

Ministry of Water & Energy (MoWE)
The Federal Democratic Republic of Ethiopia

**THE STUDY ON GROUNDWATER RESOURCES
ASSESSMENT IN THE RIFT VALLEY LAKES BASIN
IN THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA**

FINAL REPORT

MAIN REPORT

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Executive Summary

1. Background of the Study

Ethiopia launched the Universal Access Program (UAP) in 2005 due to its low rate of access to safe water, which at the time in rural and urban areas remained at approximately 38%. The UAP aims to achieve water supply coverage of 98% in rural areas and 100% in urban areas by 2012. After that the target year was changed to 2015 and water supply coverage of 100% in both rural and urban area. Presently, however, there is a lack of information to accurately grasp the abundance of groundwater resources in Ethiopia, having an adverse effect on the sustainable use and effective development of groundwater resources. Meanwhile, out of the need to acquire information on groundwater potential for water resource development, Ethiopia has worked towards capacity development through its national master plan—the Ethiopian Groundwater Resources Assessment Program (EGRAP)—by establishing the Ethiopia National Groundwater Database (ENGDA), implementing a survey of groundwater potential, making hydrogeological maps and founding the National Groundwater Institute (NGI). However, due to its ineffective operation, an improved plan was re-established until the end of phase-3 in 2014, with phase-1 of the new program EGRAP+ (or new EGRAP) starting from 2007 until 2010, in an attempt to revitalize it. The EGRAP+ activates the discussion for the introduction of ENGWIS (Ethiopian National Groundwater Information System), because of the establishment of a GIS/Database system.

Based on the above background, the Government of Ethiopia requested the Government of Japan to implement a survey on groundwater potential with the purpose of making hydrogeological maps for the Walikte, Wolisso and Ambo areas, and a development study with the purpose of technology transfer to relevant engineers.

In response, JICA dispatched a Preliminary Study Team in December 2008, and a Detailed Planning Team in July 2009; narrowed the target area to the Rift Valley Lakes Basin, and at the same time made a Study Plan, the content of which includes grasping this area's groundwater potential, producing hydrogeological maps, and establishing water supply plans for small towns in the target area. Wherein, the Scope of Works (S/W) was signed and exchanged in July 2009.

This Study will contribute towards achieving the goals of EGRAP+ and UAP by implementing a study on groundwater potential in the Rift Valley Lakes Basin—the result of which will be hydrogeological maps of this area and the establishment of water supply plans.

2. Evaluation of Groundwater Potential and Making Hydrogeological Maps

The main objective of this Study is to implement a survey to evaluate the groundwater potential of the major aquifers, to produce hydrogeological maps for the Rift Valley Lakes Basin (hereafter RVLB).

(1) Physiography and Meteorology & Hydrology

The RVLB is located about 190 km south of the capital Addis Ababa. It is bounded by the limits of $37^{\circ}00'$ – $39^{\circ}30'$ east longitude and $5^{\circ}00'$ – $8^{\circ}30'$ north latitude. The area is topographically characterized by a depression zone with steep marginal faults along its edges. The area of the basin is about $53,000\text{km}^2$. The main lakes are Ziway, Langano, Abijata, Shalla, Awassa, Abaya, Chamo, and Chew Bahir in RVLB. Most lakes were formed by tectonic activities or by caldera. The major basin will be divided into the following four

major groups: 1. Ziway-Shalla Basin, 2. Awassa Basin, 3. Abaya-Chamo Basin, 4. Chew Bahir Basin. The four main basins were further divided into 14 (fourteen) sub-basins. RVLB is a closed basin independent from the surrounding basins. The result of hydrological analysis conducted with groundwater modeling indicate that evaporation from the lake surface accounts for about 95% of the annual average evaporation amount from the entire basin. Daily flow data from 36 stations were collected. The main patterns are characterized by a high level of correlation with the precipitation pattern of rainy and dry seasons in the same area. Regarding meteorological factors, firstly precipitation, the average annual rainfall amounts range from 492mm for minimum value to 2,582mm for maximum value. The average of the 72 stations in the rift valley basin is 1,079mm. The rainy season is July to September for most of Ethiopia, but in RVLB the rainy season is unclear. The values of monthly Average Evaporation from four out of five stations are relatively close to each other, ranging between 1,395mm for minimum value and 1,963mm for maximum value. The average annual temperature for all 52 stations used for the analysis is 19.6 °C.

The RVLB consists of SNNPR and Oromia Region with a population of about 9.0 million (as of 2006). The main industries are agriculture, manufacturing, and services in RVLB.

(2) Topography and Geology

The study area belongs to the **African Rift**. The African Rift originates from Aden Junction and continues in the direction of SW- SSW, traversing longitudinally eastern African countries such as Djibouti, Eritrea, Ethiopia, Kenya, Uganda, and Tanzania. The Rift Valley Lakes Basin could be divided into two areas in a large sense. The northern portion of the area around the lakes of Ziway to Awassa is almost flat in the valley bed. The southern area, from Lake Abaya to Chew Bahir, has relatively precipitous terrain. The geological structures are characterized by two major rifts, the Main Ethiopian Rift (MER) and the South-western Ethiopian Rift (SWR), both of which are encompassed in RVLB.

The oldest volcanic activities are basalt and rhyolite flows in Oligocene, by middle Miocene, the rift was formed in some parts with containment basaltic flows. In Pliocene, a huge pyroclastic flow covered the northern part of the study area. In Pleistocene, Wonji Fault Belt (WFB), which is the main spreading axis of MER, is formed at the rift floor, and floor basalt and rhyolite are erupted along WFB. The history of volcanic activity in RVLB is that the large rhyolitic calderas and volcanic chains composed of separate basaltic lava domes are observed. The volcanic activities are mainly recognized in late Pliocene to early Pleistocene stage and in middle Pleistocene to recent stage.

A reliable hydrogeological map was created based on a detailed geological map. Therefore, in the preliminary survey of geology in the field, the RVLB was divided into seven areas in accordance with the aspects of geology and distribution. The strata of each area were correlated based on the specific geology (a key bed), and the correlation chart was described. Finally, the stratigraphy in RVLB was created and the geological map was completed in the RVLB.

(3) Groundwater Potential and Hydrogeology

Three (3) aquifers were identified by the study of existing well inventory, new borehole data and the geological survey. The aquifers are classified into the following criteria.

Aquifer 1 [Alluvium and lacustrine deposits] = 1B – 1C

Aquifer 2 [Pleistocene tuff, tuff breccia and basaltic rock units] = 3A – 3B (tuff = 1B)

Aquifer 3 [Plio-Pleistocene tuff and basalt] = 3A – 3C

According to the Discharge (Q, l/sec), Specific Capacity (l/min/m) and Transmissivity, aquifer 2 gave highest score in discharge, specific capacity and transmissivity. Basaltic tuff breccia – volcanic breccia scored mean discharge of 6.3 l/min, mean specific capacity of 134 l/min/m and mean transmissivity of 242 m²/day. Aquifer 1 is also a good aquifer according to its nature of formation (sand, gravel). Most of this aquifer is shallow and unconfined. It should be noted that this aquifer is easily affected by surface pollution as well as seasonally affected by the water table. Aquifer 3 is mainly distributed at the southern portion of entire study area. This aquifer is also stored in fissure in the volcanic rock. The distribution of this rock unit is said to be very limited. The aquifer mainly occupies at the southern part of the study area, and it may become a potential aquifer in those remote areas in the south.

The aquifer classification is shown in Table 1. The hydrogeological map was made based on this classification.

Table 1: Aquifer Classification in RVLB

Period/Epoch	Stratigraphy	Name of strata	Major Lithology	Aquifer Code	Nature of Aquifer	Remarks
Cenozoic	Quaternary	Al / Q	Alluvium, unclassified fluvial deposits	1B	Aquifers with intergranular permeability	Good permeability at the sand layer and aquiclude at clay
		lac 2	Bulbula Lacustrine Deposits	1C	Aquifers with intergranular permeability	Permeability is high at sand and gravel. Clayey layer may become aquicard
		Pm _{volcan}	Corbetti Pumice Flow & Fall Deposits/ Corbetti Rhyolite	3C	Aquifers with fracture permeability	It may be good aquifer if the lower layer become aquicard
		rb	Butajira Recent Basalt	3C	Aquifers with fracture permeability	Low permeability at the massive basalt. It may be good aquifer if the lower layer become aquicard
		lac 1	Meki Lacustrine Deposits	1B	Aquifers with intergranular permeability	It may be good aquifer if the lower layer become aquicard
	Pleistocene	Y	Langano Poorly Welded Pumiceous Pyroclastics	1B	Aquifers with intergranular permeability	Partially good aquifer at the existance of lower aquicard
		ob	Kulmusa Highly Welded Tuff	3B	Aquifers with fracture permeability	The lower aquicard is essential, however it has good potential aquifer
		W	Ketar River Acidic Volcanic Sedimentary Rocks	1B	Aquifers with intergranular permeability	The permeability is high knowing that the massive aquicard existance at lower layer
		G	Gonde Strongly Green Welded Tuff	3A	Aquifers with fracture permeability	The fractures and fissures are well developed and form good aquifer in the area
		tb	Adami Tulu Basaltic Pyroclastics	3A	Aquifers with fracture permeability	The fractures and fissures are well developed and form good aquifer in the area
	Tertiary	ba	Ogolche Pleistocene Basalt	3B	Aquifers with fracture permeability	Even massive basalt, fracture and fissures are partially developed. The fissure zones are recognized as good aquifer
		lak e	Lekansho Lacustrine Deposits	1C	Aquifers with intergranular permeability	Semi consolidated formation. Partially good aquifer has been formed
		rh	Gademotta Rhyolite	3A-3C	Aquifers with fracture permeability	The layer is defined as the upper portion of hydrogeological basement. Fracture basalt, rhyolite and permeable pumice layer has capacity of good aquifer
		N2b	N2b Basal	3A		
		NQs	NQ s Rhyolite	3C		
	Miocene	rht/N1_2n	N1_2n Rhyolite	3C	Localized aquifers with fracture and intergranular permeability	The basic nature of these formations are not clearly understood. Alternation of basalt and rhyolitic tuff. The possible aquifer may be locally developed fracture rich rocks and tuff
		N1n	N1n Basalt	3B		
		N1ar	N1ar Rhyolite	3B		
		Ngs	Sharenga Rhyolite	3C		
		Ngu	Upper Basalt	3C		
	Eocene-Orogenic	Ngb	Beyana Tuff	3C	Localized aquifers with fracture and intergranular permeability	
		Ngm	Middle Basalt	3C		
		Pgs	Shole Welded Tuff	3C		
		Pgl	Lower Basalt	3C		
		Mes	Adigrat Sandstone, Antaro Limestone	4D		
Pre-Cambrian	Pre	Biotite Gneiss, Pegmatite	Biotite Gneiss, Granite, Biotite Metagranite	4D	Localized aquifers with fracture and intergranular permeability	

References: (1) Laury and Albritton 1975, (2) Mohr et al. 1980, (3) EIGS-GLE 1985, (4) Woldegabriel et al. 1990, (5) GSE 1994, (6) GSE 2002, (7) EWTEC 2008

The possibility of groundwater development based on the hydrogeological map is as follows below;

a. Unconsolidated Quaternary sediments surrounding Rift Valley Lakes

Lacustrine deposits (lac2, lac1) are represented by sand, gravel, and mud layers which are distributed in the areas surrounding Lake Ziway to Lake Awassa, Lake Abaya, Lake Chomo

and Chew Bahir (with some salt lakes). Quaternary sediments (Al, Q = sand, mud and gravel) are distributed around the lakes and rivers. The high groundwater potential areas in this type of deposits are distributed at relatively highland areas to the northeast to east of Lake Ziway and lowland west of Lake Ziway, in particular, alluvial and Lacustrine deposits were recognized widely and thickly in western area of Lake Ziway with high groundwater potential, and the areas of flat along the Bilate River and northern Lake Abaya also have high groundwater potential.

b. Hydrogeological condition of northern Pleistocene volcanic zone

The main aquifer in this area is Pleistocene tuff, tuff breccia and basaltic rock units which printed as light blue color in the Hydrogeological map. Early Pleistocene volcanic deposits, rhyolitic tuff – tuff (W), rhyolite – andesitic welded tuff (G), basaltic tuff breccia – volcanic breccia (tb), basalt (ba), are the most promising potential aquifers in the entire Study area. Hydrogeological map seems to be covered with the rhyolitic tuff – tuff (W) layer, but it should be noted that the other volcanic members exist underneath. High potential areas for water extraction are to the north of Lake Abaya that are chiefly occupied by this type of volcanic rocks. Specific areas are at the intersection of eastern escarpment to central plain and valley east of Lake Ziway to east of the Bilate River, and at the intersection of western escarpment to central plain of rift valley of Awassa to Dila.

c. Hydrogeological condition of southern Tertiary volcanic and basement

Major lithology of this rock unit is alteration of Tertiary basalt and rhyolite and its members. Mesozoic sandstone, limestone (Mes) and Precambrian biotite gneiss, granite (Pre) are also observed in limited area. These formations considered to be the hydrological basement rocks in the entire basin. Plio Pleistocene fissure rich rhyolite lava and tuff (rh) are potential storage for groundwater. Basalt lava and basaltic pyroclastics (N2b) are also considered as potential aquifers. There are some other potential aquifers such as tuff and basalt (N1n) and rhyolite and basaltic lava (N1ar), and the JICA observation wells obtained the high productivity as the results of pumping test in the distributed area of old basalts (Pgl) at Arba Minch and its surrounding area. But the continuity of these layers is unclear and not well understood. The potential of the aquifer is limited by its means of production. The well information in this area is very limited, therefore the qualitative feature and the flow direction of aquifer is not known. It shall be noted that further investigation is required by conducting more drilling and adding inventory.

(4) Groundwater recharge

The recharge amount can be estimated by the calculation of groundwater discharge amount using equality of the recharge and discharge amounts in a long hydrological cycle. The river water is formed by surface runoff from the precipitation and groundwater discharge to the river. The former is the surface runoff and interflow, the latter is discharge into rivers, discharge into lakes, and discharge to outside the basin, and so on. The most important component is considered to be the discharge into river streams. The two methods (programs: PART (USGS,2007) , RAT (Monash University, 2006)) in this study were selected because both are considered to be reliable and used to separate the groundwater (base flow) component and direct runoff component from daily river flow data. The Table 2 was shown as the groundwater recharge (= Base flow) calculated using the evaporation in each lake that the rainfall was subtracted multiplied by BFI (Base Flow Index).

Table 2: Groundwater Recharge Amount in Major Lake Basins in RVLB

Sub-basin	Ziway	Langano	Abijata	Shalla	Awassa	Abaya	Chamo	Chew Bahir
Groundwater recharge	611.1	285.5	66.6	54.8	43.1	377.4	199.0	315.7

(Unit: Mm³/year)

(5) Future Simulation by Groundwater Models

The simulation of groundwater models was executed in the selected four sub-basin (Ziway-Shalla, Bilate, East Abaya, and West Abaya). The calibration results of the groundwater models reflected the actual conditions in each sub-basin. Also, the fluctuation calculation of groundwater level was executed in accordance with the usage of groundwater in future using the groundwater model. Consequently, the drawdown of groundwater is max. 5.6m (average 1.3m) and the area is limited in case of using the maximum yield of four scenarios. It means it has a very low impact on the groundwater environment.

3. Water Supply Plan

The water supply plan was drawn out for the all small towns requested from two regions with a population of less than about 10,000 people in RVLB using the hydrogeological map.

