
Rhyolite	4	11.8	5	8.2	4	2.16	0.61	1.25	4	348.07	34.39	129	5	159.8
Tuff	–	–	–	–	–	–	–	–	1	217.8	217.8	217.8	3	92.3
Phonolite	2	50	20	35	2	44.64	0.521	22.58	2	39528	102.4	19815	3	233.7
Welded tuff	1	4	4	4	–	–	–	–	3	996.2	60.4	595	3	34.6
Pumice	4	16.68	1.6	7.1	4	7.14	0.311	2.44	1	16.56	16.56	16.56	4	113
Ash	4	12	1	4.1	1	12	12	12	–	–	–	–	4	55.9
Pyroclastics	3	30	1	11.8	1	7.14	7.14	7.14	–	–	–	–	3	264.3
Sand/Gravel	5	9.2	2	4.9	5	6.66	0.17	2.26	–	–	–	–	5	95.6
Lacustrine deposit	5	4.5	1.3	2.6	3	0.65	0.06	0.34	–	–	–	–	5	75.4
Alluvium	3	8	6	6.8	2	1.6	0.6	1.1	1	965.9	965.9	965.9	3	44

Source: the Project Team, Data: reference ①, ②

Basalt and ignimbrite are recognized as the aquifer compared to other layers and the average depth is deeper and yield is high production. The basalt and ignimbrite are good aquifers. It is better to select the fracture zone of each layer, not a massive layer as a good aquifer.

c. Correlation of layers with JICA wells and existing wells

The geological sections were completed in accordance with the results of observation of the JICA well samples. The correlation with strata and JICA wells and the results of pumping test of the JICA wells are shown in Table 2.2.21. The aquifers for the existing well data with columnar sections were decided in reference to the stratigraphy with the geological map and sections (refer to Table 2.2.20). The aquifer information obtained by the pumping tests was utilized for the evaluation of groundwater potential described in Chapter 4. The columnar sections of the existing wells will be attached in the data book of the final report.

Table 2.2.20: Existing and JICA Wells Correlated with Strata

Age			Stratigraphy	Litholigy	Correlated existing and JICA wells	Distribution
Cainozoic	Quarternary	Holocene	Alluvium & Lacustrine deposits (Qal)	sand, clay, gravel, lucstrin	Be-12, NZ-136, NZ-137(and above Al), NZ-21, NZ-22, NZ-23, NZ-31, NZ-40,NZ-149, NZ-150, NZ-152(and above Luc)	Around Lake Beseka, Lake Koka mainly
			Recent rhyolitic dome & lava flows (Qr2)	rhyolitic domes with obsidian lava flows	–	From Adama to Bofa and Kone to around Fentale volcano mainly
			Holocene basalts (Qb2)	glassy basalt & aphyric basalt and scoria cone	–	From Adama to Furuta and Bofa, and from around Lake Koka to Kone caldera and around Fentale volcano
		Pleistocene	Fentale ignimbrite (Qi3)	pare green strongly welded tuff with fiamme	Be-15, NZ-14, Be-40, Be-43, Be-52	Around and the west area of Fentale volcano
			Fentale volcanic rocks (Qf)	Rhyolite, Trachyte, tuff & agglomerate	–	Around Fentale volcano
			Boseti - Kone pumice fall (Qp2)	pumice fall	–	From around Mojo to around Fentale volcano
			Kone ignimbrite (Qi2)	greenish consolidated to welded fine tuff	NZ-7, Be-47	From around Kone caldera via Fentale volcano to Asebe Teferi area
			Pleistocene basalts (Qb1)	aphyric basalt and scoria cone	NZ-10, NZ-120, NZ-140, NZ-142, Be-48	All area of the Study area
			Sobebor volcanic sand (Qs)	tuff ring, maar deposits	–	Koeko-Kone-Fentale and around Mojo
			Zikwala trachytes (Zt)	Trachyte	–	Around Mt. Zikwale山
			Chefe Donsa pyroclastic deposits (Qp1)	Pumice and tuff with intercalated with poorly welded tuff	ES-18, ES-19, ES-20, NZ-118, NZ-119	All area except around Debre-Brihan of north area of the Study area
			Pleistocene rhyolites (Qr1)	rhyolite	ES-4, ES-14, NZ-121	From around Lake Koka to Fentale volcano area
			Dino ignimbrite (Qi1)	Greenish grey welded tuff with fiamme	WH-8, WH-12, WH-22, AR-2, ES-3, NZ-114	All area except around Debre-Brihan of north area of the Study area
	Tertiary	Pliocene	Bofa basalts (Tb3)	aphyric basalt	WH-51, AR-1, AWBH-3, AWBH-4N, AWBB-5	All area except around Debre-Brihan of north area of the Study area
			Chilalo Trachy basalts (Tt)	Trachytes and Trachybasalts	–	Only Adama-Furuta－Bofa area
			Upper Nazret pyroclastic deposits (Ti3)	light to dark grey welded tuff with fiamme	ES-15, ES-16, AM-1, AM-2, AM-3, AdTW5, NZ-39	From Mojo to Lake Koka and north area of the Study area
			Lower Nazret pyroclastic deposits (Ti2)	pumice and tuff	WH-26, WH-52	All area except Koeke-Kone-Fentale areas
			Pliocene rhyolites (Tr2)	rhyolite with pumiceous tuff	–	All area except around Debre-Brihan of north area of the Study area
		Miocene	Anchar basalts (Tb2)	aphyric basalt	WH-1, WH-24, WH-54, AM-6, AdTW1	From around Mojo to north area of the Study area and east area of Awash area
			Debre Birhan ignimbrite (Ti1)	upper conglomerate, tuff. sand, alternation & greenish compacted to welded fine tuff	–	From around Mojo to north area of the Study area and south area of Adama
			Huse Ridge rhyolites (Tr1)	white- bluish gray ryolite and tuff	–	East area from around Awash and NE-SW direction around Huge Ridge
			Alaji basalts (Tb1)	plagioclase aphyric basalt	WH-6, WH-7, AR-4, AR-5, AR-6, AM-12, AdTW2, AdTW3, NZ-9, AWBH-1, AWBH-2, AWBH-6, AWBH-9, AWBH-11, AWBH-12	All area except around Lake Koka

