Chapter 4

Hydrogeology

4 Hydrogeology

4.1 Data collection of hydrogeology

4.1.1 Existing study and mapping

The geological map, hydrogeological map in relation to the hydrogeology and main reports have been collected for the references of the Study (refer to Table 4.1.1). Those reports and maps are collected mainly from Geological Survey of Ethiopia (hereafter refered to as "GSE"), MoWIE, and Ministry of Water Irrigation and Energy (hereafter refer to as "MoWIE"), et al. The geological maps in the Study area have been published as Debre Birhan (NC37-11), Dire Dawa（NC37-12）, Akaki Beseka Area (NC37-14), and Nazret (NC37-15) maps and reports. The hydrogeological maps have been created as the hydrogeological map in Ethiopia (scale: 1:2,000,000) and as the hydrogeological map in Nazret and Addis Ababa area (scale: 1:250,000 respectively).

Table 4.1.1: List of References

i)	Geological maps and explanation reports
	• Geological map of Nazret, Ethiopian Institute of Geological Surveys (EIGS), 1978 • Geology and Developing of the Nazret area, northern Ethiopia rift, Kazmin etc. EIGS 1978 • Geological map of Dire Dawa, EIGS, 1985 • Geological map of Debre Birhan, Geological Survey of Ethiopia (GSE), 1993 • Geology of Debre Birhan area, Daniel Mesheha etc. compiled, GSE, 2010 • Geological map of Akaki Beseka area, GSE, 1997 • Geology of Akaki Beseka, Efrem Beshawered compiled, GSE, 2010 • Geology of Addis Ababa map sheet, GSE, 1997 • Geology of Addis Ababa city, Getahun assigned, GSE, 2007
ii)	Hydrogeological maps and reports
	• Hydrogeology (Map) of the Nazret, EIGS, 1985 • Hydrogeology (Report) of the Nazret area (NC37-15), Gtahun Kebede, EICS, 1987 • Hydrogeological map of Ethiopia (1:2,000,000) compiled by Tesfaye Chernet and the Regional Geology Department, EIGS, 1988 • Hydrogeological map of Addis Ababa sheet (NC37-10), GSE, 2010 • Hydrochemical map of Addis Ababa sheet (NC37-10), GSE, 2010 • Hydrogeological report of Addis Ababa sheet (NC37-10), GSE, 2010
iii)	Project reports
	• Geothermal reconnaissance study of selected sites of the Ethiopian rift system, EIGS, 1987 • Fentale irrigation based interated development project, Oromia Water Works Design and Supervision Enterprise (OWWDSE), 2007 • Evaluation of water resources of the Ada'a and Becho plans groundwater basin for irrigation development project, Water Works Design and Supervision Enterprise (WWDSE), planned by Ministry of Water Resources (MoWR), 2009 • Allaidege plain groundwater resources assessment project, WWDSE planned by MoWR, 2009
ⅳ)	Drilling reports
	• Well completion report for well drilling Funyan Ajo, 2003 • Well completion report for Asebot town, 2008 • Technical well completion report on Bakiko water supply project, 2005 • Well completion report for well drilling at Oda Keneni,2003 • Technical well completion report on Geneda Ta'a water supply project, 2005 • Well completion report for well drilling at Hunde Missona, 2004 • Completion report of deep water well drilling in Kurfa Wachu village, 2008 • Well completion report for well drilling at Wolda Jajela, 2004 • Technical well completion report on Calalaka Ta'a water supply project, 2005 • Report on physical & Chemical analysis of water at Baka, Sararoo, and Caroraa, • Drilling report at Milinoztuftuewde, Fayo, Burka Misra, and Tu, 2002-2003 • Completion report of Abomsa deep well, 2008 • Watcha Dole well completion report, 2013

	• Completion report of Abasa-Goroba deep wel, 2008 • Well completion report for Marfe Village, 2009 • Well completion report for Shamp Godo Kebele, 2009 • Technical report on water well drilling and completion works undertaken at Cheffe Mishoma, 2007 • Water well drilling completion report in Bote#1 site, 2013 • Water well drilling completion report in Bote#2 site, 2013 • Completion report for Mojo well, 2008 • Well completion report of Ilmo Chukela Borehole, 2012 • Waber Chukala well completion report, 2013 • Well completion report at Fatole & Kurma Fatole, 2013 • Well completion report at Kachachule Guja & Daglagala Jida, 2013 • Six boreholes drilling, construction and testing project, 2013 -Well completion report of well 01 Kuntlshile hama district - Well completion report of well 02 Manjikso waji district - Well completion report of well 03 Dhinque Cheleba district - Well completion report of well 04 Wara Jarsa district • Well completion report at Kallo Kabite, Adada Dambala and Giche Garbabo, 2013 • Well completion report at Tulu Ree, Foche, Wabor Cale amd Cheleleka, 2007 • Well completion report of Agemso Rogicha borehole, 2012 • Well completion report of Bishan Tino borehole, 2012 • North showa zone Minjar Shenkora Woreda in Agirat kebele test /production wells drilling supervision report, 2011 • Water well drilling report format; Agirat water well, Agirat-2 and Mstw#2, 2011-2012 • Groundwater investigation report for rural kebeles in Minijar-Shenkora, 2007 • Study review to locate borehole sites and drilling supervision report for Arerti town, 2006 • Well drilling supervision report for Samsenbet area community water supply, 2008
v)	References and reports in relation to the Lake Beseka
	• The study of Beseka Lake levels, Sir William Halcrow and partners, 1978 • Study of Lake Beseka, MoWR, 1999 • Growing lake with growing problems: integrated hydrogeological investigation on Lake Beseka, Eleni Ayalew Belay, 2009 • National lakes of Ethiopia, Tenalem Ayenew, 2009, AAU Press. • Study and design of Lake Besaka level rise project Ⅱ, WWDSE, planned by Ministry of Water and Energy (MoWE), 2011 • Assessment and evaluation of cause for growth of Lake Besaka and design mitigation measures, OWWDSE, planned by MoWE, 2013
vi)	References and reports in relation to the Study as a whole
	• F. Mazzarini et al. (1999) Geology of Debre Zeyt area (Ethiopia)(with a geological map at scale:100,000), Acta Volcanologica-11, 131-141 • W. George Darling, et al. (1996) Lake-groundwater relationships and fluid-rock interaction in the East African Rift Valley: isotopic evidence, Journal African Earth Sciences 22, 423-431 • Tesfaye Chernet (1982) Hydrogeology of the lakes region, Ethiopia, EIGS • Seifu Kebede et al. (2008) Groundwater origin and flow along selected transects in Ethiopian rift volcanic aquifers, Hydrogeology Journal 16, 55-73 • Caroline Le Turdu et al. (1999) The Ziway-Shala lake basin system, Main Ethiopian Rift: Influence of volcanism, tectonics, and climatic forcing on basin formation and sedimentation, Palaeogeography, Palaeoclimatology, Palaeoecology 150, 135-177 • G. M. DI Paola (1972) Geology of the Corbetti Caldera Area (Main Ethiopian Rift Valley) • P. Mohr et al. (1980) Quaternary Volcanism and Faulting at O' A Caldera, Central Ethiopian Rift, Bull. Volcanol, 43-1, 173-188 • Elias Altaye et al.(1986) A Review Geological and Geophysical Exploration of Corbetti Geothermal Project, Ethiopia, 8th NZ Geothermal Workshop, 205-210 • Giday Woldegabriel et al. (1990) Geology, geochronology, and rift basin development in the central sector of the Main Ethiopia Rift, Geological Society of America Bulletin 102, 439-458 • Giday Woldegabriel et al. (2000) Volcanism, tectonism, sedimentation, and the paleoanthropological record in the Ethiopian Rift System, Geological Society of America special paper 345, 83-98 • Bridget R et al. (2006) Global synthesis of groundwater recharge in semiarid and arid regions, Hydrological processes 20, 3335-3370 • W.M. Edmunds (2010) Conceptual models for recharge sequences in arid and semi-arid regions using isotopic and geochemical methods, Cambridge University Press • Halcrow Group Limited and Generation Integrated Rural Development Consultants (2008) Rift Valley Lakes Basin Integrated Resources Development Master Plan Study Project, MoWR

4.1.2 Summary of previous studies

Most of the collected data, reports and studies are related to various geological and hydrogeological studies in the RVLB and Awash River Basin. In relation with the hydrogeological study of Awash River Basin area, two important studies with hydrogeological points of view have been made and overviews of each project are as follows;

In the existing study in regard to the hydrogeology, the contents of "Hydrogeology of the Nazret Area", 1987, and the recent study regarding the Lake Beseka are illustrated briefly. As mentioned for the study of Lake Beseka in Chapter 11, only hydrogeological study around Lake Beseka is explained in this section.

Hydrogeology of the Nazret Area (NC 37-15)

The study called "Hydrogeology of the Nazret area" investigates the hydrogeology of Nazret, an area of about 18,000km^2 to the southeast of Addis Ababa. It covers parts of the western and eastern highlands with the MER in the central and north which includes parts of Awash, Wabi Shebelle and the Zwai drainage basins covered by the Mesozoic sediments in Wabi Shebelle, Tertiary and Quaternary volcanics, lacustrine sediments and alluvium.

The hydrogeological mapping is to determine the occurrence, movement, quality and quantity of groundwater in the area, and is based on inventory of springs, existing wells (hand dug wells and boreholes), and on pumping test analysis. In the area where sufficient data are not available, qualitative interpretation based on observation of the geology and structure is discussed.

The permeability of volcanic rocks, sedimentary rocks in Wabi Shebelle area and unconsolidated sediments of alluvium and lacustrine sediments are evaluated as high, moderate and low by the qualitative values of existing wells and springs and field observation. Consequently, The high permeable aquifer in the area are the Fantale group of "Ignimbrites", the recent basalts, some of the Nazret group of "Ignimbrites", lacustrine sediments around Debre Zeit and alluvium in Metehara area.

The groundwater quality of these aquifers is with high salinity and high fluoride. However, groundwater in the lacustrine sediments and in the recent basalts is relatively fresh. Other aquifers show the moderate or low productivity with varying chemical quality.

Depth to groundwater is generally between 20 and 100 m below ground surface. However, the area around Dera has exceptionally large depth to groundwater of about 260 m.

Lake Beseka Level Rise Project Ⅱ Volume-Ⅱ Annex A-Hydrogeology Report

The main objective of this project is to control the water level of the continuously rising and expanding Lake by discharging the Lake water in to Awash River in a controlled manner without jeopardizing the river water quality.

The main investigation items are hydrogeology, meteorological and hydrological studies, irrigation water management, water quality modeling of Lake release, environmental and socio-economic survey and engineering remedial measures. The conclusion of the water quality and hydrogeology study is as follows;

- There is dilution of the lake water from about 7500 μS/cm to 5400 μS/cm corresponding to a change of about 28% dilution of lake water salinity over the last 12 years (from 1998 to 2010).

- The electrical conductivity of the hot springs has decreased from about 2390 μ S/cm to 1670 μ S/cm corresponding to a dilution of 30% over the last 12 years.
- There is a tendency of increasing calcium in the Lake due to recharge of fresh water from the catchment and farm drains.
- There is decreasing trend of fluoride in groundwater and in Lake Beseka as a result of fresh water recharge.
- The average yearly rate of groundwater level rise in Lake Beseka area over the last 12 years has been estimated to be 20 cm.
- The groundwater inflow rate from the western side of the Lake has increased from about 1.5m^3/sec in 1998 to about 1.731m^3/sec in 2010 due to an increase in the groundwater level corresponding to increased transmissivity of the aquifer flow section.
- Considered annually, the groundwater inflow from the western side of the lake is 52.42 million cubic meters (MCM).
- The groundwater outflow in the northeastern part of lake is analytically determined as 1.18 MCM which is considered insignificant for the lake water balance.
- There was no groundwater slope change in the western part of the lake at least over the last 12 years and there is a decrease in groundwater slope in the northeastern part of the lake due to groundwater mound caused by anthropogenic influence in the form of recharge from irrigation.

4.1.3 Existing well data

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

Well inventories managed by MoWIE:

- ENGWIS databases which have been inputted until the ENGWIS project was suspended in 2010. The number of wells increased from 60 to 823 in Progress Report 2 (PR/R2).

Mainly well records mentioned in existing reports:

- Hydrogeology (Map) of the Nazret, EIGS, 1985
- Evaluation of water resources of the Ada’a and Becho plains groundwater basin for irrigation development project, WWDSE, planned by MoWR, 2009
- Allaidege plain groundwater resources assessment project, WWDSE planned by MoWR, 2009
- Study and design of Lake Besaka level rise project Ⅱ, WWDSE, planned by MoWE, 2011

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

- Existing well data including columnar section and pumping test record in West Hararge Zone. The number of wells increased from 94 to 418 in PR/R2.
- Existing well data including columnar section and pumping test record in Arsi Zone. The number of wells increased from 6 to 8 in PR/R2.
- Existing well data including columnar section and pumping test record in East Shewa Zone
- Well completion reports and well data in Arerti（Amhara Region）woreda, Lomme（Oromia Region） woreda

The well inventory which has been arranged in regard to the above existing data contains the following items. The type of wells is restricted to borehole in principal, and the dug wells have been excluded from the well inventory.

- Temporary well name
- Location data (zone, woreda, town)
- Latitude, Longitude
- UTM（X-coordinate, Y-coordinate）
- Elevation
- Construction date and well conditions (as of construction)
- Well depth
- Static water level
- Dynamic water level
- Yield
- Transmissivity (T)
- Specific capacity (Sc)
- Screen position

The duplication of each data has been confirmed based on the location name and coordinates of wells, because the dates are the same, even if the data sources are different.
The total data extracted from those files are 1,524 points. However, the items included in the data are not filled out, and some coordinates of wells are missed in the inventory. Therefore, the total number of considered point well sources is 1,365 excluding data that has no coordinates. Newly 763 point data in the Study area has been included in the ENGWIS inventory; however the items regarding the groundwater data are not filled out. From now, it needs to fill in the ENGWIS inventory through the C/P of MoWIE.

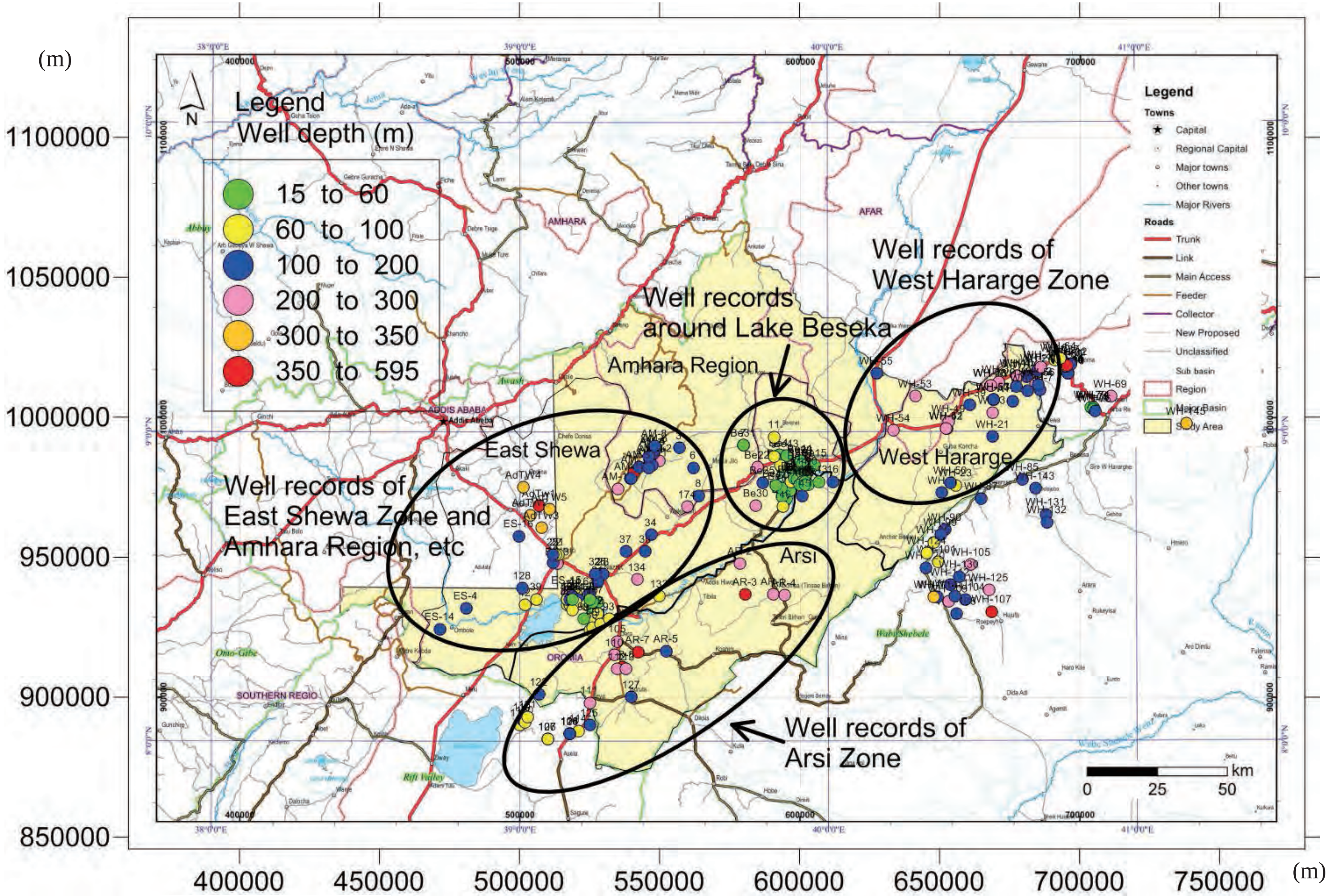
The number of basic data in groundwater has been arranged in the Table 4.1.2 below.

The location map of the existing wells for the well inventory in each Study area is shown in Figure 4.1.1. The yield data of each existing well is also shown in Figure 4.1.2.

Table 4.1.2: Number of Data by Parameter in Well Database (with coordinates)

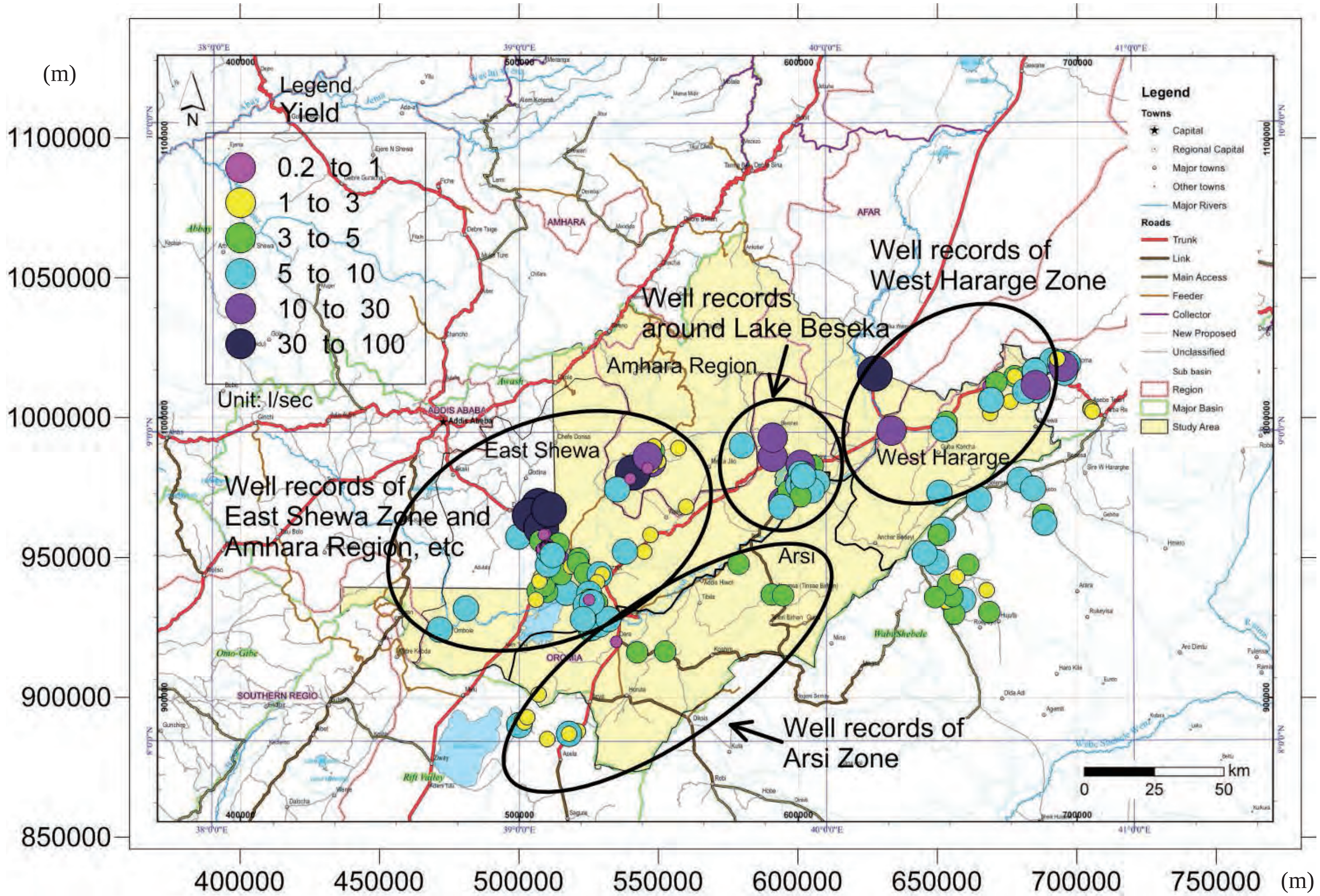
Parameter	Number of information
Static Water Level (SWL)	339
Dynamic Water Level (DWL)or Draw down (m)	154
Yield	305
Transmissivity (T)	55
Specific Capacity (Sc)	150
Water Quality Data	128
Geological Columnar Section	87

Source: the Project Team, Data: reference①, ②



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

Figure 4.1.1: Location Map of Existing Wells



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

Figure 4.1.2: Yield of Existing Wells

There are existing wells in the Study area in each zone of Oromia Region; in particular, there is much data in the north side around Lake Koka and around Lake Beseka. Also, the existing wells are concentrated along the Awash-Harar road in West Hararge zone. The springs and hand dug wells mainly exist along the rift valley ridge in West Hrarge and Arsi zones (see Figure 4.1.6). The results of the arrangement of well data are as follows;

a. West Hararge Zone

a.1 Number of wells and depth of wells

The well depth of almost all wells along Awash-Harar road located in the east of Study area in West Hararge Zone is 120m-250 m deep, and the depths of eight wells are less than 100 m (37 m is minimum depth). Eleven wells are more than 250 m deep. The total number of wells without drilling depth data is 42 points (14 are outside of the Study area). The number of wells is few (about three points) along the rift valley ridge in West Hararge, and well depth is less than 200 m. Twenty-three well data points were collected along the rift valley ridge in the south east side of Study area out of West Hararge Zone.

Table 4.1.3: Existing Well Data in West Hararge Zone

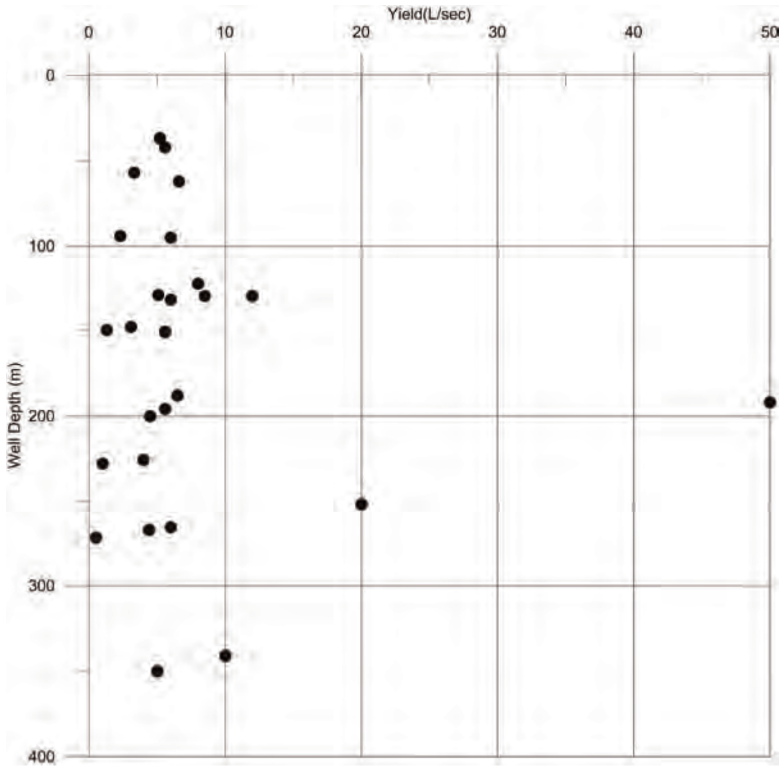
ID Number	Easting (m)	Northing (m)	Elevation (m)	Depth (m)	SWL (m)	DWL (m)	Yield (L/sec)	TOP (m)	SC (L/sec/m)	Columnar Section
WH-1	685360	1017109	1412	129.4	91.42	-	5.1	97.1	-	○
WH-3	668811	1001717	1220	228	60.8	88	1	-	0.037	-
WH-4	677655	1014917	1402	267.4	153	188.23	4.4	-	0.125	-
WH-6	650764	972995	1320	132	39.2	58.1	6	44	0.317	○
WH-7	685854	1009744	1528	196	86.61	170.67	5.6	168	0.067	○
WH-8	691053	1020494	1341	95	53.16	58.57	6	65	1.11	○
WH-9	681157	1014332	1466	148	90	-	3.1	-	-	-
WH-10	677652	1014917	1402	264	-	-	2.2	-	-	-
WH-11	695877	1015842	1418	51	-	-	4	-	-	-
WH-12	696722	1018866	1382	122.7	66.6	67.45	8	69	9.41	○
WH-13	669175	1006477	1282	37	6	14.72	5.2	-	0.596	-
WH-14	695477	1016353	1389	57	16.5	-	3.3	-	-	-
WH-15	695667	1016299	1405	42	14.5	21.2	5.6	-	0.836	-
WH-16	695608	1016170	1407	62	7.2	25.1	6.6	-	0.369	-
WH-21	669069	993048	1597	177	Artesian	-	-	30	-	○
WH-22	676209	1005803	1353	150	67.05	88	1.3	111	0.06	○
WH-23	655718	975718	1605	78	18	-	-	-	-	-
WH-24	684940	1016759	1423	188	99.23	99.3	6.5	99	92.86	○
WH-26	668144	1011413	1327	272	162	256.63	0.51	183	0.0054	○

ID Number	Easting (m)	Northing (m)	Elevation (m)	Depth (m)	SWL (m)	DWL (m)	Yield (L/sec)	TOP (m)	SC (L/sec/m)	Columnar Section
WH-30	695873	1015826	1413	120	-	-	-	-	-	-
WH-31	696719	1018863	1387	105	-	-	-	-	-	-
WH-32	684294	1011906	1459	200	-	-	-	-	-	-
WH-33	687372	1018853	1378	-	-	-	-	-	-	-
WH-34	686247	1017940	1387	250	-	-	-	-	-	-
WH-35	677356	1011149	1434	150	-	-	-	-	-	-
WH-36	680652	1014328	1455	-	-	-	-	-	-	-
WH-37	694125	1019865	1327	120	78	-	6	-	-	-
WH-38	671235	1012743	1341	226	156	-	4	-	-	-
WH-39	660737	1004315	1140	127	-	-	-	-	-	-
WH-40	657745	1005906	1144	-	-	-	-	-	-	-
WH-41	652511	996025	1106	350	53.28	120.83	5	-	0.089	-
WH-42	650907	997415	1046	-	-	-	-	-	-	-
WH-43	668149	1011415	1335	272	-	-	-	-	-	-
WH-44	681409	1009313	1400	151	53	57.97	5.6	-	1.131	-
WH-45	687371	1018850	1376	-	-	-	-	-	-	-
WH-46	693001	1021056	1316	-	-	-	4.4	-	-	-
WH-47	694136	1019853	1329	-	-	-	-	-	-	-
WH-48	674163	1025893	2266	-	-	-	-	-	-	-
WH-49	653270	998630	1072	200	39.45	83.25	4.5	-	0.103	-
WH-50	653928	976613	1561	186	19	-	-	-	-	-
WH-51	669172	1006468	1412	150.7	53.4	58.35	5.6	100	1.131	○
WH-52	652464	996002	962	266	62.27	120.83	6	68	0.102	○
WH-53	641424	1007510	892	257	72.95	-	-	102	-	○
WH-54	633631	995259	962	252	101.17	138.81	20	114	0.521	○
WH-55	627464	1015684	823	192	75.66	76.78	50	72	44.64	○
WH-56	685362	1011710	1366	130	92.5	-	12	-	-	-
WH-57	669172	1006468	1412	130	91.42	91.5	8.5	-	106.5	-
WH-60	695124	1018271	1373	341	-	-	10	-	-	-
WH-61	695550	1018517	1362	350	-	-	-	-	-	-
WH-64	692995	1021060	1321	94	-	-	2.3	-	-	-

SWL: Static water level, DWL: Dynamic water level, TOS: Top depth of screen, SC: Specific capacity, With columnar section:○ Source: the Project Team, Data: reference 1）of ②

a.2 Yield of existing wells

The well depth of 100-300 m is consistent in almost all wells in West Hararge Zone, and one well depth is more than 350 m. Few well depths are less than 100 m. The yield in almost all drilling points is less than 10 L/sec. However, the well depth of more than 350 m has a yield of more than 10 L/sec, and 2 to 6 L/sec yield is observed in wells of less than 100 m in depth. The relationship between well depth and yield is shown in Figure 4.1.3. This figure shows that the yield is less or equal to 10 L/sec, except for three well points, regardless of the geological conditions or the well depth.



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

Figure 4.1.3: Yield and Drilling Depth in West Hararge Zone

b. Around Lake Beseka

b.1 Number of wells and depth of wells

In the west side and south west of Lake Beseka, there are three wells of 116m, 200m and 205m in depth. However, in the surrounding area of Lake Beseka, the main well depth is less than or equal to 60 m and there are five wells of more than 60m in depth. The total number of existing wells is 68 points. The depth of existing wells is not clear around the west of the Fentale volcano located in the north east of Lake Beseka. A new well, under WWDSE jurisdiction, was drilled for irrigation purposes in 2014. The well are is located about 6km east of Metehara Town.