(1) Water Supply Plan for Requested Small Towns

The number of requested small towns is 82 (SNNPR: 52, Oromia Region: 30), and the water supply plan can be planned. The main necessity items are as follows: 1) Target year: 2015, 2) Water demand unit: 20L/c/d, 3) Water source: groundwater, 4) Models of water supply facilities: 10 types. The issues of O&M in the existing water supply committee are lack of necessary manpower, keeping the records and information and water tariff reviewed based on budget balance. Technically, the shortage of water supply amount occurs because of the aging water supply facilities and the occurrence of water leakages. The facilities are not performed appropriate repair, maintenance, accounting due to the lack of the technical and administrative knowledge. The water supply plan for requested 82 small towns with the substantial plan of O & M is as follows;

Table 3: Approximate Size (Items) of Water Supply Facilities of 82 small towns

Requested	Small Town	Population	Well	Pump	Total Pipes	Tank	Tap	Project Expence
	number	2015	nos.	nos.	km	nos.	nos.	USD
SNNPRS	52	323,204	108	108	494.3	56	923	65,011,594
Oromia R.	30	227,695	62	62	394.5	33	651	49,084,101

1USD=75.85Yen (November 2011JICA Exchange Rate)

(2) Water Supply Plan for High Priority Small Towns

The classification and prioritization of small towns were conducted to decide on the priority of implementation in regard to the water supply plan of requested small towns. Prioritized small towns are extracted by the next categories such as ground water potential, water quality, water coverage, beneficiary population & ratio. Small towns selected finally are: 11 towns in SNNPR and 9 towns in Oromia Region. The water supply plan for the high priority small towns is as follows;

Table 4: Approximate Size (Items) of Water Supply Facilities of High Priority small towns

High Priority	Small Town	Population	Well	Pump	Total Pipes	Tank	Tap	Project Expence
	number	2015	nos.	nos.	km	nos.	nos.	USD
SNNPRS	11	71,770	21	21	86.9	13	205	162,229
Oromia R.	9	63,354	23	23	113.2	10	181	143,205

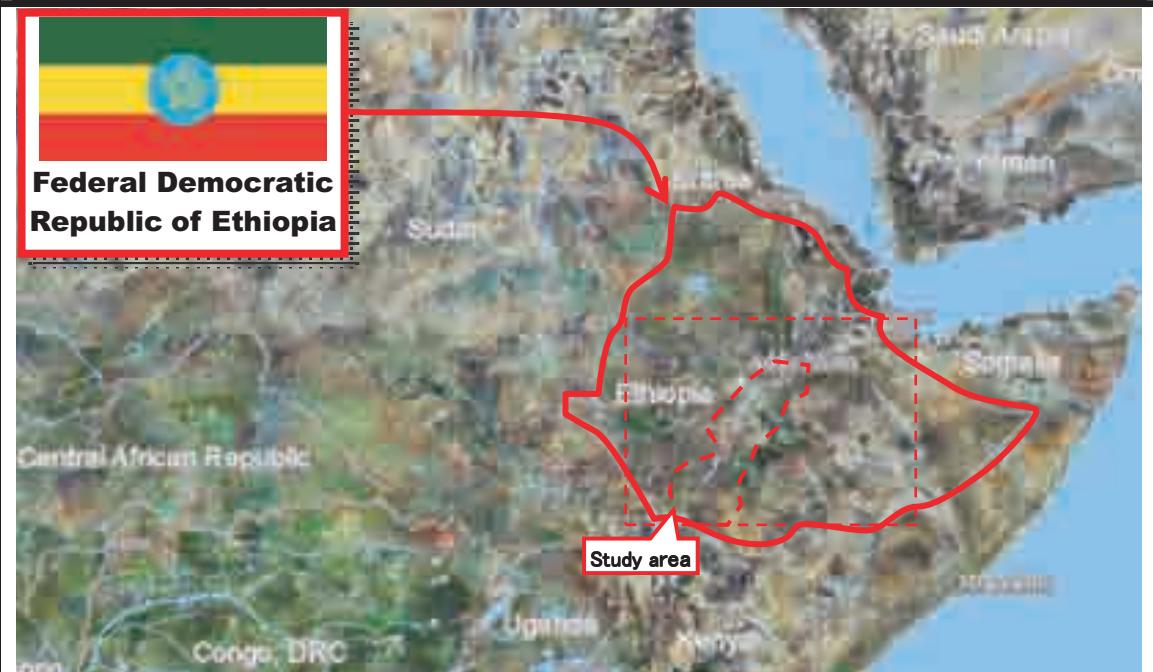
1USD=75.85Yen (November 2011JICA Exchange Rate)

The evaluation for the high priority small towns was executed based on the socio-economic evaluation. The result was that the ATP (Ability to Pay) cost went over the O&M cost. Moreover, organization and institutional evaluation, natural/social environmental evaluation and technical aspects were also no problem for the water supply plan.

4. Technology Transfer Workshop

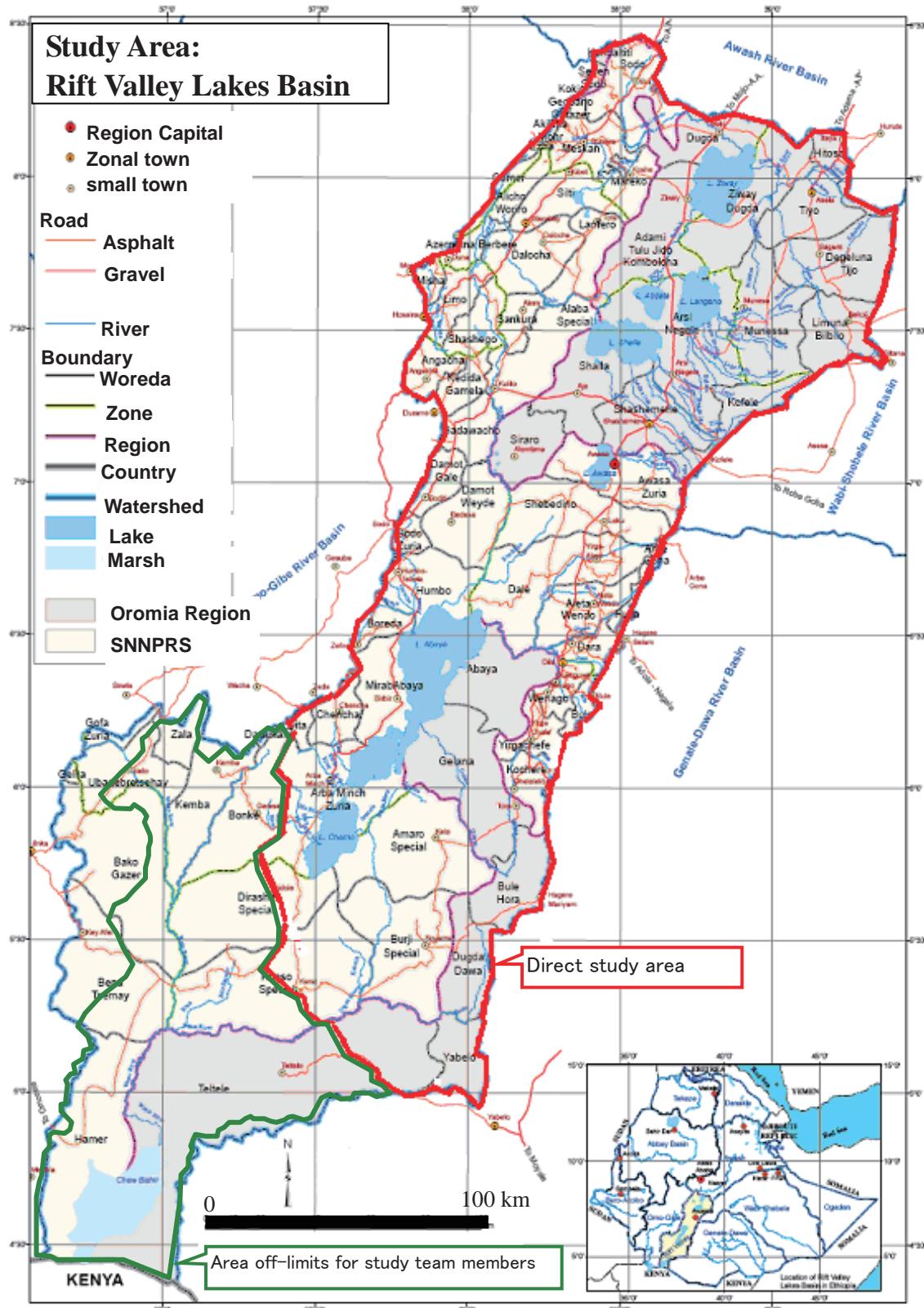
The workshop was performed as a part of technology transfer to the implementation agency, C/P of the EWTEC, GSE and AAU and private companies associated with the C/P personnel. The C/P personnel basically have a high level of attainment and knowledge, so the actual technical contents were transferred in collaboration with them. In fact, the TEM training was conducted with TEM machines, the field survey in RVLB for the volcanic geology workshop, the software training was held using the GIS and groundwater modeling, and the isotopic workshop actually used the isotopic analysis machine at AAU.

Location of Ethiopia



Location of Study Area





C O N T E N T S

Executive Summary

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LIST OF ABBREVIATIONS

AAWSA	Addis Ababa Water Supply and Sewerage Authority
AAU	Addis Ababa University
AFD	Agence Française de Développement
BoFED	Bureau of Finance and Economic Development
CIDA	Canadian International Development Agency
CPI	Consumer Price Index
CRS	Catholic Relief Services
CSA	Central Statistical Agency
DfID	Department for International Development
DTH	Down the Hole Hammer
EAP	Economically Active Population
EIA	Environmental Impact Assessment
EIGS	Ethiopian Institute of Geological Survey
ENGDA	Ethiopian National Groundwater Database
ENGWIS	Ethiopian National Groundwater Information System
EPE	Environmental Policy of Ethiopia
EPSA	Ethiopian Postal Service Agency
EROAM	Economic Resources Optimization and Allocation Model
ETC	Ethiopian Telecommunications Corporation
EU	European Union
EWTEC	Ethiopian Water Technology Center
FINDA	Finnish Development Agency
GDP	Gross Domestic Product
GEF	Global Environmental facility
GIS	Geographic Information System
GINI	Gross National Income
GPS	Global Positioning System
GRP	Gross Regional Product
GSE	Geological Survey of Ethiopia
GTZ	German Technical Cooperation
HES	Horizontal Electric Sounding
HICE	Household Income, Consumption and Expenditure
IEE	Initial Environmental Examination (Evaluation)
IDC	
JICA	Japan International Cooperation Agency
KfW	Kreditanstalt für Wiederaufbau
MER	Main Ethiopian Rift
MoE	Ministry of Mines
MoH	Ministry of Health
MoWE	Ministry of Water & Energy
MP	Master Plan
NGOs	Non-Government Organizations
NMSA	National Meteorological Services Agency
NWP	National Water policy
PA	Preliminary Environmental Assessment
PASDEP	Plan for Accelerated and Sustained Development and Poverty
RHBs	Regional Health Bureaus
ROE	Rest of Economy

RVLB	Rift Valley Lakes Basin
RVS	Rift Valley Study
RWBs	Regional Water Bureaus
RWS	Rural Water Supply
SNNPRS	Southern Nations, Nationalities and Peoples' Regional State
TVETC	Technical and Vocational Education and Training College
UAP	Universal Access Program
UNDP	United Nations Development Programme
UNICEF	United Nations International Children Fund
UTM	Universal Transversal Mercator
VES	Vertical Electric Sounding
WASHCO	Water Supply and Health Committee
WFB	Wonji Fault Belt
WHD	Woreda Health Desk
WLR	Water level Recorder
WMO	World Meteorological Organization
WRDF	Water Resources Development Fund
WSDP	Water Supply Administration Agency
WWMEO	Woreda Water, Mining and Energy Office

Project Photos (1/5)

First year (January to July)



Discussion of IC/R

The explanation and discussion of IC/R were carried out on 26 Jan. of 2010. M/M was also exchanged on 4 Feb.



Geological survey (1)

Lowlands of the Rift Valley can be viewed from the escarpment of west Butajira. The lowland consists of Quaternary deposits.



Geological survey (2)

Outcrop of welded tuff was distributed near Bilate River. Hydrogeologist 1 picks over the lithology.



Geological survey (3)

Shala Lake (left) and Abijata Lake (right) can be viewed from the national park. The geology of the surrounding area mainly consists of a tuff layer.



Geological survey (4)

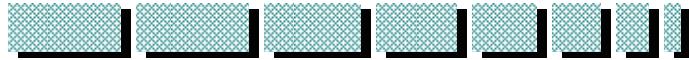
The scene is the intake from deep well is conducted on the way to west from Shashamane. The concentration of fluoride is about 1.5mg/L.

Team Excursion

The team went on an excursion so that each member could get an understanding of each other's fields of expertise.

Project Photos (2/5)

First year (January to July)



Electric sounding

The electric sounding was carried out at the No1 observation well point. The nearby inhabitants of No1 were employed for the survey.



Small town survey (1)

The interview surveys were conducted with the local consultant at target small towns.



Small town survey (2)

The water tanks were set in Kela (SNNPRS) of the requested small town. Most small towns have water supply facilities.



Observation well drilling (1)

This is the scene of installation of casing at No3 drilling point. The drilled materials consisting of mostly pumice can be seen near the machine.



Observation well drilling (2)

Rotary drilling with mud pump at No2 point. The condition of the mud needs to be adjusted.



Observation well drilling (3)

The situation of well head was confirmed at No1 point. The cap was uncovered for checking.

Project Photos (3/5)

Second year

(November 2010 to January 2011)



Geological survey

Basalt lava of Quaternary Pleistocene distributed in Dila Town in the south of the study area. These strata were recognized in the second year.



Water resources survey

Hand pump was set at requested small town of northern part of Yirga Chefe. There are facilities such as this besides the town water supply.



Workshop (WS) of TEM method

The WS of TEM method is held by specialist of the Study Team at EWTEC in Dec. The WS entailed inside lectures and practical training.

TEM method electromagnetic survey

TEM method of electromagnetic survey is carried out in Tora area northwest of Lake Abijata.

An induction coil can be seen in the forefront.



Observation well drilling

The first drilling of the second year was at No5 point along the Bilate River. However, drilling was interrupted with hole trouble at 83m in depth.



Workshop (WS) of volcanic geology

The WS for volcanic geology was conducted in the field in Jan. There were 16 participants. AAU professor also explained geology.

Project Photos (4/5)

Second year

(February 2011 to July 2011)



Geological survey (1)

Fault cliff distributed to the west of Asela Town. The orientation of this cliff is the same as the graben formation of the Rift Valley. Welded tuff of Quaternary Pleistocene is distributed there.



Geological survey (2)

A view of the plateau from the west slope of the Rift Valley area overlooking the Bilate River. Acidic volcanic sedimentary rocks are predominantly distributed in this area.



Observation well drilling (1)drilling No.9N

Well cleansing at No.9N point. Drilling has reached a depth of 200 m. The maximum pumping discharge is 16m/s in the pumping test. Water level decrease is almost 9m.



Observation well drilling (2)drilling No.4

No.4 point as planned to drilling depth 250m is in the flat area to the south of Awassa. (157m in depth as of now) However, groundwater level is 7m in depth, that is, high artesian pressure makes it very tough to continue drilling.



Water resource survey(1) Dalbo Atowa

Requested small town, 9km from Sodo. Water feeding rate is 6%, and another facility beside the existing town water supply is under review.



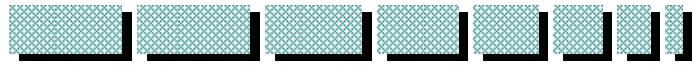
Water resource survey(2) Lemo Sirba

Requested small town 45km south of Asela. Natural groundwater spring is observed. Water feeding rate is 32% as of now .

Project Photos (5/5)

Second year

(December 2010 to January 2012)



No5N Drilling point hot spring

Artesian well of No5N drilling point appeared at near area of Dimutu in SNNPRs. Temperature: 54degree, Yield: 100L/sec. Water quality: Fluoride is high.



Workshop of water quality & isotopic analysis

The WS for water quality and isotopic analysis was held at Addis Ababa University. AAU professor also explained the basis of Isotopes.



Workshop of groundwater modeling

The WS of groundwater modeling was held by the expert of the Study team with the aim of teaching groundwater modeling methods.



Workshop of GIS

The WS of geographical information system (GIS) learning was held. Participants acquired methods of computerizing collected data using GIS software.



Discussion of IT/R

The explanation and discussion of IT/R were carried out on 24 June of 2011. M/M was also exchanged on 4 July.



Technology Transfer Seminar

The all results of survey in RVLB were explained through the technology transfer seminar on 12 January of 2012 in Addis Ababa.

Chapter 1

Introduction

1 Introduction

1.1 General

This Final Report covers the results of the Study on Groundwater Resources Assessment in the Rift Valley Lakes Basin (hereinafter the Study) according to the Minutes of Meeting (hereinafter M/M) agreed upon between the Ministry of Water Resources (name was changed to the Ministry of Water and Energy in October 2010) of the Federal Democratic Republic of Ethiopia (hereinafter Ethiopia) and the Japan International Cooperation Agency (hereinafter JICA).

JICA organized a Japanese Study Team (hereinafter the Study Team) consisting of 12 experts of the many fields relevant to the Study. The Study commenced in January 2010 and completed at the end of February 2012. The Study of the first year was executed from January to September of 2010 and the Progress Report (1) was described. The second year field work of Project executed from November 2010 to July 2011. And the Progress Report (2) and Interim Report were described. This Final Report finalized the all field survey results of the Project as of the beginning of July 2011 and the results of work in Japan until the end of October 2011. The Study is implemented during this term based on cooperation with the implementation and counterpart (hereinafter C/P) organizations, mostly from within Ethiopia's Ministry of Water and Energy (hereinafter MoWE).

1.2 Background of the study

Ethiopia launched the Universal Access Program (UAP) in 2005 due to its low rate of access to safe water, which at the time in rural and urban areas remained at approximately 38%. The UAP aims to achieve water supply coverage of 98% in rural areas and 100% in urban areas by 2012. Presently, however, there is a lack of information to accurately grasp the abundance of groundwater resources in Ethiopia, having an adverse effect on the sustainable use and effective development of groundwater resources. Meanwhile, out of the need to acquire information on groundwater potential for water resource development, Ethiopia has worked towards capacity development through its national masterplan—the Ethiopian Groundwater Resources Assessment Program (EGRAP)—by establishing the Ethiopia National Groundwater Database (ENGDA), implementing a survey of groundwater potential, making hydrogeological maps and founding the National Groundwater Institute (NGI). However, due to its ineffective operation, an improved plan was re-established until the end of phase-3 in 2014, with phase-1 of the new program EGRAP+ (or new EGRAP) starting from 2007 until 2010, in an attempt to revitalize it. The EGRAP+ activates the discussion for the introduction of ENGWIS (Ethiopian National Groundwater Information System), because of the establishment of a GIS/Database system.

Based on the above background, the Government of Ethiopia requested the Government of Japan to implement a survey on groundwater potential with a purpose of making hydrogeological maps for the Walikte, Wolisso and Ambo areas, and a development study with a purpose of technology transfer to relevant engineers.

In response, JICA dispatched a Preliminary Study Team in December 2008, and a Detailed Planning Team in July 2009; narrowed the target area to the Rift Valley Lakes Basin, and at the same time made a Study Plan, the content of which includes grasping this area's groundwater potential, producing hydrogeological maps, and establishing water supply plans for small towns in the target area. Wherein, the Scope of Works (S/W) was signed and exchanged in July 2009.

This Study will contribute towards achieving the goals of EGRAP+ and UAP by

implementing a study on groundwater potential in the Rift Valley Lakes Basin—the result of which will be hydrogeological maps of this area and the establishment of water supply plans.