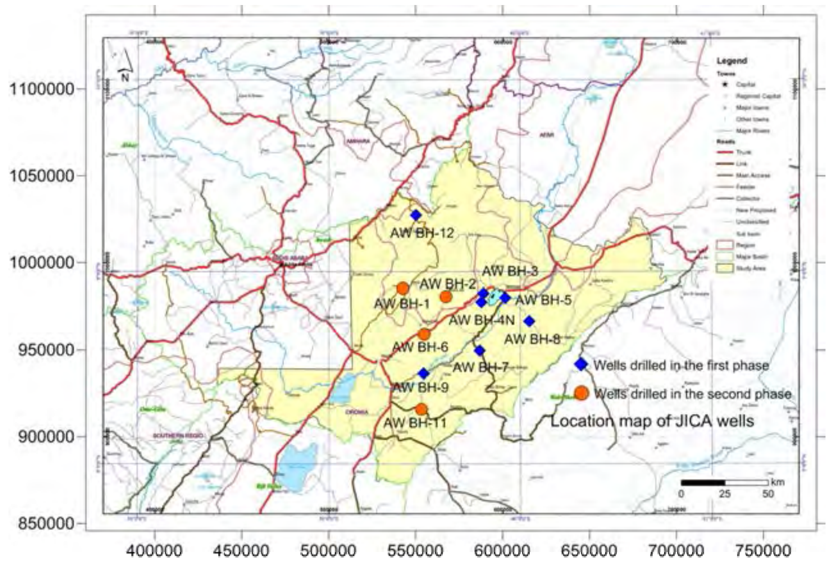
Source: the Project Team, Data: reference ①の 1), 4), ② and 3) of ③

Table 2.2.21: Strata Observed in JICA Wells and Results of Pumping Tests

Well ID	Sub Basin	Woreda	Kebele	Eastings	Northings	Elevation (m)	Depth (m)	Strata Name	Aquifer	Yield (L/sec)	SWL (m)	DWL (m)	Sc (L/sec/m)	T (m^2/min)	S
AW BH-1	SB5-L	Arerti	Kersha	542642	985361	1760	228	Ti3, Tb2, Ti1, Tb1	Ti3, Tb1	12.09	13.86	58.06	0.27	0.0819	0.03108
AW BH-2	SB-BSK-W	Arerti	Melka Jilo	567414	980822	1151	250	Qi3, Qp1, Qi1, Tb3, Tb1	Tb1	6.25	174.79	174.92	48.00	0.0083	$6.63*10^{-3}$
AW BH-3	SB-BSK	Metehara	Tututa	589167	982682	1032	204	Qb1, Qi1, Tb3	Tb3	6.30	68.56	68.56	–	–	–
AW BH-4N	SB-BSK	Metehara	Tututa	587754	977437	1044	117	Qb1, Qi1, Tb3	Tb3	11.12	87.91	89.10	9.34	1.1676	$1.167*10^{-7}$
AW BH-5	SB-BSK	Metehara	Gelecha	601565	980024	959	140	Qi3, Qi1, Tb3	Tb3	7.60	2.90	54.73	0.15	0.0034	$1.61*10^{-4}$
AW BH-6	SB-BSK-W	Welenchi	Feto	552789	958778	1357	247	Qb1, Qi1, Tb3, Ti3, Tb1	Tb3, Tb1	6.25	175.46	176.57	5.63	0.0166	$6.63*10^{-9}$
AW BH-7	SB4-R	Merti	Abo Mesa	586813	949687	1239	250	Qi1, Tb3, Tb1	–	–	–	–	–	–	–
AW BH-8	SB4-R	Metehara	Fateledi	615265	966369	1221	208	Qr2	–	–	–	–	–	–	–
AW BH-9	SB3-L	Welenchi	Araso Bero	555025	936983	1424	272	Qi1, Tb3, Ti2, Tb1	Tb1	3.50	139.92	174.57	0.10	0.0037	$7.41*10^{-4}$
AW BH-11	SB3-R	Sire	Gesala Chacha	553313	916009	1810	227	Qp1, Qi1, Ti2, Tb1	Ti2, Tb1	10.19	69.86	79.66	1.04	0.7281	$1.61*10^{-4}$
AW BH-12	SB5-L	Shola	Sekoru	550405	1027427	2858	220	Ti1, Tb1	Tb1	5.00	163.71	165.89	2.29	0.1303	$1.06*10^{-6}$

Alluvium & lacustrine deposits (Qal)	Recent rhyolitic dome & lava flows (Qr2)	Holocene basalt (Qb2)	Fentale ignimbrite (Qi3)	Fentale volcanic rocks (Qf)	Boseti - Kone pumice fall (Qp2)	Kone ignimbrite (Qi2)	Pleistocene basalts (Qb1)	Sobebor volcanic sand (Qs)	Zikwala trachytes (Zt)	Chefe Donsa pyroclastic deposits (Qp1)	Pleistocene rhyolites (Qr1)	Dino ignimbrite (Qi1)	Bofa basalts (Tb3)	Chilalo Trachy basalts (Tt)	Upper Nazret pyroclastic deposits (Ti3)	Lower Nazret pyroclastic deposits (Ti2)

Pliocene rhyolites (Tr2)	Anchar basalts (Tb2)	Debre Birhan ignimbrite (Ti1)	Huse Ridge rhyolites (Tr1)	Alaji basalts (Tb1)



Source: the Project Team, Data: reference 3)of ③

Reference materials

① Main well records mentioned in existing reports:

1) Hydrogeology (map) of the Nazret, EIGS, 1985
2) Evaluation of water resources of the Ada'a and Becho plans groundwater basin for irrigation development project, WWDSE, planned by MoWR, 2009
3) Allaidege plain groundwater resources assessment project, WWDSE planned by MoWR, 2009
4) Study and design of Lake Besaka level rise project Ⅱ, WWDSE, planned by MoWE, 2011
5) Growing lake with growing problems: integrated hydrogeological investigation on Lake Beseka, Ethiopia, ELENI AYALEW BELAY, 2009
6) Assessment and evaluation of causes for Beseka Lake level rise and design mitigation measures PartⅡ: Study for medium and long term solutions (Main report final), MoWIE and OWWDSE, 2014
7) Groundwater origin and flow along selected transects in Ethiopian rift volcanic aquifers, Seifu Kebede et all, 2008

② Well drilling records including well columnar section and pumping test record:

1) Existing well data including columnar section and pumping test record in West Hararge Zone
2) Existing well data including columnar section and pumping test record in Arsi Zone.
3) Existing well data including columnar section and pumping test record in East Shewa Zone
4) Well completion reports and well data in Arerti（Amhara Region）woreda, Lomme（Oromia Region） woreda
5) WWDSE, 2014 Irrigation data（Well depth 595m）

③ Others references

1) Editing: Japanese Association of Groundwater Hydrology, Science for brand-name spring water, 1994
2) Hydrogeological map of Ethiopia (1:2,000,000) compiled by Tesfaye Chernet and the Regional Geology Department, EIGS, 1988
3) Data (including photo on site) from field survey and interview, etc by the Project Team

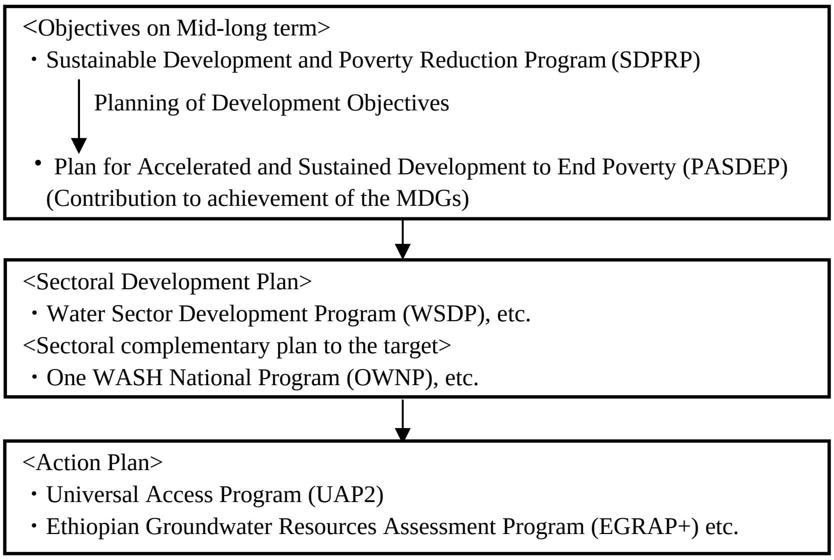
2.3 Socio-economic conditions

2.3.1 Development plan and related laws

a. National level (Federal Democratic Republic of Ethiopia)

The discussions on a development strategy regarding poverty reduction in Ethiopia were commenced in the year 1999. The countermeasure programs and plans against water shortage shown below are developed.

The objectives and development chart about these plans and policies shown above are indicated on Figure 2.3.1.



Source: the Project Team, Data: Result of survey in this Project

Figure 2.3.1: Related Chart of Ethiopian Water Sector Policies and Plan

2.3.2 Socio-economic conditions in the Middle Awash River Basin

a. Population and demographic characteristics

The population of Ethiopia reaches 86 million in the years 2012 and 2013 (population growth rate: approx. 2.7%), and the population number is on a continuing upward trend every year. This number shows that more than 32 million people are living in Oromia Region. The area in Oromia Region is the largest region in Ethiopia as shown in Table 2.3.1. The statistics in 2007 shows the population around 6.5 million in the Middle Awash River Basin (in which around 2.7 million is from Addis Ababa). However, the ratio between male and female is balanced in both city and rural area.

Table 2.3.1: Population Census Data of each Ethiopian Regional State in 1994, in 2007, and in 2013

Region	Population (1994)	Population (2007)	Population (2013)*1)	Area (km^2)	Remarks
Addis Ababa	2,112,737	2,739,551	3,104,000	527	City
Afar Region	1,106,383	1,390,273	1,650,000	72,053	Regional Capital: Asayita
Amhara Region	13,834,297	17,221,976	19,212,000	154,709	Regional Capital:Bahir Dar

Region	Population (1994)	Population (2007)	Population (2013)*1)	Area (km^2)	Remarks
Benishangul-Gumuz Region	460,459	784,345	1,028,000	50,699	Regional Capital: Asosa
Dire Dawa	251,864	341,834	395,000	1,559	City
Gambela Region	181,862	307,096	406,000	29,783	Regional Capital: Gambela
Harar	131,139	183,415	215,000	334	City
Oromia Region	18,732,525	26,993,933*2)	32,220,000	284,538	Regional Capital: Adama
Somali Region	3,152,704	4,445,219	5,318,000	279,252	Regional Capital: Jijiga
Tigray Region	3,136,267	4,316,988	5,062,000	84,722	Regional Capital: Mek'ele
SNNPRs	10,377,028	14,929,548	17,887,000	105,476	Regional Capital: Awasa
Total	53,477,265	73,750,932	86,614,000	1,063,652	

Source: Central Statistical Agency(CSA), Britannica Book of the Year (1999)
*1) The data in 2013 is quick estimation value with bulletin.
*2) The breakdown of this value is 3,317460 (Male 1,679,153 Female1, 638,307) in urban area, and 23,676,473 (Male 11,915,853 Female 11,760,620) in rural area.

a.1 Ethnic groups

Ratio of ethnic groups in Oromia Region is Oromo people (around 88%), Amhara (around 7%) Gurage (around 1%) and others (4%).

a.2 Religion

The Muslim is the largest religion (around 48 %) in Oromia Region followed by Ethiopian orthodox (around 30%) and y protestant (around 18%) and others (around 4%).

a.3 Language

In Oromia Region, the local people mainly speak Oromiffa language (around 84%) though there are some people speak Amhara language(around 11%) as national common language.

b. Local administrative divisions

Ethiopia is composed of 9 regional government and 2 administrative cities except Addis Ababa. Each region is composed of many zones. Each zone is composed of many woredas. Each woreda is composed of several towns and regional kebeles.