Table 4.1.4: Existing Well Data Around Lake Beseka

ID Number	Easting (m)	Northing (m)	Elevation (m)	Depth (m)	SWL (m)	DWL (m)	Yield (L/sec)	TOP (m)	SC (L/sec/m)	Columnar Section
Be1	601152	980062	953.14	-	4.6	-	-	-	-	-
Be2	603938	979874	949.5	-	4	-	-	-	-	-
Be3	600941	979443	953.36	-	5.62	-	-	-	-	-
Be4	592664	986463	981.29	53.3	30.94	-	-	29.3	-	○
Be5	602168	979920	950.24	-	4.5	-	-	-	-	-
Be6	601259	977156	957	62	6.4	-	8	-	-	-
Be7	600867	976796	951	32	4.76	-	6.5	-	-	-
Be8	601097	976963	964	65.5	15.26	-	-	-	-	-
Be9	600767	976710	947	32	12.65	-	6	-	-	-
Be10	602298	979030	950	42	6.27	-	23.2	-	-	-
Be11	602192	976337	968.31	52	15.9	-	10	-	-	-
Be12	600048	976634	959	48	15.32	-	6.5	12	-	○
Be13	600885	972384	990	-	42.7	-	-	-	-	-
Be14	603967	980053	-	-	-	-	-	-	-	-
Be15	605405	982881	949.8	30	6.15	-	4	15	-	○
Be16	600186	976837	960	62	13.2	-	10	-	-	-
Be17	594785	969889	987.96	40	33.43	-	10	-	-	-
Be18	595371	971036	975.74	37	25.65	-	3	-	-	-
Be19	596616	973698	965.23	37	14.68	-	3	-	-	-
Be20	602009	979970	950.95	32	2.8	-	-	-	-	-
Be21	588477	988474	1005	-	52.8	-	-	-	-	-
Be22	584990	982082	1120	200	159.5	-	-	-	-	-
Be23	591516	993908	994.6	-	43.47	-	-	-	-	-
Be24	589343	992721	985.1	-	32.95	-	-	-	-	-
Be25	586845	976572	1050	116	90.7	-	-	-	-	-
Be26	604599	986801	958.1	-	7.71	-	-	-	-	-
Be27	604682	978812	952	-	10.18	-	-	-	-	-
Be28	592939	984497	964.01	-	2.23	-	-	-	-	-
Be29	600250	984000	960.16	56	13.6	-	-	-	-	-
Be30	584500	968500	1200	205	177	-	-	-	-	-
Be32	600646	980333	953.39	-	4.04	-	-	-	-	-
Be33	594409	984369	955	-	-	-	-	-	-	-

ID Number	Easting (m)	Northing (m)	Elevation (m)	Depth (m)	SWL (m)	DWL (m)	Yield (L/sec)	TOP (m)	SC (L/sec/m)	Columnar Section
Be34	595426	984300	952.6	-	1.75	-	-	-	-	-
Be35	601116	979750	963.36	-	5.14	-	-	-	-	-
Be36	593879	971578	967.37	20.4	20.4	-	-	-	-	-
Be37	600517	982590	953	21.55	3.71	-	-	-	-	-
Be38	600305	982301	953.21	-	3.7	-	-	-	-	○
Be39	599903	979853	953.93	50.65	4.43	-	-	18.65	-	○
Be40	598914	980723	953.02	30.24	3.24	-	-	11	-	○
Be41	593282	982350	953.24	16.3	2.3	-	-	-	-	-
Be42	593035	982691	958.32	73	8.18	-	-	17.25	-	○
Be43	595362	986153	973.83	59	23.16	-	-	24	-	○
Be44	600252	984352	958.93	50.5	8.62	-	-	-	-	○
Be45	596921	976889	955.14	71.45	4.2	-	-	-	-	○
Be46	593389	974555	955.53	46.3	4.54	-	-	-	-	○
Be47	591413	975520	959.35	29.45	7.7	-	-	-	-	○
Be48	598043	978183	965.16	50.45	14.25	-	-	28.75	-	○
Be49	599940	977965	963	23.5	4.62	-	-	-	-	-
Be50	599118	977968	958.64	42.45	8.08	-	-	-	-	○
Be51	590483	970777	1020	-	57.62	-	-	-	-	-
Be52	600331	981811	953.42	44.45	3.65	-	-	23	-	○
Be53	600207	981559	952.84	-	3.85	-	-	-	-	-
Be54	599916	977954	964	-	7.9	-	-	-	-	-
Be55	591853	994109	994.6	-	43.47	-	-	-	-	-
Be56	591843	993329	1001	-	48.28	-	-	-	-	-
Be57	589634	992954	985.1	-	32.95	-	-	-	-	-
Be58	609923	985407	967	-	63.29	-	-	-	-	-
Be59	596854	974753	973	-	15.57	-	-	-	-	-
Be60	605069	983266	952	-	6.09	-	-	-	-	-
Be61	602707	975416	963	-	23.02	-	-	-	-	-
7(Be31)	580000	990000	1000	50.6	25	-	6.7	25	-	○
10	601000	983000	1000	56	13.6	14.98	12	-	8.7	○
12	602000	979000	950	42.6	8.8	-	2	-	-	○
14	601000	980000	950	49.6	11.19	14.43	7	-	-	○

ID Number	Easting (m)	Northing (m)	Elevation (m)	Depth (m)	SWL (m)	DWL (m)	Yield (L/sec)	TOP (m)	SC (L/sec/m)	Columnar Section
16	612000	977000	-	100	-	-	-	-	-	○
136	601000	976000	960	42	20.6	30.1	6	32	0.6	○
140	600000	976000	960	45	25.6	30.6	8	24.5	1.6	○
142	602000	976000	966	52	42.8	49.3	8	30	1.2	○
ALPW3512	606822	984277	938	595	46.65	62.10	100	111.4	6.5	○

SWL: Static water level, DWL: Dynamic water level, TOS: Top depth of screen, SC: Specific capacity, With columnar section:○

Source: the Project Team,
Data: reference 1), 4) and 5) of ②

b.2 Yield of existing wells

In the east to southwest of Lake Beseka, the main well depth is less than 60 m. The yield of these wells is 3 to 10 L/sec. In the northwest of Lake Beseka, there are wells of less than 60 m and 100 m deep, and yield is 6-12 L/sec. The yield may be affected by the difference of drilling depth and aquifer. Allmost all wells indicate less than 60m deep, there is no clear relationship between well depth and yield.

c. Arsi Zone

c.1 Number of wells and depth of wells

Data from seven wells have been collected around the southeast escarpment in Arsi Zone, which continues from Rift Valley Lakes Basin (RVLB). The coordinates and the depths of these seven wells can be confirmed, and their depths are: three wells are more than 400 m deep and two of which are located around Dera Town; the remaining four wells are from 170 m to 288 m deep.

There are 11 existing wells around the road from Dera to Asele, and six wells are within the Dera area, of which five are between 200 m and 300 m or deeper and one is less than 100 m deep). The remaining five of the abovementioned eleven wells are outside of the Study area, and the drilling depth of each well is between 70 and 170 m deep.

Table 4.1.5: Existing Well Data in Arsi Zone

ID Number	Easting (m)	Northing (m)	Elevation (m)	Depth (m)	SWL (m)	DWL (m)	Yield (L/sec)	TOP (m)	SC (L/sec/m)	Columnar Section
AR-1	590639	936870	1530	288	120.22	136.57	4.4	180	0.27	○
AR-2	578805	947750	1200	236	132.25	138.57	3.4	126	0.29	○

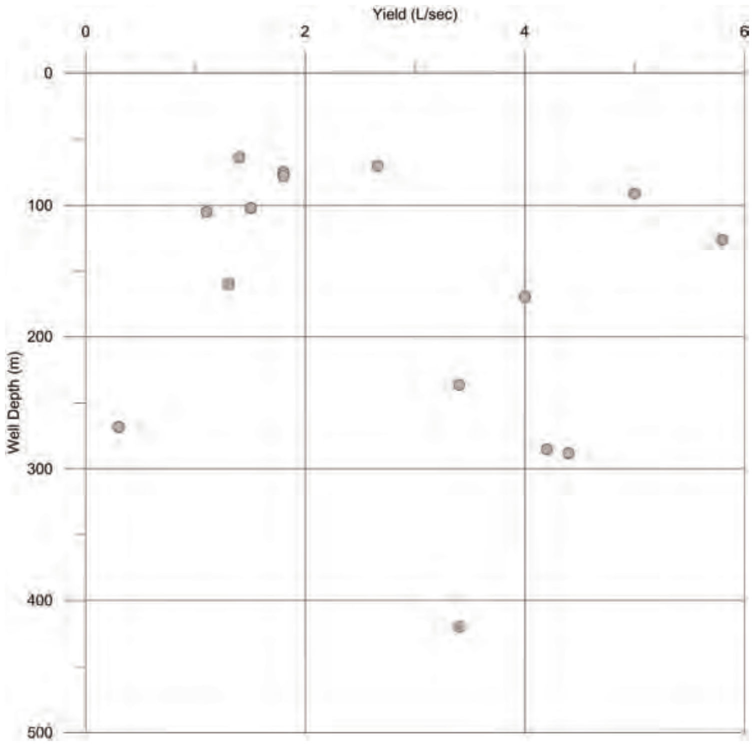
ID Number	Easting (m)	Northing (m)	Elevation (m)	Depth (m)	SWL (m)	DWL (m)	Yield (L/sec)	TOP (m)	SC (L/sec/m)	Columnar Section
AR-3	580609	936751	1618	400	-	-	-	274	0.09	○
AR-4	594564	936407	1719	285	154.35	199	4.2	201	0.07	○
AR-5	552351	916424	1795	170	61.85	120.6	4	86	-	○
AR-7	542260	916154	1664	420	295.45	297.68	3.4	-	1.525	○
AR-8	536828	910778	1752	400	Dry	-	-	-	-	-
105	535000	920000	1650	268	256	-	0.3	-	-	○
107	510000	885000	1700	60	16.5	-	-	-	-	-
110	534000	915000	1840	200	-	-	-	-	-	○
111	525000	898000	2110	266	245	-	-	-	-	-
112	535000	910000	1750	200	-	-	-	-	-	-
113	538000	910000	2110	200	-	-	-	-	-	○
114	521000	888000	2360	75	-	-	1.8	-	-	○
116	518000	887000	2400	126	-	-	5.8	-	-	-
118	500000	890000	1650	91	42.7	43.4	5	-	7.14	○
119	501000	892000	1650	102	83	-	1.5	-	-	○
120	502000	891000	1650	63.5	42.8	-	1.4	-	-	○
121	503000	893000	1680	78	52.8	-	1.8	-	-	○
122	507000	901000	1770	160	128	-	1.3	-	-	-
124	518000	887000	2150	105	80	80.25	1.1	-	4.4	○
125	525000	890000	2230	170	-	-	-	-	-	-
126	510000	885000	1750	70	22.6	-	2.66	-	-	-
127	540000	900000	2000	193	-	-	-	-	-	-

SWL: Static water level, DWL: Dynamic water level, TOS: Top depth of screen, SC: Specific capacity, With columnar section:○

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

c.2 Yield of existing wells

Data from seven wells have been collected around the escarpment in the east of Arsi zone, which continues from RVLB. Three wells out of seven wells are 200 to 300 m in depth and yield is 3 to 5 L/sec. The well of 420 m depth has 3.4 L/sec yield around Dera town in Arsi zone. In the wells known yield data, one well, near Dera town, is more than 250 m depth and yield is less than 1 L/sec, and another well, near Sire town, is less than 200 m, and the yield is 4 L/sec. The other wells along the road to Asela have 1 to 3Ll/sec yield mainly (one well only indicates a yield of more than 5L/sec) and no correlation with well depth. The relationship between well depth and yield is shown in Figure 4.1.4. This figure shows that there is no correlation between well depth and yield.



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

Figure 4.1.4: Yield and Drilling Depth in Arsi Zone

d. East Shewa Zone, Amhara Region and others

d.1 Number of wells and depth of wells

There are a few wells along the road between Kone, Caldera, and Nazret (Adama). The total number of wells is 6 points and well depth is 100-205 m. There is little well data because the villages and small towns are few between this road and the Awash River.

The total number of wells in North Shoa zone in Amhara region located in northwest of the Study area is 16 points and well depth is mainly 100 m to less than 200 m, but the two wells are more than 300 m in depth.

Data has been collected on 33 existing wells (equivalent to data on 13 wells when accounting for duplication of those that are close to each other) in the Wonji sugar plantation located in the south of Adama in the southwest of the Study area. Most of the wells are shallow, at a depth of 30-67 m, the deepest one in this area being 200 m and ten wells are 100 m to less than 200 m in depth. Data has been collected for a few wells in the surrounding area of the plantation, and the depth of wells is 60-90 m. About 15 wells, after excluding those that are duplicated, exist around Koka Dam, and the depth of these wells is approximately 100 m. Eleven wells that are 60 to 200 m deep were located in the west of Koka Dam, around Mojo and Adama.

Data has been collected on 38 existing wells around Lume Woreda near the Mojo area. However, the depth of 12 out of the 38 wells is not clear. The shallow wells are 15 to 50 m deep, and the deeper wells are 100 to 280 m deep. The depth of five other wells in the Adda-Becho Groundwater Evaluation Project of Debre Zed is deep because one well is 370 m deep and the remaining four wells are about 350 m deep. However this project area is out of the study area of hydrogeological mapping.

Table 4.1.6: Existing Well Data in East Shewa Zone, Amhara Region and others

ID Number	Easting (m)	Northing (m)	Elevation (m)	Depth (m)	SWL (m)	DWL (m)	Yield (L/sec)	TOP (m)	SC (L/sec/m)	Columnar Section
LO-1	510038	937615	1633	130	-	-	4.12	-	-	-
LO-2	506730	937464	1651	100	-	-	2.22	-	-	-
LO-3	506569	938054	1661	250	-	-	4.44	-	-	-
LO-4	509134	939939	1682	120	-	-	3.76	-	-	-
LO-5	508030	943076	1711	120	-	-	2.9	-	-	-
LO-6	507296	941463	1694	105	-	-	2.96	-	-	-
LO-7	515176	943875	1750	160	-	-	3.9	-	-	-
LO-8	510372	947373	1754	110	-	-	5.55	-	-	-
LO-9	510614	952023	1804	68	-	-	5.12	-	-	-
LO-10	507728	955897	1842	48	-	-	3.97	-	-	-
LO-11	514334	954970	1880	101	-	-	3.8	-	-	-
LO-12	521272	949734	1898	252	-	-	3.3	-	-	-
LO-13	518460	946916	1849	185	-	-	2.5	-	-	-
LO-14	521115	948060	1904	283	-	-	3	-	-	-
LO-15	523525	944293	1736	120	-	-	3.8	-	-	-
LO-16	509597	958520	1844	-	-	-	0.33	-	-	-
LO-17	508823	957924	1850	-	-	-	0.3	-	-	-
LO-18	508994	955227	1831	-	-	-	-	-	-	-
LO-19	509913	952151	1795	-	-	-	0.2	-	-	-
LO-20	509891	952058	1797	-	-	-	0.2	-	-	-

ID Number	Easting (m)	Northing (m)	Elevation (m)	Depth (m)	SWL (m)	DWL (m)	Yield (L/sec)	TOP (m)	SC (L/sec/m)	Columnar Section
LO-21	509800	952640	1798	-	-	-	0.25	-	-	-
LO-22	508447	952941	1814	-	-	-	0.33	-	-	-
LO-23	508194	952954	1814	-	-	-	0.3	-	-	-
LO-24	508165	953217	1815	-	-	-	0.33	-	-	-
LO-25	509619	953910	1815	15	-	-	0.42	-	-	-
LO-26	509531	954026	1816	15	-	-	0.2	-	-	-
LO-27	513568	957880	1841	-	-	-	-	-	-	-
LO-28	510565	954590	1814	15	-	-	0.25	-	-	-
LO-29	510679	954123	1817	32	-	-	-	-	-	-
LO-30	510365	954125	1810	15	-	-	0.25	-	-	-
LO-31	509917	953997	1810	25	-	-	0.33	-	-	-
LO-32	509961	953356	1802	25.5	-	-	0.25	-	-	-
LO-33	509806	953792	1819	15	-	-	0.25	-	-	-
LO-34	510245	953283	1800	-	-	-	0.22	-	-	-
LO-35	509677	953088	1807	-	-	-	0.3	-	-	-
LO-36	510599	952248	1806	38	-	-	-	-	-	-
LO-37	510895	952183	1800	35	-	-	0.25	-	-	-
LO-38	511654	950667	1780	16	-	-	0.33	-	-	-
ES-3	513615	947586	1779	203	50.12	103.72	16.68	64	0.311	○
ES-4	480885	931783	-	125	79.2	81.51	5	84	2.16	○
ES-14	471568	924324	1771	186	58	62.95	9.2	102	1.86	○
ES-15	516888	937379	1616	200	16.1	21.95	9.2	110	1.57	○
ES-16	499760	957578	1910	152	54.85	56.2	9.2	66	6.81	○
AM-1	547301	984124	1771	300	141.3	-	25	155	-	○
AM-2	549970	984541	1754	280	190	-	1	190	-	○
AM-3	540905	980439	1847	351	120	-	30	136	-	○
AM-4	547674	987202	1753	140	133	-	2.8	-	-	-
AM-5	547621	986845	1750	155	128.4	-	3.7	-	-	-
AM-6	548417	988083	1745	162	115.7	116.33	4.5	104	7.14	○
AM-7	546500	984583	1745	186	-	-	-	-	-	○
AM-8	548235	989763	1256	150	127	-	1.5	-	-	-
AM-9	542651	982173	1791	151	91	-	-	-	-	-

ID Number	Easting (m)	Northing (m)	Elevation (m)	Depth (m)	SWL (m)	DWL (m)	Yield (L/sec)	TOP (m)	SC (L/sec/m)	Columnar Section
AM-10	539660	977988	1887	144	-	-	-	-	-	-
AM-11	547292	982768	1766	180	147	149	2.53	-	-	-
AM-12	535224	974501	1978	285	187	188.55	5.5	192	3.55	○
AdTw1	507013	968324	1877	370	21.05	37.69	37	82	2.22	○
AdTw2	503928	965114	1885	303	24.95	66	43	40	1.048	○
AdTw3	507887	960487	1848	324	6.91	14.31	60	90	8.11	○
AdTw4	501470	974992	1911	336	20.3	-	-	-	-	○
AdTw5	510700	967019	1908	384	51.12	69.06	57	126	3.18	○
1	527000	967000	2200	-	-	-	-	-	-	-
2	546000	986000	1720	134	129	134.8	12	-	1.76	○
3	557000	989000	1750	198.1	188.9	-	1	-	-	○
4	540000	978000	1900	184.4	115.8	-	0.76	-	-	○
5	546000	982000	1800	184.4	115.8	135.8	0.75	-	0.03	-
6	562000	982000	1150	102	-	-	-	-	-	-
8	564000	972000	1320	102.7	-	-	-	-	-	-
9	591000	986000	1020	83.2	34.54	-	12	45	-	○
11	591000	993000	1000	71	46.2	-	11.76	50	-	○
15	617000	993000	950	-	-	-	-	-	-	-
18	512000	948000	1780	104	39	-	-	54	-	○
21	514000	951000	1780	61.9	12.2	-	2.52	-	-	○
22	513000	951000	1780	61.9	36.6	57.9	1.3	-	0.06	○
25	512000	951000	1780	152.4	-	-	5.3	-	-	-
26	529000	944000	1650	120	100	-	8	-	-	-
28	530000	944000	1600	158.6	31.2	43.4	2.75	-	0.22	-
31	528000	941000	1600	117.3	103.6	106.6	2.5	-	0.83	○
32	527000	944000	1650	105	95	-	-	-	-	-
34	547000	958000	1495	185	-	-	1.1	-	-	-
35	552000	959000	1400	-	-	-	-	-	-	-
36	545000	952000	1495	167.6	136.1	160.5	1.36	-	0.05	-
37	538000	952000	1580	125	-	-	5	-	-	-
38	562000	942000	1230	-	-	-	-	-	-	-
39	506000	935000	1650	93	24	-	2	50	-	○

ID Number	Easting (m)	Northing (m)	Elevation (m)	Depth (m)	SWL (m)	DWL (m)	Yield (L/sec)	TOP (m)	SC (L/sec/m)	Columnar Section
42	502000	933000	1600	70	45	-	-	-	-	-
43	525000	924000	1600	76	56.6	-	3.5	-	-	-
44	520000	937000	1546	60.7	15	-	-	-	-	-
45	520000	935000	1578	60.5	32	-	-	-	-	-
46	517000	935000	1532	96.3	19	-	-	-	-	-
47	517000	933000	1577	90	17	-	-	-	-	-
48	518000	933000	1603	60	46	-	-	-	-	-
49	518000	933000	1584	81.4	23	-	-	-	-	-
50	519000	936000	1595	100.2	45	-	-	-	-	-
52	517000	935000	1600	80	50	-	-	-	-	-
53	518000	935000	1574	100.1	27	-	-	-	-	-
54	521000	935000	1560	107.5	29	-	-	-	-	-
55	520000	934000	1577	73.8	31	-	-	-	-	-
56	519000	931000	1613	92	62	-	-	-	-	-
57	519000	935000	1555	42.4	11	-	-	-	-	-
64	525000	937000	1540	103.6	14.9	17.56	9.2	85.6	3.46	○
68	525000	935000	1540	47	14	17.2	3.2	-	1	
69	525000	935000	1540	24.5	8.6	-	-	-	-	○
76	524000	933000	1540	73		-	5	-	-	-
77	528000	934000	1540	33	8.6	-	3	-	-	-
78	528000	930000	1540	59	13.7	-	5	-	-	-
79	526000	930000	1540	31	11	-	1.2	-	-	-
83	528000	930000	1540	50	12.4	-	3	-	-	-
84	525000	928000	1540	84	7.05	26.68	2	-	-	-
87	528000	930000	1540	82		-	-	-	-	-
89	526000	925000	1540	69	7.2	-	5.5	-	-	-
91	529000	926000	1540	70.4	6	-	5.5	-	-	-
93	532000	928000	1540	63		-	6	-	-	-
96	526000	934000	1540	49	8.9	-	5.4	-	-	-
99	523000	928000	1540	58	10.9	16.8	5.8	-	0.98	-
108	518000	887000	2130	120	90	102	-	-	0.02	-
116	518000	887000	2400	126	-	-	5.8	-	-	-
126	510000	885000	1750	70	22.6	-	2.66	-	-	-

ID Number	Easting (m)	Northing (m)	Elevation (m)	Depth (m)	SWL (m)	DWL (m)	Yield (L/sec)	TOP (m)	SC (L/sec/m)	Columnar Section
128	501000	939000	1600	120	-	-	-	-	-	-
129	525000	935000	1540	32	-	-	0.27	-	-	-
132	523000	935000	1560	-	24.4	-	-	-	-	-
133	550000	936000	1450	80	-	-	-	-	-	-
134	542000	942000	1500	200	190	-	-	-	-	-
135	502000	980000	950	-	-	-	-	-	-	-
137	603000	976000	960	51	85.9	90.4	5	-	1.1	-
139	601000	977000	960	74	14	16	8	-	4	-
141	602000	977000	960	42	-	-	8	-	-	-
143	607000	977000	1000	55	26	30	5.5	-	1.37	-
144	605000	974000	980	-	69.1	70.1	6.5	-	6.5	-
145	601000	972000	980	100	83	88	4.5	-	0.5	-
146	594000	968000	1000	73	50	-	5.5	-	-	-
147	602000	979000	950	-	14.9	-	8	-	-	-
169	576000	950000	1238	-	31.26	-	-	-	-	-
174	560000	968000	-	205	-	-	1.5	-	-	-

SWL: Static water level, DWL: Dynamic water level, TOS: Top depth of screen, SC: Specific capacity, With columnar section:○

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

d.2 Yield of existing wells

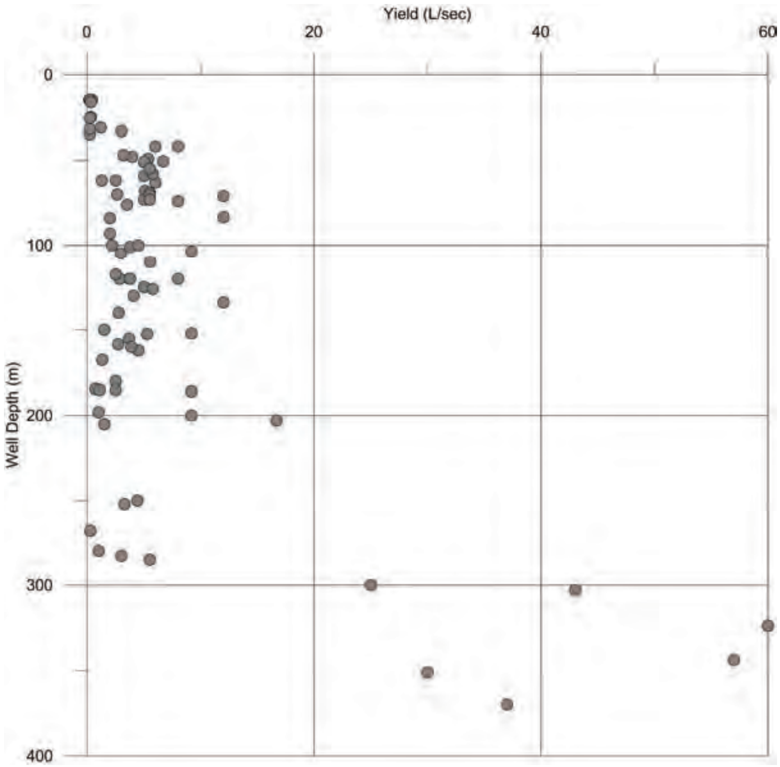
There are six wells along the road between Kone, Caldera, and Nazret (Adama). Four wells out of six wells have yield information. The well depth is 100-205 m and the yield is 1 to 1.5 L/sec (only one point is 5L/sec yield).

The total number of wells in the North Shoa zone of the Amhara region located in the northwest of the Study area is 16 well points. Well depth is mainly 100 m to less than 200 m, and the main yield is less than or equal to 3L/sec and 5L/sec. Two wells are more than 300 m in depth and yield is 25 to 30L/sec. Eleven wells out of 16 wells have yield data.

In the Wonji sugar plantation located in the south of Adama in the southwest of the Study area, most of the wells are shallow, at a depth of 30-67 m, the deepest one in this area being 200 m and ten wells are 100 m to less than 200 m depth. The yield is 3 to less than 10 L/sec.

Data has been collected on 38 existing wells around Lume Woreda in the Mojo area. However, out of 38 wells, the depth of 12 wells is not clear. The shallow depth wells are 15-30 m, and deep wells depth are 100-280 m. The shallow depth wells to the north of Mojo town have 1 to 3 L/sec yield. The 200 m depth well has 15L/sec, and an average for all wells of 1 to 5 L/sec. The depth of five other wells in the Adda-Becho Groundwater Evaluation Project of Debre Zeit (new name is Bishoftu) is deep because one well is 370 m in depth and the remaining four wells are about 350 m in depth. These wells have more than 30 L/sec yield except one well, and the yield of two wells is 50 to 60 L/sec. However this project area is out of the Study area for the hydrogeological mapping.

The relationship between well depth and yield is shown in Figure 4.1.5. This figure shows that the yield values are mainly concentrated to less than 20 L/sec without any relationship to depth, and the six points in the right corner of this figure belong to the Adda-Becho Groundwater Evaluation Project.



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

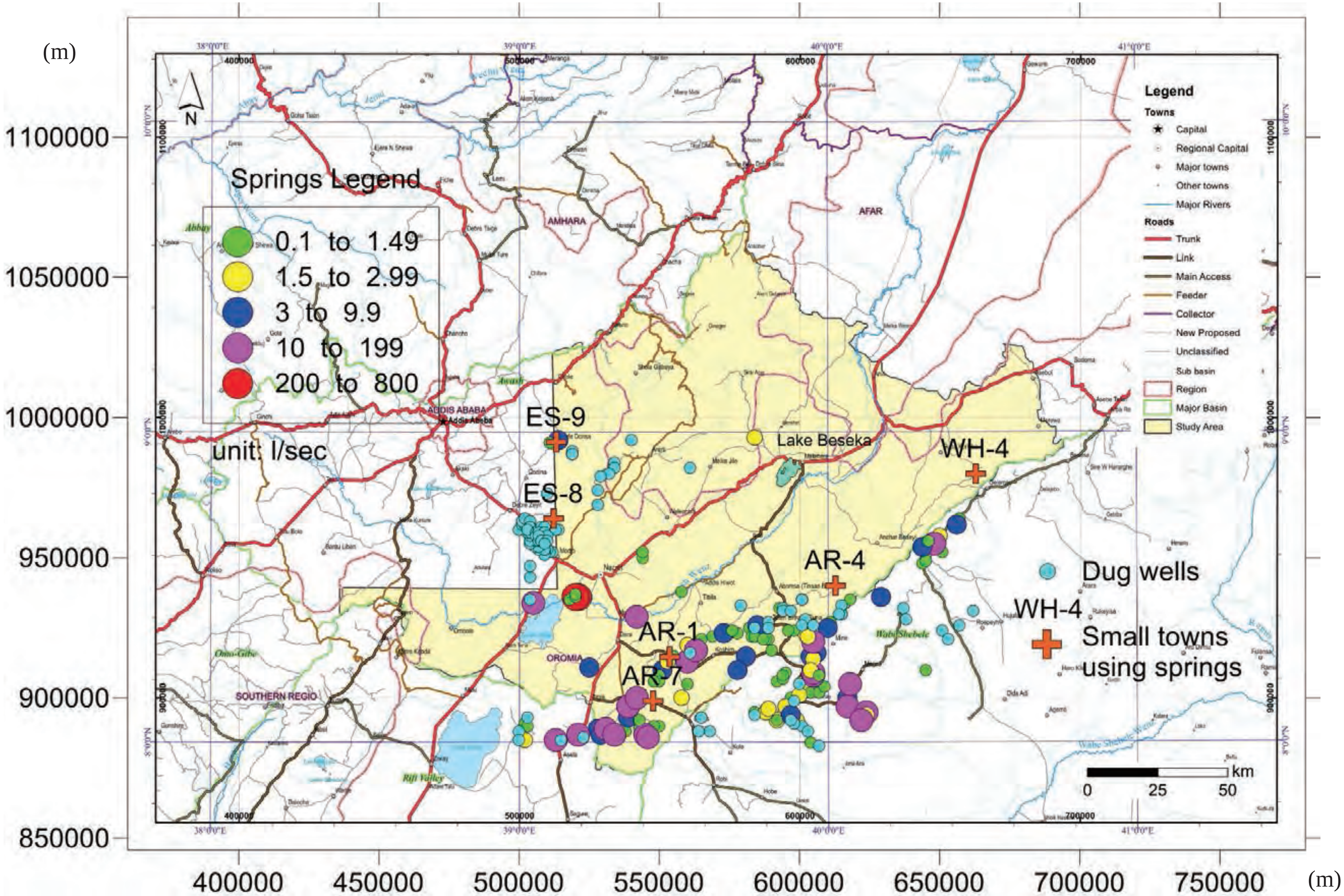
Figure 4.1.5: Yield and Drilling Depth in East Shewa Zone, Amhara Region and others

4.1.4 Spring data

The total spring data extracted from existing report are 162 points (Source: Hydrogeology of Nazret, 1985). According to existing data, springs are distributed along the escarpment from RVLB to the southwest area of this Study in NE-SW direction (refer to Figure 4.1.6). In Awash lowland, the springs have discharged from the border between highland and rift floor along the faults mainly. Yield of springs, 1-3 L/sec, make up about 70% in the Study area and two springs, yield of 500-700 L/sec, have been recognized near Lake Koka. The Fluoride concentration of 21% and 11% of water samples exceeded the WHO standard (1.5 mg/L) and Ethiopia standard (3.0 mg/L), of the total 131 points of the Study area. The highest value is more than 20 mg/L in one point. According to survey of small towns, six small towns out of 30 towns have utilized springs. The survey results of spring yield correspond to the existing data of spring yield in the small towns with known spring yields out of 6 small towns. So there is a high probability that the accuracy of existing data is high (for example, ES-9 and AR-4 of Figure 4.1.6). The remaining small towns out of 6 small towns, WH-4 and ES-8 of Figure 4.1.6, keep off from the existing springs, so it is possible that these small towns have used another spring or piped water supply from the existing springs (refer to Figure 4.1.6).