1.3 Objectives of the study

The objective of this Study is to implement a survey to evaluate the groundwater potential of the major aquifers, to produce hydrogeological maps for the Rift Valley Lakes Basin. As the results of survey, the others are that it is to establish water supply plans for towns of less than about 10,000 people; while at the same time, to improve the MoWE' capacity in water supply planning.

1.4 Scope of the study

This Study will be implemented according to the Scope of Work (S/W) concluded on July 23, 2009 and the Minutes of Meeting (M/M) of these discussions. The work in the below study contents and schedule are implemented by the study team; and as the Study progresses the reports mentioned under progress of study are prepared, then explained and discussed with the Ethiopian government. The main works are as follows;

Phase I : Basic study

Phase II: Detailed study

1.5 Work schedule

Phase-1 is to start in January of 2010, and phase-2 is to end in March of 2012. The basic schedule is outlined below in Table 1.1, while more detailed work contents are shown in as the work flow.

Table 1.1: Outline of the study schedule

The Study on Groundwater Resources Assessment
in the Rift Valley Lakes Basin in Ethiopia, Final Report (Main Report)

JICA
KOKUSAI KOGYO CO., LTD.

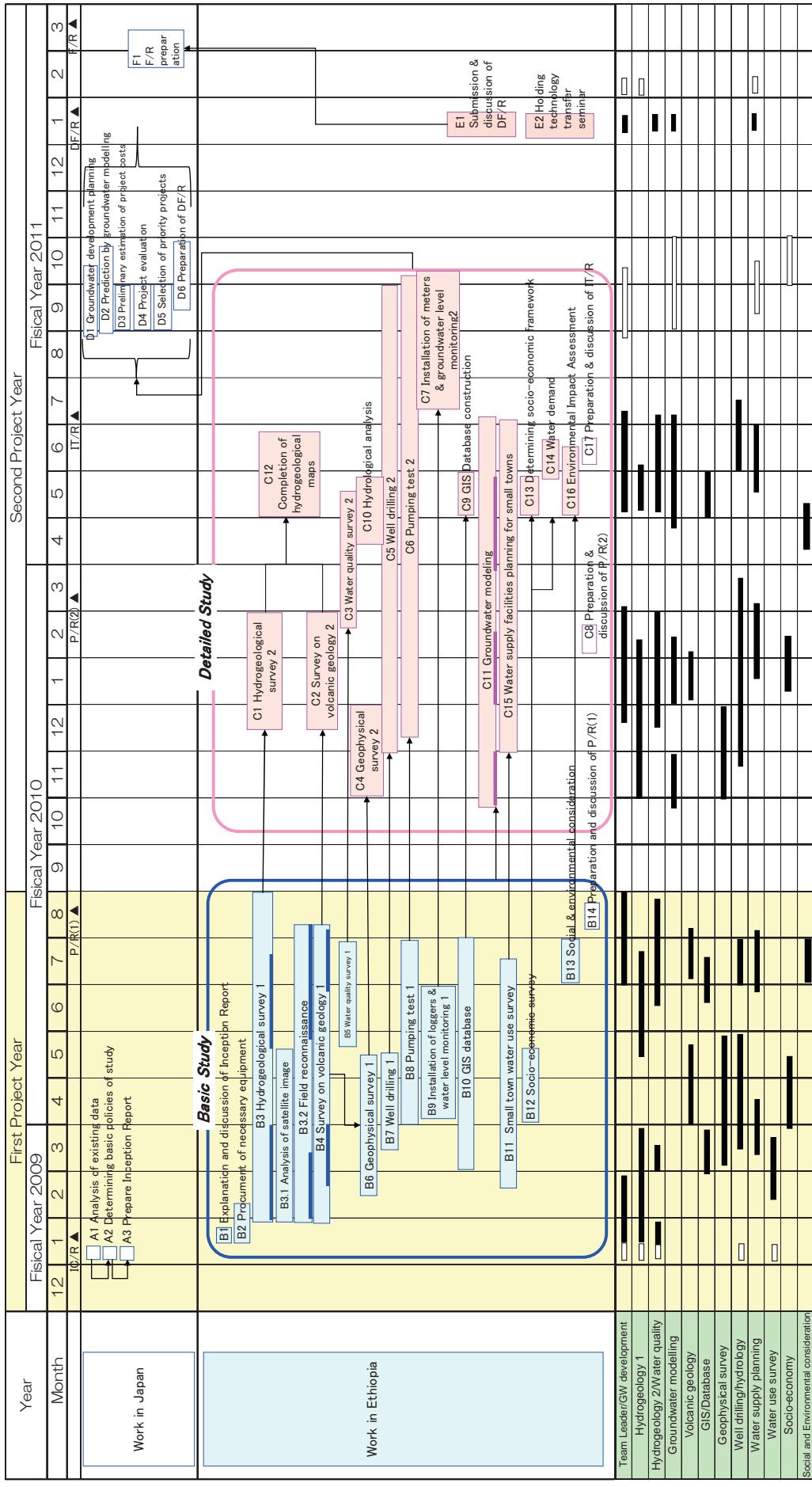


Figure 1.1: Flowchart for study

1.6 Study area and small towns requested

1.6.1 Study area

The study area is the Rift Valley Lakes Basin as shown in Figure 1.2, and the target regions are SNNPRS and Oromia Region State.

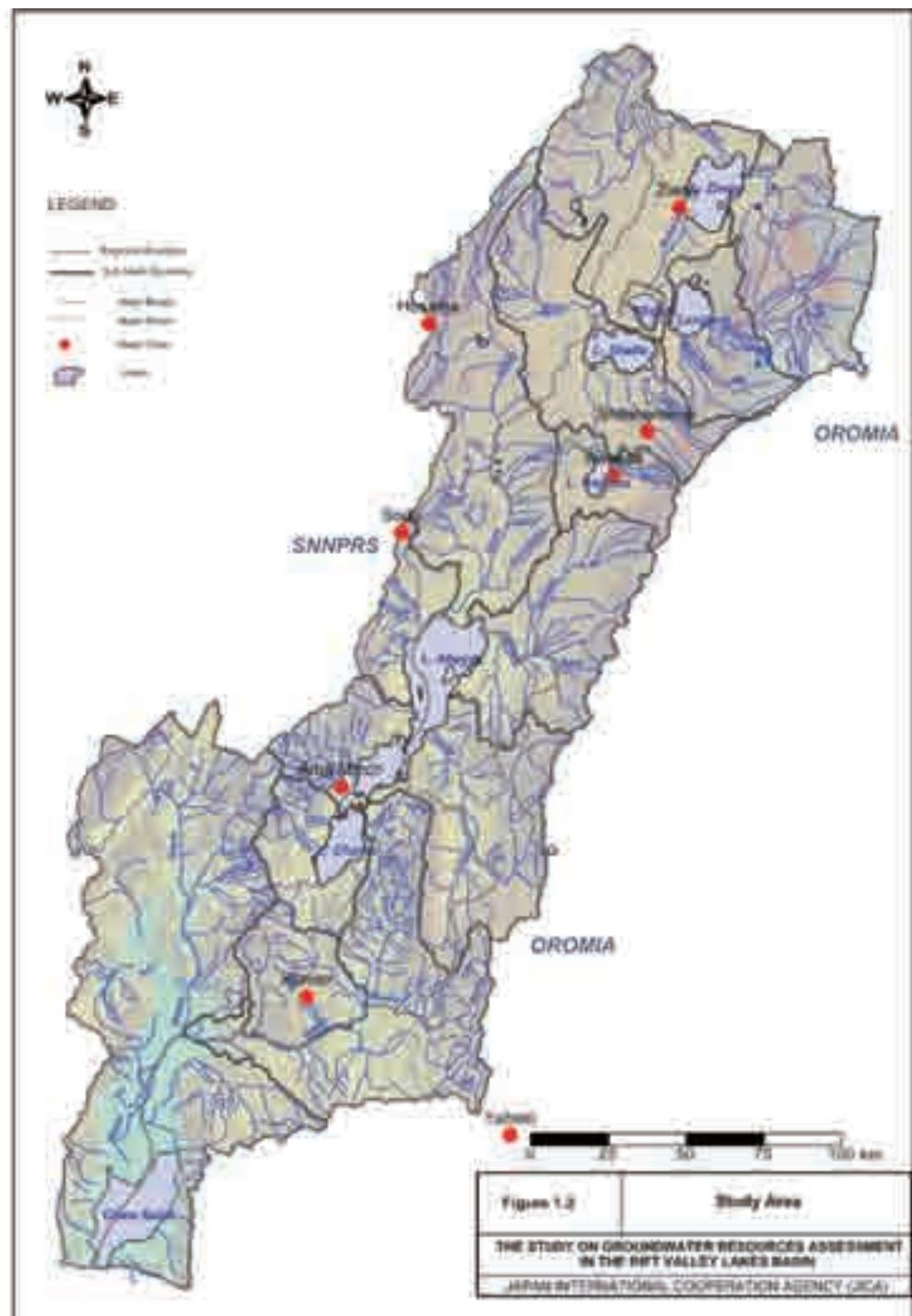


Figure 1.2: Study area

1.6.2 Small town requested

In this Study, small towns with a population of less than about 10,000 people are targeted as a general rule. The number of small town requests which the Study team received from the staff of SNNPRS and Oromia Region are shown in Table 1.2.

Table 1.2: Number of small towns requested

Name of Zone		Number of small towns requested
SNNPR s	Gurage	6
	Hadiya	6
	Kembata Timbaro	3
	Sidama	9
	Gedeo	4
	Wolayita	4
	Gamo Gofa	10
	Siliti	10
Sub total		52
Oromia R	Arsi	10
	West Arsi	7
	East Shewa	8
	Borena	5
Sub total		30
Total amount		82

1.7 Study team and persons involved

1.7.1 Study team

The JICA Study Team is composed of the following twelve (12) experts, with Mr. Toshiyuki Matsumoto, senior chief engineer of Kokusai Kogyo Co., Ltd., as team leader and one (1) coordinator of undertakings relevant to the project. The personnel and assignment plan is as shown in Table 1.3.

Table 1.3: Members of Study team

Area	Name	Nationality
Team leader/Groundwater development plan	Toshiyuki MATSUMOTO	Japanese
Hydrogeology 1	Hisayuki UKISHIMA	Japanese
Hydrogeology 2 / Water quality	Kensuke ICHIKAWA	Japanese
Groundwater modeling	Peifeng LEI	Chinese
Volcanic geology	Toshiaki HOSODA	Japanese
GIS Database	Yoshimizu GONAI	Japanese

Geophysical survey	Tsugio ISHIKAWA	Japanese
Well drilling / Hydrological survey	Naoki YASUDA	Japanese
Water supply planning	Hiroshi TAKASHIMA	Japanese
Water use survey for small towns	Jun KAKINUMA	Japanese
Socio-economic survey	Masaru OBARA	Japanese
Social and environmental consideration	Norikazu YAMAZAKI	Japanese
Project coordinator	Yosuke YAMAMOTO	Japanese

1.7.2 Persons involved

The members of this Study on the Ethiopian side for the steering committee are: the MoWE (Ministry of Water and Energy) as the responsible agency; Ethiopia Groundwater Resources Assessment Program (EGRAP) as the implementing agency; and Ethiopia Water Technology Center (EWTEC), Geological Society of Ethiopia (GSE), Addis Ababa University (AAU) as C/P; and staff of SNNPRS and Oromia Region State. The list of project members of the Ethiopian side is as follows:

Table 1.4: Members of the Ethiopian side

Name	Affiliation	Role of works
Mr. Abera Mekonnen	MoWE Chief Engineer	Chairman of SC*
Mr. Tesfaye Tadesse	MoWE/EGRAP	Responsible agency /C/P leader
Mr. Zebene Lakew	MoWE	Member of SC*
Mr. Girum Admasu	MoWE	Responsible agency
Mr. Muhuddin Abdela	GSE	C/P
Mr. Sileshi Mamo	GSE	C/P
Mr. Mulgeta Kinfu	MoWE/EWTEC	C/P
Mr. Tamiru Fekadu	MoWE/EWTEC	C/P
Prof. Dr. Gezahegn Yirgu	AAU/Volcanology	C/P
Prof. Dr. Tenalem Ayenew	AAU/Hydrogeology	C/P
Mr. Meskelu Tumiso	SNNPRS Water Bureau	C/P
Mr. Fekadu Lebecha	Oromia Region Water Bureau	C/P
Ms. Ghrmawit Haile	MoWE/WRDF**	Member of SC*

*: SC: Steering Committee, **: WRDF: Water Resources Development Fund

Chapter 2

General Condition of Study Area

2 General Condition of Study Area

2.1 General

This chapter describes the general condition concerning the national and social situations in the study area. The study area is located about 190 km south of the capital Addis Ababa. It is bounded by the limits of $37^{\circ}00'$ – $39^{\circ}30'$ east longitude and $5^{\circ}00'$ – $8^{\circ}30'$ north latitude. The area is topographically characterized by a depression zone with steep marginal faults along its edges. The study area is an independent basin; therefore it is called **Rift Valley Lakes Basin (RVLB)**. The RVLB consists of SNNPRs and Oromia Region with a population of about 9.8 million (as of 2006). The main industries are agriculture, manufacturing, and services in RVLB.

2.2 Meteorology and hydrology

2.2.1 Meteorology

The meteorological conditions of a given wide and independent area affect the formation of water resources and consumption in that area more than other conditions. The main factors are as follows; 1) Precipitation (rainfall), 2) Evapotranspiration, and 3) Other factors such as temperature.

a. Analysis of rainfall

The main analyses are as follows; 1) Spatial distribution of precipitation, 2) Long term trends in changes of rainfall amount, and 3) Cyclic features and probability of precipitation. Two kinds of data were collected for the analysis. One is the daily precipitation measurement record collected directly from the observation stations in the study area (70 stations) and the other is a set of monthly averaged data downloaded from WMO (World Metrological Organization) website (from 10 stations). The oldest of data for the original data in the observation term is 1951 and the latest data is 2010. All data used for precipitation analysis were checked before at first, and all the obviously error data were erased or modified. The collected data was verified before analysis and the apparent errors found were all corrected. The average annual rainfall amount shows that the values range from 492mm to 2,582mm in each area, showing a 5-fold difference that is considered large. The average of the 72 stations in the rift valley basin is 1,079mm. Location and annual precipitation amount for each station used for the analysis are shown in Figure 2.1.

As there is no clear relation between topography (altitude of stations) and annual average precipitation (The altitude of original data: 582m-2875m). The coverage area of each precipitation station was delineated by using the standard hydrological analysis method of Thiessen division. The distribution of precipitation in the fourteen sub-basins area from $1,000\text{km}^2$ to $13,000\text{km}^2$ based on the large rivers is shown in Figure 2.2. And the seasonal variation of precipitation in the rift valley area and that for the entire country was compared in Figure 2.3.

Trend of precipitation change was analyzed using the data of stations having relatively long period of observed data in the rift valley area. The results were that the relation between the long period of data and the precipitation change was found to have little correlation. However, this indicates that the precipitation is slightly on the rise with increased value of year.

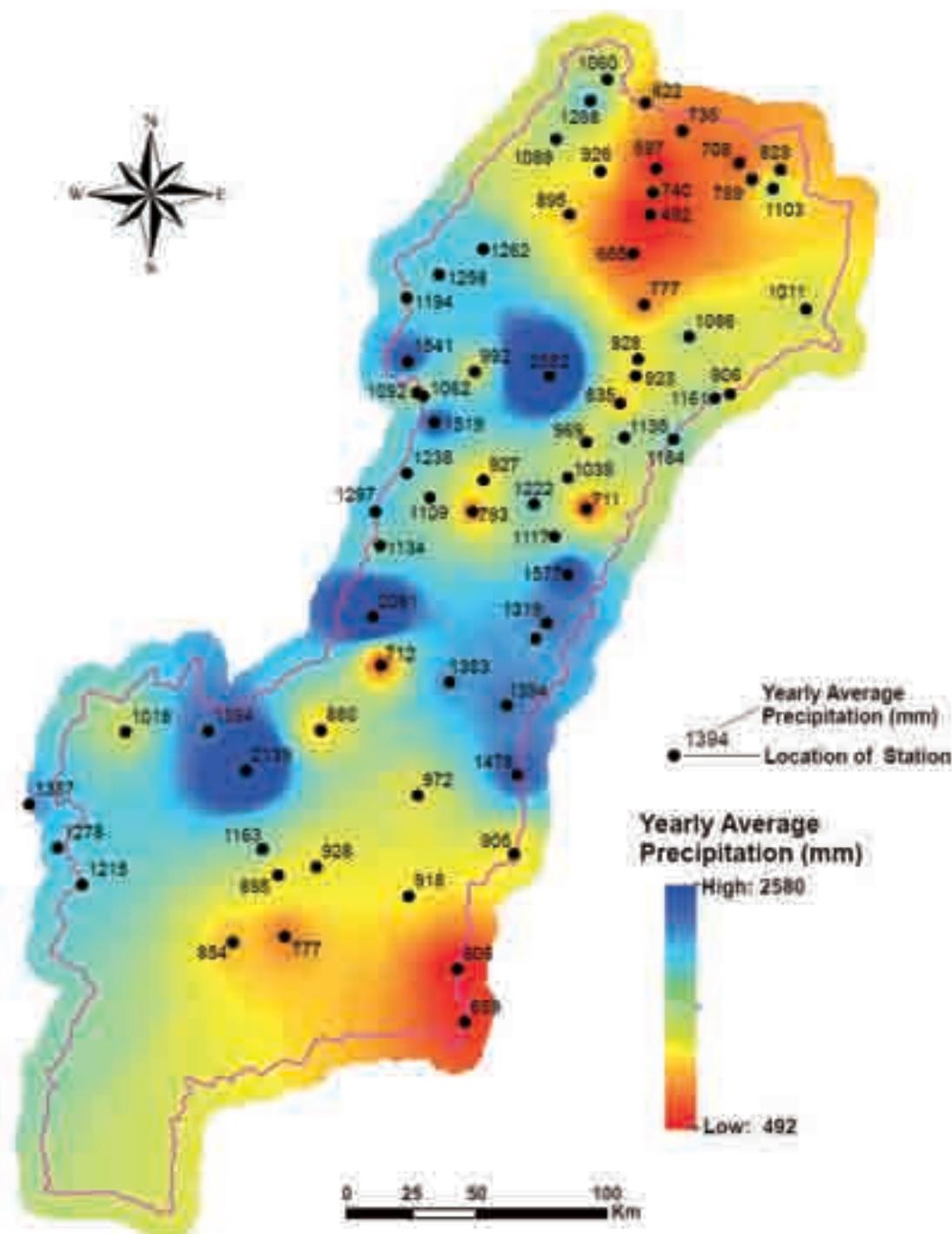


Figure 2.1: Location and Annual Precipitation of Each Station in RVLB

Analysis of the period of precipitation change was utilized using the Awassa station data having long data period and shorter period of missing data for the analysis. The results were that, as shown in Table 2.1, the analyzed 30-year data (1981-2010) includes 5 cycles of precipitation. Trends indicate that the dry year is about 790mm, and the wet year is about 1,160mm at a 10 year probability in regard to precipitation change.