Oromia region is divided into 18 zones, as is shown in Table 2.3.2. And the target towns of this project are in East Shewa zone, Arsi zone, and West Hararge zone.

Table 2.3.2: 18 Zones in Oromia Region

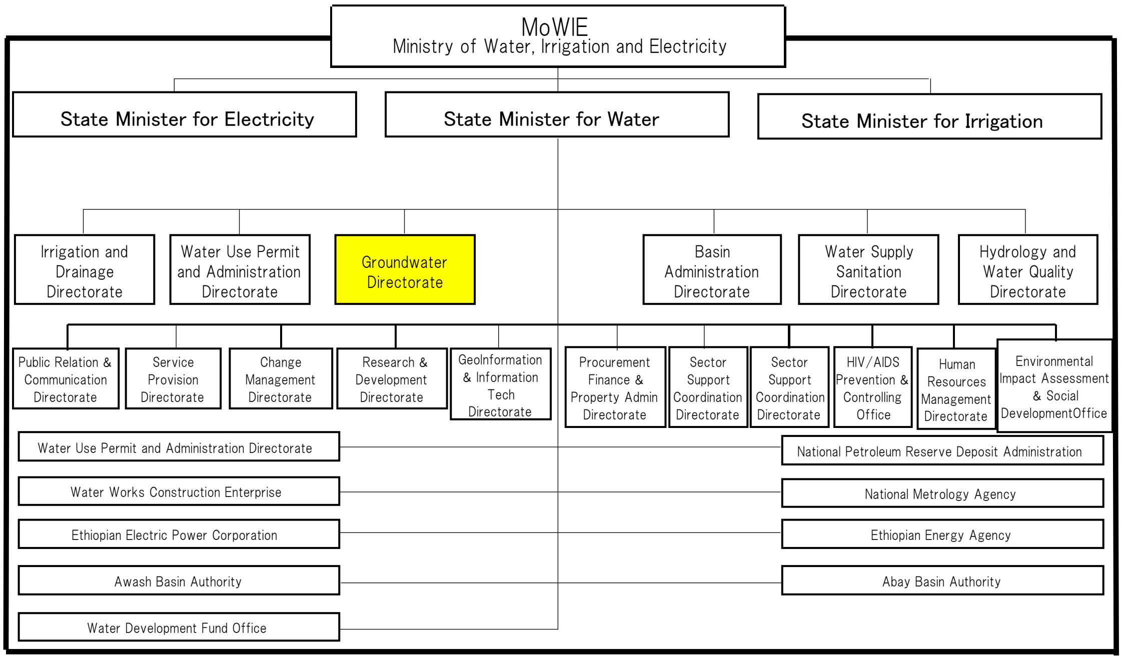
Zones in Oromia Region				
East Shewa	Arsi	Qelam	Illibabur	Jimma
North Shewa	West Arsi	Horo Guduru	West Hararge	Burayu Special zone surrounding A.A.
West Shewa	Borena	East Wallega	East Hararge	
South-west Shewa	Guji	West Wallega	Bale	

Source: the Project Team, Data: Result of survey in this Project

The majority of Project C/Ps belong to the Ministry of Water, Irrigation, and Electricity, and Oromia regional Water, Mines and Energy Bureau. The structure of these organizations is described below.

b.1 Ministry of Water, Irrigation and Electricity (MoWIE)

MoWIE started from 2013 September. It had been called as MoWE for 3 years from September 2010 to August 2013. The irrigation department was added at the time of this name change. In addition, the Energy department was changed to the Electricity department because of the organizational reformation of the Ethiopian government, which was conducted in October 2015. The organization structure of MoWIE is shown in Figure 2.3.2. The main C/P belongs to Groundwater Directorate.

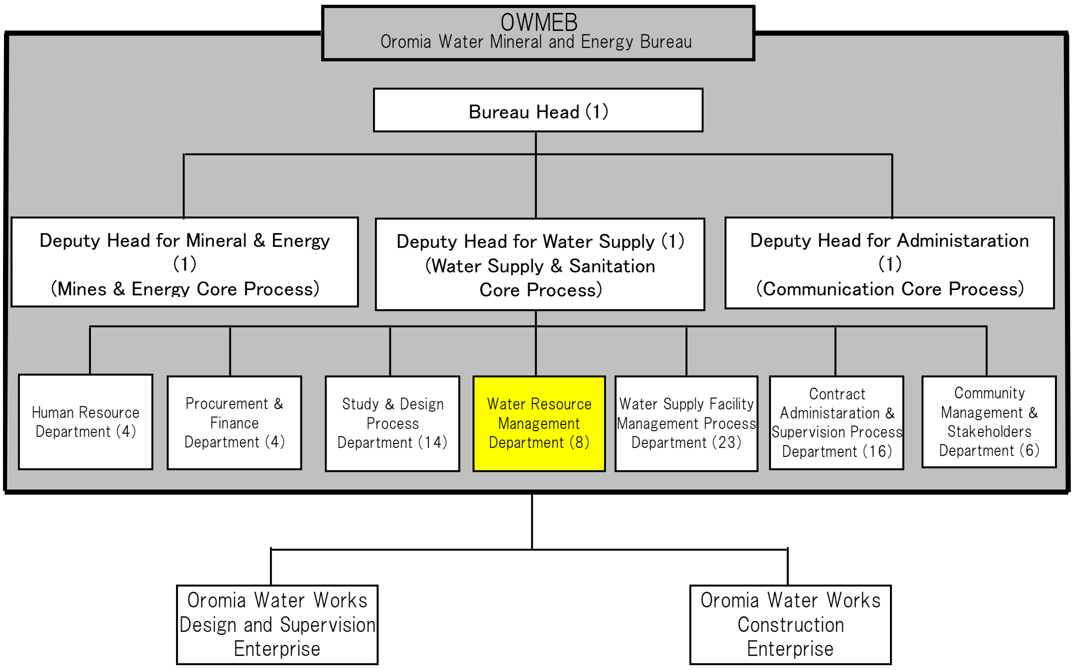


Source: MoWIE

Figure 2.3.2: Organization Structure of the Relevant Department in MoWIE

b.2 Oromia regional Water, Mines, and Energy Bureau (OWMEB)