4.1.5 Others (Hand Dug wells)

The total hand dug well data collected from “Hydrogeology of Nazret, 1985” are 196 points. The digging depth less than 10 m accounts for about 30% of the whole data. There are lots of more than 30 m wells in depth and some wells of more than 50 m depth have been described in the report. The static water levels of each dug well are near the digging depth, therefore, it is not expected the yield in these area. However, wells drilling are being implemented in areas of low groundwater potential where boreholes and springs are not suitable. The number of hand dug wells that exceeded the WHO standard for fluoride concentration and Ethiopia standard for that was about 20% and 6% of 32 spring points analyzed in water quality test. The location of hand dug wells is shown in the Figure 4.1.6 in the same map of spring location. According to Figure 4.1.6, the hand dug wells have mainly distributed in the west side of Study area and the ridge of Rift valley. In the west side of Study area, in particular around Mojo town, the alluvium and lacustrine deposits are suitable for the target layers of hand dug well. On the other hand, the hand dug well is very few around Lake Beseka area because there are no layers which suitable for hand dug well. The distribution of alluvium clay or slit layers, 12 m to 17 m depth from surface and also of rock layer without the alluvium affect the drilling of hand dug well.



Source: the Project Team,
Data: reference ①1), ④

Figure 4.1.6: Location Map of Spring and Hand Dug Wells

4.2 Groundwater potential

4.2.1 Groundwater occurrence and flow

a. Yield of existing wells

The yield of existing wells is divided to six stages using the legend below; Yield: less than 1 L/sec (poor), 1 L/sec to less than 3 L/sec (low), 3 L/sec to less than 5 L/sec (medium), 5 L/sec to less than 10 L/sec (high), and more than 10 L/sec (very high). The information of yield with drilling depth in each area is as follows; the 95 wells out of 220 wells are less than 100 m deep. The relation of yield and depth of the existing wells are shown in Figure 4.2.1.

- The well depth of 100-300 m is in almost all wells in West Hararge Zone, and one well depth is more than 350 m, few well depths are less than 100 m. The yield in almost all drilling points is less than 10 L/sec. However, the well depth of more than 350 m has more than 10 L/sec, and 2 to 6 L/sec yield is recognized in wells of less than 100 m depth.

- In the east to southwest of Lake Beseka, main well depth is less than 60 m. The yield of these wells is 3 to 10 L/sec. In the northwest of Lake Beseka, there are wells of less than 60 m and 100 m depths, and yield is 6-12 L/sec. The yield may be affected by the difference of drilling depth and aquifer.

- There are six wells along the road between Kone Caldera and Nazret (Adama). Four wells out of six wells have information of yield. The well depth is 100-205 m and yield is 1 to 1.5 L/sec (Only one point is 5 L/sec yield).

- The total number of wells in North Shoa zone in Amhara region located in northwest of the Study area is 16 well points, well depth is mainly 100 m to less than 200 m, and main yield is less than or equal to 3 L/sec and 5 L/sec. Two wells are more than 300 m depth and yield is 25 to 30 L/sec. Eleven (11) wells out of 16 wells have the yield data.

- In the Wonji sugar plantation located in the south of Adama in the southwest of the Study area, most of the wells are shallow, at a depth of 30-67 m, the deepest one in this area being 200 m and ten wells are 100 m to less than 200 m depth. The yield is 3 to less than 10 L/sec.

- Data of 38 existing wells are collected around Lume woreda in Mojo area. However, out of 38 wells, the depth of 12 wells is not clear. The shallow depth wells are 15-30 m, and deep wells depth are 100-280 m. The shallow depth wells in the north Mojo town have 1 to 3 L/sec yield. The 200 m depth well has 15 L/sec, and an average for all wells of 1 to 5 L/sec. The depth of five other wells in Adda-Becho Groundwater Evaluation Project of Debre Zeit is deep because one well is 370 m depth and remaining four wells are about 350 m depth. These wells have more than 30 L/sec yield except one well, and two wells yield is 50 to 60 L/sec.

- Seven (7) wells data have been collected around east escarpment in Arsi zone, which is continued from RVLB. Three wells out of 7 wells are 200 to 300 m depth and yield is 3 to 5 L/sec.

- The well of 420 m depth has 3.4 L/sec yield around Dera town in Arsi zone. In the wells known yield data, one well, near Dera town, is more than 250 m depth and yield is less than 1 L/sec, and another well, near Sire town, is less than 200 m, and yield is 4 L/sec. Two (2) wells have 1 to 3 L/sec yield, and no correlation with well depth, along the road to Asela.

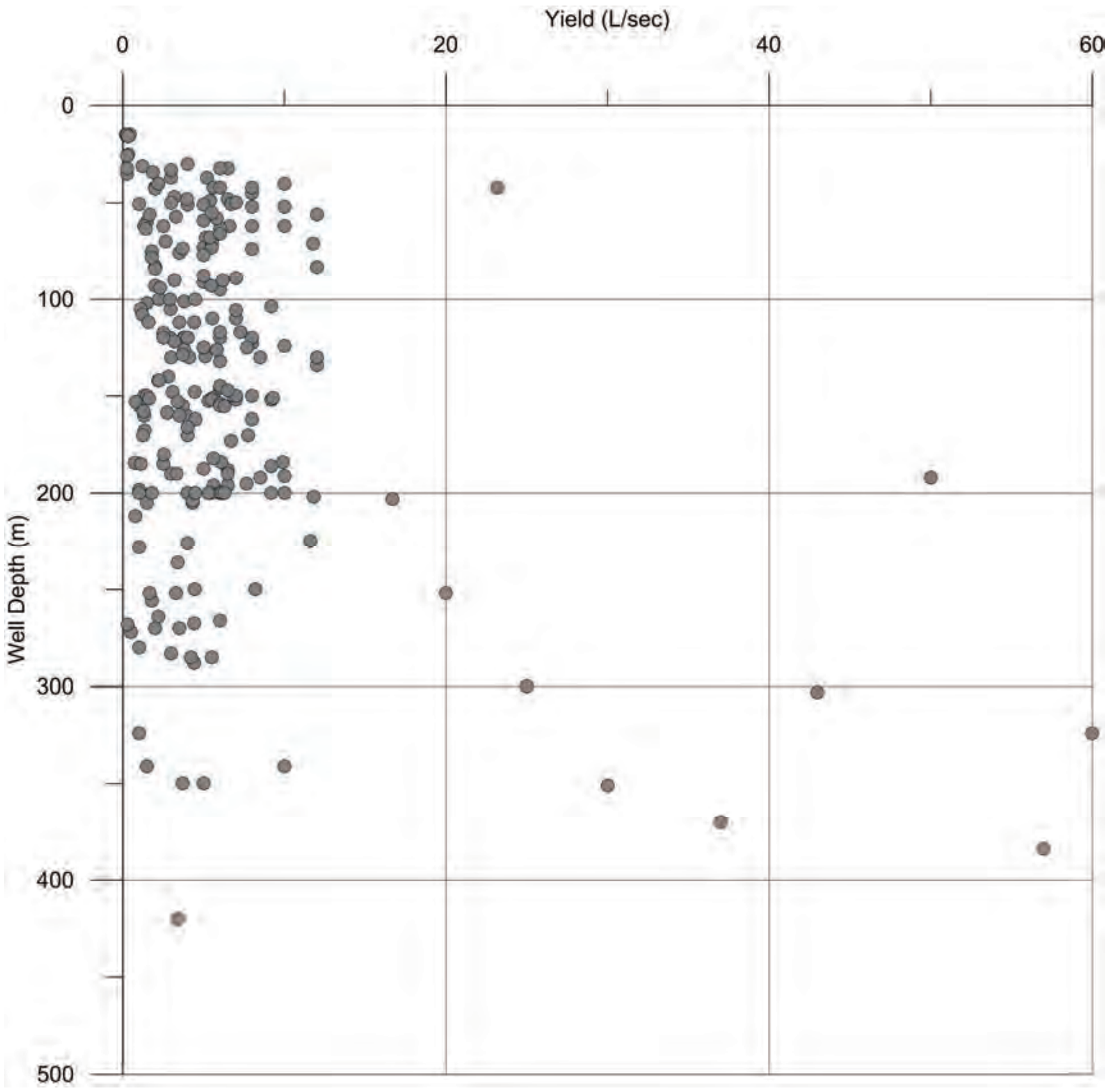


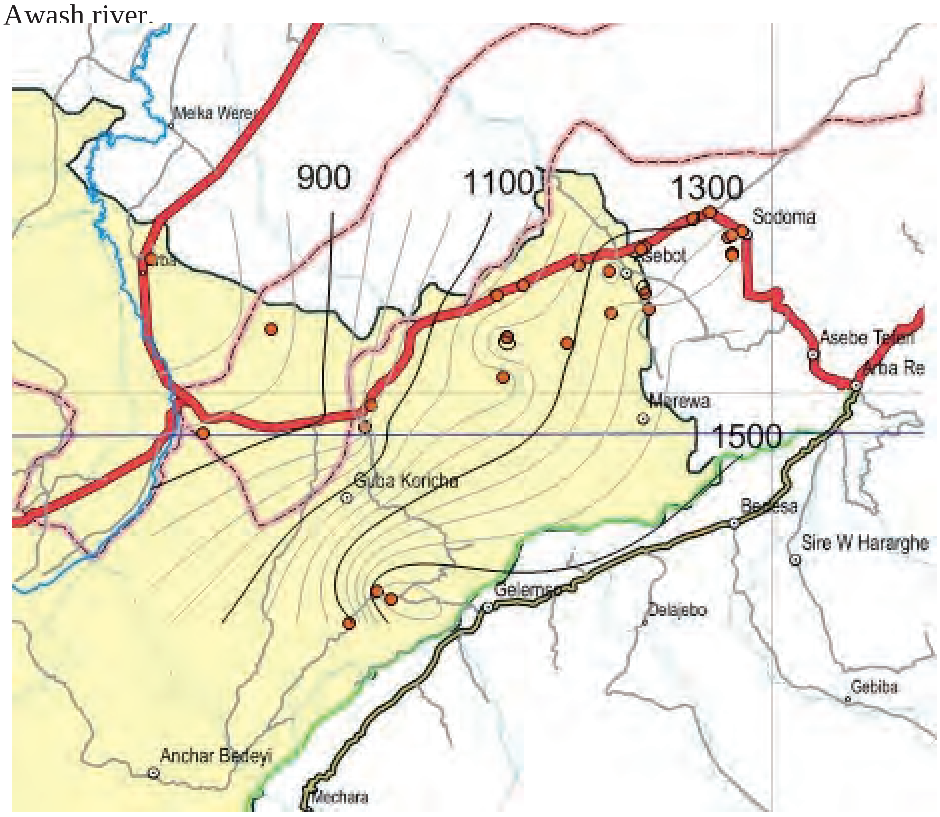
Figure 4.2.1: Relation between Yield and Depth of the Existing Wells

b. Static water level contour map

In a groundwater basin not influenced artificially, groundwater basin is divided into recharge area where groundwater is replenished and discharge area where groundwater flows out depending on the water flow in groundwater basin. There are three types of groundwater flow system: 1) Regional flow system; groundwater occurs in the whole groundwater basin based on the large scale geography, 2) Intermediate flow system; groundwater occurs in the meddle size area based on the ups and downs of geography in the small scale compares to the regional flow system, and 3) Local flow system; groundwater occurs in the small size area based on the ups and downs of geography locally. However actual flow pattern changes intricately by the geological condition, for example the continuous or isolated distribution of permeable layer.

In this time, the static water level map (groundwater level contour map) was created by using the static water level of each existing well due to the groundwater flow survey. The characteristic of groundwater flow in each small area of Study area is as follows;

- In West Hararge area, the screen position of the existing columnar section correlates to the basalt and ignimbrite in the Miocene, and these layers are main aquifer in this area. Groundwater level contour map is shown in Figure 4.2.2. Main direction of groundwater flow is the flow line from south east ridge of rift valley to northwest or west side of Awash river.



Source: the Project Team, Data: reference ①1), 3) and ②1)

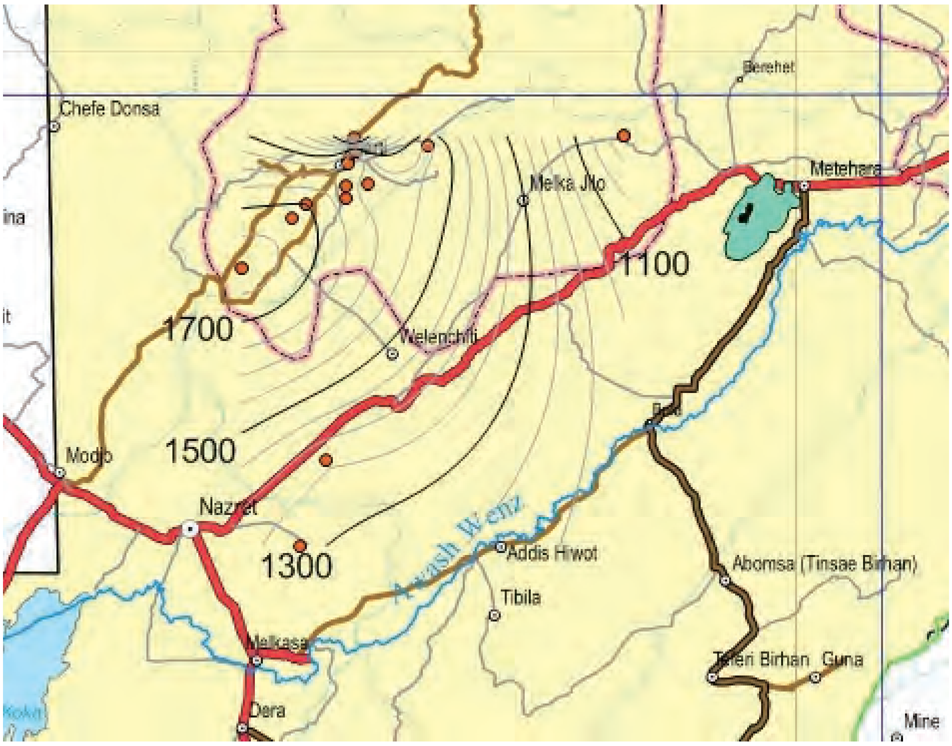
Figure 4.2.2: Groundwater Level Contour Map in West Hararge Area

- Volcanic deposits of Pleistocene in the Rift Valley floor cover the basalt and Nazret Group layer in the Amhara area, west side of Lake Beseka. In the north west of this area, the ridge of northeast–southwest direction consisted of basalt layer below Nazret Group. Although there is scant groundwater information on existing wells, the flow line is generally considered from northwest ridge of rift valley to east or to southeast, Lake Besaka and Awash River. Moreover, flow line bears partly to north direction (refer to Figure 4.2.3).

- Geological stratigraphy is in the east of Lake Koka to Dera town that form the upper part, alluvium and lacustrine deposit, volcanic deposits in Pleistocene. And Bofa basalt, Nazret group in Miocene covered by upper layers and basalt below Nazret Group distribute in this area. Groundwater level is very deep around Dera town area, and it is considered the flow line concentrates into Dera town from surrounding areas. And flow line bears partly from south to Lake Koka probably (refer to Figure 4.2.4).

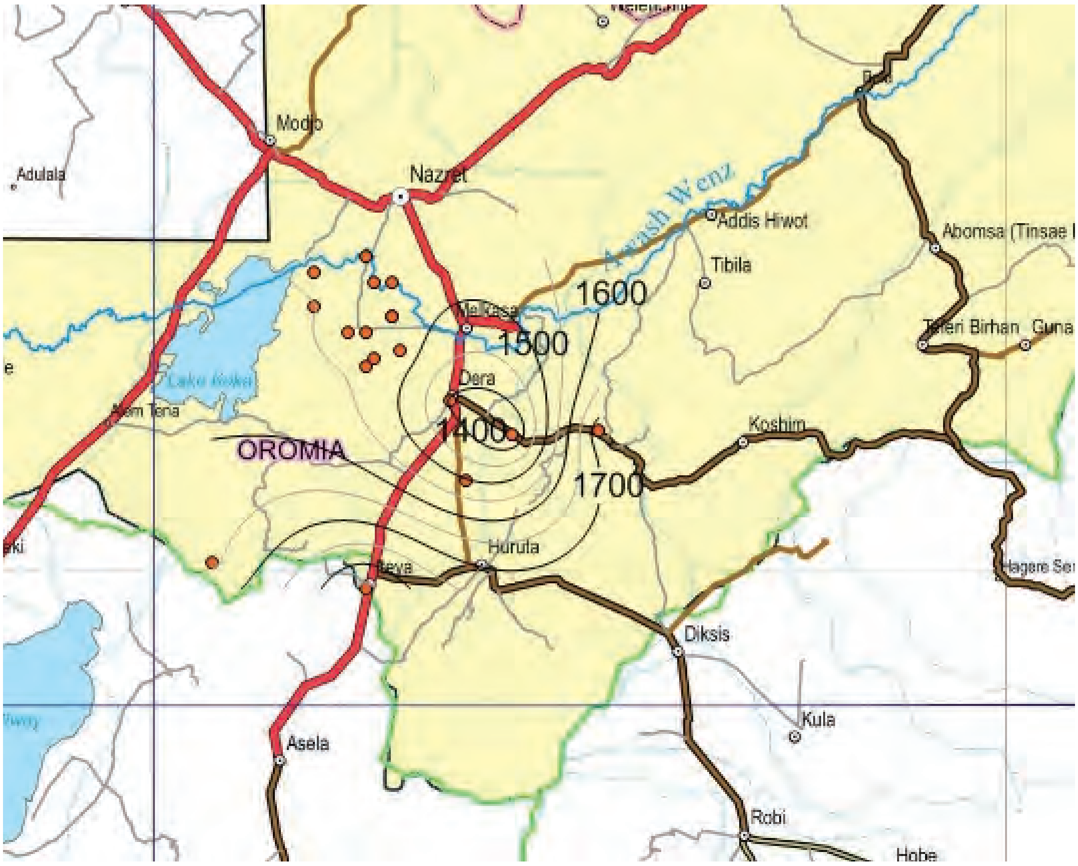
- In the north to east and west of Lake Koka, there are existing wells with groundwater information. Main geology is that alluvium and Nazret Group below distribute, and Bofa basalt also distributes in north side. Main line flow is considered from north or northwest to south or south east. This is flow line bearing to Lake Koka (refer to Figure 4.2.5).

- For the existing wells concentrated around Lake Beseka, a large-scale groundwater level contour map has been created. The alluvium is mainly distributed to the south of Lake Besaka, Fantale acidic volcanic deposits, Pleistocene basalt, Dino ignimbrite and Bofa basalt distribute below alluvium. The direction of flow line is considered from south west to north east (refer to Figure 4.2.6).



Source: the Project Team, Data: reference ①1), ②4)

Figure 4.2.3: Groundwater Level Contour Map in Amhara Area

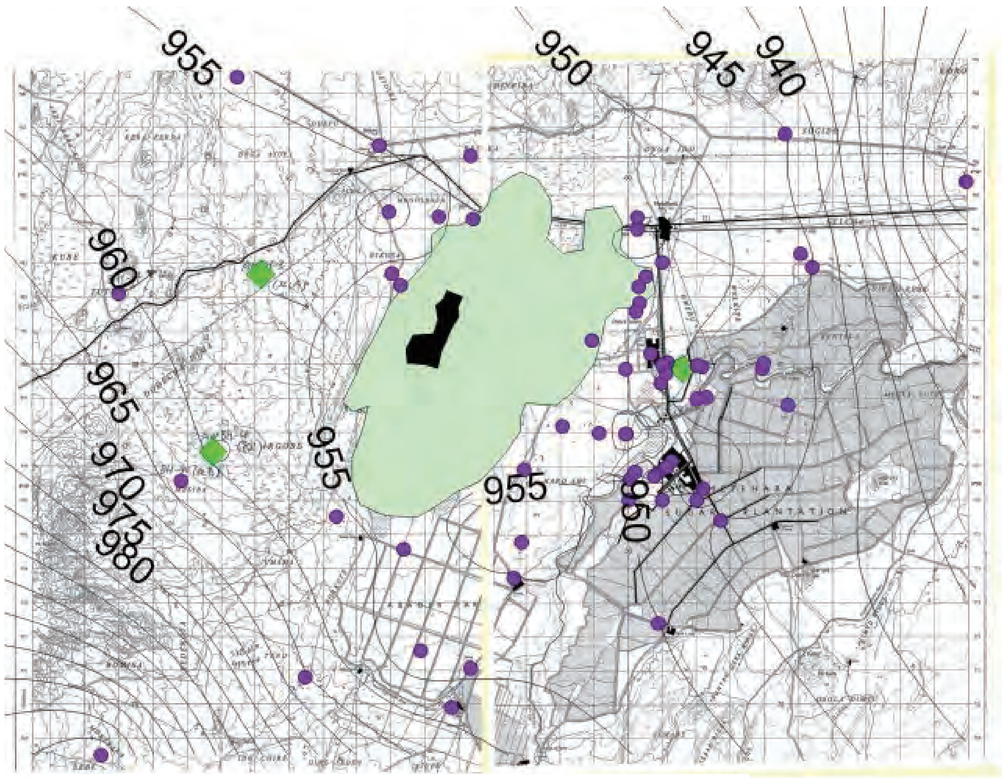


Source: the Project Team, Data: reference ①1), ②2), 3)

Figure 4.2.4: Groundwater Level Contour Map in East of Lake Koka to Dera Town

Source: the Project Team, Data: reference ①1), 2), ②2), 3)

Figure 4.2.5: Groundwater Level Contour Map in North to East of Lake Koka



Source: the Project Team, Data: reference ①1),4)

Figure 4.2.6: Groundwater Level Contour Map around Lake Beseka

4.2.2 Classification and characteristic of aquifers

Table 4.2.1 shows the hydrogeological aspects of the aquifer and the basic quantitative values. The volcanic deposits consisting of tuff rings including scoria cones, marl and volcanic bodies in the small area were excluded.

Table 4.2.1: Aquifer Unit Classification and Characteristics

Geologic age	Aquifer unit name	Code	Hydrogeological characteristics
Quaternary Pleistocene -Holocene	Holocene deposits	Qal (including Lacustrine deposits)	• Along the Awash River, alluvial sediment covers a small area. • The Alluvium around Lake Beseka consists of sand, mud and gravel, and the thickness of alluvium reaches about 11-40m. Most of the boreholes in these areas have yield from 3 to 7L/sec. • The lacustrine sediment distributes widely in the Wonji, Debre Zeit, Mojo, Koka and Nazret areas. This sediment is about 50m thick in the Wonji area, and mainly consists of gravel and sand. • In the Wonji area, the yield of the borehole ranges from 1 to 7L/sec. • In northeast of Debre Zeit, the lacustrine

Geologic age	Aquifer unit name	Code	Hydrogeological characteristics
			sediment which has a thickness of more than 60m (maximum), is composed of coarse sand with pebbles. The average value of specific capacity is 0.4 to 1.1L/sec/m.
	Recent Basalts	Qb2	• They are products of fissure eruption and are highly vesicular, and can store an appreciable quantity (amount) of groundwater. • They are considered to have a high permeability. • However it is difficult to predict whether or not an impermeable layer exists below.
	Fentale Ignimbrite/Kone Ignimbrite	Qi3/Qi2	• "Fentale Group of Ignimbrites (Qwi2)" shows different hydrogeological characteristics in different areas. • To the west and south of the Fentale volcano, this welded tuff is greyish green, fresh, columnar jointed with blisters and crevasses. So these fractures act as groundwater conducts, some existing boreholes have a yield of 7L/sec. Such layers in this area have high permeability. • On the other hand, east and northeast (behind Awash town) of the Fentale volcano, the same group is highly weathered and joints are filled with clay materials. An existing well drilled up to 200m in a valley was found to be dry. In this area, these layers are considered to have low permeability. • On the whole, the average of the yield is 6L/sec, and of the specific capacity is 3L/sec/m, the results indicates the middle permeability.
	Pleistocene Basalts	Qb1	• They are vertically and horizontally jointed. • Drawdown is small by the existing borehole and specific capacity is more than 7L/sec/m in some areas. Other yields are 1.4 and 1.6L/sec respectively. • The basalt layer occurs at 50m to 70m depth of the existing wells around Lake Beseka. The record of yield is sparse, but there are partial records of 8 to 12L/sec. • Therefore, these groups of basalt are considered to have moderate permeability.
	Chefe Donsa pyroclastic deposits	Qp1	• "Unwelded Rhyolitic Pumice and Unwelded Tiffs (Qwpu)" corresponding to W shows rhyolitic pumice and un-welded tuffs interbedded with clay. • The clay beds have reduced its permeability, so it is considered to have low permeability. • The yield is 1 to 5L/sec, and the average of the specific capacity is 4 L/sec/m.
	Dino Ignimbrite	Qi1	• "Dino Ignimbrites (Qwi)"corresponded to

Geologic age	Aquifer unit name	Code	Hydrogeological characteristics
			this layer are jointed and faulted. • The average of specific capacity of the existing well gives 2.2L/sec/m. It is grouped as moderately permeable formation. The average of the yield indicates more than 6L/sec. • The JICA well correlates to this horizon, but the screen position is below this horizon.
Tertiary Pliocene	Bofa basalts	Tb3	• Columnar jointing is very well developed with openings of 2-3cm joints and a distance of 1m between joints in the outcrop. • In the Bofa area, the depth to groundwater is more than 100m due to the deep nature of the vertical joints. And most of the precipitation infiltrates into the groundwater. • About eight kilometers southeast of Bishoftu, a borehole drilled on the Bofa basalt gives an appreciable quantity of water at a depth of 36m. • The JICA well correlates to this horizon, and yield is 4.4 to 11L/sec and the specific capacity is 0.15 to 9L/sec/m. • In general Bofa basalts are expected to have high to medium permeability.
	Lower and upper Nazret Pyroclastic deposits	Ti3/Ti2	• “Nazret Group of Ignimbrites (Nn)” shows variable permeability in different areas. • Geology consists of Ignimbrites, welded tuffs, ash flows, rhyolites and tuffs. • The group to the northeast of Melka Jilo and north of Kone Caldera is jointed and faulted and a borehole drilled in this formation has a yield of 6.7L/sec. In this area, these groups have high permeability. • In the Koka area, the strata are composed of pyroclastics containing tuffs with silt and silty sands and is jointed and faulted. However, there is no information on the yield of borehole(s). Thermal springs near points have a discharge of 38 - 798L/sec. • The average yield is 15L/sec as a whole, specific capacity is more than 2L/sec/m. There are highly productive areas in the Study area. • In the other areas, they predominantly consist of ash flow and tuff, and bore holes drilled in this formation have low yields according to the information.
	Pliocene rhyolite	Tr2	• Tr2 consists of older alkaline and peralkaline rhyolite domes and flows • They are generally grouped as formations of middle permeability by fractured aspects.
Tertiary Miocene	Anchar Basalt	Tb2	• It consists of basalts interbedded with tuff • Basalt layers occur without tuff interbeds

Geologic age	Aquifer unit name	Code	Hydrogeological characteristics
			(in the valley of Cherora), Nine can have high permeability. • Yield is 6 to 8L/sec in the West Hararge area. • However, in most places, as it occurs interbedded with tuff which lowers its permeability, it is grouped as a moderately permeable formation, but high permeability is shown in the fracture zone. • The average of the yield is 9L/sec and of the specific capacity is 3.8L/sec/m
	Alaji Basalt	Tb1	• It is vesicular at the top, flow banded in the middle and massive at the bottom. • It is faulted, however in some places, it is found interbedded with red paleosoil beds which reduce its permeability. Some springs with discharge of up to 2.7L/sec emerge from the contact of the basalt and the red beds. • So this basalt is grouped as a moderate aquifer, but high permeability is shown in the fracture zone. The average yield is 16L/sec as a whole, specific capacity is 2.7L/sec/m. There are highly productive areas in Study area. • The existing wells in the northwest area of Mojo obtain the yield of 37 to 60L/sec in the wells of the 300m to 380m in depth.

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

4.2.3 Evaluation of aquifer potential

Three (3) types of aquifers were identified by the study of the existing well inventory, new borehole data and the geological survey.

1) Alluvium and lacustrine deposits

2) Quaternary Pleistocene tuff, and welded tuff and basalt

3) Tertiary Pliocene, Miocene tuff, and welded tuff and basalt

Aquifer and productivity classifications are carried out and shown in Table 4.2.2 below by the geological classification in the project area in consideration with the aquifer classification using the geological divisions for the whole area of Ethiopia.

Table 4.2.2: Modified Hydrogeological Map - Aquifer Classifications and Definitions

No.	Description	Lithology	Productivity Classes	
1	Extensive aquifers with intergranular permeability	Unconsolidated sediments, alluvium, elluvium, colluvium, lacustrine sediments, poorly cemented sandstone	A	High
			B	Moderate
			C	Low
3	Extensive aquifers with fracture permeability	Volcanic rocks, basalts, rhyolites, trachyte, ignimbrites	A	High
			B	Moderate
			C	Low
5	Main geothermal areas	Common occurrence of thermal groundwater in fractured volcanic rocks and subordinate unconsolidated sediments	No classes	

Source: GSE, 1988 (reference 2) of ③), modified partly

Each aquifer and strata are classified by Table 4.2.2 based on the geological stratigraphy in the project area. The productivity is also classified by the yield and specific capacity calculated by the pumping test. The yield in the project area can be divided into the values below on the whole.

A: High yield (equal to or more than 10 L/sec)

B: Middle yield (5 L/sec to less than 10 L/sec)

C: Low yield (less than 5 L/sec)

The specific capacity related to the pump capacities in the project area can be divided into the values below.

A: High specific capacity (equal to or more than 4 L/sec/m)

B: Middle specific capacity (2 L/sec/m to less than 4 L/sec)

C: Low specific capacity (less than 2 L/sec/m)

The evaluation of productivity is carried out by a combination of both of the above (specific capacity and yield). In addition, the transmissibility is treated as a reference because of the lack of data. Table 4.2.3 below shows the aquifer classification and information of the existing wells and JICA wells.