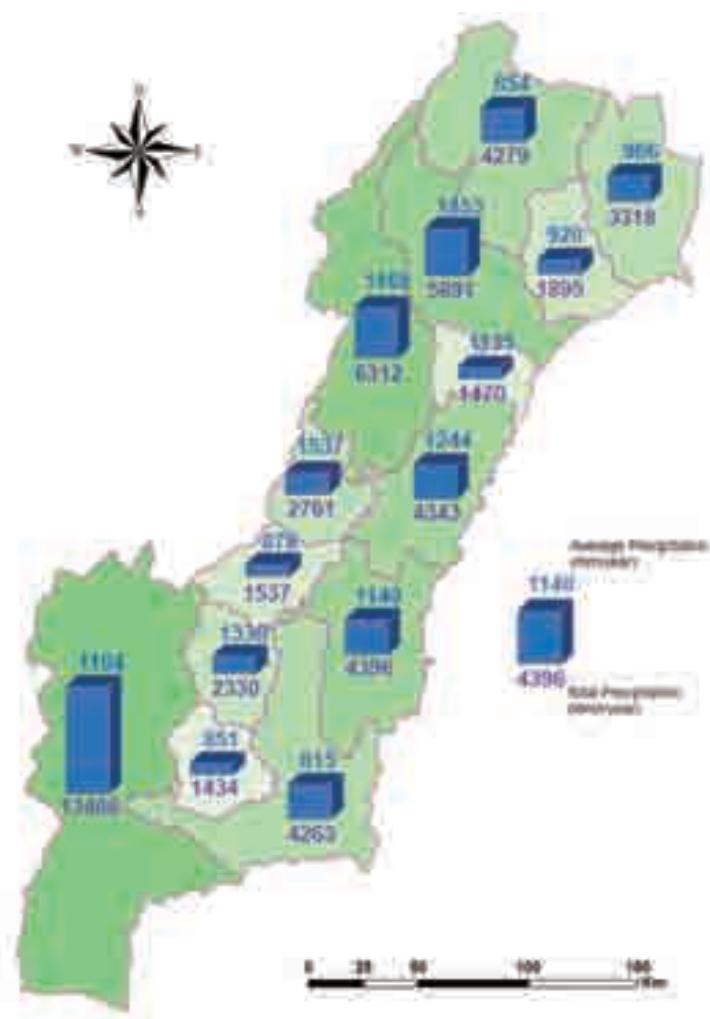


Figure 2.2: Distribution of Precipitation over Sub-basins in RVLB

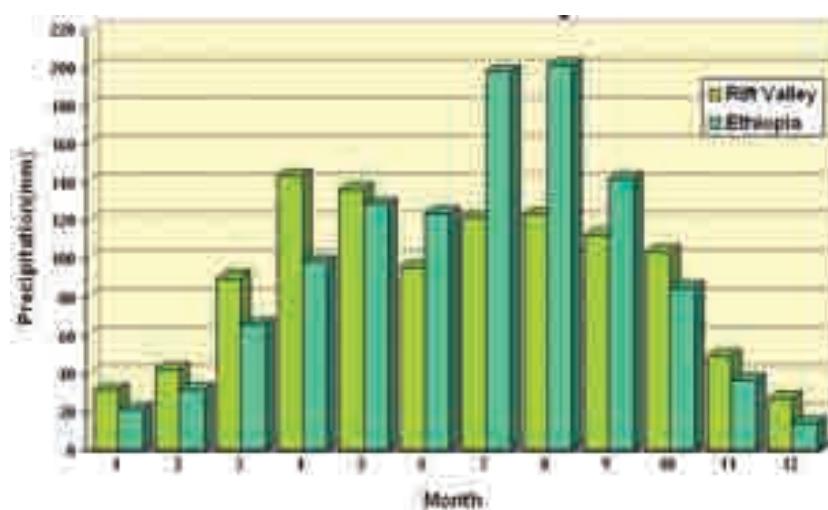


Figure 2.3: Comparison of Annual Precipitation Pattern between RVLB and Entire Ethiopia

Table 2.1: Results of Analysis for Precipitation Cycle

Sequence	Duration	Wet Year	Drought Year
1	-1985	- 1983	1984 -1985
2	1986 - 1994	1986 - 1989	1990 - 1994
3	1995 – 2004	1995 - 1998	1999 - 2004
4	2005 - 2009	2005 - 2007	2008 - 2009
5(?)	2010 -	2010 -	--

b. Evaporation

Only five stations have evaporation data in the RVLB area. The values of monthly average, and maximum and minimum are all based on the monthly average of all five stations. However, the maximum values were all taken from one station. The values of the monthly Average Evaporation from the other four stations except one are relatively close to each other with their range between 1,395mm and 1,963mm. The monthly average, maximum and minimum values of evaporation over the five stations are illustrated in Figure 2.4 below. In any event, there is no clear relation between the amount of evaporation and the elevation of the stations.

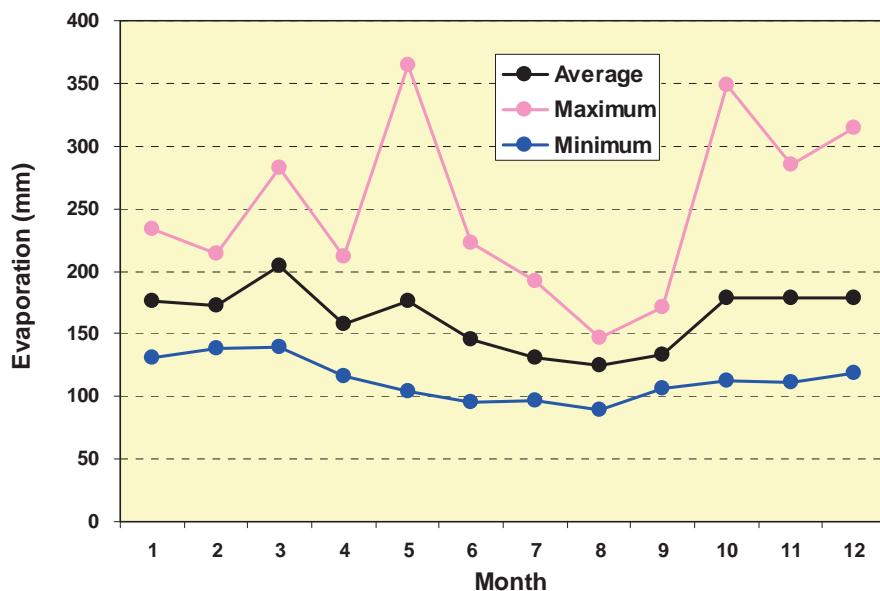


Figure 2.4: Figure Monthly Average Evaporation Fluctuation of the 5 Stations.

c. Temperature

Out of all the stations from which meteorological data was collected, 52 stations have temperature data. The average annual temperature for all 52 stations used for the analysis is 19.6 °C, and the maximum and minimum values are 27.1 °C (Beto station) and 12.3 °C (Kawakoto_Alico station) respectively. The annual trend of change in average temperature over the 52 stations is illustrated in the following Figure 2.5.

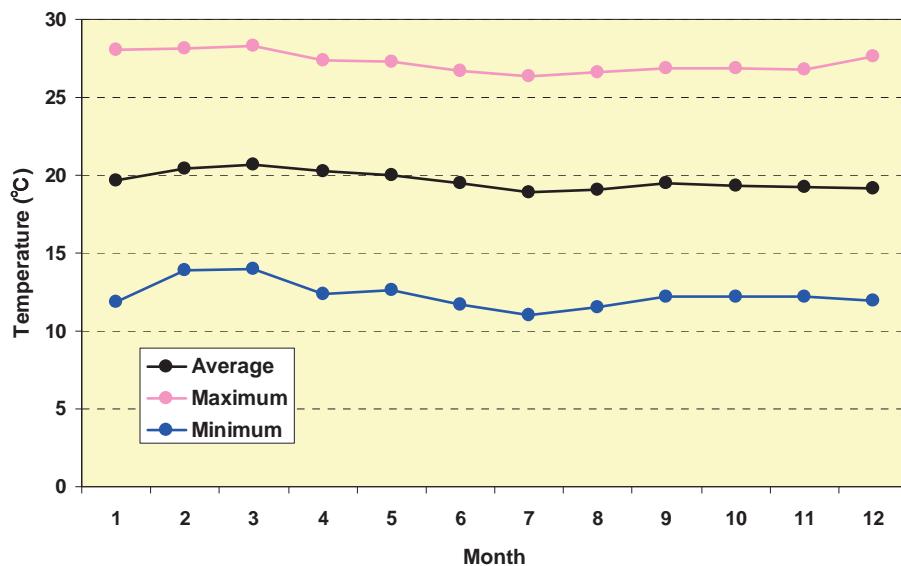


Figure 2.5: Monthly Average Temperature Fluctuation of the 52 Stations.

2.2.2 Lakes of the study area

As the name suggests, the Rift Valley Lakes Basin has plenty of lakes in all sizes. The lakes are chiefly distributed in the center low profile of the valley and flat lands created by the rift. Dozens of lakes can be observed including small caldera lakes. In this section, the lake water will be examined as a potable water source. The main lakes are Ziway, Langano, Abijata, Shalla, Awassa, Abaya, and Chamo (refer to Table 2.2).

The major specification of the respective lakes is tabulated in Table 2.2. The largest lake in the study area is Lake Abaya, and it has a surface area of 1,160km², but the mean water depth is only 7m meaning the volume is 8.2km³. On the other hand, Lake Shalla has a surface area of only 409km² (which is one third of Lake Abaya), but it has a maximum depth of 266m, and average depth is 87m, for a volume of 36.7km³ (4 times more than Lake Abaya).

Table 2.2: Specification of the Major Lakes

Lake	Altitude	Surface Area	Max. depth	Av. depth	Volume
	m.a.s.l	km ²	m	m	km ³
Ziway	1636	440	8.95	2.5	1.1
Langano	1582	230	47.9	17	5.3
Abijata	1578	205	14.2	7.6	1.61
Shalla	1558	409	266	87	36.7
Awassa	1697	129	22	11	1.3
Abaya	1285	1160	13	7	8.2
Chamo	1235	551	13	6	3.3

Water Balance and Level Regime of Ethiopian Lakes as Integral Indicators of Climate Change (2008, A.M. Mikhailovich D, B.A. Getahum, the 12th World Lake Conference)

Lake Ziway, Lake Langano, Lake Abijata and Lake Shalla were formed by tectonic depression with volcanic activities; in particular, Lake Shalla was influenced by the formulation of caldera and the depth of water of Lake Shalla is deeper than that of the other lakes. Lake Awassa was formulated in the central caldera and the Lake Abaya and Lake Chamo are tectonic lakes spindled along the rift valley. In the beginning of Holocene, a large scale lake was formed, encompassing an area from the present-day Lake Ziway to Lake Shalla (so-called the old Lake Ziway) by the influences of rainfall in the warm humid climate as a result of climate changes. The area of the Old Lake Ziway is confirmed by the distribution of Lacustrine deposits.

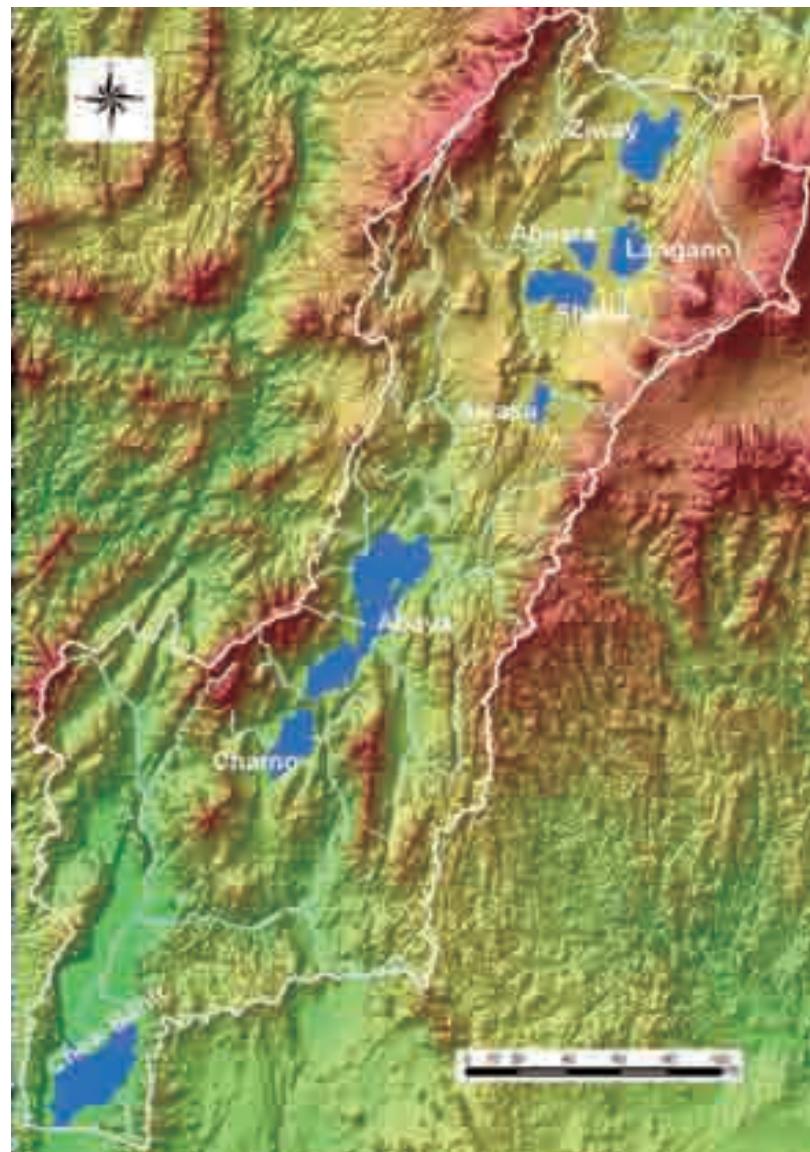


Figure 2.6: Distribution of Main Lakes in RVLB

2.2.3 Sub-basins

As above, the eight lakes are distributed in the lowland in RVLB, and these basins are independent hydrological closed systems. The major basin will be divided into following four major groups:

1. Ziway-Shalla Basin, 2. Awassa Basin, 3. Abaya-Chamo Basin, 4. Chew Bahir Basin

However, it is too large scale classification for the purpose of this study, which is to grasp the hydrogeological relationship between basins and geological settings. Therefore these basins are divided into sub-basins.

a. Classification of sub-basin

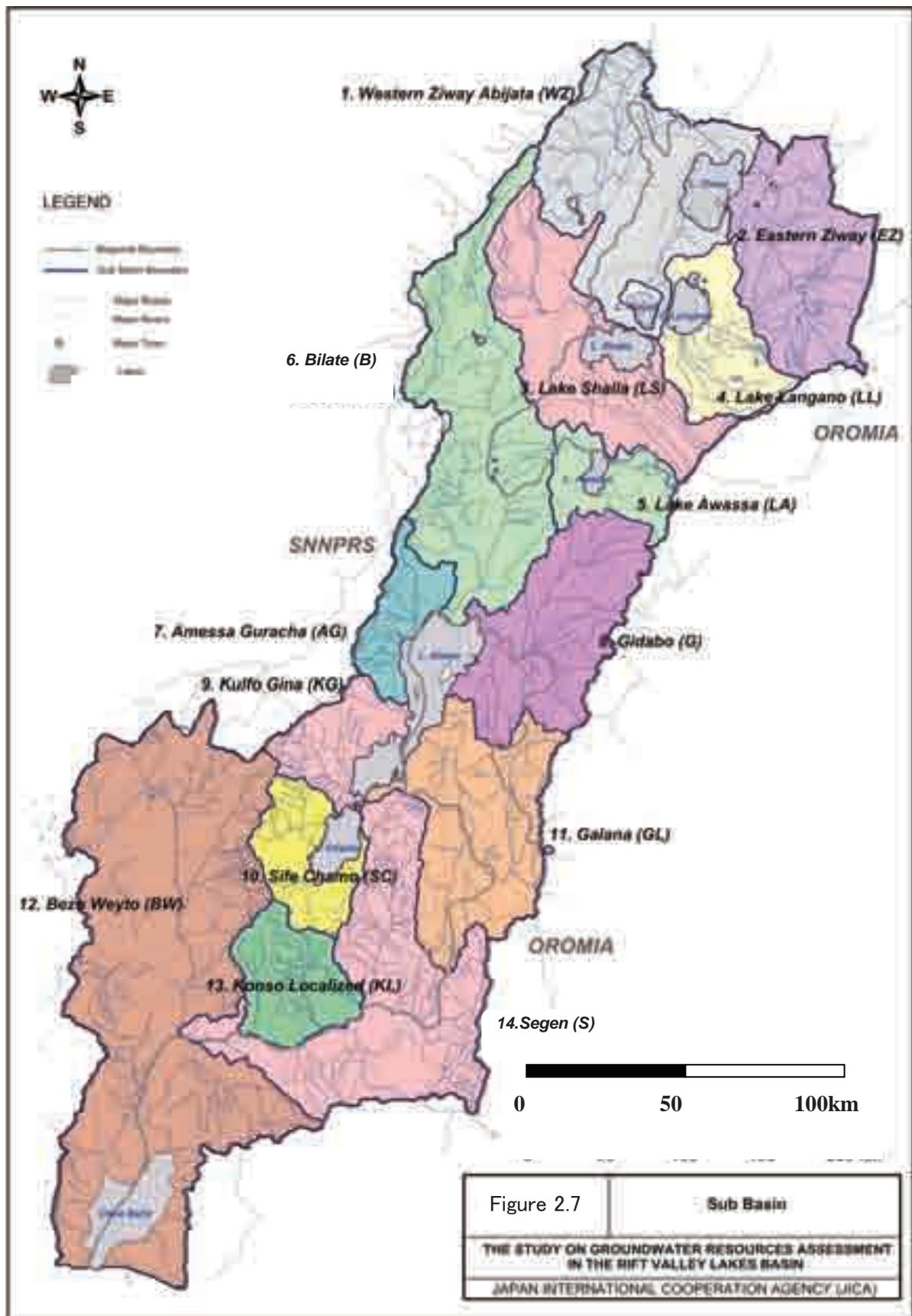
The major basins are classified into sub-basins in accordance with the river end of the respective rivers and its characteristics.