In Oromia region, the department of water supply works includes Oromia regional Water, Mines and Energy Bureau. The organization structure is shown in Figure 2.3.3. OWMEB consists of three core processes, which are: mines and energy, water supply and sanitation, and communications.. This new structure was implemented in September 2013. The water supply and sanitation department is further divided into 7 units. The main C/P belongs to water resources management department.



Source: OWMEB
*Note: Some values in brackets are the number of staffs.

Figure 2.3.3: Organization Structure of the Relevant Departments in OWMEB

c. Regional economy

Oromia region is the largest region in the country, and agriculture is the basic industry after Addis Ababa. In 2012, 80% of regional population was engaged in agriculture, and agriculture contribution reaches 42% of total regional GDP.

More than 80 % of the male population is engaged in agriculture. The female population is engaged in other industries except agriculture.

In Oromia Region, there are not only agriculture resources but also tourism resource such as Awash National Park and Sodere hot springs, and water resource such as Awash River and Rift Valley lakes.

c.1 Agriculture

The main crops of agriculture production in Oromia Region are cereals. The other grains such as pulses and oilseeds are relatively little. The agriculture products in large quantities are sugarcane, coffee, potatoes, khat (preference crops) and cut flowers. In the middle of Awash River Basin, the national farms in large scale for sugarcane lie in Wonji/Wonji Shewa and Metehara. In case of livestock, main animals are cattle, sheep, goats, and poultry chickens.

c.2 Condition of social infrastructure (road, electricity, etc.)

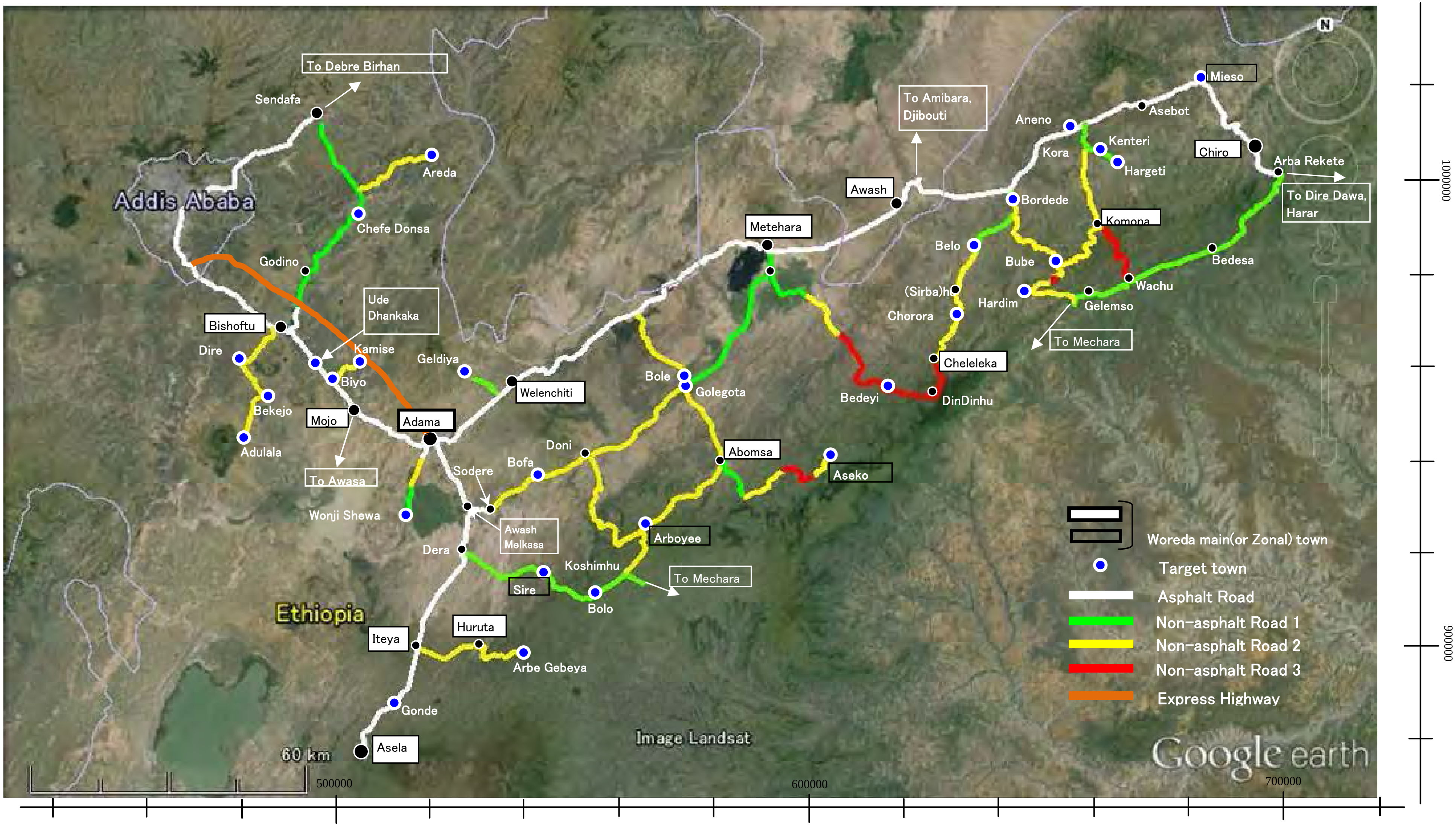
c.2.1 Road condition

Improvement of infrastructure to develop rural area economy is very important. The current infrastructure in the Middle Awash River Basin is described below.