Table 4.2.3: Aquifer Parameters and Units of Existing Wells and JICA Wells

	Aquifer	Symbol	Main lithology	Q(l/sec)			Specific Capacity (l/sec/m)			Transmissivity (m^2/day)		
				AVE	MAX	MIN	AVE	MAX	MIN	AVE	MAX	MIN
1	Alluvium and Lacustrine deposits	Qal (including Lc)	fine sand, clay	5.2	6.5	3.0	1.1	1.1	1.1	966.0	966.0	966.0
			gravel, mud	3.3	6.5	0.8	0.4	0.8	0.1	-	-	-
2	Quaternary Pleistocene Tuff, Welded tuff and Basalt	Qi3/Qi2	Strongly and consolidated welded tuff,	5.7	7.0	4.7	3.1	3.1	3.1	501.0	996.2	60.4
		Qb1	Aphyric basalt	7.4	12.0	1.4	3.2	8.7	1.2	189.2	189.2	189.2
		Qp1	Pumice & tuff intercalated with poorly welded tuff	2.2	5.0	1.0	4.4	7.1	1.6	-	-	-
		Qr1	Rhyolite	5.3	9.2	1.8	1.9	2.2	1.9	102.7	171.0	34.4
		Qi1	Greenish grey welded tuff	6.2	16.7	1.3	2.2	9.4	0.1	284.8	1044.0	0.1
3	Tertiary Pliocene, Miocene Tuff, Welded Tuff and Basalt	Tb3	Aphyric basalt	7.0	11.1	4.4	3.3	9.3	0.2	33.7	107.0	0.0
		Ti3/Ti2	Welded tuff, pumice and tuff	15.4	57.0	0.5	2.3	6.8	0.0	337.9	1230.0	0.5
		Tb2	Aphyric basalt	9.0	20.0	4.5	3.8	7.1	0.5	102.4	102.4	102.4
		Tb1	Porous plagioclase aphyric basalt	13.2	60.0	3.5	5.9	8.1	0.1	287.4	1150.0	0.0

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

The aquifer units are classified in accordance with the geological stratigraphy in the project area and each aquifer can be divided into the Ethiopian aquifer units modified as shown in Table 4.2.2. Table 4.2.4 includes the evaluation of aquifer potential in reference to the aquifer information of Table 4.2.3. The hydrogeological map is created based on these evaluations.

Table 4.2.4: Aquifer Classification and Productivity

Age			Area: Nazret-Mt.Boseti	Area: Kone-Mt.Fantale	Area: Mojo-Arerti-Debre Birhan	Area: Awash-Asebe Teferi	Area: Lake Besaka (1:100,000)	This study	Aquifer Units of Ethiopia	Productivity Level
Cainozoic	Quarternary	Holocene	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium (Qa)	Alluvium (Qal)	1	C
Cainozoic	Quarternary	Holocene	Recent rhyolitic domes & lava flows	Recent rhyolitic domes & lava flows				Recent rhyolitic domes & lava flows (Qr2)	5	–
Cainozoic	Quarternary	Holocene	Holocene basalts	Holocene basalts			Holocene basalts (Qb2)	Holocene basalts (Qb2)	3	C
Cainozoic	Quarternary	Pleistocene basalt	Fantale ignimbrites	Fantale ignimbrites	Fantale ignimbrites	Fantale ignimbrites	Fentale ignimbrites (Qi3)	Fentale ignimbrites (Qi3)	3	B
Cainozoic	Quarternary	Pleistocene basalt		Fantale volcanic rocks			Fentale volcanic rocks (Qf)	Fentale volcanic rocks (Qf)	3	C
Cainozoic	Quarternary	Pleistocene basalt	Boseti pumice falls	Kone pumice falls	Boseti pumice falls			Boseti & Kone pumice falls (Qp2)	1	C
Cainozoic	Quarternary	Pleistocene basalt		Kone ignimbrites		Asebot welded tuffs	Kone ignimbrites (Qi2)	Kone ignimbrites (Qi2)	3	B
Cainozoic	Quarternary	Pleistocene basalt	Pleistocene basalts	Pleistocene basalts	Pleistocene basalt	Dofan basalt	Pleistocene basalts (Qb1)	Pleistocene basalts (Qb1)	3	B
Cainozoic	Quarternary	Pleistocene basalt		Tuff ring deposits	Maar deposits		Sobebor volcanic sand beds (Qs)	Sobebor volcanic sand beds (Qs)	5	–
Cainozoic	Quarternary	Pleistocene basalt			Zikwala Trachytes			Zikwala Trachytes (Qt)	3	C
Cainozoic	Quarternary	Pleistocene basalt	Chefe Donsa pyroclastic deposits		Chefe Donsa pyroclastic deposits	Awash Arba Volcano-sedimentary rocks		Chefe Donsa pyroclastic deposits (Qp1)	1	B
Cainozoic	Quarternary	Pleistocene basalt	Pleistocene rhyolites					Pleistocene rhyolites (Qr1)	3	C
Cainozoic	Quarternary	Pleistocene basalt	Dino ignimbrites	Dino ignimbrites	Dino ignimbrites	Dino ignimbrites	Dino ignimbrites (Qi1)	Dino ignimbrites (Qi1)	3	B
Cainozoic	Tertiary	Pliocene	Bofa basalt	Bofa basalts	Tulu Rie basalts	Bofa basalt	Nuea Hira basalts (Tb)	Bofa basalts (Tb3)	3	B
Cainozoic	Tertiary	Pliocene	Chilalo Trachybasalts					Chilalo Trachybasalts (Tt)	3	B
Cainozoic	Tertiary	Pliocene	Nazret pyroclastic deposits: Upper		Nazret pyroclastic deposits: Upper		Old ignimbrites (Ti)	Upper Nazret pyroclastic deposit (Ti3)	3	A
Cainozoic	Tertiary	Pliocene	Nazret pyroclastic deposits: Lower		Nazret pyroclastic deposits: Lower	Adele rhyolitic tuffs		Lower Nazret pyroclastic deposits (Ti2)	3	A
Cainozoic	Tertiary	Pliocene	Chefeko rhyolites	Birenti-Hada rhyolites	Mt. Bokan rhyolites	Gara Gumbi rhyolites	Birenti-Hada rhyolites (Tr)	Pliocene rhyolites (Tr2)	3	B
Cainozoic	Tertiary	Miocene			Tarmaber-Megezeze basalts	Anchar basalts		Anchar basalts (Tb2)	3	B
Cainozoic	Tertiary	Miocene			Debre Birhan ignimbrites			Debre Birhan ignimbrites (Ti1)	3	C
Cainozoic	Tertiary	Miocene				Huse Ridge rhyolites		Huse Ridge rhyolites (Tr1)	3	C
Cainozoic	Tertiary	Miocene	Alaji basalts		Kesem basalts	Alaji basalts		Alaji basalts (Tb1)	3	A

Source: the Project Team, Data: reference ④

4.2.4 Groundwater recharge and yield

The middle Awash river basin is divided into thirteen sub-basins, and the basic flow (groundwater recharge) was estimated using the annual rainfall, run-off coefficient of river and basic flow index in the sub-basins (refer to Table 4.2.5). Figure 4.2.7 includes sub-basins with the annual mean groundwater recharge (x $10^6 m^3$/year), target small towns and model existing well points.

Table 4.2.5: Result of Groundwater Recharge Estimation by Sub-basins

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

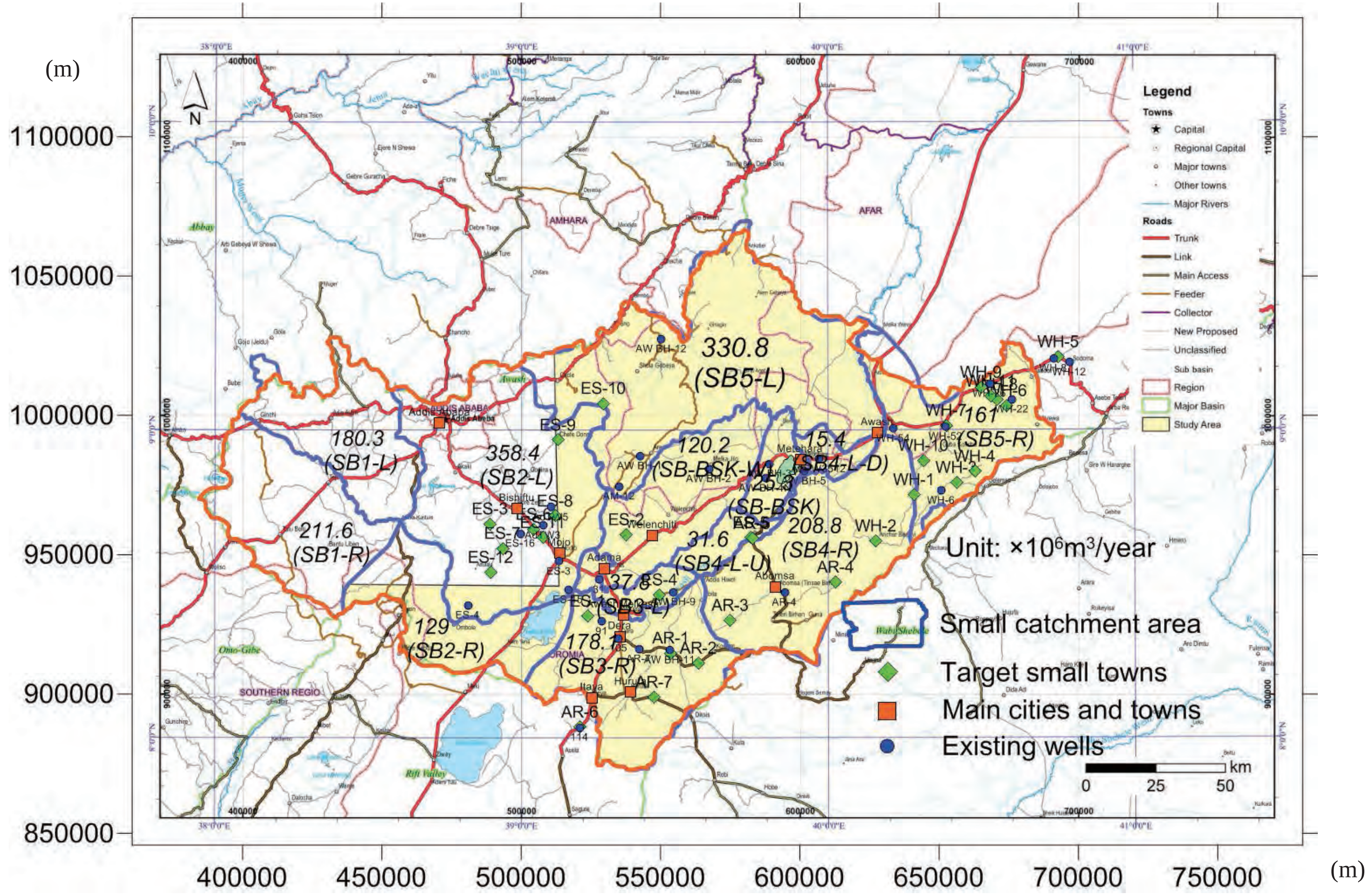
Source: the Project Team, Data: Result of hydrology survey in this Project

A comparison was made between the groundwater recharge value in the each sub-basin and the estimated groundwater usage as of 2035 calculated by adding estimated groundwater pumping volumes for 2035 for estimates (by estimating water usage demand using 2035 population projections based on current pumping volume data) for the main medium to large cities and planned pumping volumes (based on an assumption of maximum water usage of the estimated water demand in 2035 using a maximum daily per capita water demand unit of 50L/c/day) in the small towns in the target area. The main medium to large cities are Addis Ababa, Bishoftu (old name: Debre Zeit), Mojo, Adama (old name: Nazret), Huruta, Itaya, Welenchiti, Dera, Awash Melkasa, Abomsa, Metehara and Awash. However, as Adama, Metehara and Awash are using surface water and Hurta, Itaya, Welenchiti, Dera and Awash Melkasa are using the spring water, therefore the values from such towns and cities were excluded from the abovementioned calculation of estimated groundwater pumping volumes for 2035.

Further, the water usage volume as of 2035 is calculated (based on the assumption that representative existing wells are continuously used until 2035) by multiplying the current pumping volume by the estimated population growth rate (approx. 2.23 times that of 2015) of neighboring target small towns.

The ratio between the groundwater recharge and yield (well pumping capacity) is shown in Table 4.2.6 as approximately 1 to 5% in the major sub-basins for which data was obtained. Therefore, it is considered that groundwater wells drilled in these sub-basins will produce a sufficient pumping yield, as shown in the results of Table 4.2.6.

The ratio between the groundwater recharge and yield in the SB2-L sub-basin shows more than 35%, because a large city, Addis Ababa, and medium-sized towns, Bishoftu and Moji which have large yields are included in this sub-basin, as shown in Figure 4.2.7. Although the yield of the existing well in SB4-L-D is very large (yield: 100L/sec), the area of the sub-basin is narrow and has low recharge of groundwater. So the ratio is about 45% in the SB4-L-D.



Source: the Project Team, Data: reference ④

Figure 4.2.7: Location Map of Sub-Basin, Small Towns and Model Existing Wells

Table 4.2.6: Ratio between Groundwater Recharge and Yield

Sub-Basin	Yield in big and middle towns (Estimation as of 2035) (Y1) [$10^6 m^3$/year]	Yield in target small towns (Estimation as of 2035) (Y2) [$10^6 m^3$/year]	Yield in model existing wells (Estimation as of 2035) (Y3) [$10^6 m^3$/year]	Amount of total yield [$10^6 m^3$/year] (Y=Y1+Y2+Y3)	Groundwater recharge(GWR) [$10^6 m^3$/year]	Y/GWR [%]
SB2-L	120.90	2.25	11.0	134.15	358.4	37.4
SB3-L	-	0.25	0.42	0.67	37.8	1.8
SB3-R	-	1.65	1.49	3.14	178.1	1.8
SB4-L-U	-	0.32	-	0.32	31.6	1.0
SB4-R	0.36	1.46	0.30	2.12	208.8	1.0
SB5-R	-	2.06	3.36	5.42	161.0	3.3
SB-BSK-W	0.59	0.14	0.49	1.22	120.2	1.0
SB5-L	-	-	1.59	1.59	330.8	0.5
SB-BSK	-	-	1.29	1.29	25.3	5.0
SB4-L-D	-	-	7.03	7.03	15.4	45.6

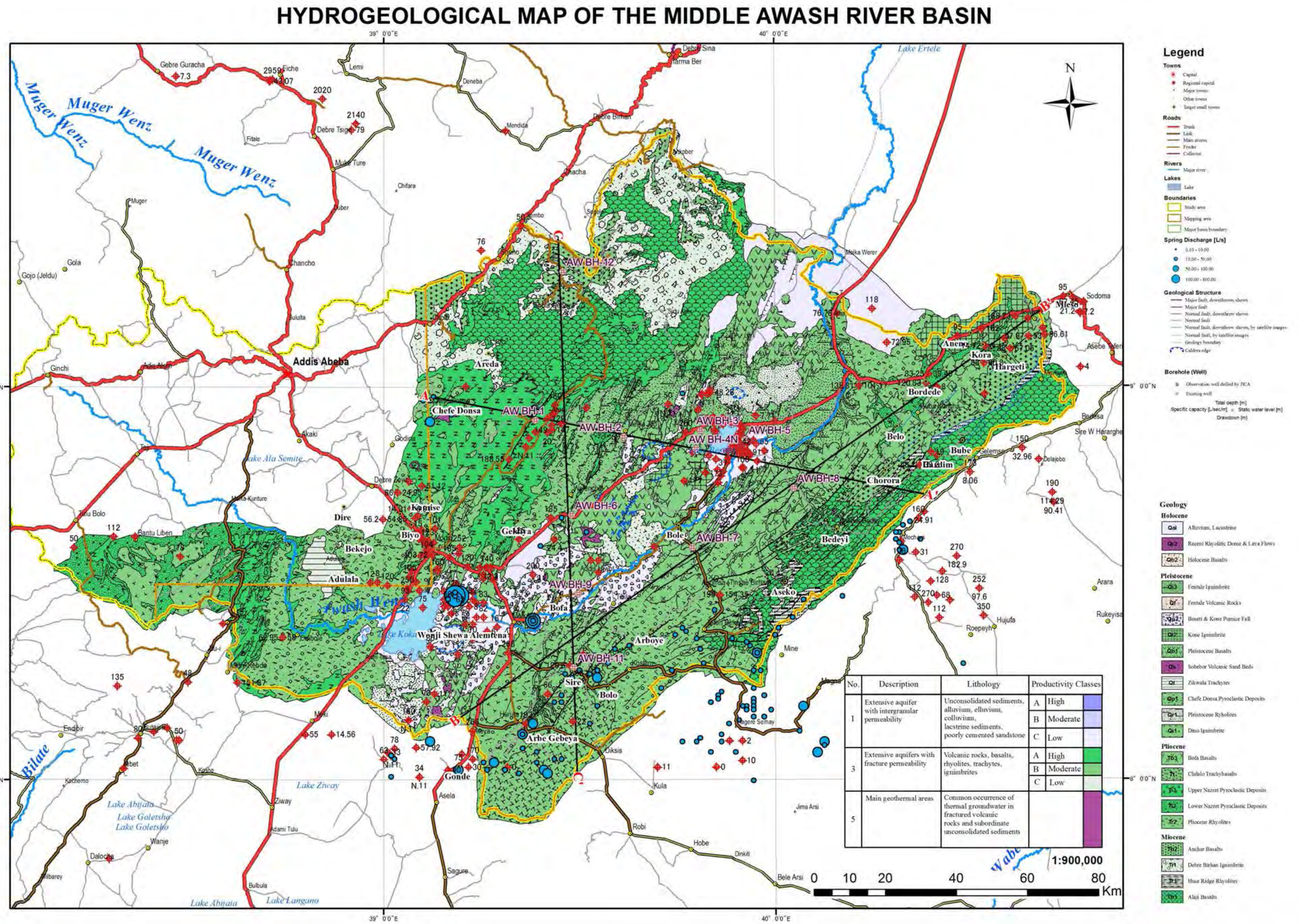
Source: the Project Team, Data: Calculation by project member

4.3 Hydrogeological map and groundwater flow

The hydrogeological map was created in accordance with the evaluation of productivity based on the relationship between the geology and aquifer units and aquifer information. It is possible to use the hydrogeological map to make a judgement about the actual capacity (groundwater potential) of aquifers in the project area. Judging from the map it is considered that each sub-basin will be able to supply a sufficient amount of groundwater to meet water usage demand based on the fact the ratio between groundwater recharge and estimated yield is low.

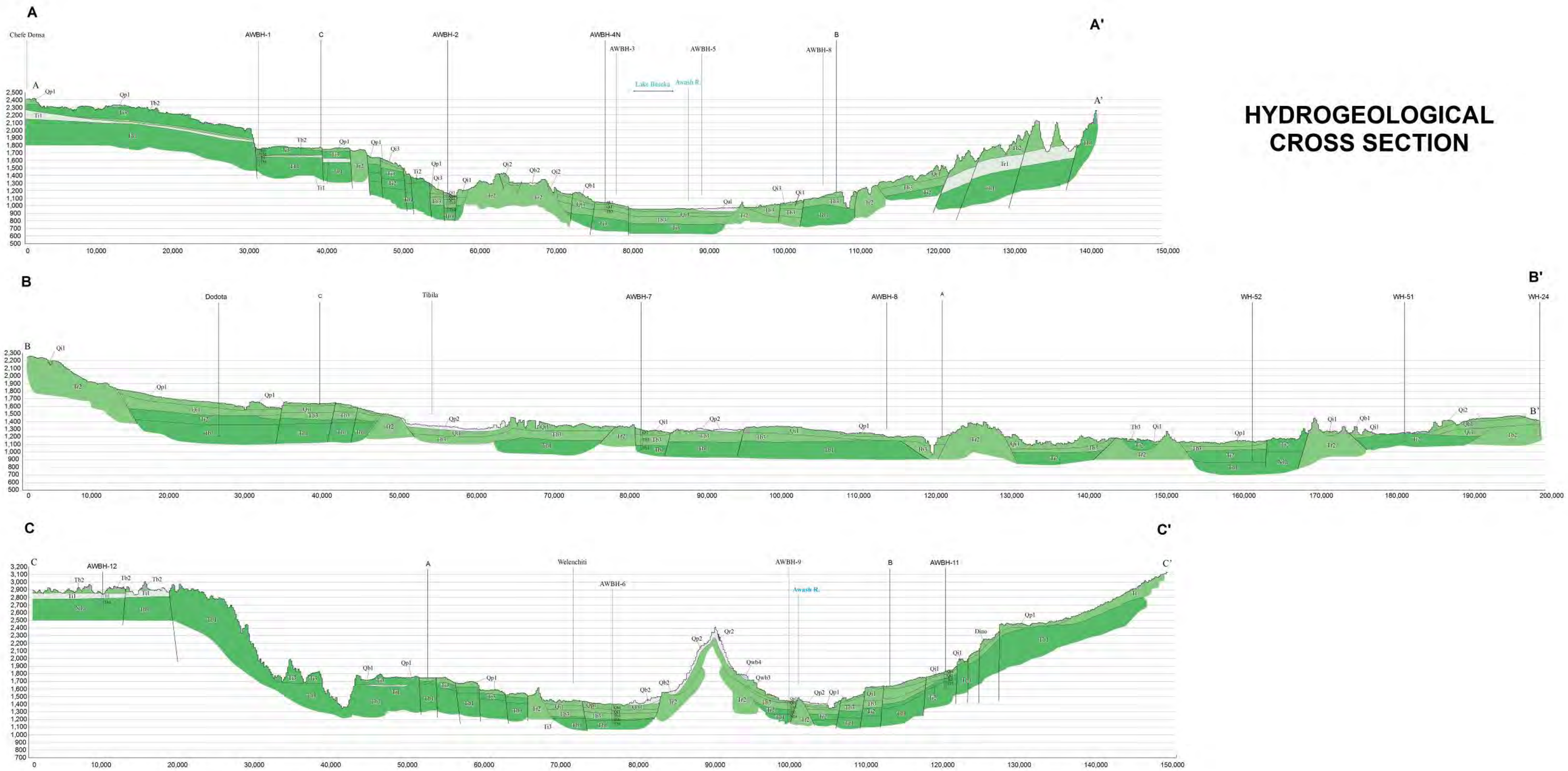
The hydrogeological map and cross-sections are shown in Figure 4.3.1 and Figure 4.3.2. Moreover the hydrogeological maps with hydrogeological cross-sections (scale: 1/250,000 and also 1/300,000) are prepared for the exhibit map.

Figure 4.3.3 shows the groundwater table contour map based on the static water level showing the confined aquifer, except the unconfined aquifer, partly using the information of JICA wells and existing wells. The direction of flow line is assumed to be from the south east and the north west of the Rift Valley highland to the rift floor of the north east to the south west along the Awash River. It is considered the groundwater flows along the geography. In Dera area located in the Arsi Zone, the flow line is in the direction of a small watershed.



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

Figure 4.3.1: Hydrogeological Map in the Middle Awash River Basin



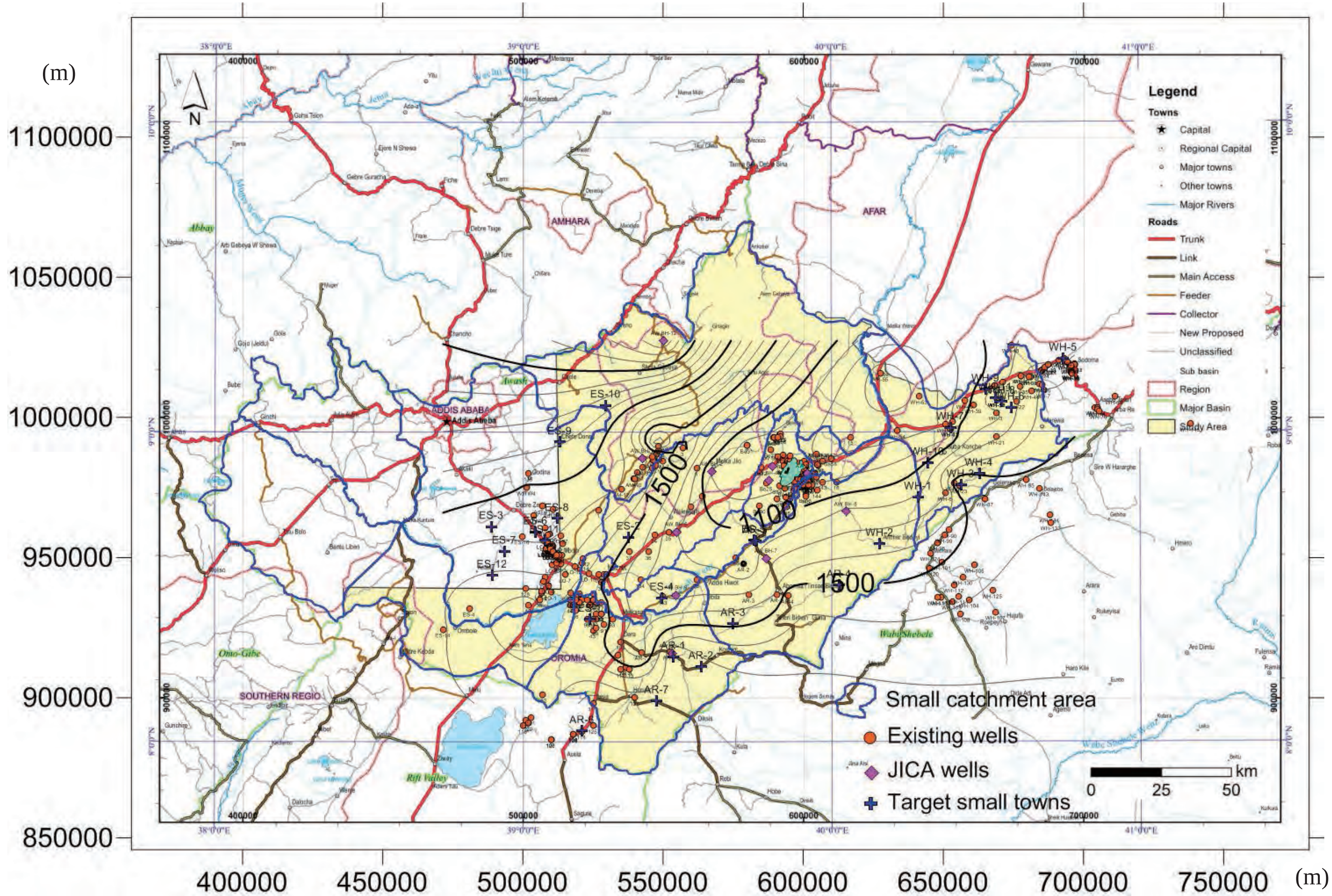
No.	Description	Lithology	Productivity Classes		
1	Extensive aquifer with intergranular permeability	Unconsolidated sediments, alluvium, elluvium, colluvium, lacstrine sediments, poorly cemented sandstone	A	High	
			B	Moderate	
			C	Low	
3	Extensive aquifers with fracture permeability	Volcanic rocks, basalts, rhyolites, trachytes, ignimbrites	A	High	
			B	Moderate	
			C	Low	
5	Main geothermal areas	Common occurrence of thermal groundwater in fractured volcanic rocks and subordinate unconsolidated sediments			

VERTICAL SCALE = 10 x HORIZONTAL SCALE

Hydrogeological Cross Section	December 2015
THE PROJECT FOR GROUNDWATER RESOURCES ASSESSMENT IN THE MIDDLE AWASH RIVER BASIN IN THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

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

Figure 4.3.2: Hydrogeological Cross Sections



Source: the Project Team, Data: reference ①, ②, ④

Figure 4.3.3: Groundwater Table Contour Map

4.4 Water quality testing

In the first phase a total of 100 samples were taken. The samples were taken from existing wells, springs, river and lake water. In the second phase a further four samples were collected from the new test wells. The samples are to be collected and analyzed by outsourcing to local companies (sampling: AWE CONSULTANTS PLC; Analysis: Water Works Design & Supervision Enterprise).

4.4.1 Results of water quality testing

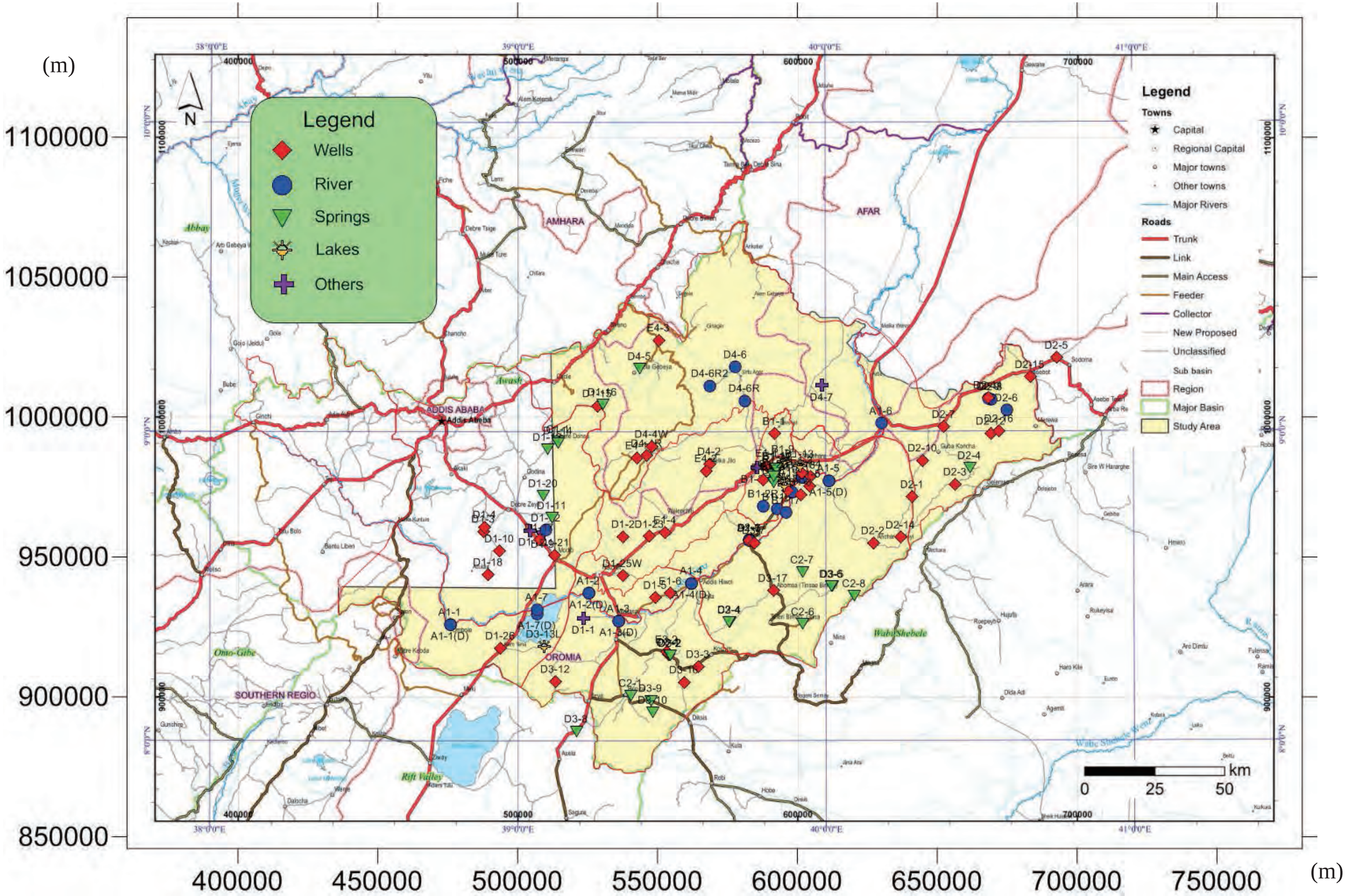
In order to grasp the characteristics of water quality from aquifers and water basins in the Study area, the sampling sites are selected by the following procedures:

- Selection in the small sub basin by topographical and river flow analysis

- From the respective small sub basins, samples are taken from the different geological (aquifer) conditions and type of sources (wells, springs, etc.) as much as possible.