In Ziway-Shalla Basin, respective sub-basins are divided according to the rivers inflowing into each lake in Ziway-Shalla Basin. Lake Awassa was considered as one independent sub-basin as Awassa sub-basin. This lake is a completely closed system with its tributaries and rivers (if not considering groundwater outflow to the other lower lakes). Lake Abaya is the largest lake in the Rift Valley Lakes Basin. The classification of the sub-basins is mainly focused on the major rivers and their tributaries flowing into this lake. Several major rivers flow into the two lakes. In Chew Bahir Basin, there are two major rivers, namely, Segen, Weyto. Haru Shet River originates its flow at the east of Lake Chamo, and other small stream networks south of Lake Chamo are defined as Konso localised sub-basin, and the area of tributaries along the Weyto River is defined as Bezo Weyto sub-basin.

Table 2.3 shows the major basins and classification of sub-basins. The classification of sub-basins and their locations are presented in Figure 2.7.

Table 2.3: Major basins and classification of sub-basins

No	Large Scale Classification	No	Sub-basins	Total Area (km ²)
1	Ziway-Shalla	1	Western Ziway-Abijata	4398
		2	Eastern Ziway	3434
		3	Lake Shalla	3762
		4	Lake Langano	1807
2	Awassa	5	Lake Awassa	1201
3	Abaya-Chamo	6	Bilate	5419
		7	Amessa Guracha	1125
		8	Gidabo	3491
		9	Kulfo Gina	1302
		10	Sife Chamo	1436
		11	Galana	3856
4	Chew Bahir	12	Bezo Weyto	12143
		13	Konso Localized	1685
		14	Segen	5230



b. Aspect of sub-basins

Characteristics of respective sub-basins in terms of topographic and hydrographic features are compiled in the following table.

Table 2.4: Topographic and hydrographic nature of sub-basins

No	Major	N o	Sub- basins	Topography	Major Stream System	Area (km ²)
1	Ziway-Shalla	1	Westen Ziway-Abijata	Steep cliff and caldera walls at the west, gentle slopes and low hilly terrain at East. Almost flat low land between East Butajira and Lake Ziway-Abijata.	Meki River is the major river in the area. Highly affected by the topographical profile which flows northerly in the west and easterly in the east. No major inflow is found near Lake Abijata	4398
		2	Easter n Ziway	Foot of Galema mountain range (altitude of 4000m) extends to cone shaped hollow. Passing fault cliff towards lower flat land of Lake Ziway. River gradient is relatively high.	Several ramiform stream networks are dominant and gather into the Ketar River. Flow direction is mainly WNW-ENE	3434
		3	Lake Shalla	Extends NW-SE direction. Steep cliffs are dominant at the margin of the valley. Flat low land around Lake Shalla. Several volcanic cones are observed.	Only minor non perennial rivers are found as inflow to the Lake. Small stream networks formed at NW-SE direction.	3762
		4	Lake Langano	At the foot of Kaka and Kubsa mountain range (4000m) with fault cliff of 100m, and reach at the flat of Lake Langano.	Only minor non perennial rivers are found as inflow to the Lake. Small stream networks formed in a NW-SE direction.	1807
2	Awassa	5	Lake Awassa	Height difference of 600m between eastern cliff and Lake Awassa. The lake is surrounded by Humo mountain range at west.	Small stream network developed in the direction of EW. Large swamp of 100km ² formed at west of the Lake	1201

No	Major	No	Sub Basins	Topography	Major Stream System	Area (km ²)
3	Abaya -Chamo	6	Bilate	Gentle slope along the Bilate River. Fault cliff and volcanic cones formed at the West.	Total length of the river exceeds 3km and it is the longest river system in the whole area. It inflows into Lake Abaya.	5419
		7	Amessa Guracha	Surrounded by a 2500m high mountain range, and forms wide flat land near Lake Abaya.	Gathering the small stream networks of all directions along the cone shaped slope of mountain range and join into the Amessa, Guracha rivers to Abaya.	1125
		8	Gidabo	300m high fault cliffs in the east. Mostly consists of steep hills but low flat land near Lake Abaya.	Major river system is Gidabo River. Collecting small streams over the direction of NS. Eastern direction near the lake	3491
		9	Kulfo Gina	Occupied by high (3000m) mountain range and rarely found flat land.	The valley developed in a NE-SW direction. The major river is Kulfo River.	1302
		10	Sife Chamo	Mountain range developed surrounding Lake Chamo	Major rivers are flowing from southern and western hills toward Lake Chamo.	1436
		11	Galana	Tectonic line developed in NS direction. Wide valley exists between Furfusa, Haro mountain ranges and joins Galena River with the direction of NS to NW.	Rivers flow in between Furfusa, and Haro mountain ranges and joins Galena River with the direction of NS to NW.	3856
4	Chew Bahir	12	Bezo Weyto	Tectonic line developed in NS direction. Predominant of fault cliff at east and west of the area.	Major river is Weyto river, and it is more than 200km in length. Flows toward the south	12143
		13	Konso Localized	Massive mountain range developed. Hilly terrain.	Short stream network has developed, and joins Segen River.	1685
		14	Segen	Mountain range along the tectonic line is abundant. Steep valleys exist along the range.	Segen River is the major river which flows in an EW direction.	5230

2.2.4 Hydrology

a. Distribution of lakes and evaporation

There are eight major lakes in the area and the main lake water level fluctuation is shown in the following figure. The water level fluctuation of Lake Abijata exhibits a declining trend from 1970 to present day, on the other hand, those of Lake Awassa and Lake Abaya shows an upward trend. The water level fluctuation of the Lake Ziway has periods of decline, however it exhibits a roughly flat trend.

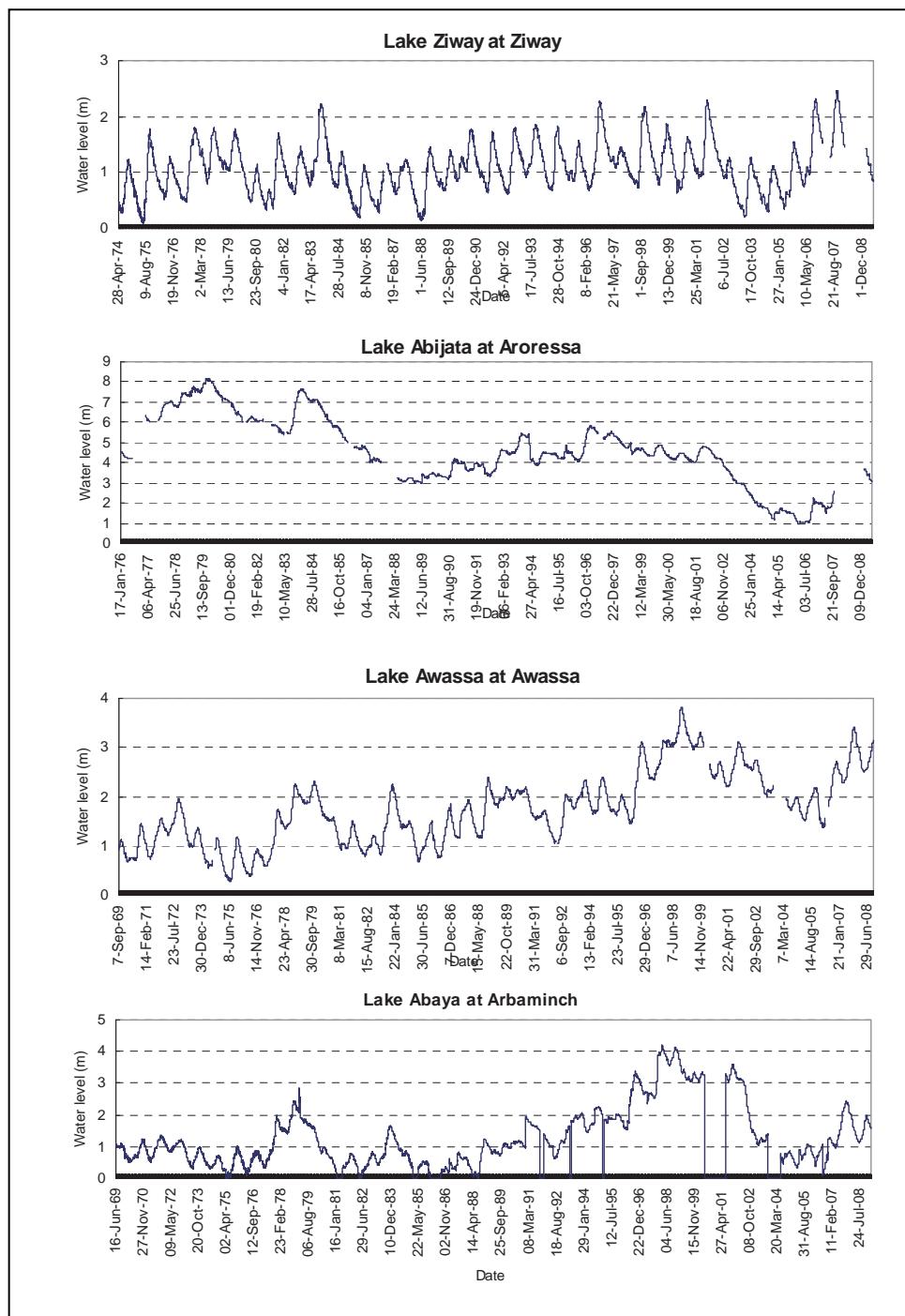


Figure 2.8: Water level fluctuation of main lakes

RVLB is a closed basin independent from the surrounding basins. The water resources formed by precipitation are simply consumed by evapotranspiration and use by human activities. The result of hydrological analysis conducted with groundwater modeling indicate that evaporation from the lake surface accounts for about 95% of the annual average evaporation amount from the entire basin. Since no clear relation is recognized between the evaporation amount and the topography of the observation stations, the Thiessen method was employed to determine the evaporation value assigned to each lake basin. As for the results of analysis, the average annual total evaporation amount from all the lakes in the study area is calculated as 6,545.2 (Mm³/year) . This evaporation amount (from lake water) is composed of inflow from rivers, inflow from groundwater, and direct precipitation over the lake surface. The effect of direct precipitation over the lake surface was calculated using the same correspondence of stations to lakes and the result is 3,461 (Mm³/year). The amount of water flowing into the lakes that are composed of inflows from river and groundwater, in the rift valley area was calculated as the inflow into the lakes as 3,084.2 (Mm³/year) (6,545.2-3,461). The evaporation from the lakes accounts for more than 95% of the net water resources amount in the study area. Therefore the water resources consumption amount for the entire study area is 3,246.5 (Mm³/year) (3,084.2/95%).

b. River flow

Daily flow data from 36 stations were collected, and the location of the stations is shown in Figure 2.9 (show 33 stations in the figure). The precision of data were improved by checking and complementation.



Figure 2.9: Location of river flow observation stations

As a result, the following four patterns of flow rates variation were recognized from the data of seasonal fluctuation of river flow (refer to Figure 2.10). The main patterns are characterized by high level of correlation with the precipitation pattern of rainy and dry season in the same area. The two peaks and one peak in flow rates are observed as in the precipitation pattern (Pattern 1 & Pattern 2). The other two patterns are particular and the points are few in the study area. In particularly, Pattern 3 probably means the record of spring station.

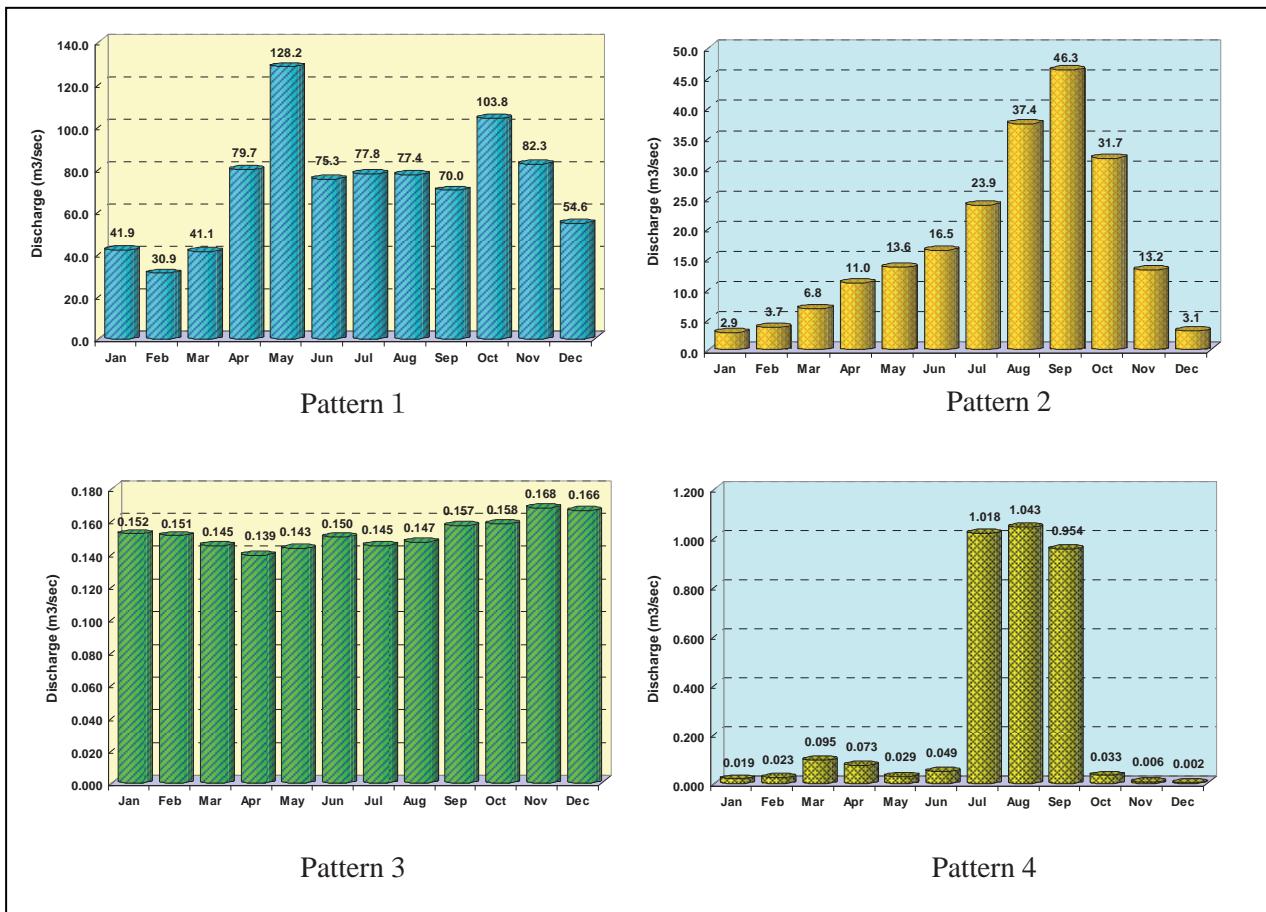


Figure 2.10: Monthly Average River Flow Pattern

2.3 Geographic characteristics, geology and hydrogeology

2.3.1 Geographic characteristics

a. General

The study area belongs to the **African Rift**. The African Rift originates from Aden Junction (see Figure 2.11) and continues in the direction of SW- SSW traverse longitudinally 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 Somalian Plate and western is Nubian Plate. The two plates are separating at a speed of 5mm/year (Stamps et. al, 2008).