Table 2.3.3: Characteristics of Legend between the Target Towns (for Access Route Map)

Type	Item	Characteristics
(white)	Asphalt Road	It is the most comfortable road to travel on. It is possible to travel at speeds of 50～80km/hr.
(green)	Non-asphalt road 1	Although it is non-asphalt road, the road surface is kept flat with heavy machineries. It is comfortably travelable all year. It is possible to travel at speeds of 30～50km/hr.
(yellow)	Non-asphalt road 2	It is non-asphalt road, and it is assumed that long time passed since its last road maintenance. The road surface is bumpy and it takes a long time to transit. It is possible to travel at speeds of 15～30km/hr.
(red)	Non-asphalt road 3	There would be considerable difficulty in passing this type of non-asphalt road. The road surface is very bumpy and there are many large and small stones on the road. Besides, the road is very steep. It is possible to travel at speeds of 10～15km/hr, however, it is not passable in the rainy season.

Source: the Project Team, Data: Result of survey in this Project



Source: the Project Team, Data: Google Earth

Figure 2.3.4: Location and Access Road for 30 Target Towns in Oromia Region

c.2.2 Electricity

The electricity of Oromia Region is mainly covered by the supply source of hydroelectric power. The power producer is Ethiopia National Electric Power Corporation. The electric supply sources of the project area in middle Awash River Basin are composed by hydropower, by wind power (over 50 units in Adama), and by thermal power. The electricity is supplied 24 hours in the area which has the electric.

However, the electric supply are still insufficient at major cities such as Adama and Bishoftu which causing a sudden black-outs especially in West Hararge zone.

c.2.3 Railway

Just like the highway construction, train railway construction project is being conducted by loan assistance from the Chinese Government. The construction project is being managed by Both Ethiopian Railway Corporation and China Railway Engineering Corporation. The construction period of each phase is as shown in Table 2.3.4.

Table 2.3.4: Construction Period and Route for Ethiopia-China Railway Project from Addis Ababa to Djibouti

Period	Route
(Phase 1) The EFY 2012 – 2015	Addis Ababa – Adama (Nazret)
(Phase 2) The EFY 2013 - 2016	Adama(Nazret) – Awash – Mieso
(Phase 3) The EFY 2013 - 2017	Mieso – Dire Dawa – Djibouti

Source: the Project Team, Data: Result of survey in this Project

2.3.3 Socio-economic conditions in the woredas with target small towns

In order to understand the current condition for the Project O&M performance, socio-economy and water supply of every woreda water management bureaus, interview surveys were conducted in 15 woredas for 30 target towns. The woredas are 6 in the East Shewa zone, 6 in the Arsi zone and 3 in West Hararge.

a. Ethnic group

Oromo people, the most common people in Oromia region, is the majority for all Woredas sharing 80% or more in 13 Woredas out of 15. Amhara people is the second majority. They share 30% in Sire Woreda and some 10% in other Woredas. Other than them, some few Guraghe (common in Southern Nations, Nationalities, and Peoples' Region; SNNPR) and Somali peoples are living. Afar and Tigray peoples can also be seen.

b. Education

The numbers of the schools as education facilities by objective Woredas are shown in Table 2.3.5. Average number of primary schools per Woreda is 41. The number of primary schools however has 18-folds difference among Woredas. There are 74 primary schools in Boset of East Shewa and are 4 only in Guba Qoricha of West Hararge, although the difference in the number of children (age 7-14) is some 2-folds only.

Table 2.3.5: Number of Schools in Woredas

No	Zone	Woreda	No. of Schools: Nursery Age0-6	Primary Age7-14	Secondary Age15-16	Preparatory Age17-18
1	East Shewa	Adama Zuria	5	18	6	1
2		Ada	6	36	25	1
3		Boset	0	74	1	1
4		Lume	3	65	1	1
5		Gimbichu	2	49	1	1
6		Liben Zikuala	0	47	1	0
7	Arsi	Sire	1	28	1	1
8		Jeju	1	28	1	1
9		Aseko	2	44	3	1
10		Merti	0	33	1	0
11		Tiyo	6	38	2	1
12		Lodehetosa	5	47	3	0
13	West Hararge	Anchar	13	39	4	2
14		Guba Qoricha	0	4	1	0
15		Mieso	3	59	2	1
		Total	47	609	53	12
		Average	3	41	4	1

Note: School in Ethiopia includes nursery school (as kindergarten), primary school (class1-8), secondary school (class 9-10) and preparatory school (vocational school; class11-12).

Source: the Project Team, Data: Result of socio-economic survey in this Project

The numbers of children and the school attendance are shown in Table 2.3.6.

Table 2.3.6: Numbers of Children and the School Attendance in Woredas

No	Zone	Woreda	No. of Children: Age 0-6	No. of Children: Age 7-14	No. of Children: Age 15-18	No. of School Attendance: Nursery sc. Age 0-6	Primary sc. Age 7-14	Secondary & Preparatory Age 15-18	School attendance rate of Age7-14 unit(%)
1	East Shewa	Adama Zuria	34852	34568	12000	2350	32156	3336	93.0
2		Ada	25649	33621	N.A	564	29720	555	88.4
3		Boset	33501	44665	22690	0	24479	1907	54.8
4		Lume	22047	31080	N.A	1800	28101	405	90.4
5		Gimbichu	24574	21074	N.A	109	18250	0	86.6
6		Liben Zikuala	18667	18659	12094	0	14344	843	76.9
7	Arsi	Sire	17954	18345	7623	102	17504	1649	95.4
8		Jeju	22413	27736	18811	199	26072	1891	94.0
9		Aseko	10210	21886	8513	400	10957	1451	48.0
10		Merti	20068	22828	10530	704	10945	955	47.9
11		Tiyo	12707	27758	11043	333	24123	1319	86.9
12		Lodehetosa	21130	26575	11884	1049	21871	3440	82.3
13	West Hararge	Anchar	15655	16789	9581	0	8478	867	50.5
14		Guba Qoricha	25020	22400	N.A	0	9124	676	40.7
15		Mieso	29261	35075	13039	202	21283	1254	60.7
		Total	279427	345584	124769	7610	267000	18618	
		Average	22247	26871	12528	710	19827	1468	73.1
		Ave(E.Shewa)	26548	30611	15595	804	24508	1174	81.7
		Ave(Arsi)	17414	24188	11401	465	18579	1784	75.8
		Ave(W.Hararge)	23312	24755	11310	67	12962	932	50.6

Source: the Project Team, Data: Result of socio-economic survey in this Project

Attendance rate for primary school is about 73% in average for all objective Woredas. The rate is lower in West Hararge, that reaches about 50% only. The attendance rate in 4 Woredas out of 6 is beyond 75% both in East Shewa and Arsi zones, while that is around 60% or less in all Woredas in West Hararge zone.