- If it is not possible to take a sample at a site, an alternative sample site will be selected within the same aquifer. However, a sample must be taken from an alternative aquifer in case a source in the same aquifer cannot be found.

The sampling point map as of the first phase is presented in Figure 4.4.1: Location Map of Sampling Points for Water Quality Testing and the list of sampling points is tabulated in Table 4.4.1.



Source: the Project Team,
Data: reference ④

Figure 4.4.1: Location Map of Sampling Points for Water Quality Testing

Table 4.4.1: Sampling List

List of Water Sampling Points

As of October 1, 2015

	Zone or Region	Detailed Place	Type of Water Sources	Number of Sampling Points: For Physio-chemical Analysis	Number of Sampling Points: For Isotope Analysis	SL. No.	Location ID (Sample ID)	Reference Coordinate: Easting	Reference Coordinate: Northing	Reference Coordinate: Notes	Remarks
A. Along the Awash River and Lake Koka											
1	East Shewa	Around Ombole (Hombole)	Awash River Water	1	0	1	A1-1	475,870	925,848	OK	Awash River
		Around North of Gefersa	Awash River Water	1	0	2	A1-2	525,366	937,056	OK	Awash River
		Around Awash Melkasa	Awash River Water	1	0	3	A1-3	536,117	927,127	OK	Awash River
		Around Doni	Awash River Water	1	0	4	A1-4	562,228	940,652	OK	Awash River
		East of Metehara Sugar Plantation	Awash River Water	1	0	5	A1-5	611,190	977,348	OK	Awash River
		Around Awash	Awash River Water	1	0	6	A1-6	630,003	997,776	OK	Awash River
		Lake Koka	Mojo River Water	1	0	7	A1-7	506,957	931,212	OK	Mojo River
2	Arsi	Around Bole (Nura Hira Farm)	Awash River Water	1	0	8	A2-1	582,735	956,054	OK	Awash River
	Sub-total			**8**	**0**						
B. Lake Besaka Area											
1	East Shewa	Around Lake Besaka	Existing Well	1	0	9	B1-1	591,850	994,110	OK	From BH-40 to ABT well
\			Awash River Water	1	0	10	B1-2R	587,951	968,181	-	From BH-53 to River/Canal
			Birka	1	0	11	B1-3R	585,463	981,926	-	From BHT-34 to Birka
			Existing Well	1	0	12	B1-4	604,677	978,810	OK	From BHM-12 to R28
			Existing Well	1	0	13	B1-5	604,309	975,247	OK	From BH-41to M21
			Existing Well	1	0	14	B1-6	601,234	972,270	OK	From BH-64 to L11
		Near the Tone spring	Spring	1	0	15	B1-7	591,607	979,363	-	Lake water?
		Spring of Southwest Side of Lake Besaka	Spring	1	0	16	B1-8	591,608	976,552	OK	
		North-western part of the Lake Besaka	Lake Besaka Water	1	0	17	B1-9	594,960	984,098	OK	
		South-eastern part of the Lake Besaka	Lake Besaka Water	1	0	18	B1-10	595,100	977,400	OK	Same point with suggestion
		South-western part of the Lake Besaka	Lake Besaka Water	1	0	19	B1-11	592,000	977,900	OK	Same point with suggestion
		Central-western part of the Lake Besaka	Lake Besaka Water	1	0	20	B1-12	593,000	981,600	OK	Same point with suggestion
		Drainage Channel of Lake Besaka	Lake Besaka Water	1	0	21	B1-13	600,905	982,406	OK	Lake outlet
		Along Wast of Lake Beseka	Spring	1	1	22	B1-14	592,612	981,509	OK	
		In Metehara Plantation	Awash River Water	1	1	23	B1-15	598,077	972,974	OK	
		From Nura Hera Farm	Awash River Water	1	1	24	B1-16	592,729	967,092	OK	Irrigation water
		Middle Awash River	Awash River Water	1	1	25	B1-17	596,078	965,762	OK	River intake point
		Metehara SP	Awash River Water	1	1	26	B1-18	601,502	978,505	OK	
		South of Lake Besaka	Lake Besaka Water	1	1	27	B1-19	595,246	975,723	OK	
		Tone Spring	Spring	1	1	28	B1-20	591,674	978,734	OK	
	Sub-total			**20**	**7**						

C. Springs in Oromia Region											
1	East Shewa	Around Chefe Donsa	Spring	1	0	29	C1-1	514,538	991,211	OK	
2	Arsi	Around Huruta	Spring	1	0	30	C2-1	540,436	900,466	OK	
		Around Sire	Spring	1	0	31	C2-2	554,300	914,700	OK	Same point with suggestion
		Around Hagere Sisay (Arboye)	Spring	1	0	32	C2-4	575,777	926,678	OK	
		Around Gona	Spring	1	0	33	C2-6	602,013	926,019	OK	
		Near the Rift Ridge	Spring	1	0	34	C2-7	601,783	944,575	OK	
			Spring	1	0	35	C2-8	620,349	936,126	OK	
Sub-total				**7**	**0**						
D. Existing Wells etc. in Three Zones of Oromia Region											
1	East Shewa	W: Adama, T: Wenjishoa Alemtena	Hand dug well	1	0	36	D1-1	523,676	928,087	-	treated river water / public tap to HD
		W: Adama, T: Galdia	Existing Well	1	0	37	D1-2	537,802	957,253	OK	borehole / public tap
		W: Adama, T: Dire	Existing Well	1	0	38	D1-3	487,831	959,121	OK	borehole / public tap, same point
			Existing Well	1	0	39	D1-4	488,302	960,739	OK	borehole / public tap
		W: Boset, T: Bofa	Existing Well	1	0	40	D1-5	549,295	935,504	OK	borehole / public tap
		W: Boset, T: Bole	Existing Well	1	0	41	D1-6	582,848	956,036	OK	borehole / public tap
			River	1	0	42	D1-7	582,869	955,926	OK	Awash River
		W: Ada, T: Ude-Dhankaka	Existing Hand Dug We	1	0	43	D1-8	504,516	959,485	OK	hand dug well at private house
			Existing Well Hand Pu	1	0	44	D1-9	509,038	958,653	OK	borehole / hand pump
		W: Ada, T: Bekejo	Existing Well	1	0	45	D1-10	493,564	952,060	OK	borehole / public tap, same point
		W: Ada, T: Kamise	Spring	1	0	46	D1-11	512,290	963,912	OK	spring/public tap
			River	1	0	47	D1-12	510,199	959,502	OK	Mojo River
		W: Gimbichu, T: Chefe Donsa	Spring	1	0	48	D1-13	510,782	988,376	OK	spring/public tap
			Spring	1	0	49	D1-14	514,534	990,700	OK	spring/under construction, same point
		W: Gimbichu, T: Areda	Existing Well	1	0	50	D1-15	528,502	1,003,923	OK	borehole/ public tap, same point
			Spring	1	0	51	D1-16	530,357	1,004,490	OK	spring, same point
		W: Lume, T: Biyo	Existing Well	1	0	52	D1-17	507,817	956,090	OK	hand dug well at private house
		W: Liben Zikuala, T: Aduala	Existing Well	1	0	53	D1-18	489,505	943,707	OK	borehole / public tap
		W: Adaa Chukala, T: (around) Rob Gebya	Spring	1	0	54	D1-20	509,200	971,800	-	Same point with suggestion,but spring
		W: Lume, T: (around) Mojo	Existing Well	1	0	55	D1-21	513,345	950,655	OK	
		W: Boset, T: (around) Welenchiti	Existing Well	1	0	56	D1-23	547,200	957,300	OK	Same point with suggestion
		W: Adama/Boset, T: East of Adama	Existing Well	1	0	57	D1-25W	537,582	943,215	-	
		W: Dugda Borra, T: (around) Alem Tena	Existing Well	1	0	58	D1-26	493,896	917,377	OK	
2	West Hararge	W: Anchar, T: Chorora	Existing Well	1	0	59	D2-1	641,147	971,552	OK	borehole/ public tap
		W: Anchar, T: Bedeyi	Existing Well	1	0	60	D2-2	627,128	954,960	OK	borehole/ public tap
		W: G/Qoricha, T: Hardiim	Existing Well	1	0	61	D2-3	656,500	975,992	OK	borehole/ public tap, same point
		W: G/Qoricha, T: Bube	Spring	1	0	62	D2-4	661,671	981,852	OK	spring/public tap

2	West Hararge	W: Mieso, T: Mieso	Existing Well	1	0	63	D2-5	692,727	1,021,244	OK	
		W: Mieso, T: Hargeti	River	1	0	64	D2-6	674,765	1,002,450	OK	Arba River
		W: Mieso, T: Bordede	Existing Well	1	0	65	D2-7	652,373	996,613	OK	borehole/ public tap
		W: Mieso, T: Kinteri	River	1	0	66	D2-8	669,263	1,006,461	OK	Kora River
		W: Mieso, T: Anano	River	1	0	67	D2-9	668,333	1,006,613	OK	Kora River
		W: Mieso, T: Belo	Existing Well	1	0	68	D2-10	644,835	984,505	OK	borehole/ public tap
		W: Mieso, T: Kora	Existing Well	1	0	69	D2-11	668,293	1,007,019	OK	borehole/ public tap
		W: Guba Korcha, T: (around) Hayu/GubaK.	Existing Well	1	0	70	D2-12	669,248	994,178	OK	One (1) deep well in each place shall be selected by the Contractor from the list (T-D02) or at site
		W: Guba Korcha, T: (around) Cheleleka	Existing Well	1	0	71	D2-14	636,945	957,053	OK	
		W: Mieso, T: (around) Asebol	Existing Well	1	0	72	D2-15	683,191	1,014,356	OK	
		W: Guba Korcha, T: (around) Dalo	Existing Well	1	0	73	D2-16	672,182	995,077	OK	
3	Arsi	W: Sire, T: Sire	Existing Well	1	0	74	D3-1	553,860	915,163	OK	borehole/ public tap, same point
			Spring	1	0	75	D3-2	554,607	914,816	OK	spring/public tap
		W: Jeju, T: Bolo	Existing Well	1	0	76	D3-3	564,563	910,815	OK	borehole/ public tap
		W: Jeju, T: Arboye	Spring	1	0	77	D3-4	575,696	926,736	OK	spring/public tap
		W: Aseko, T: Aseko	Spring	1	0	78	D3-5	612,542	939,506	OK	spring/public tap, same point
			Spring	1	0	79	D3-6	612,181	939,466	OK	spring/public tap
		W: Merti, T: Bole Golgota	Existing Well	1	0	80	D3-7	584,509	955,048	OK	borehole / public tap, same point
		W: Tiyo, T: Gonde	Spring	1	0	81	D3-8	521,004	887,665	OK	spring/public tap, same point
		W: Lodehetosa, T: Arbe Gebeya	Spring	1	0	82	D3-9	547,581	898,647	OK	spring/public tap
			Spring	1	0	83	D3-10	548,387	894,467	OK	protected by concrete, same point
		W: Hitosa, T: Northwest of Iteya	Existing Well	1	0	84	D3-12	513,517	905,453	OK	
		W: Dodotana Sire, T: (around) Haro Robi	Lake Koka Water	1	0	85	D3-13L	509,481	918,033	-	From borehole to river water
		W: Hitosa, T: (ard) Denben Kindame	Existing Well	1	0	86	D3-16	559,573	905,271	OK	
		W: Merti, T: (around) Abomsa	Existing Well	1	0	87	D3-17	591,398	937,996	OK	nearly same point
		W: Merti, T: Metehara Sugar Plantation	Existing Well	1	0	88	D3-18R	596,626	973,633	-	
4	Amhara & Afar Regions	Amhara, W: Shenkorana Minjar, T: Northeast Welenchiti	Spring	1	0	89	D4-5	543,607	1,017,258	-	Previous no D4-1
		Amhara, W: Shenkorana Minjar, T: (around) Melka Jiro	Existing Well	1	0	90	D4-2	568,582	983,234	OK	
		Amhara, W: Shenkorana Minjar, T: NE of Melka Jiro	River water	1	0	91	D4-6R	581,140	1,005,858	-	Previous no D4-3
		Amhara, W: Shenkorana Minjar, T: (around) Arerti	Existing Well	1	0	92	D4-4R	546,233	986,204	-	
		Amhara, W: Hagere Mariamna K., T: (around) Shola Gebeya	Existing Well	1	0	93	D4-4W	548,008	989,483	-	Previous no D4-5
		Amhara, W: Berehet, T: (around) Meteh Bila	River water	1	0	94	D4-6	577,900	1,017,900	-	
		Afar, W: ?, T: (around) Melka Sedi	River water	1	0	95	D4-6R2	568,803	1,011,183	-	Previous no D4-8
Sub-total				**60**	**0**						

E. Newly Drilled JICA Wells											
1	East Shewa	Around Lake Besaka (AW BH-3)	New Well	1	1	96	E1-1	589,167	982,682	-	
		Around Lake Besaka (AW BH-4N)	New Well	1	1	97	E1-2	587,754	977,437	-	
		Around Lake Besaka (AW BH-5)	New Well	1	1	98	E1-3	601,565	980,024	-	
		Around Feto (AW BH-6)	New Well	1	1	99	E1-4	552,789	958,778	-	
		Between Doni and Bofo (AW BH-9)	New Well	1	1	100	E1-6	555,025	936,983	-	
2	Arsi	Around Sire (AW BH-11)	New Well	1	1	101	E3-2	553,313	916,009	-	
3	Amhara Region	Around Balchi (AW BH-1)	New Well	1	1	102	E4-1	542,642	985,361	-	
		Around Melka Jiro (AW BH-2)	New Well	1	1	103	E4-2	567,414	980,822	-	
		Around Dehaye (AW BH-12)	New Well	1	1	104	E4-3	550,405	1,027,427	-	
Sub-total				**9**	**9**						
Grand Total				**104**	**16**						

Source: the Project Team, Data: reference ④

4.4.2 Analysis items and methodology

a. General water quality testing

General water quality tests are analysed on site and in laboratory.

a.1 Site analysis

The 12 parameters for on-site water quality measurements are as follows:

Water temperature, electric conductivity (EC), pH, oxidation-reduction potential (ORP), Fe, Mn, F, NO_3, As, NH_4, Escherichia coli and Viable bacteria

The results of site analysis are shown in Annex.

a.2 Laboratory analysis

In the laboratory, the following 22 parameters were analysed for each sample:

Taste, odor, turbidity, total dissolved solids (TDS), suspended solids (SS), pH, electric conductivity (EC), total hardness ($CaCO_3$), Calcium (Ca), Magnesium (Mg), Potassium ((K), Sodium (Na), Iron (Fe), Manganese (Mn), Chloride (Cl) Sulfate (SO_4), Nitrate (NO_3), Nitrite (NO_2), Alkalinity (CO_3^{2-}, HCO_3^-) Fluoride (F), Total Phosphorus (TP) and ammonia (NH_3+＋NH_4)

The Ethiopian standard of water quality for drinking water and the WHO guideline are shown in Table 4.4.2 below at the stage of P/R2. However, the new Ethiopian standard of water quality for drinking water was prepared under the direction of the Technical Committee for Water Quality and published by the Ethiopian Standards Agency from 2013 as Table 4.4.3 shows. From the second phase, our project also adopts the new Ethiopian standard.

Table 4.4.2: Previous Water Quality Standard of Ethiopia

Analysis items	Ethiopian (mg/L)	WHO (mg/L)	Method	Remark
Escherichia Coli	0	0	Pack test	On site
Viable Bacteria	0	0	Pack test	On site
Arsenic	0.01	0.01	Pack test	On site
Fluoride	3	1.5	ISO 10359-1:1992E	On site & in lab.
Nitrate	50	50	ISO 7890-3: 1988 E	On site & in lab.
Color	22	15	ISO 7887: 1984 E	
Turbidity	7	5	ISO 7027: 1990 E	
Taste	n.o	n.o	WHO, Vol-2, p358	
Odor	n.o	n.o	WHO, Vol-2, p358	
pH	6.5 - 8.5	6.5 - 8.5	ISO 10523: 1990 E	On site & in lab.
TDS	1776	600	WHO, Vol-2, p367	
TS	-	-		
Total Hardness	392	300	ISO 6059: 1984	
Calcium	-	-		
Magnesium	-	-		
Sulfate	483	250	ISO 9280: 1990 E	
Chloride	533	250	ISO 9297: 1989 E	
Iron	0.4	0.3	ISO 6332: 1988 E	On site & in lab.
Manganese	0.13	0.1	ISO 6333: 1986 E	On site & in lab.
Ammonium (NH3+NH4)	0.5	1.5	ISO 7150-2: 1986 E	On site & in lab.
Total Nitrogen (Excluding NO3)	-	-		
Nitrite	6	3	ISO 6777: 1984 E	
Alminium	0.4	0.2	ISO 12020: 1997 E	
Sodium	358	200	ISO 9664-3: 1990 E	
Temperature	n.o.	-	-	
Electrical Conductivity	-	-	-	On site & in lab.
Potassium	-	-		
Bicarbonate	-	-		

Source: Specification for Ethiopian Drinkikg Water Quality Guidelines, 2002

Table 4.4.3: New Water Quality Standard of Ethiopia and WHO

Analysis items	Ethiopian (mg/L)	WHO (mg/L)	Method	Remark
Escherichia Coli	0	0	Pack test	On site
Viable Bacteria	0	0	Pack test	On site
Arsenic	0.01	0.01*	Pack test	On site
Fluoride	1.5	1.5*	ES ISO 10359-1	On site & in lab.
Nitrate	50	50*	ES ISO 7890-3	On site & in lab.
Color	15	15	ES ISO 7887	
Turbidity	5	5	ES ISO 7027	
Taste	n.o	n.o	ES605	
Odor	n.o	n.o	ES605	
pH	6.5 - 8.5	6.5 - 8.5	ES ISO 10523	On site & in lab.
TDS	1000	600	ES 609	
TS	-	-		
Total Hardness	300	300	ES 607	
Calcium	75	-	ES ISO 7980	
Magnesium	50	-	ES ISO 7980	
Sulfate	250	250	ES ISO 9280	
Chloride	250	250	ES ISO 9297	
Iron	0.3	0.3	ES ISO 6332	On site & in lab.
Manganese	0.5	0.1	ES ISO 6333	On site & in lab.
Ammonium (NH3+NH4)	1.5	1.5	ES ISO 7150-2	On site & in lab.
Total Nitrogen (Excluding NO3)	-	-	-	
Nitrite	3	3*	ES ISO 6777	
Alminium	0.2	0.2	ES ISO 12020	
Sodium	200	200	ES ISO 9964-1	
Temperature	n.o.	-	-	
Electrical Conductivity	-	-	-	On site & in lab.
Potassium	1.5	-	ES ISO 9964-2	
Bicarbonate	-	-	-	

Compulsory Ethiopian Standard: Drinking water-Specifications, 2013
WHO guideline: * : Health guideline value

a.3 Isotope Analysis

The main items of isotope analysis are heavy hydrogen, Oxygen-18, Noble gases (i.e. He gas), tritium, and Carbon-14. The isotope analysis was carried out on JICA test wells. The analysis of isotopes has been entrusted to the International Atomic Energy Agency. The samples were sent to IAEA after completion of well drilling. Moreover, isotope analysis was executed by Addis Ababa University for isotopic ratios of $\delta^{18}O$ and δD for 17 samples collected around Lake Beseka in the second phase. The results of Isotope Analysis are shown in Chapter 5. Moreover, the sending of samples to IAEA from AW BH-2 and AW BH-6 (JICA wells) was delayed because of delays in drilling, so the stable isotope analysis was carried out in AAU in parallel.

4.4.3 Results of water quality testing

As mentioned above, water quality analysis was conducted by on-site testing and by laboratory analysis to obtain the general water quality condition. The results of each analysis and the original data of sampling are attached in the Data book of F/R. It is difficult to obtain a detailed value of water quality in the on-site analysis due to using the pack test (simple test) type. However, by comparing on-site and laboratory water quality testing results, it was found that on-site tests showed high fluoride concentrations, while laboratory analysis showed a tendency of relatively high fluoride concentrations. The results for main items concentration compared laboratory test values and new Ethiopian & WHO guideline values of water quality (refer to Table 4.4.3) is as follows; However the fluoride was explained in the main report of the final report. Therefore, the other items were shown in this chapter;

a. Nitrate

Nitrate has been included in the health items of WHO water quality standard. The results of the analysis showed that only one hand dug well exceeded the WHO guideline (50mg/L=Ethiopian standard value) for nitrate, and the other resources do not exceed the WHO guideline. It is possible to consider human induced pollution for the hand dug well caused by chemical fertilizers, but it is not clear if this is the cause.

b. Ammonia

The concentration of ammonia exceeds the WHO guideline (1.5mg/L=Ethiopoan standard) in almost all the river water (6 points). In particular, the concentration of ammonia exceeds the WHO guideline in dry season). There are no existing wells that exceeded the WHO guideline of ammonia concentration.

c. Manganese

Manganese partially affects the human body. However in the Study area, Manganese concentration exceeds the WHO guideline (0.1mg/L) in only three points (river, spring and well respectively).

d. Others

River turbidity exceeds the Ethiopian standard (5 NTU) in almost all points except one sampling point along Awash River and along the small river in the north of the Study area in the Amhara Region. The turbidity of Lake Beseka and Koka water fails to comply with the Ethiopian standard (1000mg/L). Almost all existing wells are within the standard for turbidity. Seven points of lake water and springs around Lake Beseka exceed the pH9. The total hardness and calcium of existing wells and springs mainly in 10 points exceed the Ethiopian standard along the Rift Valley ridge of the south in the Study area. Sodium exceeds the Ethiopian standard (200mg/L) in 17 points of lake water, springs, existing wells and JICA wells around Lake Beseka. Sodium did not exceed the Ethiopian standard in any other areas sampled. Iron was mainly recognized in the few points of river that exceeded the Ethiopian standard (0.3mg/L). The concentration of the chloride and sulfate ions exceed the Ethiopian standard (250mg/L) only in Lake Beseka.

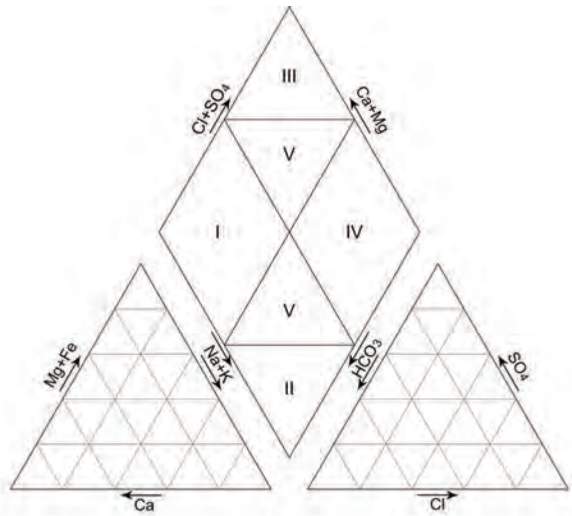
The Ethiopian standard of potassium was set up by the ESA, 2013. There is no preparation of the potassium in the water standard. At this time, under the new standard (1.5mg/l), all points of the Study area except only three points (two springs and one existing well) exceed the Ethiopian standard for concentration of potassium.

4.4.4 Evaluation of water quality

The characteristic of water quality in each sampling point is created in the Trilinear diagram and Hexadiagram.

a. Trilinear diagram

The trilinear diagram shows that the difference of water quality pattern is turned up in accordance with the location of water quality points plotted in the key diagram as below (refer to Figure 4.4.2); Trilinear diagrams do not display the concentration, but display the percent composition against total equivalent weight respectively of main cation and anion. The information on concentration of trilinear diagrams is poor, but many data can be expressed in one area. The classification of water in key diagram is as follows generally.



Source: the Project Team, Data: reference ③1)

Figure 4.4.2: Trilinear diagram

Ⅰ $Ca(HCO_3)_2$ Type（Carbonate hardness）：Shallow groundwater, River water
Ⅱ $NaHCO_3$ Type (Carbonate alkali）：Deep groundwater
Ⅲ $CaSO_4$ $CaCl_2$ Type（Noncarbonate hardness）：Hot spring, Fossiled salt water
Ⅳ Na_2SO_4 NaCl Type（Noncarbonate alkali）：Seawater, Groundwater with component of seawater
Ⅴ Intermediate range type：Intermediate-range pattern of each type

- Type Ⅰ： Water quality composition contains $Ca(HCO_3)_2$/$MG(HCO_3)_2$ type. Almost all shallow groundwater and river water are included in this type.

- Type Ⅱ： Water quality composition is $NaHCO_3$ type. This pattern contains groundwater of retention type. This type correlates to the deep groundwater relatively.

- TypeⅢ： Water quality composition is $CaSO_4$ or $CaCl_2$ type. This type mainly contains hot spring water, mineral water and fossil salt water. General river water and groundwater is a special case, if it is dotted in this type.

- Type Ⅳ： Water quality composition contains NaCl or $NaSO_4$ type. See water, groundwater with component of seawater and hot spring water belongs to this type.

- Type Ⅴ： This is intermediate pattern of each type above. River water and shallow water belong to this type mainly.

All points and each water source analyzed is plotted in trilinear diagram as Figure 4.4.3 to Figure 4.4.8. Characteristic of water quality in trilinear diagram of each water source is as follows;

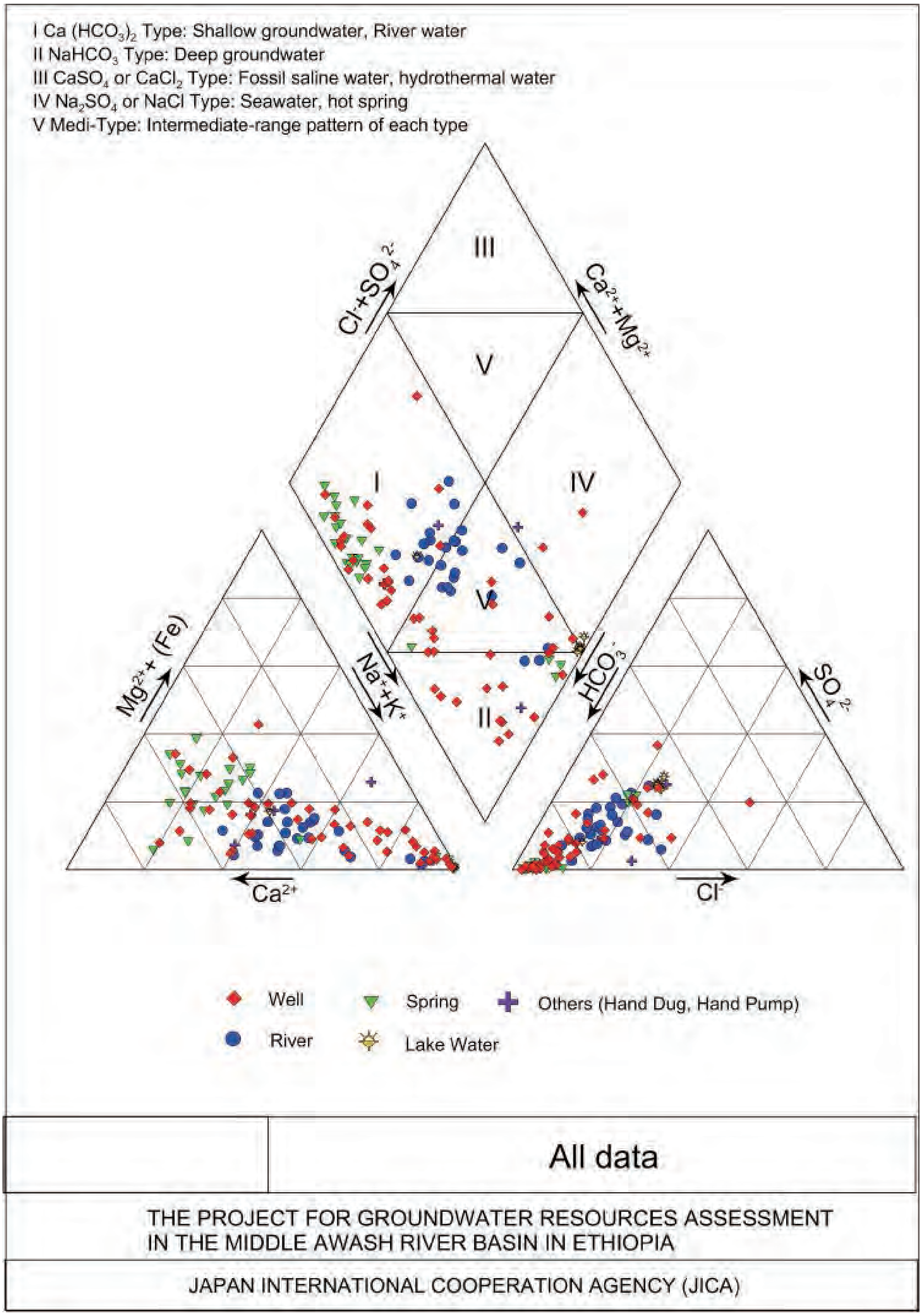
- Almost all samples of river water indicate the water quality of shallow water type. However a sample of Awash River flowing into Lake Koka is plotted in the type of intermidiate position of hot spring water and retention type. And another sample of downstream of Awash River through the Lake Besaka indicates water out of stream type. It is considered that this water is affected by the water flowing from Lake Besaka. The water quality type of Awash River belongs to the shallow groundwater and river types locating from downstream of the Lake Koka to upstream of the Lake Beseka.

- The sample of existing wells except one sample is plotted in the type of shallow groundwater, deep groundwater (retention type), and intermediate type of each type mentioned above. The plotted points are dispersed in key diagram. Only one sample is plotted in Ⅳtype. Deep groundwater type is located in rift valley floor around Lake Koka. The depth of sampling existing wells is 100 to 200 m. The sample points of shallow groundwater type are distributed in the direction of north east – south west around rift valley ridge.