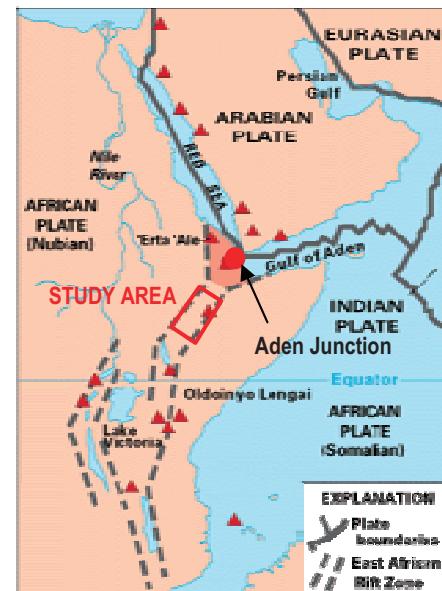


Figure 2.11: Distribution of African Rift Valley

(Source: <http://people.dbq.edu/faculty/deasley/Essays/EastAfricanRift.html>)

b. Topography

The Rift Valley Lakes Basin could be divided into two areas in a large sense. The northern portion of the area around the lakes of Ziway to Awassa is almost flat in the valley bed with several mounds of hills in the west and volcanic bodies. The hills are mostly in the shape of cone or semi-conical crests that leave the traces of past volcanic activity. The eastern terrain shows the stepwise fault scarp bounding the eastern end of the valley. The lineaments of NNE – SSW direction are mostly abundant. In contrast to the northern geomorphological conditions, the southern area, from Lake Abaya to Chew Bahir, has relatively precipitous terrain. East of Lake Abaya-Chamo is characterized by a continuous range of mountains in a N-S to NNE-SSW orientation, and the lineaments can be tracked up to Lake Awassa. ENE-WSW oriented lineaments are also abundant in the northern portion.

The geological structures are characterized by two major rifts, the Main Ethiopian Rift (MER) and the South-western Ethiopian Rift (SWR), both of which are encompassed in RVLB. The MER extends from the southern Afar margin to the Lake Chamo area, and two main fault systems have been identified in the MER: a N300E – N400E trending fault system, which characterizes mainly the rift margins, and a N-S to N200E trending fault system, the Wonji Fault Belt (WFB), which shows a number of sigmoidal, overlapping, right-stepping en-echelon fault zones, affecting the rift floor, and linear or curved in plan view over distances of up to a few tens of kilometers. They delineate many fault bounded blocks. The margins of the MER are characterized by a few widely spaced faults with very large vertical displacements, to the rift floor. The eastern margin is well developed and it is defined by a

more or less continuous system of faults, whereas the western border is marked by only a few major faults in the Mt. Guragie area.

The South-western Ethiopian Rift (SWR) is located to the west and represents roughly N-S trending basins related to the Kenya Rift, and the Gofa Basin and Range and Chew Bahir rifts dominate the area west and south of the Chamo Graben (Ganjuli graben)

2.3.2 Geology and geological structure, volcanic activities

a. General

The study area belongs to central-southern part of the **Main Ethiopian Rift (MER)** and northern part of the **South-western Ethiopian Rift (SWR)**. MER developed over a span from the Oligocene to the Quaternary. During that period, major volcanic episodes are recognized in Oligocene, middle Miocene, late Miocene, early-middle Pleistocene and Holocene (WoldeGabriel et al. 1990). Its abstract is as follows;

The oldest volcanic activities are basalt and rhyolite flows in Oligocene, exposed in and around of Abyssinia highland of the rift margins (e.g. Blue Nile Gorge), which formed lava plateau in the surrounding area. By middle Miocene, the rift was formed in some parts with containment basaltic flows. In Pliocene, a huge pyroclastic flow covered the northern part of study area. This characteristic pyroclastic flow deposit is currently observed at a depth of around 2100m in the basin floor by geothermal well, indicates a minimum of 2km of downthrow in the rift basin since its eruption (WoldeGabriel et al. 1990, WoldeGabriel et al, 2000).

In Pleistocene, Wonji Fault Belt (WFB), which is the main spreading axis of MER, is formed at the rift floor, and floor basalt and rhyolite are erupted along WFB. The volcanic activities are characterized by peralkaline fissure basaltic eruptions and rhyolitic eruptions which make volcanoes and calderas. MER was formed as symmetrical depression zone in this period and many lakes appeared and disappeared by obstruction of volcanic deposit and/or climate change (refer to Table 2.5).

Table 2.5: Correlation chart of Cenozoic Formation in the Study area

Period/Epoch		Age (Ma)	WoldeGabriel et al. (1990)	EWTEC (2008)	Halcrow (2008)
Quaternary	Holocene	0.0117	Wonji Group	Wonji Group	Wonji Group
	Pleistocene	2.58			
Neogene	Pliocene	5.33	Chilalo Trachytes	Nazareth Group	Chilalo Trachytes
			Butajira Ignimbrites		Nazret Group/Afar Group
	Miocene	23.03	Guraqhe Basalts Shebele Trachytes	"Ancher Basalts", "Arba Guracha Silicics"	"Ancher Basalts", "Arba Guracha Silicics"
Paleogene	Oligocene	33.9	Kella Basalts	A Iaji Formation	

b. General geology

The general geological conditions of RVLB were explained in this section are divided into the seven areas in the whole area. The geological map (refer to Figure 2.12) based on the field survey of geology and the existing references in RVLB are shown and the correlation chart in the study area is indicated in Table 2.6.

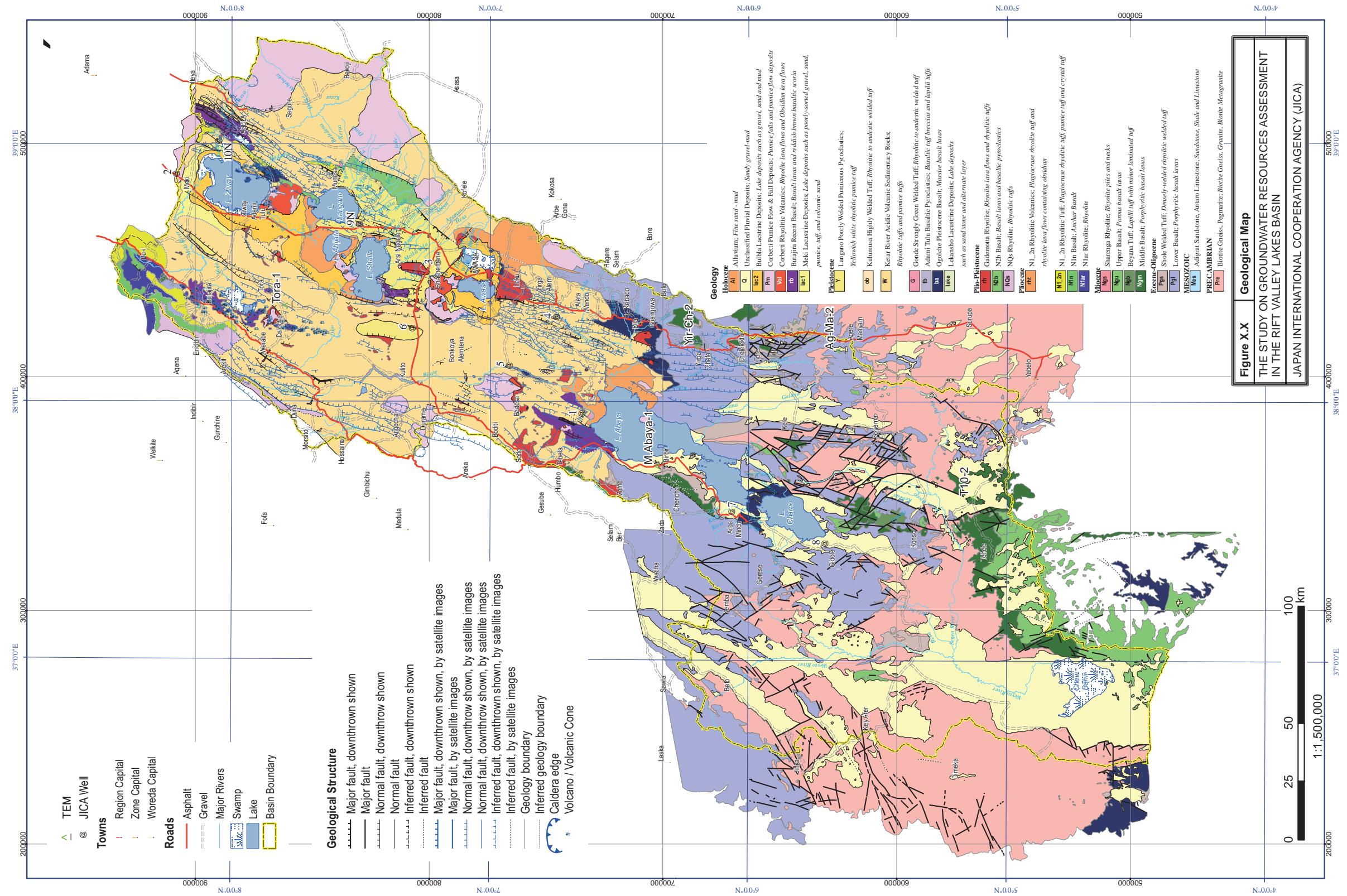
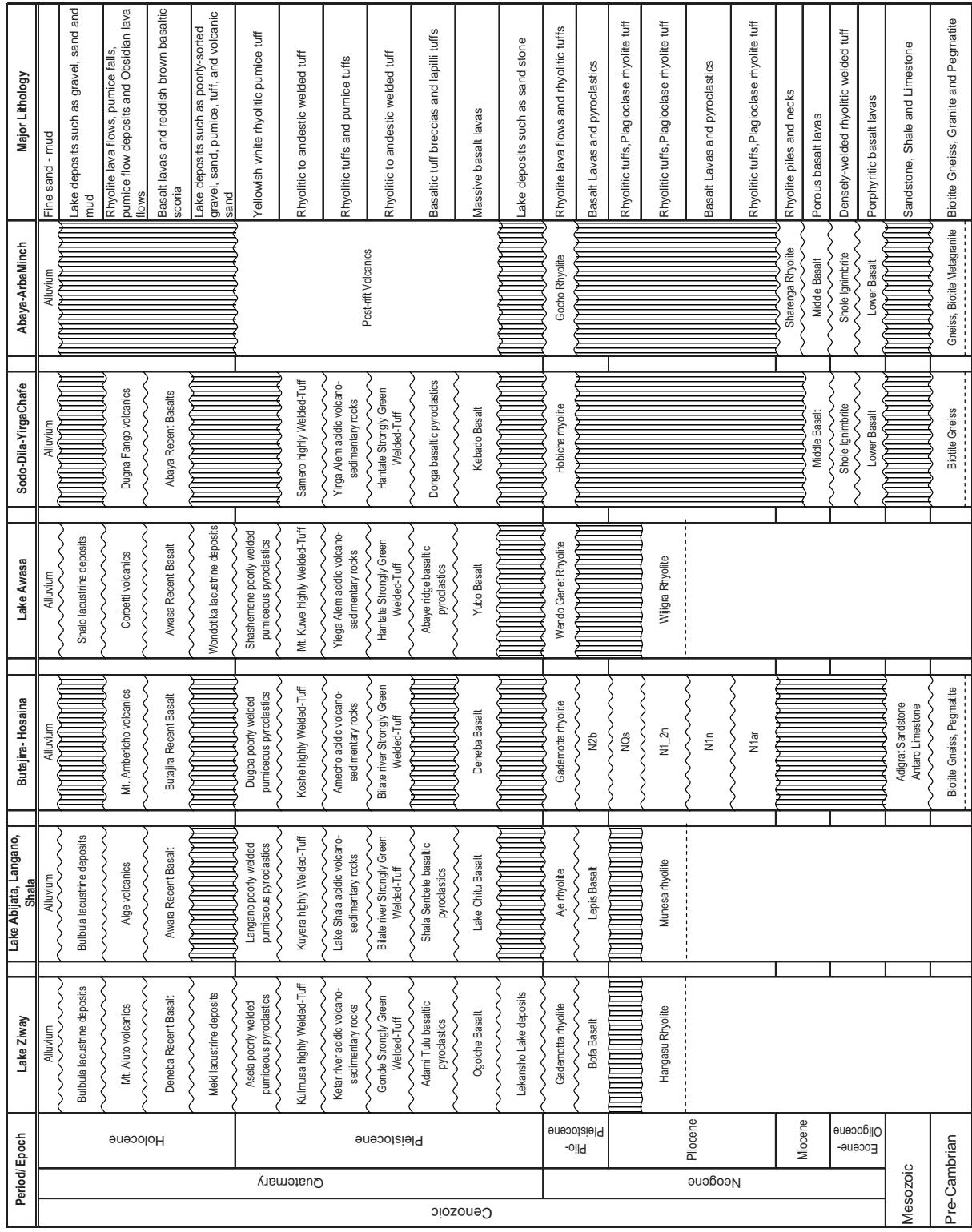


Figure 2.12: Geological Map of RVLB

Table 2.6: Correlation Chart of the Study Area



Lake Ziway and its surrounding areas are located in the central MER. The rift floor is widely covered by Holocene lake deposits. WFB is well developed on the floor and margin of MER in the area, therefore Pliocene – Pleistocene strata are generally observed at the scarps of these faults. Volcanic rocks are thickly deposited at Gademotta and Mt. Aluto, and were named as Gademotta Rhyolite and Mt. Aluto Volcanics in the Study; however, distributions of these volcanics are unclear due to overlying Holocene deposits.

The lowest unit, called Bofa Basalt, is observed only beside the fault scarp which is located at the east of Mt. Aluto. Borehole data of geothermal study indicates that the Bofa Basalt is overlain by Gademotta Rhyolite. Similar kind of rhyolite is observed to the east of Lake Ziway, so some rhyolitic volcanoes may have existed at that time. O golche Basalt, Adami Tulu Basaltic Pyroclastics and Kulumusa highly Welded Tuff overlie Gademotta Rhyolite with intercalation of lake sediments.

In Holocene, volcanic activities of rift floor basalts and rhyolite volcanoes along the WFB occurred with the development of lakes and/or swamps.

Late Pliocene (3.6Ma) tuff is observed at a depth of 2100m from Mt. Aluto by geothermal investigation that indicates approximately 2000 m subsidence occurred since Late Pliocene.

Lake Abijata-Langano-Shala and its surrounding areas are located on the basin floor of central part of MER, which composes the flat floor of Lake Ziway area. The basin floor is widely covered by Holocene lacustrine deposits; however, WFB cuts those sediments at some part, and forms step-like topography. Distribution of Lake Abijata and Lake Langano is controlled by such faults. Lake Shalla is a caldera created by a volcanic eruption.

The lowest geological unit in the area is rhyolitic tuff which outcrops at Munesa, located at the escarpment east of Lake Langano. This rhyolitic tuff is known to be distributed extensively in the surrounding area and has 3.17-3.48Ma chronological age by WoldeGabriel et al., 1990, indicates that gigantic volcanic activity occurred in this area at that time (WoldeGabriel et al 1990, Le Turdu et. al, 1999).

Bilate River Strongly Welded Tuff and upper units are well observed on the caldera wall of Lake Shala. Kuyera Highly Welded Medium Tuff and Langano Poorly Welded Pumiceous Pyroclastics are widely distributed at horsts between Lake Langano and Lake Abijata, to Shashamene Town.

In Holocene age, volcanic activities of rift floor basalt occurred in the southwest of Lake Shala, and they continued to the south toward WFB. Simultaneously, volcanic activity of rhyolite occurred in the northeast of Lake Shala.

Lake Awassa and its surrounding areas is a caldera basin which is surrounded by steep caldera wall. Late Miocene to Pleistocene volcanic rocks are exposed toward the wall. Holocene sediments are distributed on the floor of the caldera.

The lowest unit is Wendo Genet Rhyolite, which is thickly exposed at the foot of caldera wall, may have erupted from Awassa caldera. Western and southern part of caldera, Wendo Genet Rhyolite is overlain by Abaye ridge basaltic pyroclastics. Welded tuffs which are correlated to the other two areas are rarely exposed on the caldera wall.

Corbetti Volcano is prominent in Holocene volcanic activity. This volcano was active around 20,000 years ago and nowadays fumarole is found at the top.

The width of RVLB becomes narrower from the north direction and the sedimentary basin of valley is shallow and small scale relatively in Sodo-Dila-YirgaChafe and its surrounding area. Neogene Basalt erupted during early development of RVLB and older deposits than that are distributed in this area. And also the basement rocks of Pre-cambrian period and Tertiary volcanic rocks can be recognized in the RVLB.

Butajira-Hosaina and its surrounding area are located in the west area of RVLB, and are characterized by topography bounded by steps of continuous faults in direction of NNE-SSW series from valley floor to escarpment of RVLB. The Tertiary deposits mainly chop out at escarpment and the strata are distributed on the valley floor continuously contacted by the above faults.

Pre-Cambrian to Neogene formations are mainly distributed and deformed by N-S faults in Abaya – Arba Minch and its surrounding area. Pliocene to Pleistocene units are slightly distributed on the small basins which originated from the N-S faults in the above formations. Pliocene to Pleistocene units are composed of distinctive volcanic deposits, lake deposits, colluvium and alluvium. Basins are relatively smaller than northern part of RVLB and developed weakly.