Average number of children with age of 7 to 14 per primary school ranges between 400 to 900. On the other hand, because of small number of the primary schools, the number of chidlen per school reaches up to 1,920 and 5,600 in Woredas Adama Zuria (East Shewa) and Guba Qoricha (West Hararge), respectively.

c. Agriculture and land use

The composition of land use conditions is shown in Table 2.3.7. The agricultural crops, livestock numbers, livestock facilities numbers in the year of 2013 are shown in Table 2.3.8, Table 2.3.9, and Table 2.3.10.

Table 2.3.7: Composition of Land Use Conditions in Woredas

			Land use (ha)					
No	Zone	Woreda	Agriculture	Forest	Water Facility	House area	Road	Others
1	East Shewa	Adama Zuria	58,410	4,210	14,033	8,450	N.A	1,017
2		Ada	71,923	6,012	2,693	N.A	N.A	7,751
3		Boset	55,506	7,475	3,418	10,408	N.A	17,487
4		Lume	47,660	3,306	10,792	4,994	N.A	8,468
5		Gimbichu	48,798	3,003	8,258	N.A	N.A	15,015
6		Liben Zikuala	43,504	6,960	640	415	N.A	12,054
7	Arsi	Sire	29,400	2,371	1,200	4,742	N.A	9,707
8		Jeju	36,808	3,217	617	N.A	N.A	N.A
9		Aseko	16,733	12,675	502	91	N.A	N.A
10		Merti	3,200	N.A	N.A	N.A	N.A	N.A
11		Tiyo	25,900	13,000	3,200	65	3,300	129
12		Lodehetosa	28,422	2,744	4,657	N.A	N.A	10,176
13	West Hararge	Anchar	15,190	42,520	N.A	N.A	N.A	10,682
14		Guba Qoricha	17,252	3,800	N.A	5,424	N.A	35,729
15		Mieso	24,737	61,608	N.A	N.A	N.A	105,067

Source: the Project Team, Data: Result of socio-economic survey in this Project

The area of agricultural land reaches about 44% and forest covers about 16%. Sixty (60) percent of the land is therefore shared by these two types. Land area categorized in “Others” is large in Woredas such as Guba Qoricha and Mieso. This is because the area of glassland is also included in this category.

Table 2.3.8: Main Crops Yield of Agriculture in 2013 in Woredas

			Field area and Harvest of Main Crops											
			Maize		Sorghum		Teff		Wheat		Barely		Others	
No	Zone	Woreda	Land(ha)	Amount(ton)	Land(ha)	Amount(ton)	Land(ha)	Amount(ton)	Land(ha)	Amount(ton)	Land(ha)	Amount(ton)	Land(ha)	Amount(ton)
1	East Shewa	Adama Zuria	1,287	5,736	333	1,195	11,548	21,350	3,920	13,015	2,953	10,335	5,321	13,800
2		Ada	613	4,960	N.A	N.A	26,545	66,993	17,834	118,566	-	-	26,087	95,090
3		Boset	9,002	14,938	611	166	16,571	40,810	185	177	163	195	25,851	38,163
4		Lume	955	2,845	N.A	N.A	15,721	37,003	14,438	58,928	1,193	4,067	8,366	65,775
5		Gimbichu	209	842	261	628	2,231	4,573	4,047	100,997	336	1,176	14,783	34,221
6		Liben Zikuala	7,128	27,415	600	2,104	14,828	33,380	15,080	5,081	981	2,588	4,878	9,801
7	Arsi	Sire	2,200	4,288	80	202	5,780	6,948	10,200	22,745	54,800	72,412	5,690	46,766
8		Jeju	2,600	12,117	1,400	4,302	13,800	24,170	N.A	N.A	N.A	N.A	15,907	45,916
9		Aseko	1,356	7,954	1,776	9,566	577	837	N.A	N.A	N.A	N.A	29,667	2,402
10		Merti	4,074	17,926	4,365	14,577	5,802	10,001	14,454	32,850	N.A	N.A	3,245	96,350
11		Tiyo	890	4,048	0	0	12,150	20,920	13,650	31,011	5,400	13,508	4,420	8,903
12		Lodehetosa	455	1,674	57	25,660	26,570	42,257	15,754	71,316	9,016	18,390	7,084	38,019
13	West Hararge	Anchar	3,780	12,666	N.A	N.A	162	255	752	1,718	559	978	4,231	46,172
14		Guba Qoricha	0	9,335	N.A	20,615	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A
15		Mieso	3,020	1,371	14,259	12,433	N.A	N.A	N.A	N.A	39	10,237	N.A	N.A
		Total	37,569	128,115	23,742	91,448	152,285	309,497	110,314	456,404	75,439	133,886	155,530	541,378

Source: the Project Team, Data: Result of socio-economic survey in this Project

In terms of main crops, teff and wheat are dominant both in area and yield bases. Teff shares about 27% and wheat shares about 20% in cropping area. The former shares about 19% and the latter shares about 28% in yield amount.