- Almost all samples of springs belong to circular shallow water type. Two springs flowing in Lake Beseka are located in deep groundwater type in key diagram. The characteristic of groundwater flowing in Lake Beseka is expressed.

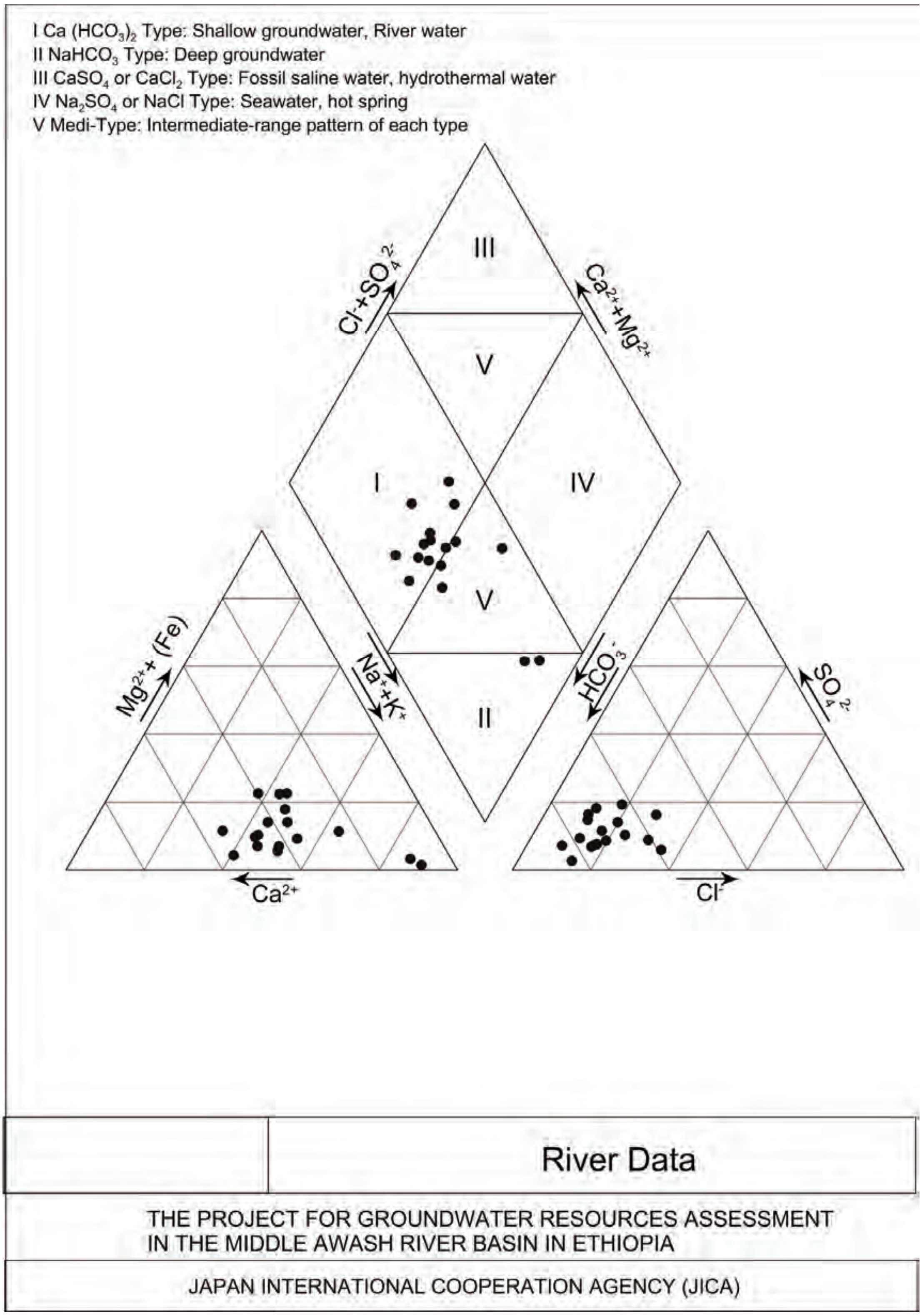
- In lake water, the difference of water quality between Lake Koka and Lake Besaka appears clearly. Lake Koka water belongs to the shallow circular water type, and Lake Beseka water belongs to the intermediate type of water with the component of seawater and deep retention groundwater. This pattern is similar with the spring flowing in Lake Besaka.

- The results of other samples, such as hand dug well, hand pump (shallow groundwater?) and birka (water harvesting facility) is dispersed in the key diagram, and there are no relations of each sample.



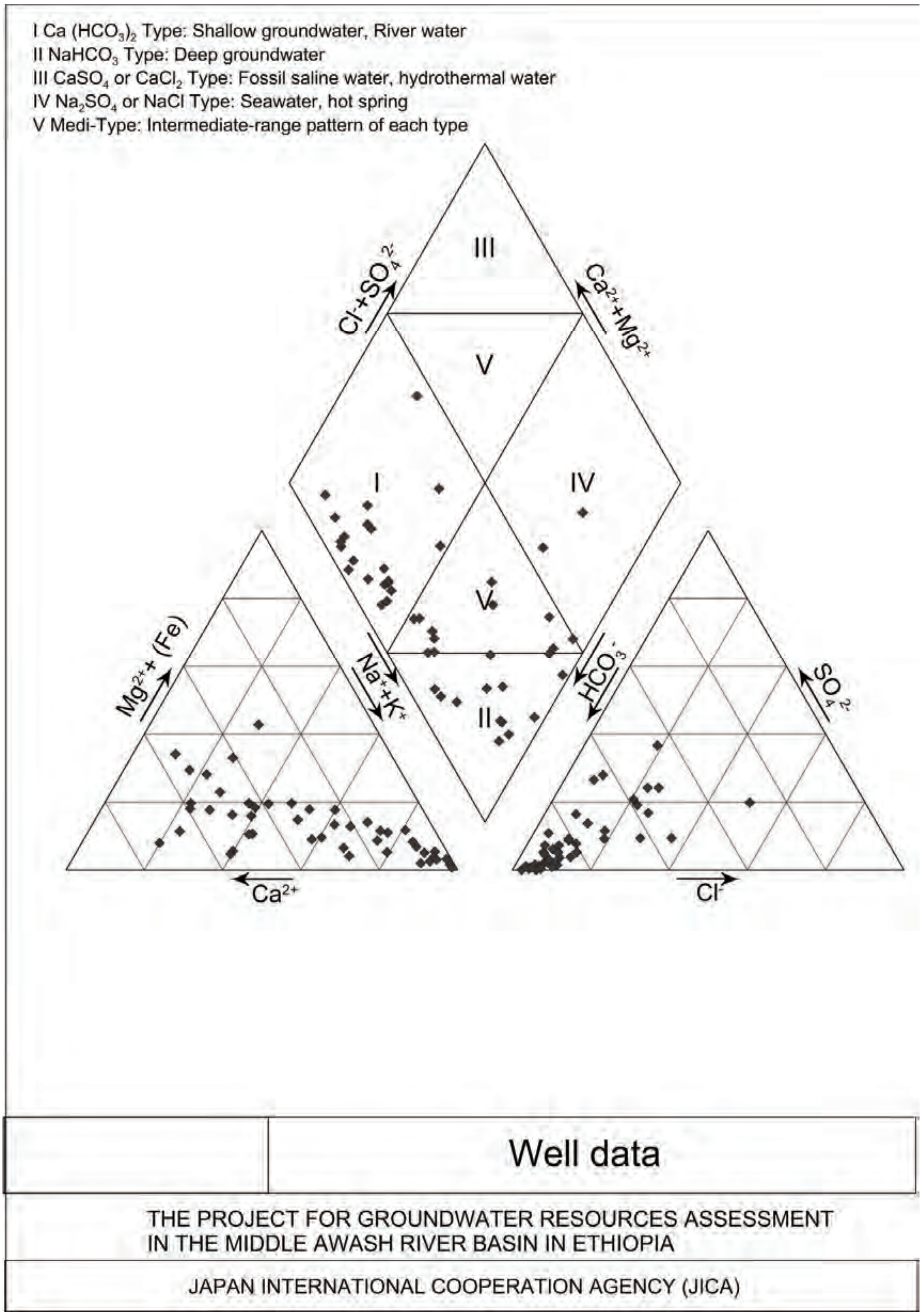
Source: the Project Team, Data: reference ④

Figure 4.4.3: Trilinear Diagram (All Data)



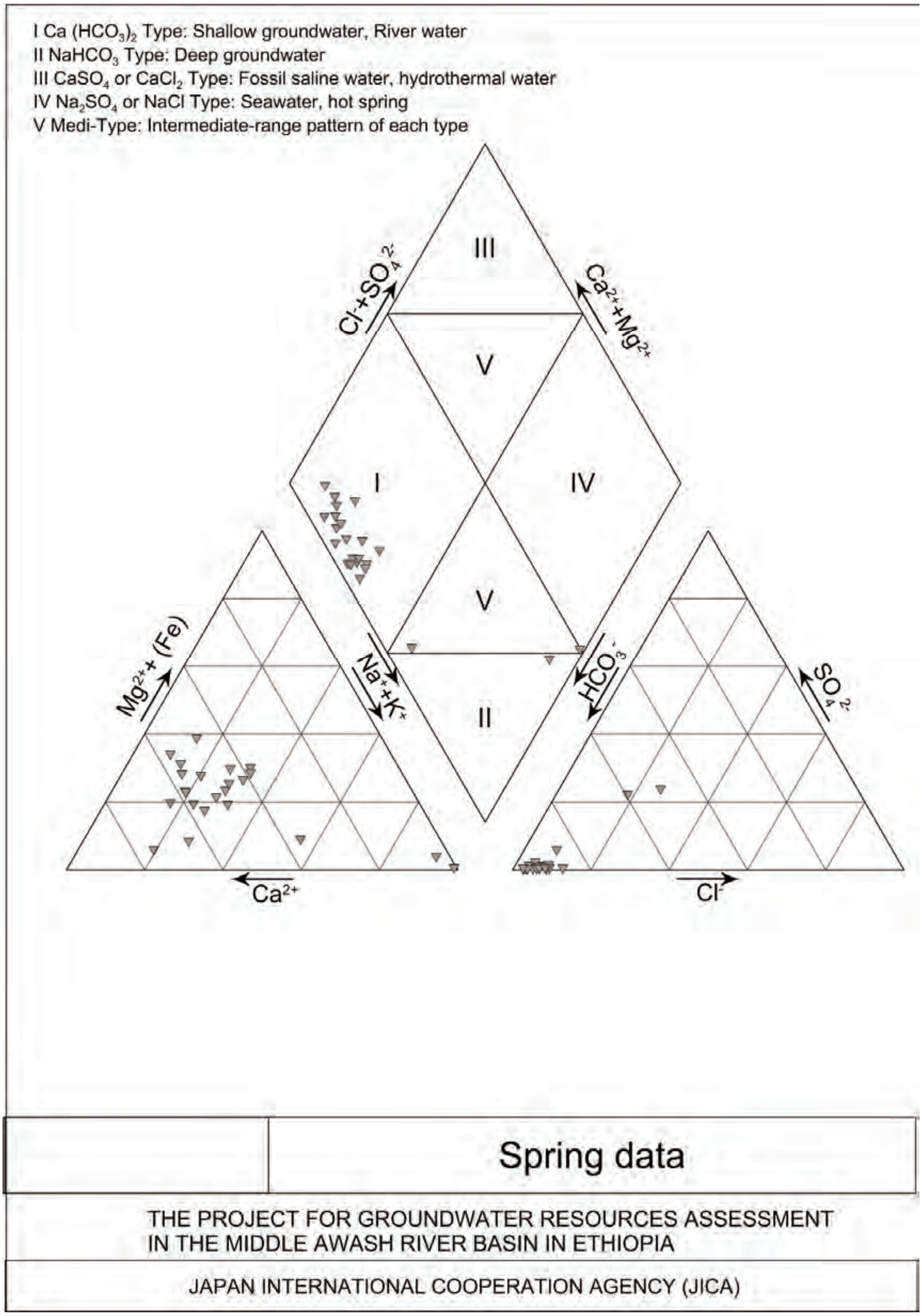
Source: the Project Team, Data: reference ④

Figure 4.4.4: Trilinear Diagram (River Water)



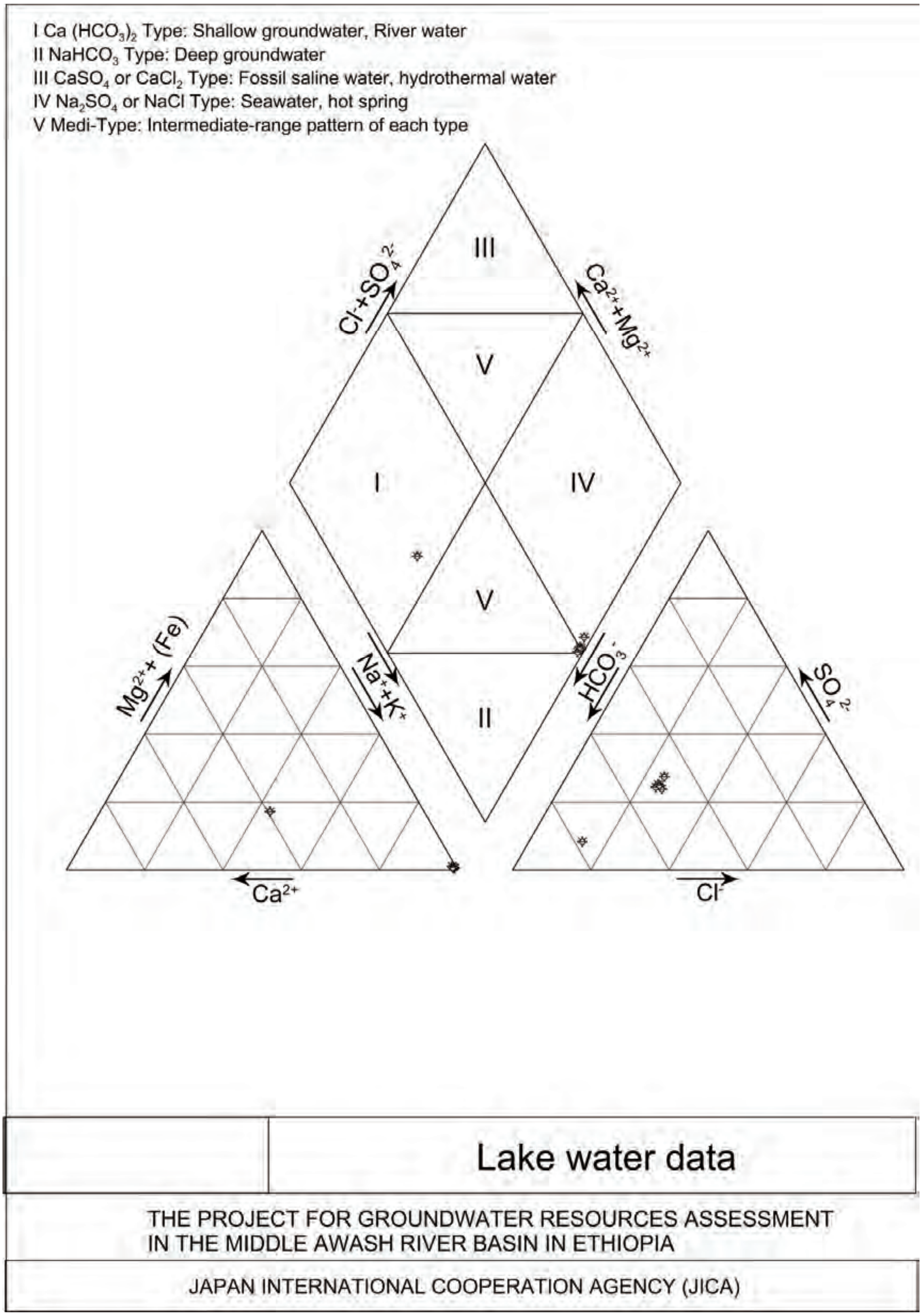
Source: the Project Team, Data: reference ④

Figure 4.4.5: Trilinear Diagram (Wells)



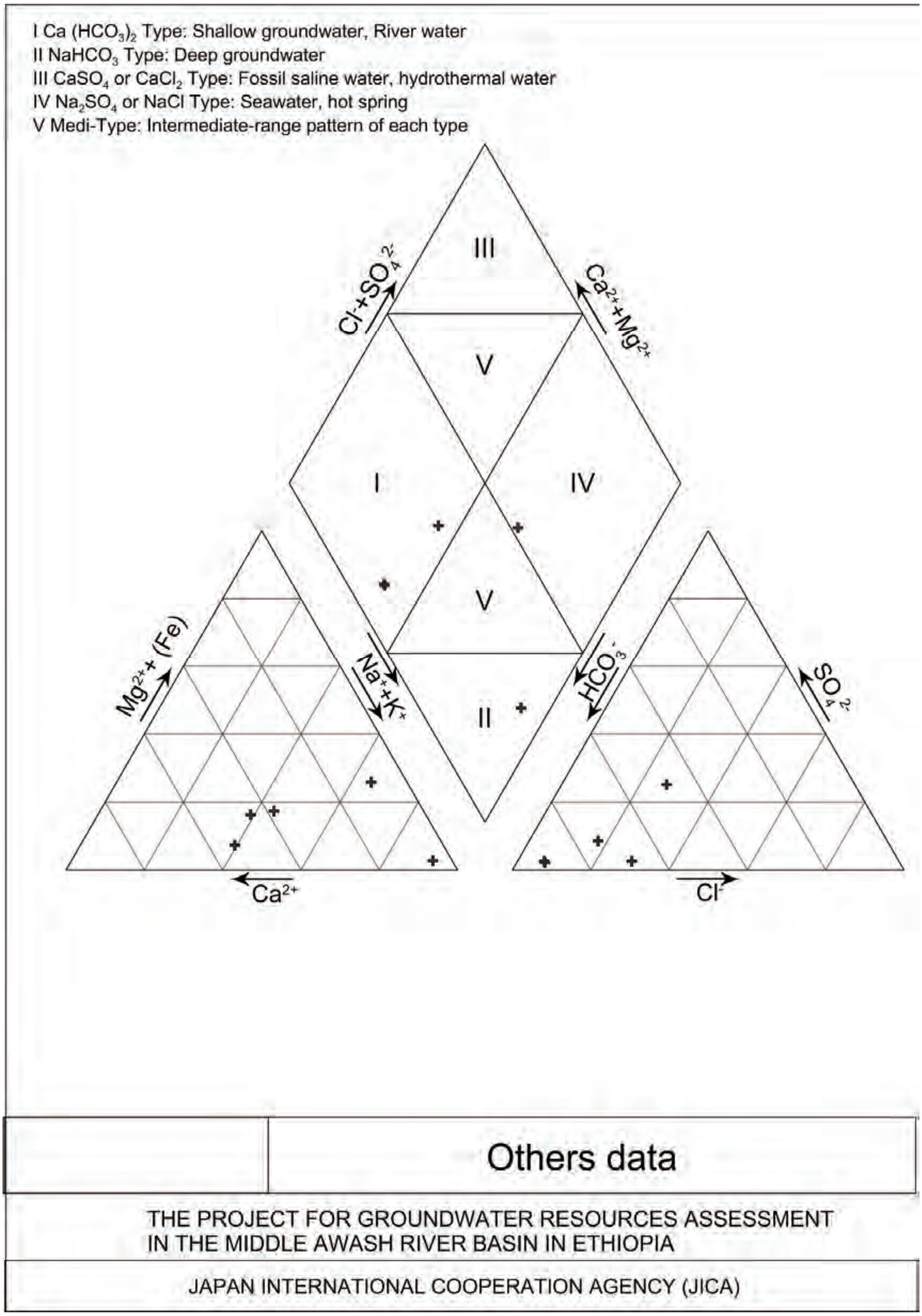
Source: the Project Team, Data: reference ④

Figure 4.4.6: Trilinear Diagram (Spring)



Source: the Project Team, Data: reference ④

Figure 4.4.7: Trilinear Diagram (Lake Water)

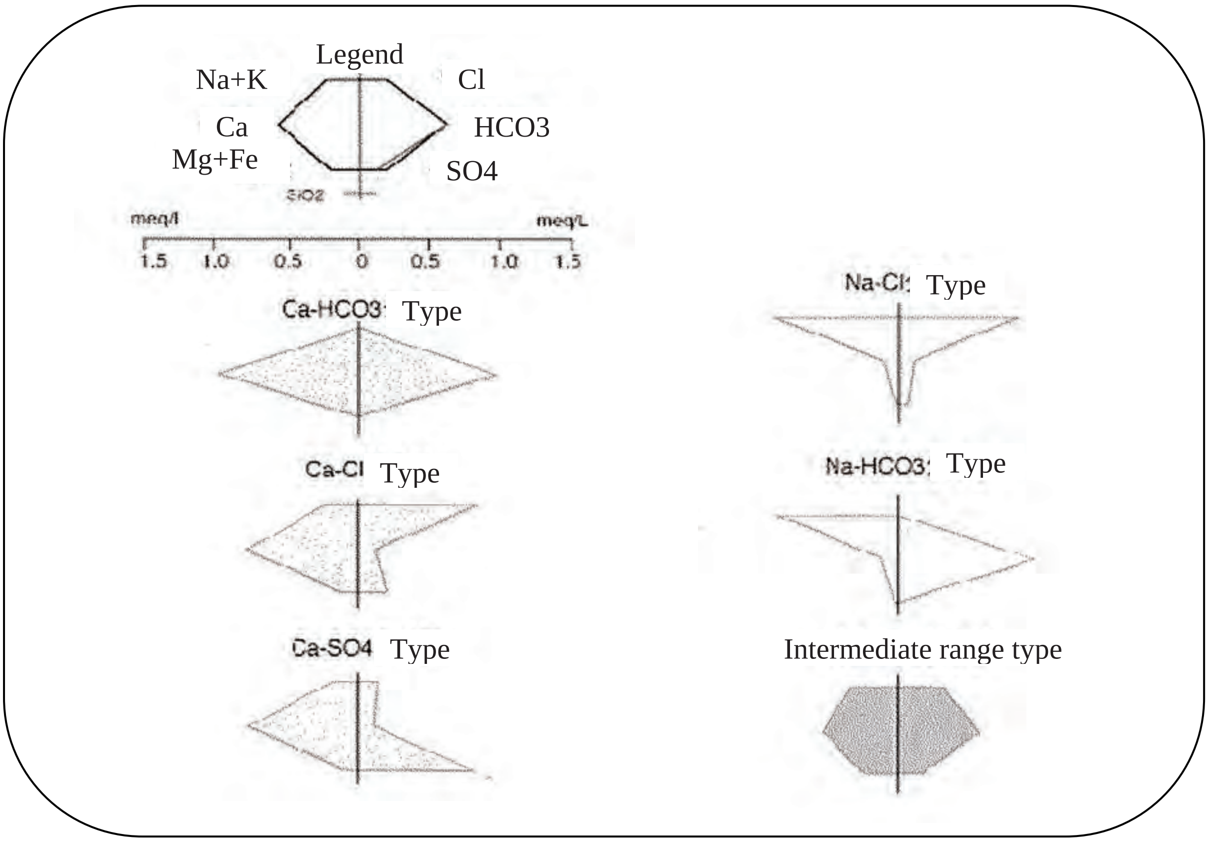


Source: the Project Team, Data: reference ④

Figure 4.4.8: Trilinear Diagram (Others)

b. Hexadiagram

The Hexadiagram contains the information of concentration and total salinity weight, and can be used to represent water quality visually. Figure 4.4.9 shows the figure which the type of key diagram in the trilinear diagram is expressed in the hexadiagram. This figure has advantage that water quality pattern is clear visually.



Source: the Project Team, Data: reference ③1)

Figure 4.4.9: Hexadiagram

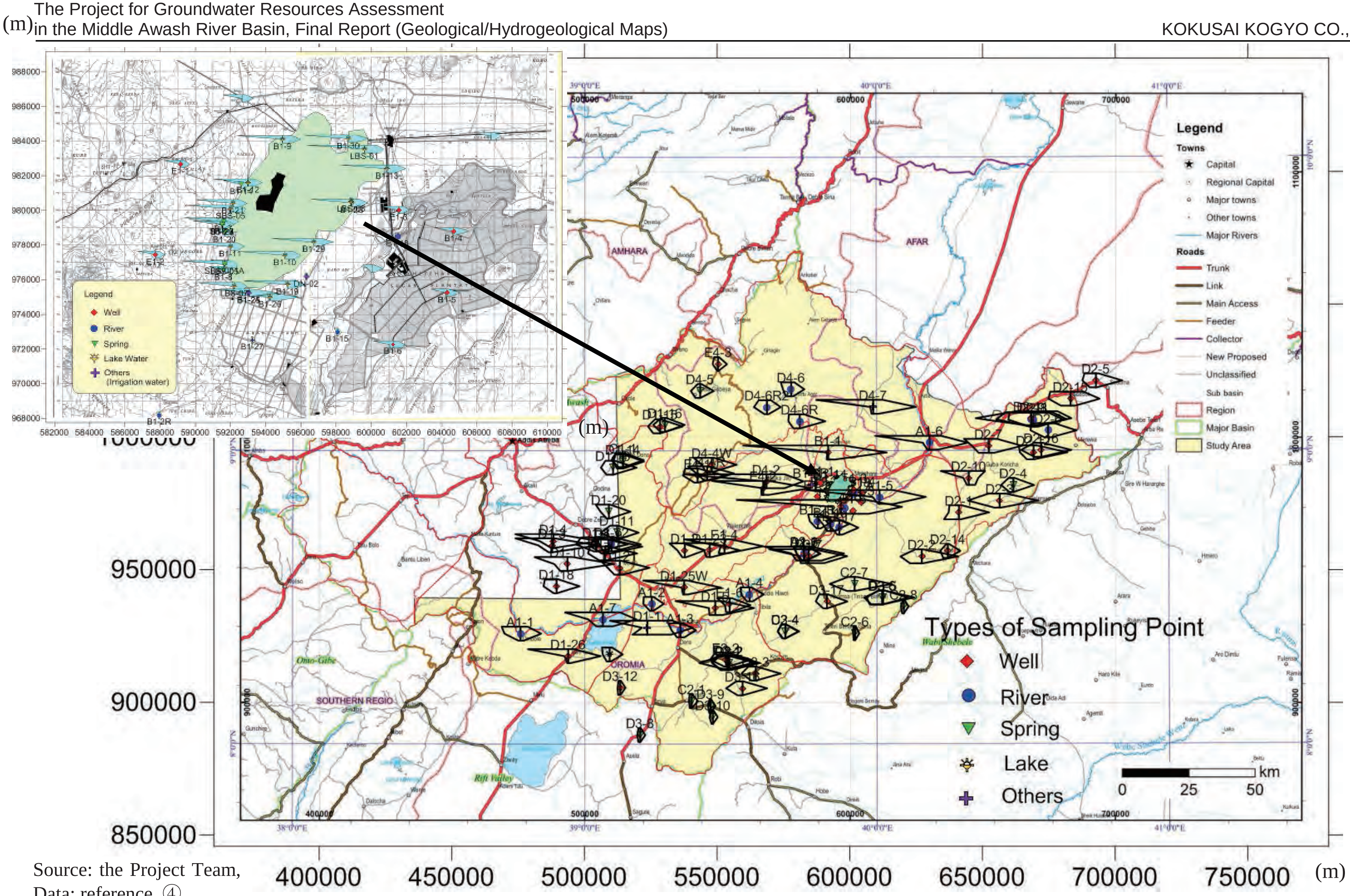
The characteristic of water resources such as existing well, river and so on is combined with the results of trilinear diagram. As mentioned above, in hexadiagram, the difference of concentration is clear by the figuration of diagram. The results of hexadiagram of each water resource plotted in the Study area map are shown in Figure 4.4.10 to Figure 4.4.15. The main characteristic of hexadiagram is as follows;

- The concentration of river water is high at the point flowing into Lake Koka and at the sampling points of downstream of Awash River through the Lake Beseka. In particular, the latter indicates the type of $NaHCO_3$, and it is considered that this water is affected by deep and retention groundwater.
- In existing wells, the groundwater of shallow type, deep and retention type and intermediate type of each type above are represented in hexadiagrams. The sampling points around Lake Koka indicate the $NaHCO_3$ type, and the concentration is high and the type is $NaHCO_3$ (not $CaHCO_3$ type) around Lake Beseka. One point in West Hararge indicates the NaCl type by the figuration.

- The samples of spring belong to the $CaHCO_3$ type in the hexadiagram, but there is a difference of concentration in each sample. Two springs of Lake Beseka is that the concentration is high and belong to the $NaHCO_3$ type by figuration. This is the type of deep and retention pattern.

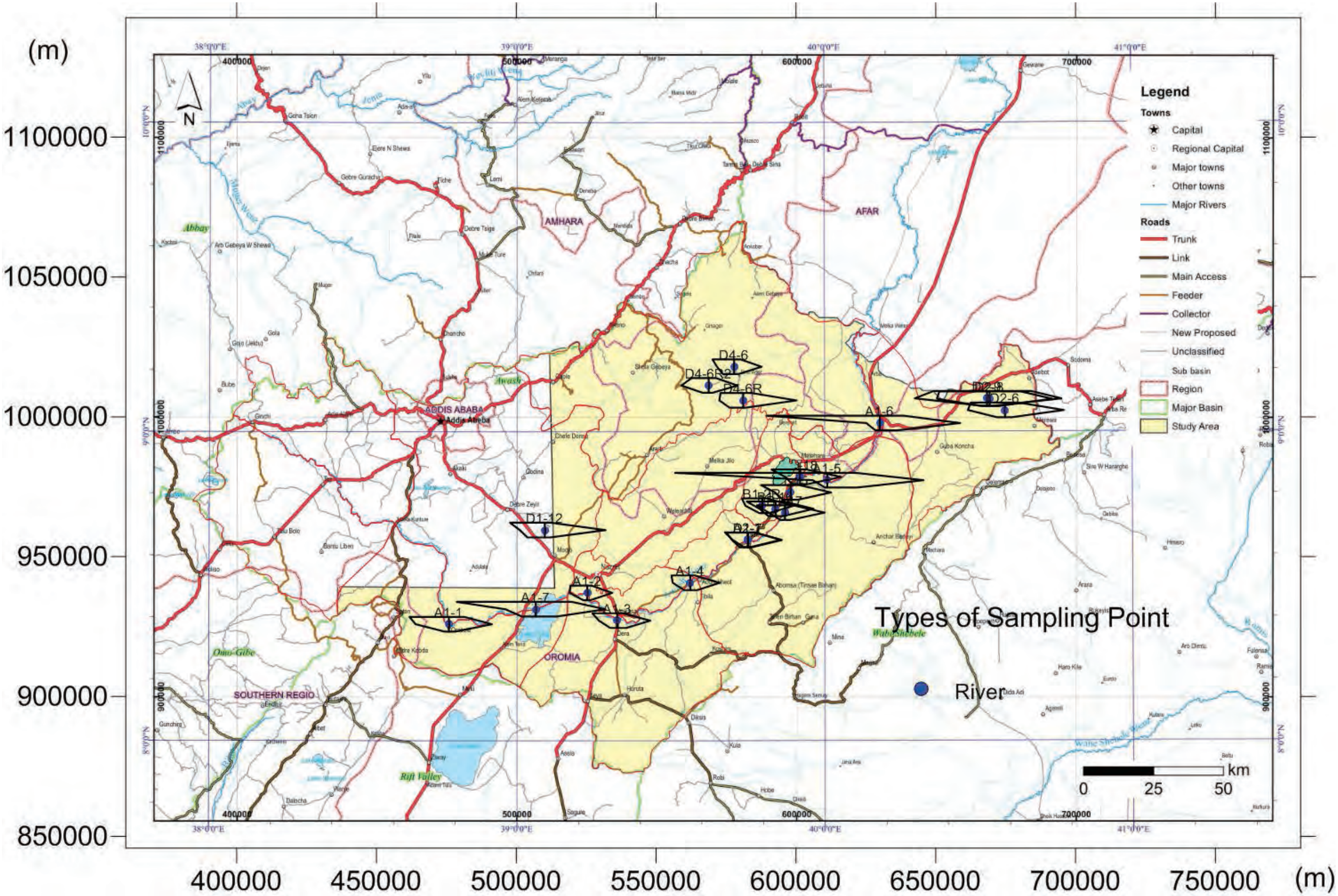
- Hexadiagram type and concentration of Lake Koka and Lake Beseka is different clearly. This difference can be attributed to the formation process of each lake. The water quality pattern in Lake Beseka is the type of water with component of seawater, deep and retention type and the concentration is also very high.