Pre-Cambrian basement rock is widely observed and forms gentle hills in Hagare Mariam – Yabelo and its surrounding area. N-S and NW-SE fault system is developed in the western part, which forms steep ridges. Neogene and Quaternary strata are mainly composed of loose sand and mud deposited in weakly-developed basins.

c. Geological unit

The stratigraphy in the study area is established based on the correlation with the strata of each area. The geological units are described as follows in the Table 2.7 ; the detail geology of RVLB is described in the supporting report.

d. General geological structure

NNE-SSW fault systems are developing at the margin and rift floor in RVLB. The degree of development is slightly different between the northern and southern parts.

Fault system in northern RVLB is characterized by the development of continuous major faults which has big displacement with minor parallel faults, and fault zones associated with volcanic activity in the rift floor. While, Pre-Cambrian and Neogene fault system in southern RVLB is neither continuous nor regular.

The difference of the development of those faults is deeply related with the development of basin in RVLB, it indicates that the basin is well developed in the northern part and poorly developed in the southern part.

WoldeGabriel et al., (1990) classified the distribution of those faults and considered that Rift Valley Marginal Faults were active at the formation of the valley and are still active. Furthermore, with the development of RVLB, spread of rift floor has been started through the development of Wonji Fault Belts since Pleistocene age.

Table 2.7: Stratigraphy in the Study Area

Period/Epoch	Stratigraphy	Name of strata	Name of Formation	Major Lithology	Distribution
	Al	Alluvium,	Alluvium	Fine sand - mud	distributed in entire RVLB
	Q	Unclassified Fluvial Deposits	Quaternary sediments	Sandy gravel-mud	distributed in entire RVLB
Holocene	Bulbula Lacustrine Deposits	Bulbula lacustrine deposits, Shab lacustrine deposits	Lake deposits such as gravel, sand and mud	locally distributed in northern part of RVLB and surrounding Lake Awassa area	
	Corbettini Pumice Flow & Fall Deposits/ Corbettini Rhyolitic Volcanics	Mt. Ambiercho volcanics, Mt. Ambiercho volcanoes, Corbettini volcanoes, Corbettini volcanoes, Dugna Fango	Rhyolite lava flows, pumice falls, pumice flow deposits and Obsidian lava flows	locally distributed from Zway to Abaya- Afba Minch area	
	Bulajira Recent Basalt	Deneba Recent Basalt, Awara Recent Basalt, Bulajira Recent Basalt, Awara Recent Basalt,	Basalt lavas and reddish brown basaltic scoria	zonally distributed on the floor of entire RVLB excluding southern part	
	Abaya Recent Basalts	Abaya Recent Basalts	Lake deposits such as poorly-sorted gravel, sand, pumice, tuff, and volcanic sand	locally distributed surrounding Lake Zway and Lake Awassa area	
Quaternary	Meki Lacustrine Deposits	Meki lacustrine deposits, Wondokta lacustrine deposits	Aseba poorly welded pumiceous pyroclastics, Langano poorly welded pumiceous pyroclastics, Dubia poorly welded pumiceous pyroclastics, Shashemene poorly welded pumiceous pyroclastics	Yellowish white rhyolitic pumice tuff	continuously distributed from Zway to Awassa area
	Langano Poorly Welded Pumiceous Pyroclastics	Langano Poorly Welded Tuff	Kulumusa highly Welded-Tuff, Kyeza highly Welded-Tuff, Koshe highly Welded-Tuff, Mt. Kuwe highly Welded-Tuff, Samero highly Welded-Tuff	Rhyolitic to andesitic welded tuff	continuously distributed from Zway to Dilaa area
	Y	Kulumusa Highly Welded Tuff	Kulumusa highly Welded-Tuff, Kyeza highly Welded-Tuff, Koshe highly Welded-Tuff, Mt. Kuwe highly Welded-Tuff, Samero highly Welded-Tuff	Rhyolitic to andesitic welded tuff	continuously distributed from Zway to Dilaa area
	ob	Ketar River Acidic Volcanic Sedimentary Rocks	Ketar river acidic volcanic sedimentary rocks, Lake Shala acidic volcanic sedimentary rocks, Ameho acidic volcanic sedimentary rocks, Yega Alem acidic volcanic sedimentary rocks	Rhyolitic tuffs and pumice tuffs	continuously distributed from Zway to Dilaa area
Pleistocene	W	Gonde Strongly Green Welded Tuff	Gonde Strongly Green Welded-Tuff	Rhyolitic to andesitic welded tuff	continuously distributed from Zway to Dilaa area
	G	Adam'i Tulu Basaltic Pyroclastics	Adam'i Tulu basaltic pyroclastics, Shala Senebe basaltic pyroclastics, Abaya ridge basaltic pyroclastics, Donga basaltic pyroclastics	Basaltic tuff breccias and lapilli tuffs	locally distributed in entire RVLB
	tb	Ogolche Pleistocene Basalt	Ogolche Basalt, Lake Chitu Basalt, Deneba Basalt, Yubo Basalt, Kehado Basalt (Post-tuff Volcanics)	Massive basalt lavas	locally distributed in entire RVLB
	ba	Lekansho Lacustrine Deposits	Lekansho Lake Deposits	Lake deposits such as sand stone and alternate layer	locally distributed in Zway and surrounding area
	Iak				
Plio-Pleistocene	rh	Gadremota Rhyolite	Gadremota rhyolite, Aje rhyolite, Wendo Genet Rhyolite, Hobicha rhyolite, Gochu Rhyolite	Rhyolite lava flows and rhyolitic tuffs	continuously distributed in entire RVLB
	N2b	N2b Basal	Bo'a Basalt, Lepis Basalt	Basalt lavas and basaltic pyroclastics	distributed only in the south of Lake Zway
	NQs	NQs Rhyolite	NQs	Rhyolitic tuffs	locally distributed in Bulajira area
	N1n	N1_2n Rhyolitic Volcanics/Rhyolitic Tuff	Munesa rhyolite, Hangasu Rhyolite, Wiljiga Rhyolite, N1_2n	Plagiocrase rhyolite tuff	locally distributed in entire RVLB
Pliocene	N1n	N1n Basalt	N1n	Anchar Basalt	locally distributed in Bulajira area
	N1ar	N1ar Rhyolite	N1ar	Rhyolite	locally distributed in Bulajira area
	Ngs	Sharanga Rhyolite	Sharanga Rhyolite	Rhyolite piles and necks	distributed only in Abaya- Afba Minch and surrounding area
Miocene	Ngu	Upper Basalt	Upper Basalt	Porous basalt lavas	continuously distributed in the south of Dilaa
	Ngb	Beyana Tuff	Beyana Tuff	Lapilli tuff with minor laminated tuff	continuously distributed in the south of Dilaa
	Ngm	Middle Basalt	Middle Basalt	Porphyritic basalt lavas	continuously distributed in the south of Dilaa
Eocene- Oligocene	Pgs	Shole Wedded Tuff	Shole Igimbrite	Densely-welded rhyolitic welded tuff	continuously distributed in the south of Dilaa
	Pgl	Lower Basalt	Lower Basalt	Porphyritic basalt lavas	continuously distributed in the south of Dilaa
Mesozoic	Mes	Adigat Sandstone, Afato Limestone	Adigat Sandstone, Afato Limestone	Sandstone, Shale and Limestone	locally distributed in Kella, northern part of Bulajira/Bulajira and HagerSelam-Yabelo area
Pre-Cambrian	Pre	Lower Gneiss, Pegmatite	Lower Gneiss, Granite, Biotite Metagranite	Biotite Gneiss, Granite, Biotite Metagranite	References: (1) Laury and Albritton 1975, (2) Mohr et al. 1980, (3) EIGS-GLE 1985, (4) WoldeGabriel et al. 1990, (5) GSSE 1994, (6) GSSE 2002, (7) EWTEC 2008

e. Volcanic activities

WoldeGariel et al. (1990) summarized the history of volcanic activity and its distribution. According to that study, large calderas by rhyolitic rocks and volcanic lines composed of single volcanic cones by basaltic rocks are observed in RVLB.

Recent volcanoes distributed in RVLB were formed by the development of WFB trending NNE-SSW, which has been formed since late Pliocene. The activity of WFB is associated with bimodal volcanic activities of basalts and rhyolites. These volcanics are classified as alkalic rocks which are rich in Na₂O and K₂O.

The volcanic activities are mainly recognized in late Pliocene to early Pleistocene stage and in middle Pleistocene to recent stage. Those basaltic rocks consist of basalt lavas and thick basaltic pyroclastics which show subaqueous volcanism in both stages. The rhyolitic activity in late Pliocene to early Pleistocene stage formed huge mountain body and calderas in this stage, it is believed from recent topographic features. Major calderas formed in this stage are as follows;

Table 2.8: Rhyolitic activity in late Pliocene to early Pleistocene stage

Caldera Name	Size	Depth	Estimated Volume	Age of Activity	Age of Depression
Gademotta	14 x 28km	300m	94km ³	1.3Ma(1)	1.1Ma(1)
Awassa	22 x 38km	300m	200km ³	2.5-1.1Ma(1)	0.2Ma(1)

(1) WoldeGabriel et al. (1990)

Rhyolite activity in middle Pleistocene to recent stage is located on the basaltic volcanic belt and forms volcanic bodies and partly associating caldera. Rhyolitic volcanoes are called from the north; Aluto, Shala (caldera), Corbetti and Dugna. In Butajira area there are no rhyolitic volcanoes, nor have there been any eruptions. Major rhyolitic volcanoes formed in this stage are as follows;

Table 2.9: Rhyolitic activity in middle Pleistocene to recent stage

Name	Size	Height (Depth)	Volume	Age of Activity	Recent activity
Aluto	10x 12km	250m	8km ³	0.27-0.021Ma(4)	Fumarole
Shala	15 x 16km	500m(2)	96km ³	0.28-0.18Ma(3)	-
Corbetti	7 x 8km x 2	600m	18km ³	0.02Ma(1)	Fumarole
Dugna	13 x 14km	600m	29km ³	---	-

References : (1) WoldeGabriel et al. 1990, (2) Le Turdu et al. 1999, (3) :Mohr 1980, (4) Laury and Albritton, 1975

2.3.3 Hydrogeology

a. Hydrogeological data collection

From the past, more than ten thousand wells and springs have been used as potable water sources in the Study area. At the collection of the additional data, effort was made to obtain the reports including the following information; 1) Coordination of water sources (some of the points were visited for data measurements), 2) Geology of the aquifers, 3) Aquifer thickness and/or screen position of the casing, 4) Description of hydrological parameters (at least the description of Q = discharge rate). The final total number of wells is 324 (including 7 new JICA Test wells), and springs, 445 in the stage of interim report.

b. Aquifer of existing wells

Aquifer characteristics were examined by utilizing existing well inventories (including completed JICA test wells). Existing well inventories includes aquifer geology, aquifer thickness and the depth (aquifer position of some wells are represented by screen position). The variation of geology of the aquifer is presented in Table 2.10.

Table 2.10: The Composition data by geological character of aquifer

No	Aquifer Geology	Other reference of description	Data No	%
1	Alluvium	-	10	3.2
2	Clay	Sandy clay	4	1.3
3	Sand	Coarse sand, lacustrine	57	18.1
4	Gravel	Sandy gravel	38	12.1
5	Sand and Gravel	Sand gravel clay	-	-
6	Basalt	Fractured basalt, weathered basalt, scoriaceous basalt	86	27.3
7	Ignimbrite	Fractured ignimbrite, scoria/ignimbrite, weathered ignimbrite	38	12.1
8	Pumice	Pumice sand, sand/pumice	23	7.3
9	Pyrolastics	-	4	1.3
10	Scoria	Scoria & sandy gravel	13	4.1
11	Tuff	Pumicious tuff, sandy tuff weathered tuff,	33	10.5
12	Welded tuff	-	2	0.6
13	Other volcanics	Trachyte, Rhyolite, volcanic sediments	7	2.2

The table above indicates that about 70% of aquifers in the area composed of volcanic rocks and its member. Potential good aquifers are gravel, pumice and scoria formations referred to the existing well inventory. The average well depth is about 50 mbsl (meters below surface level), and more than 80 mbsl for most volcanic aquifers.

It should be noted that identification of the geology of respective aquifers depends on the drilling geologist's capacity of rock identification. Down the Hole Drilling method (DTH) is common in Ethiopia and the logging engineer (geologist) shall determine the geology from small rock chip samples. If the contractor does not have enough manpower to provide the skilled geologist, then the rock will be identified as sand, gravel etc., by merely evaluating the shape and size of the rock chips. Therefore, it is a quite difficult exercise to verify the

accuracy of geological descriptions (whether they be alluvium deposits or volcanic rock chip samples). Some descriptions might actually be volcanic rock samples instead of just sand and gravel.

c. **Relation among JICA Test Well, existing well inventory and geological cross section**

The location map of JICA drilling wells was shown in Figure 2.13.

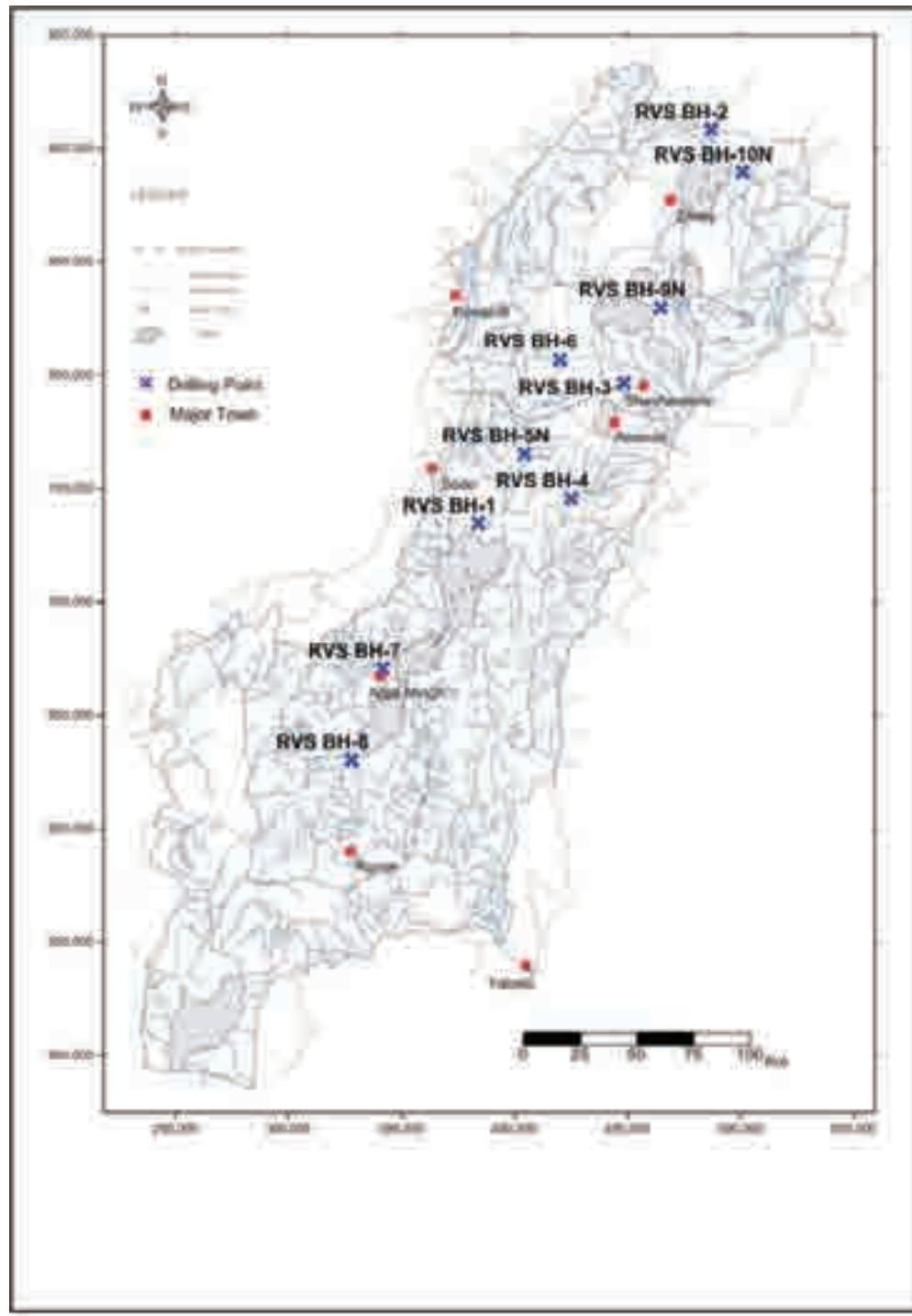


Figure 2.13: Location Map of JICA Wells

The stratigraphical analysis has been completed on a total 8 wells of 10 JICA wells presented in Table 2.11. Some wells do not have hydrogeological parameters while the pumping tests have not yet been completed. The aquifer can be divided into 2 major units, which are: Pleistocene rhyolites – andesitic welded tuff (G), and basaltic tuff breccia – volcanic breccia (tb). In accordance with this comparison, the description of each formation is quite different. Welded tuff formation is described as sand, gravel and pumice, and tuff breccia is defined as rhyolite and ignimbrite without any description of the nature of the aquifer. Therefore, the rhyolite, ignimbrite in the existing well classification is referred to as (tb). The remaining two wells were located in Arba Minch and its surrounding area and south part of Arba Minch, and the aquifer of wells consists of Basalt layer probably.