Table 2.3.9: Number of Livestock in Woredas

			No. of Livestock								
No	Zone	Woreda	Cattle	Goat	Sheep	Donkey	Chicken	Horse	Mule	Camel	Other
1	East Shewa	Adama Zuria	97,000	49,970	41,700	39,135	17,053	500	411	215	-
2		Ada	137,805	633,410	31,033	39,814	N.A	2,431	1,473	N.A	-
3		Boset	86,616	90,680	45,167	26,253	79,395	812	673	5,477	-
4		Lume	91,314	23,101	23,652	21,619	N.A	316	819	N.A	-
5		Gimbichu	106,115	39,301	44,521	26,493	51,325	5,712	906	15	-
6		Liben Zikuala	170,258	51,346	24,138	20,980	N.A	1,598	1,666	N.A	-
7	Arsi	Sire	77,206	27,206	65,584	20,709	56,339	4,473	761	4,464	-
8		Jeju	130,989	35,951	103,276	16,145	82,034	N.A	1,336	1,369	-
9		Aseko	92,038	88,270	95,447	32,853	105,214	N.A	N.A	3,354	-
10		Merti	93,371	52,323	26,781	9,200	99,715	N.A	N.A	25,210	11,349
11		Tiyo	92,711	12,050	63,033	18,356	55,320	8,937	542	N.A	-
12		Lodehetosa	112,856	33,908	146,492	35,195	121,923	7,952	1,833	N.A	-
13	West Hararge	Anchar	69,273	118,006	37,610	15,729	7,880	155	100	139	8,219
14		Guba Qoricha	67,364	70,298	23,896	17,439	81,605	128	N.A	2,921	-
15		Mieso	131,908	1,114,276		12,180	63,112	16	4	39,694	-
		Total	1,556,824	1,882,958	1,329,468	352,100	820,915	33,030	10,524	82,858	19,568

Source: the Project Team, Data: Result of socio-economic survey in this Project

Goats (31%), cattle (26%) and sheep (22%) are the dominant livestocks in all Woredas. Chickens share approx. 13% in the numeral basis. Number of camels is larger in Merti (Arsi zone) and Mieso (West Hararge zone).

Table 2.3.10: Number of Agriculture and Livestock-related Facilities

No	Zone	Woreda	No.of Agro-pastral facilities: Livestock Health Post	Cattle Trough	Farming Training Center	Agro-Extension House
1	East Shewa	Adama Zuria	5	3	7	7
2		Ada	4	5	4	4
3		Boset	2	3	3	1
4		Lume	3	2	5	3
5		Gimbichu	3	0	2	2
6		Liben Zikuala	1	0	2	2
7	Arsi	Sire	1	0	1	1
8		Jeju	6	9	20	91
9		Aseko	5	4	15	12
10		Merti	45	3	17	5
11		Tiyo	1	0	3	3
12		Lodehetosa	1	0	3	3
13	West Hararge	Anchar	8	6	19	137
14		Guba Qoricha	4	0	4	2
15		Mieso	16	132	28	90

Source: the Project Team, Data: Result of socio-economic survey in this Project

There are no clear pattern in the number of agricultural and livestock-related facilities. The number of livestock health posts are the largest with 45 in Merti Woreda. All facilities are many in Mieso, while few facilities are available in Liben Zikuala and Sire.

d. Health and Hygiene

The reporting numbers of water-related diseases at the health center of every 15 woredas for target towns are shown in Table 2.3.11. And, the types and the number of latrine as hygiene facilities are shown in Table 2.3.12.

Table 2.3.11: Number and Type of Water-related Diseases in Woredas

No	Zone	Woreda	Diarrhea	Typhoid	Malaria	Dysentery	Others
1	East Shewa	Adama Zuria	5,627	5,225	3,188	N.A	
2		Ada	2,042	N.A	N.A	N.A	
3		Boset	1,050	N.A	2,790	N.A	
4		Lume	1,250	870	5,687	N.A	
5		Gimbichu	379	171	N.A	N.A	
6		Liben Zikuala	2,170	N.A	2,598	N.A	
7	Arsi	Sire	450	250	N.A	450	
8		Jeju	850	223	850	N.A	
9		Aseko	218	122	212	231	
10		Merti	4,086	4,710	4,826	834	
11		Tiyo	N.A	594	N.A	189	
12		Lodehetosa	730	N.A	N.A	N.A	
13	West Hararge	Anchar	1,245	N.A	935	N.A	1,095 (Parasites etc.)
14		Guba Qoricha	329	128	241	72	
15		Mieso	1,563	N.A	583	55	
		Total	21,989	12,293	21,910	1,831	

Source: the Project Team, Data: Result of socio-economic survey in this Project

Diarrhea and malaria are the major diseases. Both share about 38% each. Typhoid, which shares about 21%, is also the major disease.

Table 2.3.12: Type and Number of Latrine Facilities in Woredas

			No.and type of Sanitary facilities				
No	Zone	Woreda	Simple pit	Ventilated pit	Flush latrine	Compost pit	Other
1	East Shewa	Adama Zuria	9,675	420	N.A	N.A	233
2		Ada	8,250	1,500	N.A	N.A	15,850
3		Boset	5,230	N.A	N.A	N.A	3,230
4		Lume	5,450	N.A	N.A	N.A	-
5		Gimbichu	2,358	N.A	N.A	N.A	-
6		Liben Zikuala	5,250	N.A	N.A	N.A	-
7	Arsi	Sire	2,580	N.A	N.A	N.A	890
8		Jeju	2,534	17,110	N.A	19,644	-
9		Aseko	15,368	13,542	N.A	N.A	-
10		Merti	16,809	88	54	N.A	-
11		Tiyo	N.A	N.A	N.A	N.A	-
12		Lodehetosa	3,580	N.A	N.A	N.A	3,500
13	West Hararge	Anchar	9,492	N.A	N.A	N.A	-
14		Guba Qoricha	22	N.A	N.A	N.A	-
15		Mieso	2,966	N.A	N.A	N.A	-

Source: the Project Team, Data: Result of socio-economic survey in this Project

Simple pit is dominant in the objective Woredas, while ventilated pit is relatively common in the Woredas such as Jeju and Aseko.