The Hexadiagrams of each water resources are shown in the Data book.



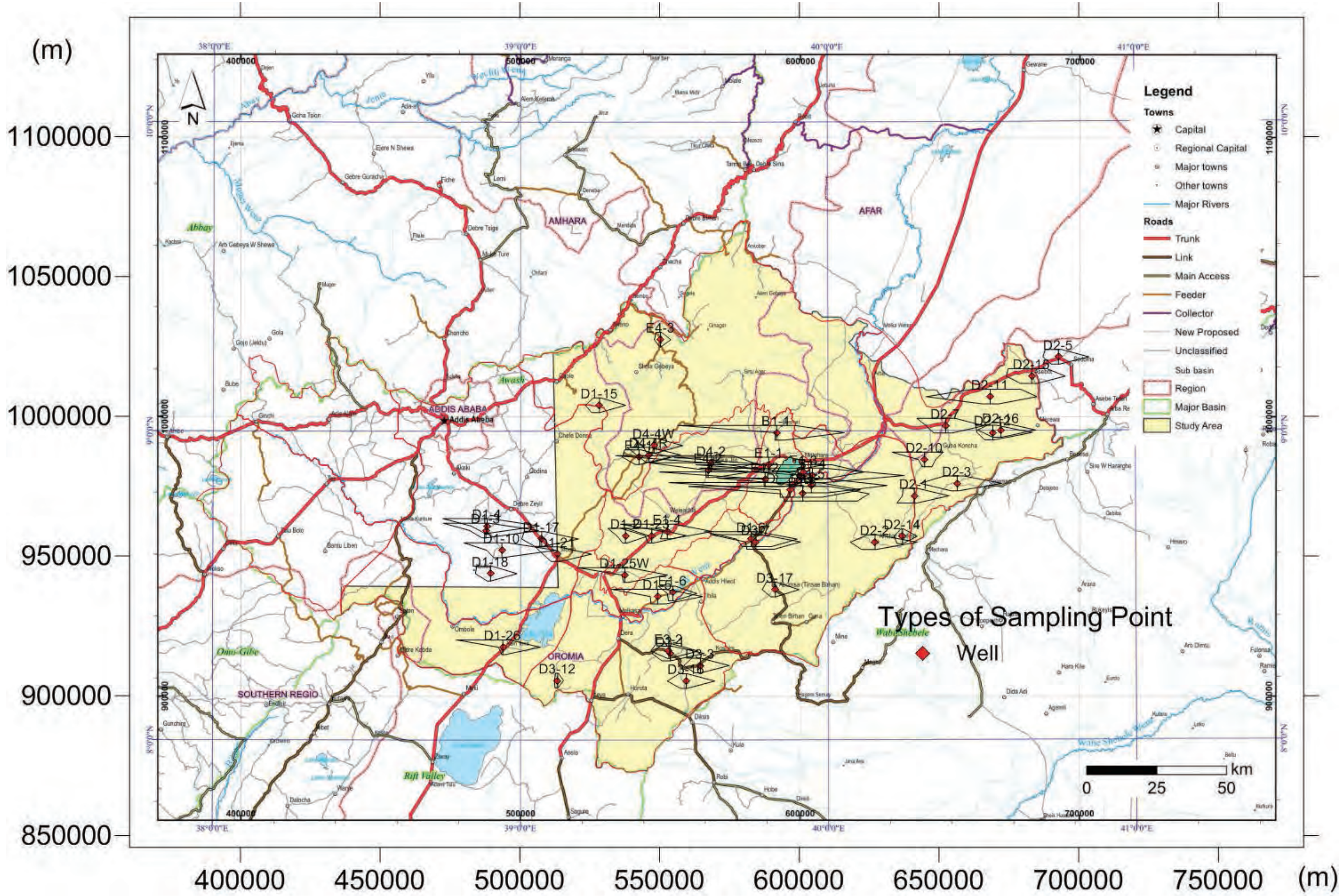
Source: the Project Team,
Data: reference ④

Figure 4.4.10: Distribution Map of Hexadiagram (All data: Data around Lake Beseka at upper left)



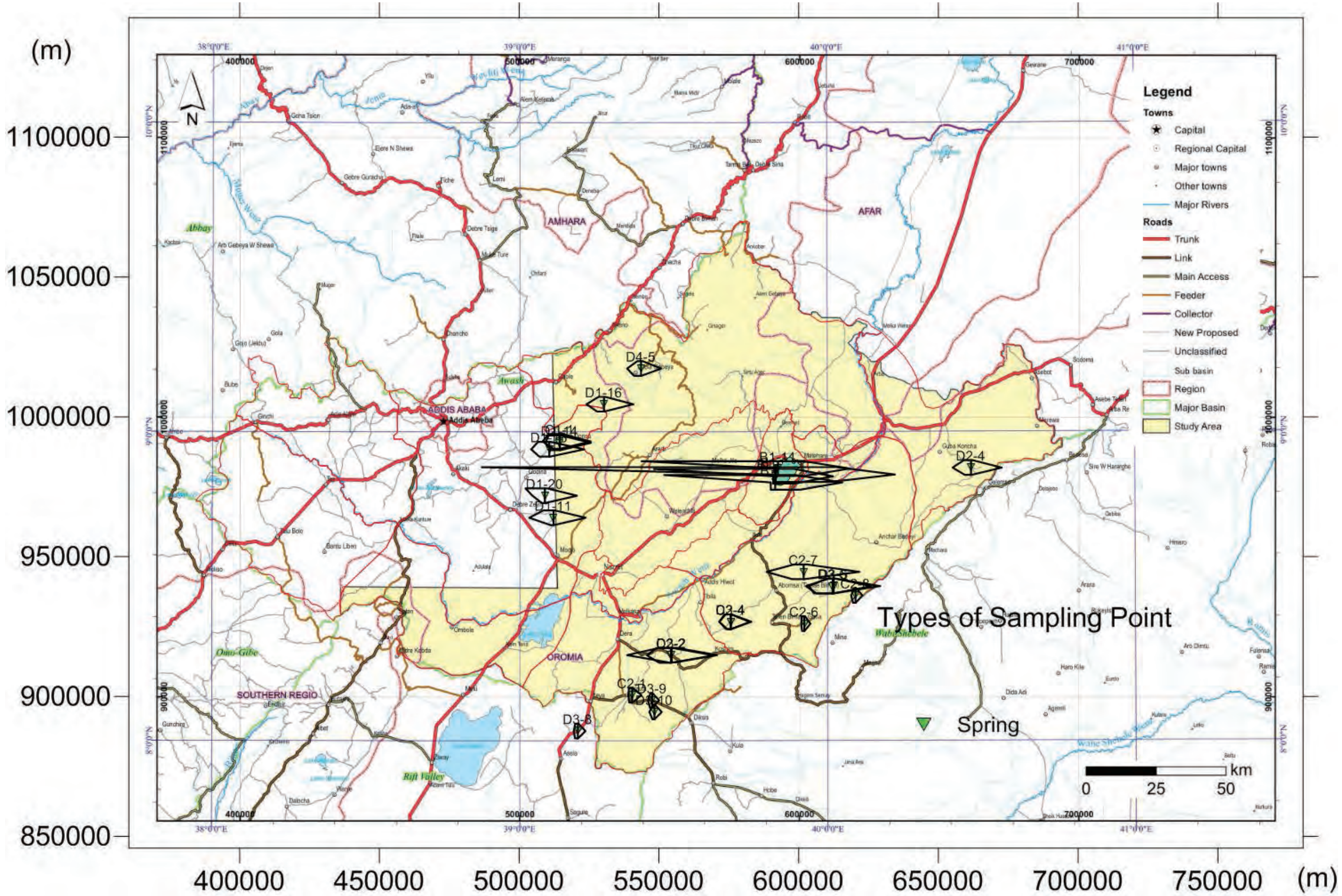
Source: the Project Team,
Data: reference ④

Figure 4.4.11: Distribution Map of Hexadiagram (River water)



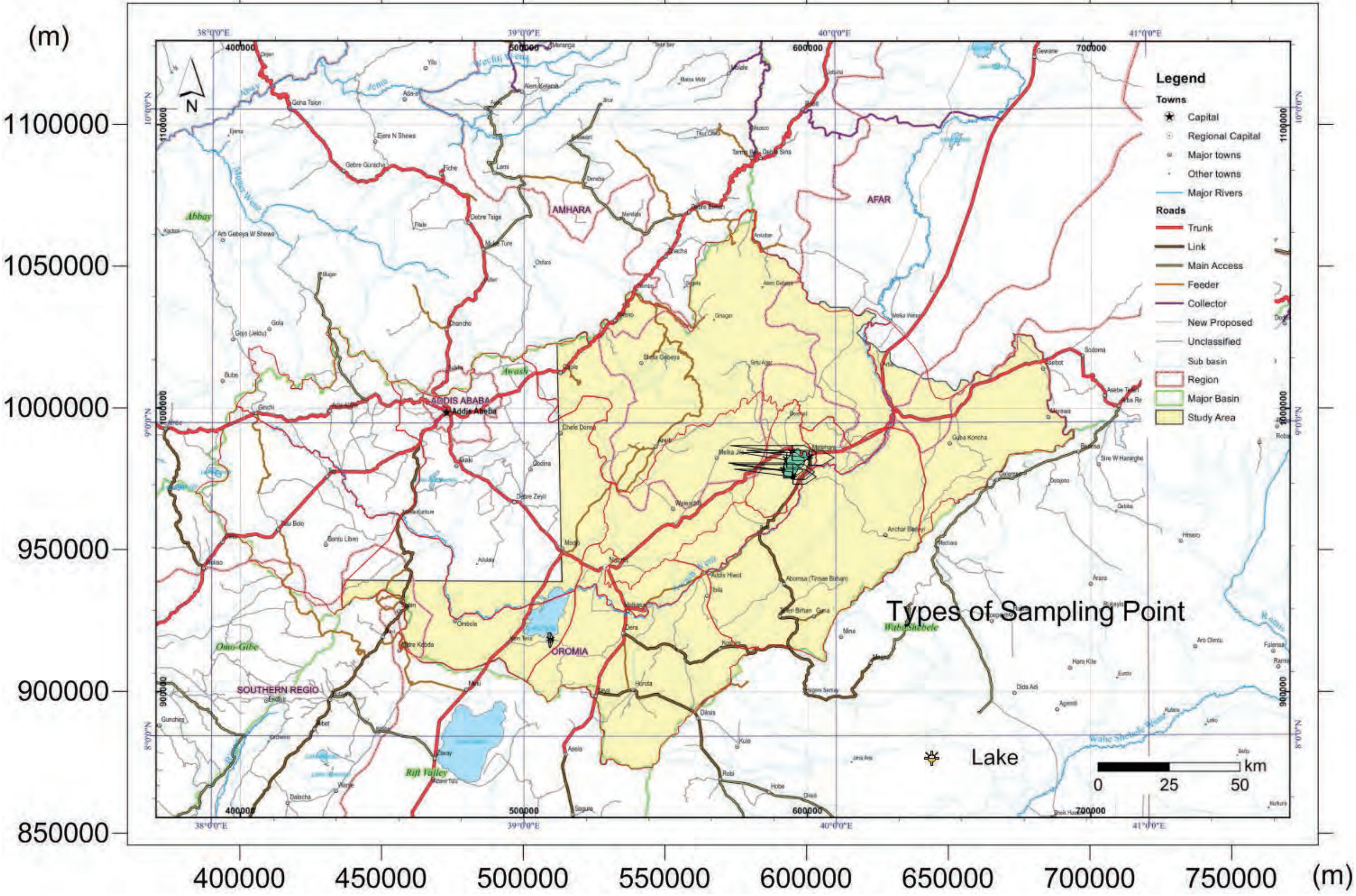
Source: the Project Team,
Data: reference ④

Figure 4.4.12: Distribution Map of Hexadiagram (Wells)



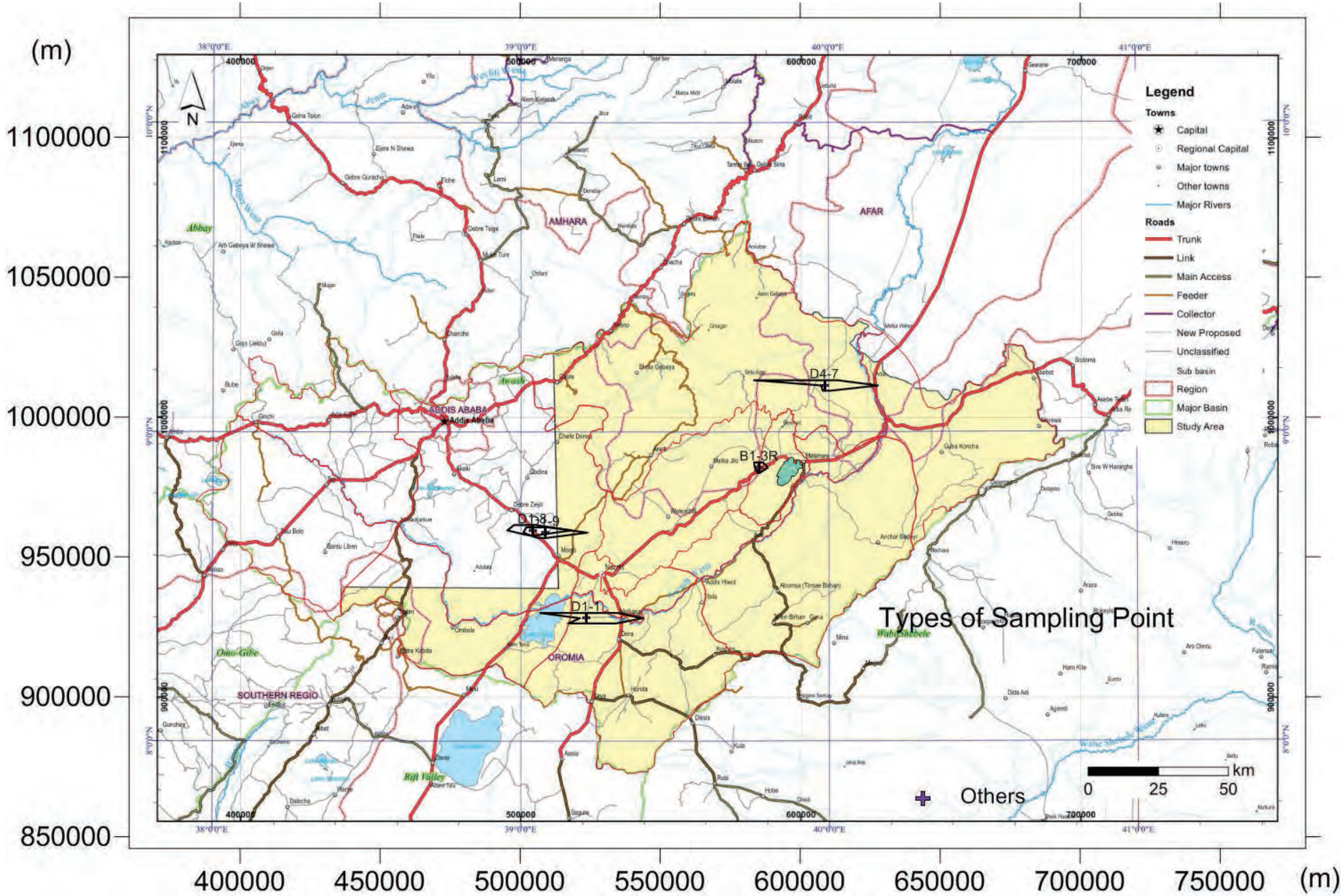
Source: the Project Team,
Data: reference ④

Figure 4.4.13: Distribution Map of Hexadiagram (Spring)



Source: the Project Team,
Data: reference ④

Figure 4.4.14: Distribution Map of Hexadiagram (Lake Water)



Source: the Project Team,
Data: reference ④

Figure 4.4.15: Distribution Map of Hexadiagram (Others)

c. Water quality of the different seasons at the same points of Awash River

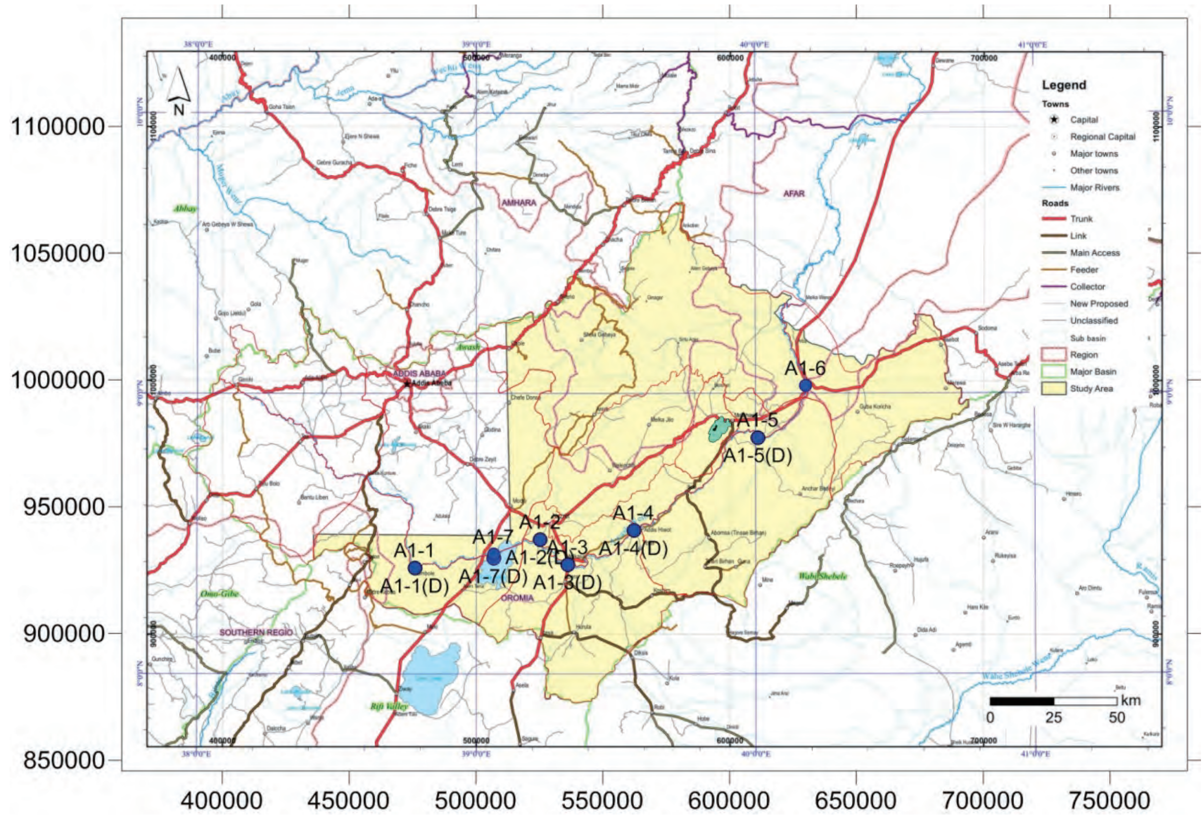
Water quality analysis was conducted at six points, approximately the same points, along the Awash River at two different seasons (the short rainy season in 2014 and the dry season in 2015) to the survey of the change of water quality. The list of sampling points in 2015 is tabulated in Table 4.4.4, and the location map of the sampling points is shown in Figure 4.4.16. The results of the water quality analysis are shown in Figure 4.4.17 and Figure 4.4.18 of the Hexadiagram and Trilinear diagram respectively.

Hexadiagrams show that the Na+K concentration of two points upstream and one point after Lake Beseka are increased in the dry season, on the other hand, the Na+K concentration is reduced in the dry season around Lake Koka. It is not clear that the Na+K concentration around Lake Koka only shows the reverse tendency. However the Na+K concentration are increased in the dry season on the whole. Trilinear diagram indicates that there is no change of water quality types because the each sample of the two seasons enters into the same area of the Trilinear diagram.

Table 4.4.4: List of Sampling Points in Dry Season 2015

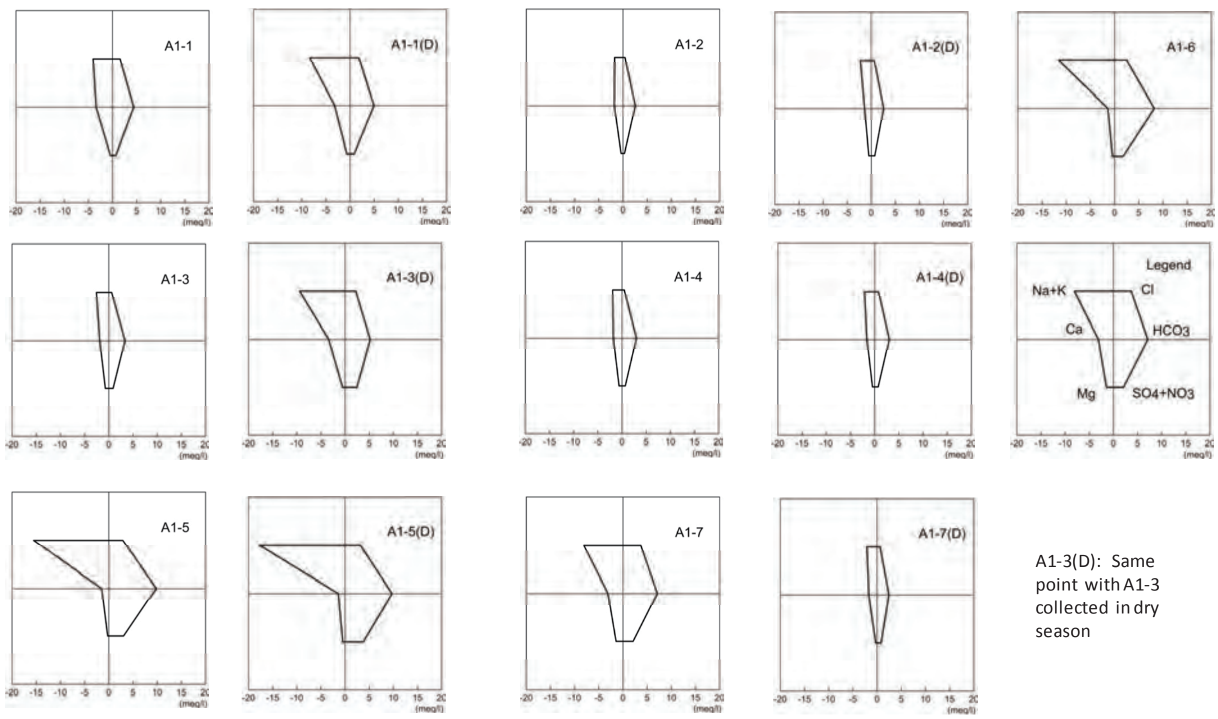
Zone or Region	Detailed Place	Type of Water Sources	SL. No.	Location ID (Sample ID)	Reference Coordinate	
					Easting	Northing
East Shewa	Around Ombole (Hombole)	Awash River Water	1	A1-1(D)	475,873	925,842
	Around North of Gefersa	Awash River Water	2	A1-2(D)	525,365	937,096
	Around Awash Melkasa	Awash River Water	3	A1-3(D)	536,207	927,203
	Around Doni	Awash River Water	4	A1-4(D)	562,223	940,652
	East of Metehara Sugar Plantation	Awash River Water	5	A1-5(D)	611,191	977,348
	Lake Koka	Mojo River Water	6	A1-7(D)	506,888	929,588

Source: the Project Team, Data: reference ④



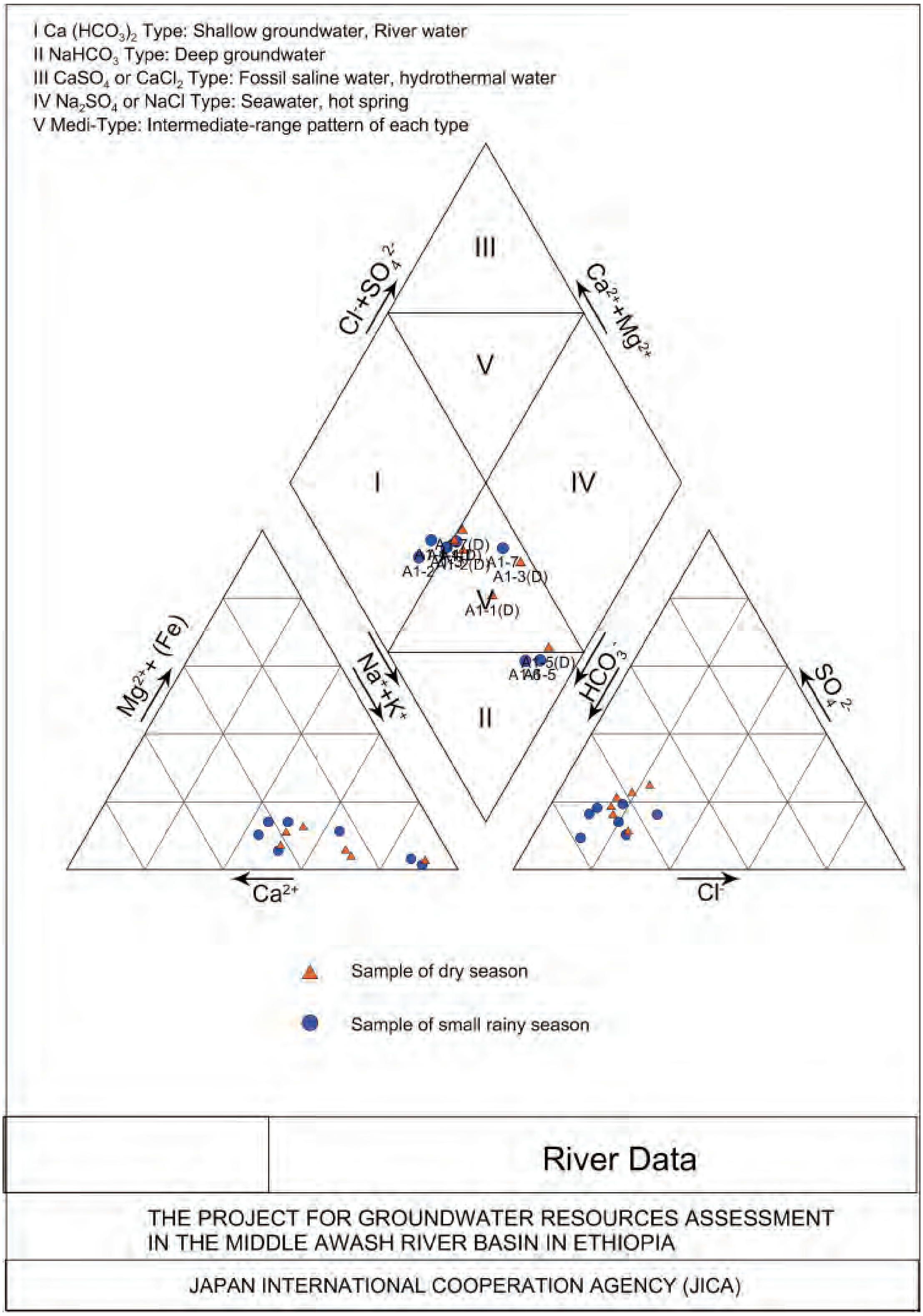
Source: the Project Team, Data: reference ④

Figure 4.4.16: Location Map of Sampling Points along Awash River (Short Rainy and Dry Seasons)



Source: the Project Team, Data: reference ④

Figure 4.4.17: The Hexa diagram of Short Rainy and Dry Season along Awash River



Source: the Project Team, Data: reference ④

Figure 4.4.18: Trilinear diagram of Short Rainy and Dry Season along Awash River

Reference

① Mainly well records mentioned in existing reports:

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

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

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

③ Others references

1) Editing: Japanese Association of Groundwater Hydrology, Science for brand-name spring water, 1994
2) Hydrogeological map of Ethiopia (1:2,000,000) compiled by Tesfaye Chernet and the Regional Geology Department, EIGS, 1988

④ Data (including photo on site) from field survey and interview, etc by the Project Team

Chapter 5

Geology and Hydrogeology around Lake Beseka

5 Geology and Hydrogeology around Lake Beseka

5.1 Topography, geology and geological structure

5.1.1 Topography

An elevation map around Lake Beseka created with the DEM data of the ALOS satellite image purchased by the project (Resolution 5 m, vertical accuracy 5 m) is shown in Figure 5.1.1. In addition, a topographic classification map around Lake Beseka created through the field work and analysis of the obtained data (ASTER DEM shaded relief map, SPOT satellite image and existing geological map) is shown in Figure 5.1.2.

The topography around Lake Beseka is divided into seven classes, such as alluvial lower plain, Basalt lower plain, middle plain, upper plain, acidic rock dome, gorge and lake taking volcanic ejecta, deposits and geological structure into consideration. Each characteristic is explained in Table 5.1.1.