Table 2.11: Comparison between JICA Wells and Existing Wells

No	BasinName	Code	Locality	Eastings	Northings	Level	Type	Depth	Upper Screen Depth	Aquifer	Q	SWL	DWL	TDD	Sc	T	S	
						(m)	(GL-m)	m	I/s	GL-m	GL0m		(L/min/m)	(m ² /day)				
JICA BH4	Gidabo	RVS BH4	Yirga Alem	424916	745491	1632	BH	244	82.00	1550	Tuff Breccia (tb)	6	7.7	44.9	37.2	9.60	27	2.90E-07
	Gidabo	SW102		424178	742349	1621	BH	141	72.00	1549	Gravel, w/fr/Rhyolite	6.5	0.5	9.12	8.62			
	Gidabo	SW101		422684	736474	1689	BH	134	95.00	1594	Ignimbrite & Sand	5	62		28.55	10.5	13.17	5.6
	Gidabo	SW112		431035	752301	1742	BH	120	72.00	1670	Volcanic Sand	6.6	9.75		69.85	5.66	2.71	4.29
BH5	Bilate	RVS BH5	Dimutu	404261	765667	1485	BH	250	28.00	1457	Basalt (Pleistocene)	100	Artesian	-	-	-	-	-
	Bilate	RVS BH1	Walayta	383591	734651	1237	BH	150	96.00	1141.00	Welded tuff (rh)	12	47.35	53.20	5.85	139.2	377	4.80E-08
	Bilate		Siaro1	410305	767729	1663	BH	221.7	130.00	1533	Gravel, sand	5	146.1				24.1	2.70E-05
	Bilate		Siaro2	411579	765908	1708	BH	300	162.00	1546		14	146.6					
	Bilate		Chericho	397591	750809	1330		111	15.40	1315	Basalt gravel, sand	5.6	5.65		1.93	12.90	211.7	
BH12	EasternZiway	RVS BH2	Meki	486788	907743	1688	BH	147	105.00	1583	Tuff Breccia (tb)	8.5	90.6	93.43	2.83	1731.00	914.4	2.03E-03
	EasternZiway		Alem Tena	493472	917127	1660	BH	102	58.90	1601	Highly weathered Ignimbri	7.2	57.4	57.52	0.12		60.4	0.987
BH10	EasternZiway	RVS BH10	Yabelo BW	500339	889953	1674	BH	200	94.00	1580	Welded tuff (G)	19	25.32	34.05	8.73	148.80	521	5.80E-11
	WesternZiway/Abijata	SW176		437406	858687	1822	BH	243	204.50	1618	sand + gravel	4.7	152.8	190	37.2			207
BH9	LakeLangano	RVS BH9	Konso	464826	829769	1635	BH	200	86.00	1549	Welded tuff (G)	16	43.41	52.37	8.96	114.00	261	3.00E-05
	WesternZiway/Abijata	SW189		439050	889444	1835	SW	31	21.45	1814	Pumice	2	10					20
BH3	LakeShalla	RVS BH3	Sheshemene	447623	795610	1801	BH	247	190.00	1611	Tuff Breccia (tb)	1	171	179.7	8.7	43.80	12.5	1.10E-02
	Lake Shalla	RVS BH6	Kenche	420114	807271	1869	BH	356	266.00	1603	Welded tuff (G)	4.6	247.6	253.2	5.6	51.60	88	2.00E-03
	LakeAwassa	SW162		436398	790447	1714	BH	66	45.00	1669	Sand	5.9	40.6					
BH7	LakeAwassa	SW160		437444	789560	1720	BH	45.4	31.22	1689	Tuff	5.5	34					
	Kulfo Gina	RVS BH7	Arba Minchi	341700	670517	1198	BH	200	86.00	1112	Basalt (Pgl)	16	4.89	53.8	48.91	20.4	41	1.70E-04
	Sife Chamo	RVS BH8	Chamo South	327946	630717	1157	BH	152	50.00	1107	Basalt (Pgl)	26	15.3	17.89	2.59	-	1015	4.80E-02



JICA borehole



Existing well inventory

Since all JICA test wells are completed, the data of wells were input in the cross-sections that were produced by the geological survey. To analyze the relation of lithofacies of stratigraphy and the aquifer, geological cross sections were established from detailed geological field reconnaissance. Existing aquifer information was partially projected on the geological cross section. It seems to be the aquifer units of basalt are correlated with the Plio-Pleistocene rhyolite lava flows and rhyolitic tuff (rh) and basalt lavas and basaltic pyroclastics. The upper formation of major aquifer of Pleistocene welded tuff and tuff breccia is potential aquifer. Pumice tuff formation is also a potential aquifer if aquiclude underlies this layer.

Table 2.12: Lithofacies and Aquifer Geology

Period/Epoch	Stratigraphy	Name of Formation	Aquifer Geology	Distribution
Cenozoic	Quaternary	AI	Alluvium	distributed in entire RVLB
		Lac	Bulbula lacustrine deposits, Shalo lacustrine deposits	locally distributed in northern part of RVLB and surrounding Lake Awassa area
		Pm volcan	Mt. Aluto volcanics, Alge volcanics, Mt. Ambiencho volcanics, Corbett volcanoes, Dugna Fango volcanoes	locally distributed from Ziway to Abaya- Arba Minch area
		br	Deneba Recent Basalt, Awara Recent Basalt, Butajira Recent Basalt, Awasa Recent Basalt, Abaya Recent Basalt	widely distributed on the floor of entire RVLB excluding southern part
		Lac	Meki lacustrine deposits, Wondolika lacustrine deposits	locally distributed surrounding Lake Ziway and Lake Awassa area
	Pleistocene	Y	Asela poorly welded pumiceous pyroclastics, Langano poorly welded pumiceous pyroclastics, Dugba poorly welded pumiceous pyroclastics, Shashemene poorly welded pumiceous pyroclastics	Tuff
		ob	Kulmusu highly Welded-Tuff, Kuyera highly Welded-Tuff, Koshe highly Welded-Tuff, Mt. Kuwe highly Welded-Tuff, Samero highly Welded-Tuff	Ignimbrite Welded Tuff
		W	Ketar river acidic volcano-sedimentary rocks, Lake Shala acidic volcano-sedimentary rocks, Amecho acidic volcano-sedimentary rocks, Yiega Alem acidic volcano-sedimentary rocks	Tuff
		G	Gonde Strongly Green Welded-Tuff, Bilate river Strongly Green Welded-Tuff, Hantate Strongly Green Welded-Tuff	Pyroclastics Welded Tuff
		tb	Ogolcha Basalt, Shala Sennete basaltic pyroclastics, Abaye ridge basaltic pyroclastics, Donga basaltic pyroclastics	Scoria
	Tertiary	ba	Lepis Basalt, Deneba Basalt, Yubo Basalt, Kebab Basalt	Basalt
		Lak	Lekansho Lake deposits	locally distributed in Ziway and surrounding area
Mesozoic	Plio-Pleistocene	rh	Gademotta rhyolite, Aje rhyolite, Wendo Genet Rhyolite, Hobicha rhyolite, Gedro Rhyolite	Pumice Basalt
		N2b	Bofa Basalt, Lepis Basalt	Basalt
		NQs	NQs	located only in the south of Lake Ziway and east of Lake Awassa area
	Pliocene	rht/N1_2	Munesa rhyolite, Hangasu rhyolite, Wijigra rhyolite, N1_2N	Basalt
		N1n	Nin Basalt	locally distributed in Butajira area
		N1ar	N1ar Basalt	locally distributed in Butajira area
	Miocene	Nas	Sharengia Rhyolite	located only in Abaya- Alba Minch and surrounding area
		Nau	Upper Basalt	continuously distributed in the south of Dila
		Nab	Beyana Tuff	continuously distributed in the south of Dila
	Eocene-Origocene	Ngm	Middle Basalt	continuously distributed in the south of Dila
		Pgs	Shole Ignimbrite	continuously distributed in the south of Dila
		Pgl	Lower Basalt	Basalt?
	Mes		Adigrat Sandstone, Antaro Limestone	locally distributed in Kella, northern part of Butajira
Pre-Cambrian	Pre		Biotite Gneiss, Granite, Biotite Metagranite	distributed in Kella, northern part of Butajira and Hager Selam-Yabero area

References: (1) Laury and Albritton 1975, (2) Mohr et al. 1980, (3) EIGS-GLE 1985, (4) WoldeGabriel et al. 1990, (5) GSE 1994, (6) GSE 2002, (7) EWTEC 2008

2.4 Socio-economic conditions

The Government of Ethiopia has a decentralized structure, and consists of Federal level Ministries, 9 Regional States Administrations, 2 Administrative Areas (Addis Ababa and Dire Dawa), and about 550 Woreda (District) level administrations. Each Woreda consists of a number of *Kebeles* (villages), which is the lowest level of government at the community level.

2.4.1 Regional socio-economy

a. Land area and population

The Southern Nations, Nationalities and People's Region State (SNNPRS) is one of the nine Federal Regional States of Ethiopia. The region covers an area of about 110,000 sq km, which is almost 10% of the total size of Ethiopia. The RVLB covers an area of about 32,000 sq km. The population in all area of SNNPRS is more than 15 million, and more than about 6.59 million in RVLB. The capital of the Region is Awassa. Based on ethnicity and language identities, the Region is divided into: 13 Zones, under which there are 125 Woredas, 8 Special Woredas, and 19 autonomous town administrations. There are 3,561 rural Kebeles and 90 towns which have a municipality. There are ten Zones of SNNPRS in RVLB.

On the other hand, Oromia Region is the largest of the 9 national Regional States of Ethiopia, in terms of population and also in terms of land area. The Oromia region covers an area of more than about 353,000 sq km, but the area in the region of RVLB is 20,000sq km, less than that of SNNPRS. And the population of all area in Oromia Region is 26.5 million, and about 2.3 million in RVLB. The capital of Oromia Region is Adama. Oromia Regional State is administratively divided into 17 Zones, 301 Woredas (262 rural districts and 39 urban centers under reform) and more than 6,630 Peasant and Urban Dwellers Associations/Gandas. There are five Zones of Oromia Region in RVLB.

b. Regional economy

b.1 SNNPRS

The per-capita gross regional product at current factor cost in SNNP Region in 2004-05 was about 1,059 Birr. The General Price Trend in the SNNPR remained below 6% over the period 1994 to 1999, but increased to over 7% since 2002. The average contribution of Agriculture to the regional economy (measured at constant factor cost) declined from 63% in the period of 1992-1994 EFY to 47% in the period 1995-97. On the other hand, the contribution of Industry increased from 15% to 24% during the same period, while Services increased from 22% to 29% during the same period, thereby indicating the structural transformation of the economy from agriculture toward industry and services.

It can be seen that tillable land comprises less than half of the total land area, three-fourths of farmers undertake crop and livestock activities at the same time, farms of less than 1.0 ha comprise 80% of all farms, main crops are corn, potatoes and sweet potatoes, and main livestock are cattle, poultry and sheep. It can be concluded that the agriculture in the SNNP Region is small scale subsistence farming, producing products mostly for family consumption. Although land plowing is done with hand-made wooden plows and a pair of oxen, farmers who own 2 oxen or more comprised only 20% of the total.

b.2 Oromia Region

Within the Oromia Regional State, agriculture is the main economic activity, providing livelihood to about 89% of the population. The small scale peasant holder farming type accounts for about 98% of the total agricultural production in the Regional State. Agriculture contributes 66.7% of the Region's gross regional product (GRP), while Services contribute 21.2% and Industry with 12.1%. For the years 1999/00 to 2005/06, the average annual growth rates of agriculture, industry and services were, respectively, 7.7%, 3.5% and 5.6% (refer to Table 2.13). During the latest consecutive three years 2003/04 to 2005/06, the average annual growth rates of the three sectors (agriculture, industry and services) were 18.4%, 3.5% and 8.3%, respectively.

Table 2.13: Sector Composition

Gross Regional Product (GRP)	Composition (%)	Growth Rate 1999-2005 (%)
Primary Sector (Agriculture)	66.7	7.7
Secondary Sector (Industry)	12.1	3.5
Tertiary Sector (Services)	21.2	5.6

In the year 2001/02 the land area cultivated with cereals, pulses, oilseeds, vegetables and root crops totaled 3,532,670 hectares (44.2% of the country's total cultivated land), while the production volume of these crops reached 54,338,050 quintals (47.8% of the country's total production). The contribution of the Region increased in the year 2004/05, when, according to the Agricultural Sample Survey, the Region's contribution was 46.6% and 52.3% of the country's total cultivated land area and production volume, respectively.

Oromia made the largest industrial contribution to Ethiopia's economy, with an estimated 60% of foreign exchange earnings. The largest proportion of Ethiopia's export commodities originated in Oromia, including the following products: coffee, oilseeds, leather products, fruits and vegetables, flower, gold, etc. The Oromia Regional State accounted for about 40% of the country's GDP, to which the industrial sector contributed about 12.1% of the total Regional GDP.

2.4.2 Socio-economic framework

Basically, the analysis of socioeconomic framework implies the estimation of the economic growth rates during the anticipated project implementation period, in order to estimate the increase in water demand that should be incorporated into the project formulation so as to take into account the effect of economic growth on the increasing water demand.

The method of projecting past trends into the future depend on the data source, because it is equivalent to projecting past trends. This implies that the outcome will depend on the base years of the data to be projected. In Ethiopia, the Central Statistical Agency is the office that publishes statistical data, and this source was used for the projection of past data. Two sources of statistical data were used: Statistical Abstract 2007 and Statistical Abstract 2011. All the projections including the above two sources are presented in the following Table 2.14.

Table 2.14: GDP Growth Rate & Estimated GDP for Ethiopia

Data Source	Year	GDP Growth Rate Sources & Estimated GDP Projection for Ethiopia (%)						
		StatAbs2007	StatAbs2011	African	CIA	IMF/Afric	Halcrow	本調査
		GDP Growth (%)	GDP Growth (%)	Dev Bank 17-Sep-10	Factbook 2011	Business M 18-Apr-11	Projection (%)	Framework (%)
Statistical data	2001		1.28					
Statistical data	2002		-2.00					
Statistical data	2003	11.78	11.78	11.7				
Statistical data	2004	12.67	12.67	12.6				
Statistical data	2005	11.78	9.39	11.5				
Statistical data	2006	11.28	13.90	11.8				
Projection/Stat data	2007	11.28	11.43	11.2				
Projection/Stat data	2008	11.04	10.32	9.9	11.6			
Projection/Stat data	2009	10.80	10.42	10.16	8.7			
Projection	2010	10.56	14.97	9.79	7.0			
Projection	2011	10.32	16.20	9.42	4.50	8.1	5% - 7%	7%
Projection	2012	10.09	17.44	9.05	2.20	8.1	5% - 7%	7%
Projection	2013	9.85	18.67	8.69	-0.10	8.1	5% - 7%	7%
Projection	2014	9.61	19.91	8.32	-2.40	8.1	5% - 7%	7%
Projection	2015	9.37	21.14	7.95	-4.70	8.1	5% - 7%	7%
Projection	2016	9.13		7.58			5% - 7%	6%
Projection	2017	8.89		7.21			5% - 7%	6%
Projection	2018	8.65		6.84			5% - 7%	6%
Projection	2019	8.41		6.47			5% - 7%	6%
Projection	2020	8.17		6.11			5% - 7%	6%
Projection	2021	7.93		5.74			5% - 7%	6%
Projection	2022	7.69		5.37			5% - 7%	6%
Projection	2023	7.46		5.00			5% - 7%	6%
Projection	2024	7.22		4.63			5% - 7%	6%
Projection	2025	6.98		4.26			5% - 7%	6%
Projection	2026	6.74		3.89			5% - 7%	5%
Projection	2027	6.50		3.53			5% - 7%	5%
Projection	2028	6.26		3.16			5% - 7%	5%
Projection	2029	6.02		2.79			5% - 7%	5%
Projection	2030	5.78		2.42			5% - 7%	5%
Projection	2031	5.54		2.05			5% - 7%	5%
Projection	2032	5.31		1.68			5% - 7%	5%
Projection	2033	5.07		1.31			5% - 7%	5%
Projection	2034	4.83		0.95			5% - 7%	5%
Projection	2035	4.59		0.58			5% - 7%	5%
<i>Sources:</i>								
		<i>Statistical Abstract 2007, Statistical Abstract 2011, CSA</i>						
		<i>Own Projection based on statistical data</i>						
		<i>Ethiopia's Economic Growth, AfDB, 17 September 2010</i>						
		<i>Ethiopia, CIA Factbook 2011</i>						
		<i>African Business Magazine, 18 April 2011</i>						
		<i>RVLB Integrated Resources Development Master Plan, Halcrow</i>						
		<i>Statistical Data</i>						
		<i>Projection</i>						
		<i>Short term growth rate</i>						
		<i>Medium term growth rate</i>						
		<i>Long term growth rate</i>						

The projecting of GDP in our study indicates the above mildly declining trend from 7% to 5%. The population growth rate which the study uses is shown in Table 2.15 in consideration with the above GDP growth rate.

Table 2.15: Population Growth Rates for the Study

Year	Adopted Low Population Growth Rates		
	Total	Rural	Urban
2011-2015	3.30%	3.00%	5.20%
2016-2020	2.80%	2.50%	4.70%
2021-2025	2.50%	2.10%	4.40%
2026-2030	2.30%	1.80%	4.20%
2031-2035	2.10%	1.60%	4.00%

The economic growth rate and economic structure in future (see to Table 2.16) are utilized in the study.

Table 2.16: Economic Growth Rates & Economic Structure for the Study

Basin Economy & Development Sectors	Baseline (2008)	Short Term (2011-2015)	Med. Term (2016-2025)	Long Term (2026-2035)
Annual growth rate	7%	7%	6%	5%
Economic Structure				
Agriculture	69%	58%	47%	36%
Industry	8%	10%	12%	13%
Services	23%	32%	41%	51%
Employment				
Agriculture	74%	62%	50%	38%
Industry	7%	12%	17%	23%
Services	19%	26%	33%	39%

(Quote Halcrow 2009、Rift Valley Integrated Resources Development Mater Plan Study Project in part concerning Table 2.15 and Table 2.16)