Table 5.1.1: Classification and Characteristics of Topography around Lake Beseka

Classification	Characteristics
Alluvial lower plain	This is mainly composed of the flood plain of Awash River and the flat plain formed by young ignimbrite of Mt. Fentale. It is the lowest topographic plain in the area located at the center of the rift.
Pleistocene basalt lower plain	This is mainly formed by the numerous lava flows of Pleistocene basalts and has an undulating land surface. Although this plain is one step higher than the alluvial lower plain, it is also distributed in the central part of the rift.
Middle plain	This plain is one step higher than the alluvial lower plain and the Pleistocene basalt lower plain, and bounded from them by the NE-SW or NNE-SSW faults. It is composed of volcanic ejecta of the Oligocene to the early Pleistocene (Dino ignimbrite and Bofa basalts) and the plain surface which is relatively flat slightly inclines towards the center of the rift.
Upper plain	This plain is mainly composed of older basalts (Miocene) and the major fault escarpments of the MER are developed in this area.
Acidic rock dome	This is dome topography composed of Tertiary to Quaternary rhyolites and trachytes which form the major part of Mt. Fentale, Kone caldera, Mt. Birenti, Mt. Hada etc. or lava plateau of these rocks.
Gorge	This is topography formed in the middle plain through the dissection by the Awash River and the Arba River. The gorge developed along the Arba River is parallel to the NE-SW faults but that along the Awash River has been developed free from any fault trends.
Lake	Lake Beseka

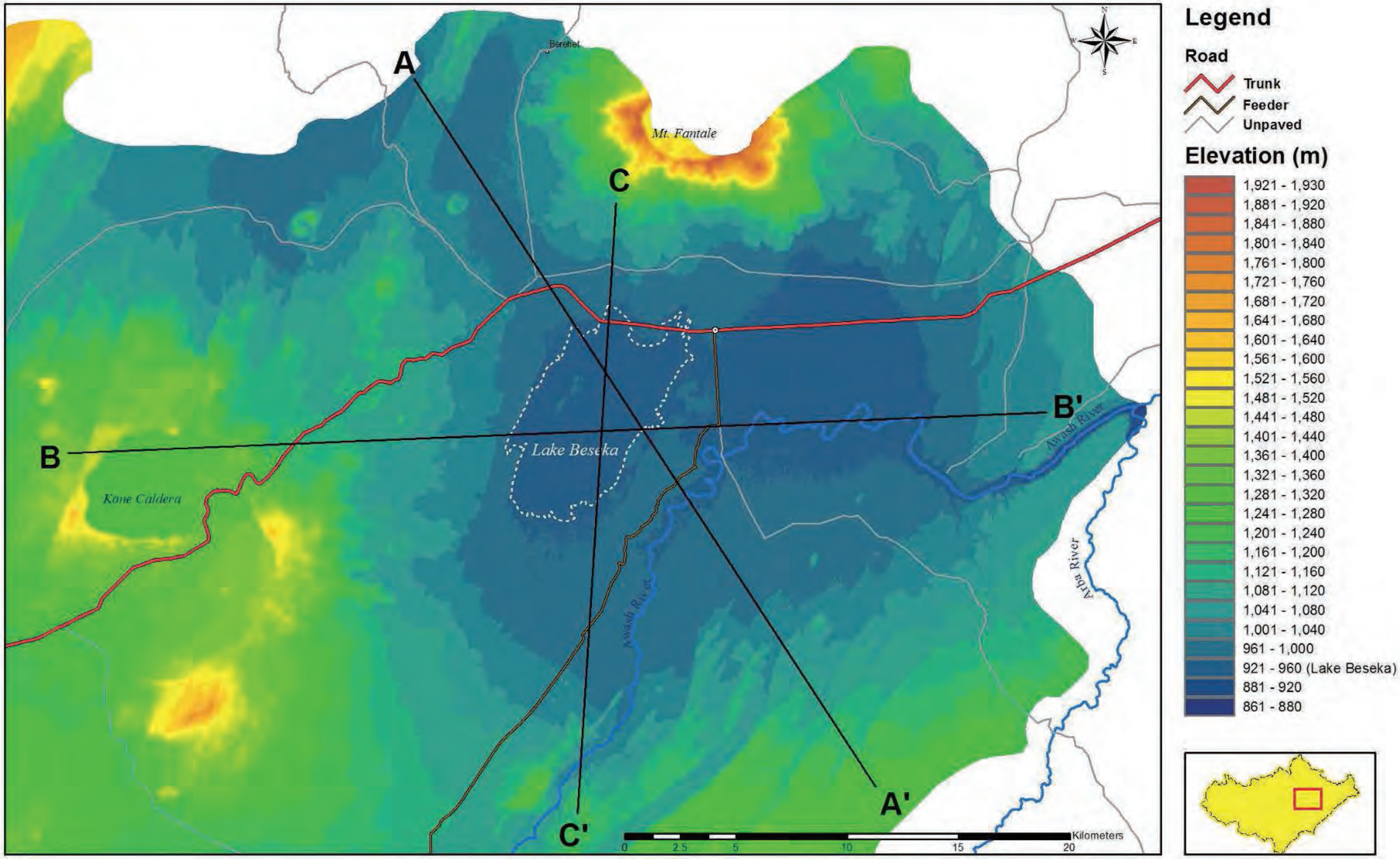
Source: the Project Team

The elevation becomes lower from the rift margin hills or plateaus composed of Tertiary basalts and pyroclastic rocks through the major MER fault escarpments and numerous normal faults which form repeated small horsts and half grabens until it comes to the center of MER. Lake Beseka is a structural lake which has been formed at the very center of the MER. One of the possible causes of the formation of the lake could be that the groundwater which used to be gathering and flowing at the center of the MER was banked up by the emersion of Mt. Fentale, which resulted in the rise of groundwater level and ultimately the lake was formed at the present location.

The surface water that is the Awash River is also considered to have previously flowed along the central part of the MER, which is lowest in elevation. However, after the emergence of the Fentale volcano the route of the Awash River changed to the east to bypass Mt. Fentale.

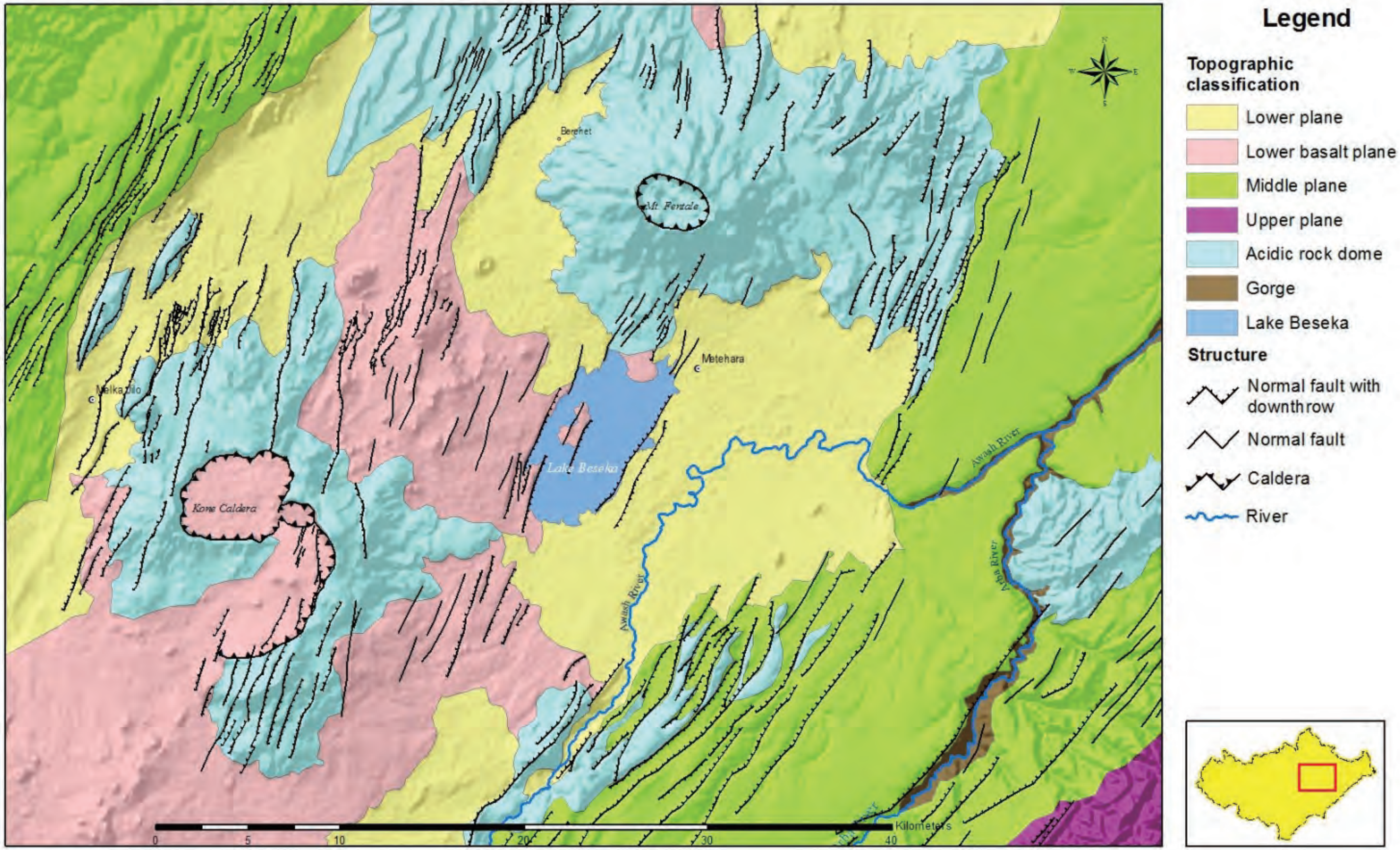
This hypothesis is supported by the existence of a deep gorge (elevation gap reaches up to about 170 m at maximum) dissected in the middle plain which is one step higher than the lower plain by the Awash River. This gorge has been developed free from any fault trends unlike that of Arba River which is almost parallel to a fault trend.

This detour of the Awash River around Mt. Fentale starts from the east edge of Metehara sugar plantation at the east of Lake Beseka extends about 50 km until the river goes back to the lower plain of MER in the north of Mt. Fentale.



Source; Project Team Data: ALOS, Resolution 5 m, vertical accuracy 5 m

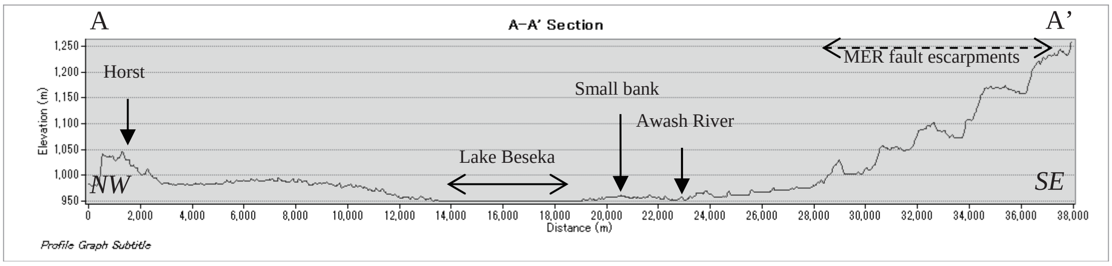
Figure 5.1.1: Elevation Map around Lake Beseka



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

Figure 5.1.2: Topographic Classification Map around Lake Beseka (background: shaded relief map created from ASTER DEM data)

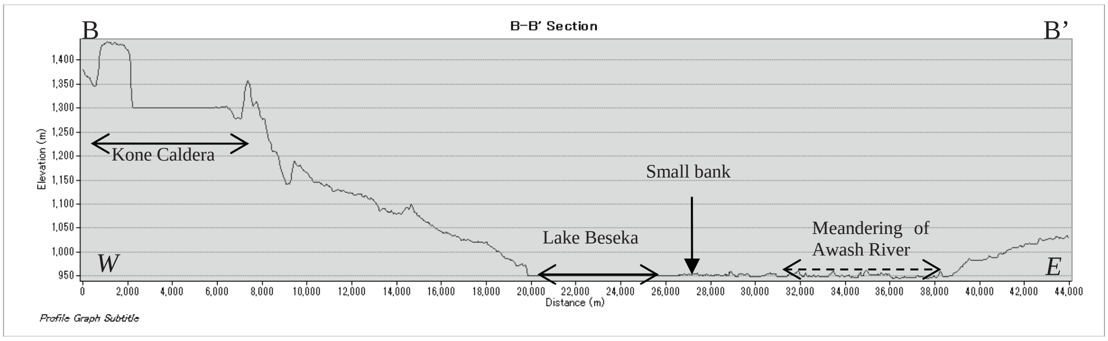
NW-SE section (A-A') in the elevation map (Figure 5.1.1) shows that the elevation of the surface of Lake Beseka is the lowest and there is a small bank, 10 to 15 m high between the lake and the Awash River existing at the east side of the lake (Figure 5.1.2). In the southeastern part of the section, it is observed that horsts and grabens are repeated and the height is gradually increasing towards the southeast. In the northwest part of the section, there is a gentle depression between the Fentale mountain and the Kone Caldera but it is separated from the depression area distributed at the north of the Kone Caldera by a horst extending NNE direction.



Source: the Project Team, Data: ALOS, Resolution 5 m, vertical accuracy 5 m

Figure 5.1.3: NW-SE Topographic Section around Lake Beseka (A-A')

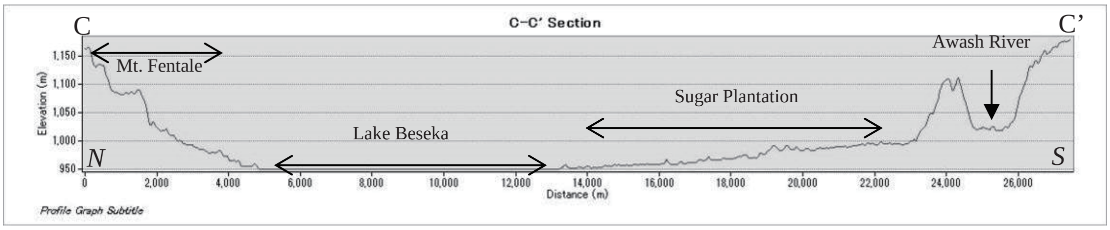
E-W section (B-B') shows the bank at the east of Lake Beseka is very small and the elevation of Lake Beseka and the Awash River is almost the same or the latter is a little lower (Figure 5.1.4). Towards the west of Lake Beseka, basaltic lavas continue to increase in elevation gradually until the Kone Caldera.



Source: the Project Team, Data: ALOS, Resolution 5 m, vertical accuracy 5 m

Figure 5.1.4: E-W Topographic Section around Lake Beseka (B-B')

N-S section (C-C') shows that the lake and the sugar plantations located at the south of the lake are topographically continuous. It is assumed that the surface water from the plantations pours into the lake directly, considering the slope direction (Figure 5.1.5). However, inflow of the surface water from the plantations to the lake was not observed when the project team visited the site in May 2015 because of the dry season.



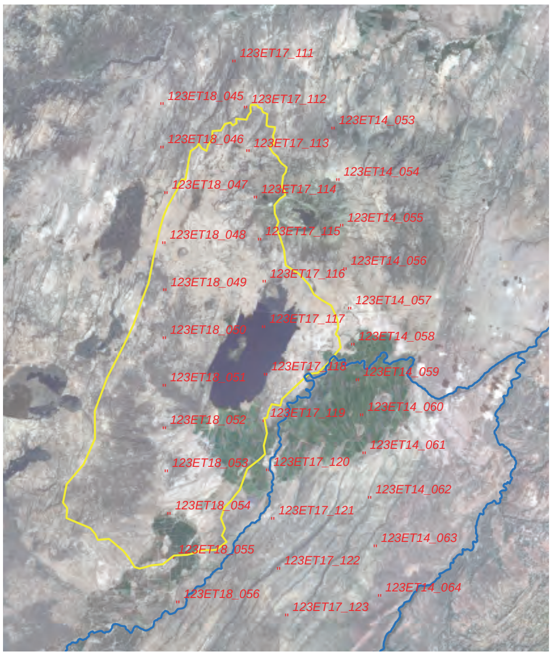
Source: the Project Team, Data: ALOS, Resolution 5 m, vertical accuracy 5 m

Figure 5.1.5: N-S Topographic Section around Lake Beseka (C-C')

Distribution of faults around Lake Beseka indicates that the lake is a tectonic lake considering the shape of the lake and the dominating northeast trending structure. This is particularly evident in the micro topography of the northeast trending normal faults on the north of the lake. Among such faults, normal faults with openings of about 20 m, which extend towards the eastern shoulder of the Fentale volcano, are also observed at the site. These faults are assumed to be extending into Lake Beseka.

Topographical analysis around Lake Beseka through aerial photos

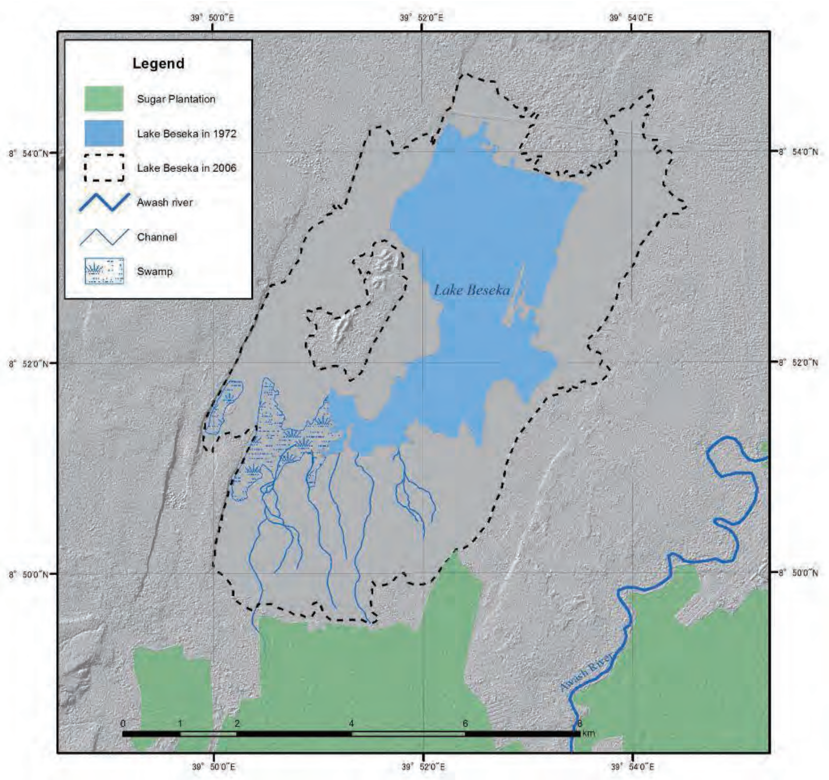
Using the 37 obtained aerial photos (Figure 5.1.6), topographical classification, fault topography analysis and analysis for paleo-channel flowing into Lake Beseka were conducted. The result of topographical classification and fault topography analysis were reflected to the geological map around Lake Beseka.



Source: the Project Team, Data: SPOT satellite image

Figure 5.1.6: Index map of aerial photos used for the topographical analysis

The aerial photos were taken in January 1972 (dry season), which was around the time when the water level of Lake Beseka began to rise. The outline shape of Lake Beseka at that time, adjacent swamp area and distribution of paleo channels were traced through the stereoscope as shown in Figure 5.1.7. The outline shape of Lake Beseka (black dot line) and the sugar plantation area (green) obtained from ALOS captured in 2008 are superimposed in the same map. The area of Lake Beseka in 1972 (11.7 km^2) was about 28% of that in 2008 (42.3 km^2). There are swampy areas at the southwest of the lake and 6 to 7 lines of paleo-channels flowing into the lake from the south to the north are also observed. From these photos it was not possible to confirm that there was water in the channels at that time, although vegetation was developed along the channels. The paleo-channels appear to start from the northern edge of the sugar plantation, causal relationship between the channel and the plantation was unclear only from these aerial photos. However, the inflow of surface water to Lake Beseka was observed only from the southern part.



Source: the Project Team, Data: ALOS DEM

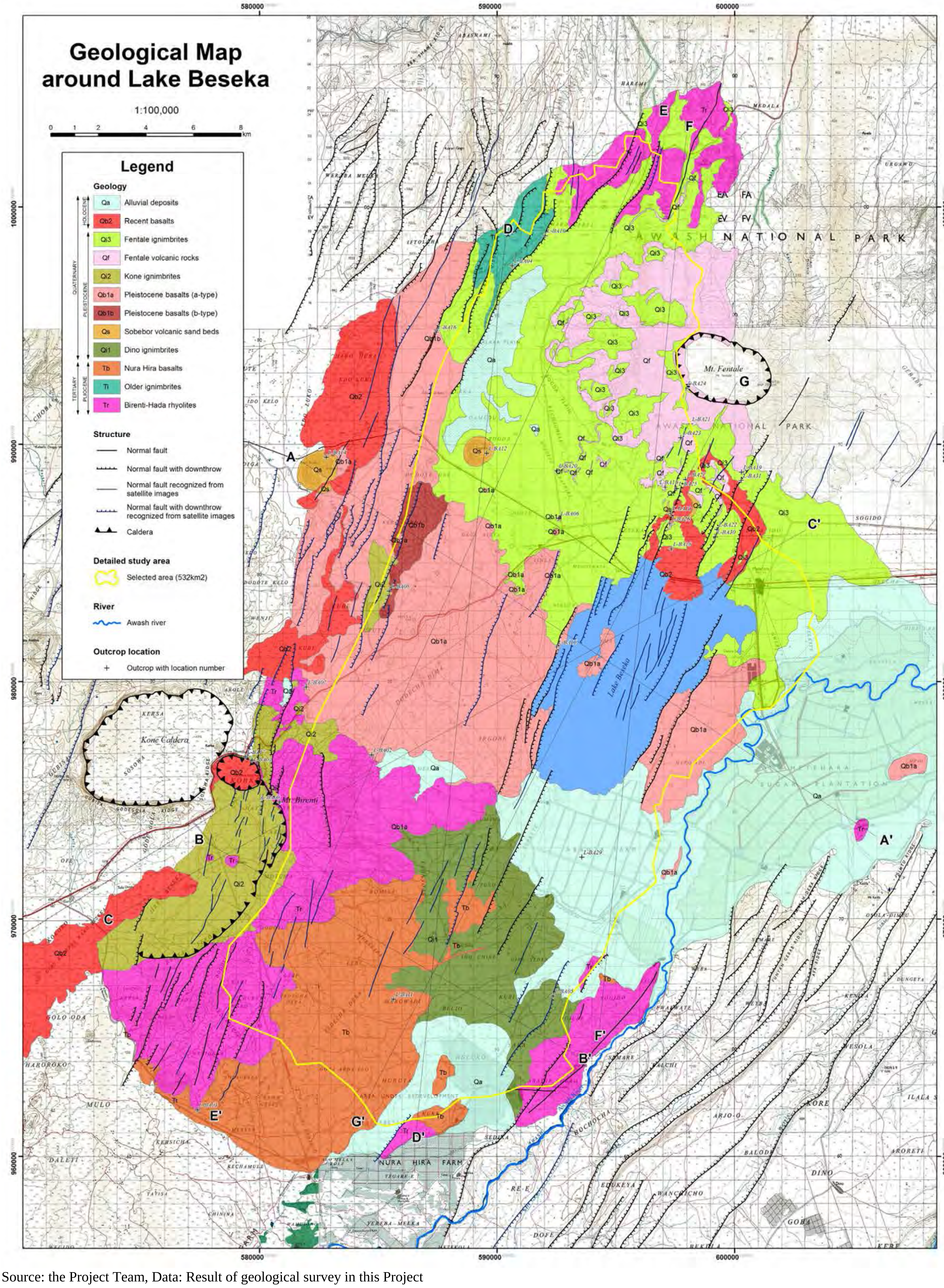
Figure 5.1.7: Paleo-channel flowing into the southern part of Lake Beseka

5.1.2 Geology

a. Geological units

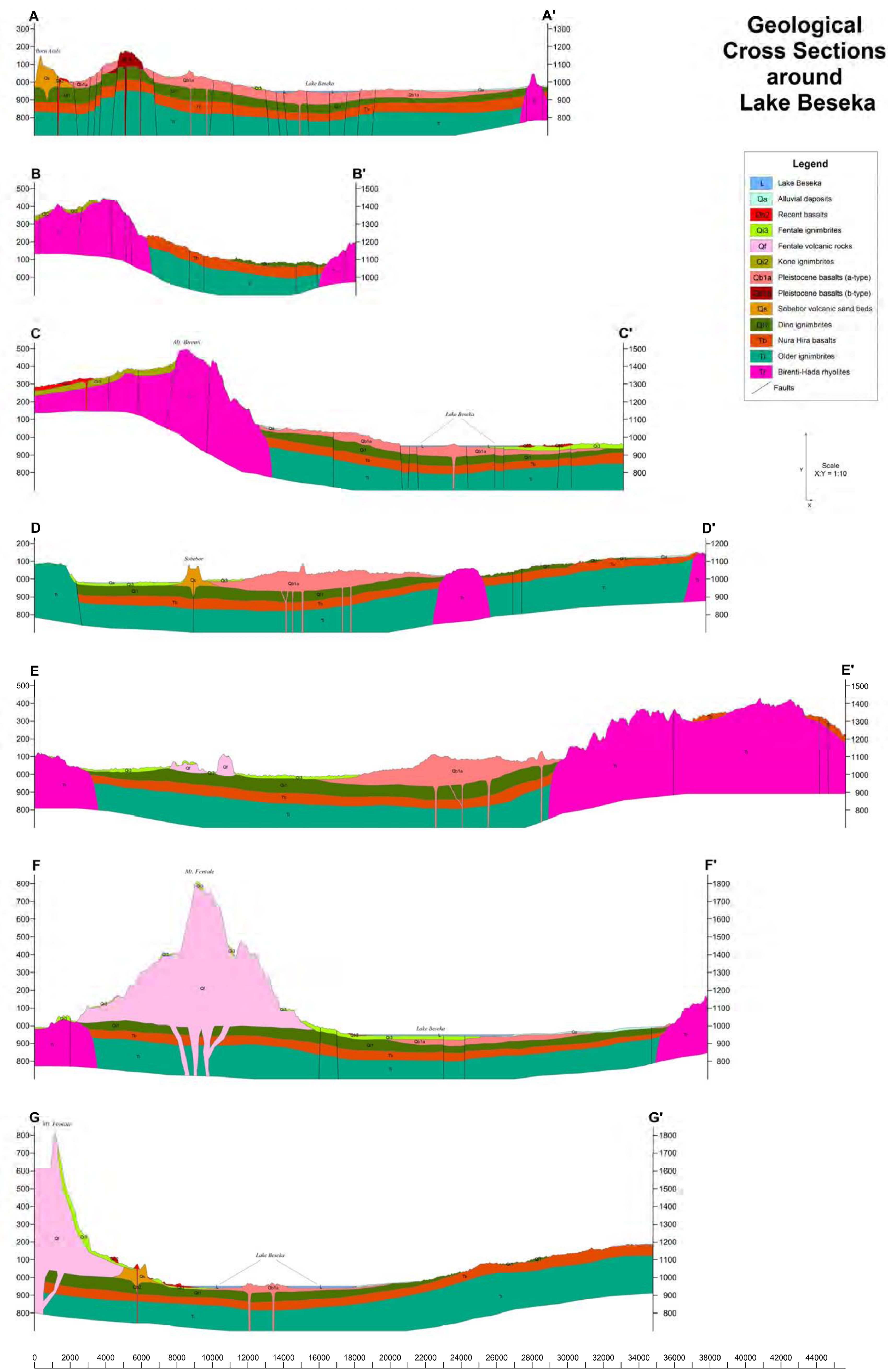
A detailed geological map of an Awash River sub-basin which extends from the northwestern foot of Mt. Fentale to the Nura Hira farm including Lake Beseka (hereinafter referred to as the detailed study area) was prepared at a scale of 1:100,000 (532 km^2). As for existing geological maps of this area, there is a map of 1:250,000 compiled by Kazmin and Berhe (1978) and a map of 1:100,000 by EIGS and ELC (1987). The former includes a larger area from around Nazret to Metehara and the established stratigraphy and the described names of each geological unit are still often quoted in other research papers and reports. The latter is an output of a comprehensive geothermal study including petrological analysis. However, there still needed a further detailed study and discussion for the geological boundaries and stratigraphy of the area around Lake Beseka. Therefore, a detailed geological field survey was conducted and the geological map of the area was revised. A geological map and sections of the detailed study area are shown in Figure 5.1.8 and Figure 5.1.9.

The locations of outcrops expressed by the location numbers (L-BA**) in this chapter are expressed in the geological map around Lake Beseka.



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

Figure 5.1.8: Geological Map around Lake Beseka



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

Figure 5.1.9: Geological section around Lake Beseka

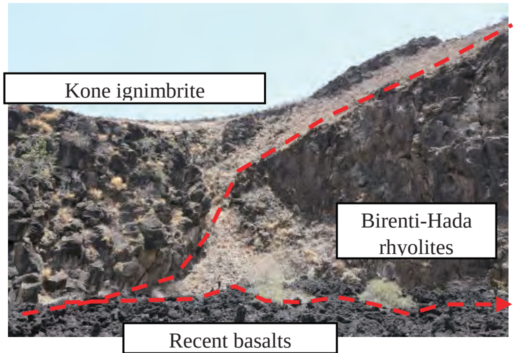
1) Birenti-Hada rhyolites

This unit is fine to coarse grained rhyolites mainly distributed in Mt. Birenti and Mt. Hada in the west to the southwest of the detailed study area. In addition, the rhyolites distributed around Mt. Abadir and Mt. Dekaki in the south and north of the detailed study area, respectively are also considered as the same horizon due to the characteristics of the rock facies and topography.

The rhyolites are gray to greenish gray in color, and the matrix is fine grained and often glassy with flow structures, and scattered with hornblende and feldspar phenocrysts. Generally platy joints develop around the surface and the inside of the lava body is massive. Obsidian bands develop from around Mt. Bilenti to the southwards. Coarse grained rhyolites with feldspar phenocrysts 1 to 3 mm in size are distributed at Mt. Mekidera exceptionally.

It is observed that these rhyolites are unconformably overlain by the Kone ignimbrite at the east wall of Korke caldera (L-BA01), by the Pleistocene basalts at the northeast foot of Mr. Birenti (L-BA02) and by the Nura Hira basalts at the south foot of Mt. Hada (L-BA03).

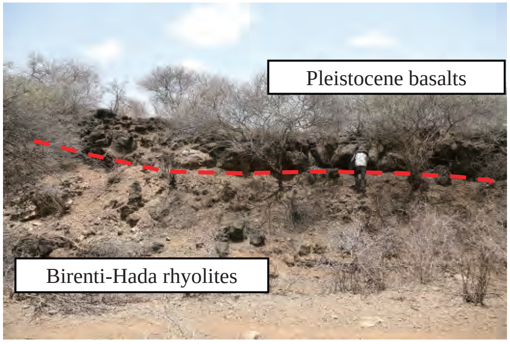
In the existing geological maps, Kazmin and Berhe (1978) and EIGS and ELC (1987) have shown “Unwelded rhyolitic pumice and unwelded tuff” or “Welded tuff” around Mt. Birenti. However, this study revealed that rhyolites are distributed wider and the stratigraphical position is lower than previously considered. Therefore, this unit is newly named as Birenti-Hada rhyolites.



The Birenti-Hada rhyolites overlain by the Kone ignimbrite (north wall of Korke caldera). L-BA01


Obsidian bands developed around the peak of Mt. Bilenti. L-BA09


Platy joints of the Birenti-Hada rhyolites.



The Birenti-Hada rhyolites overlain by the Pleistocene basalts. L-BA02

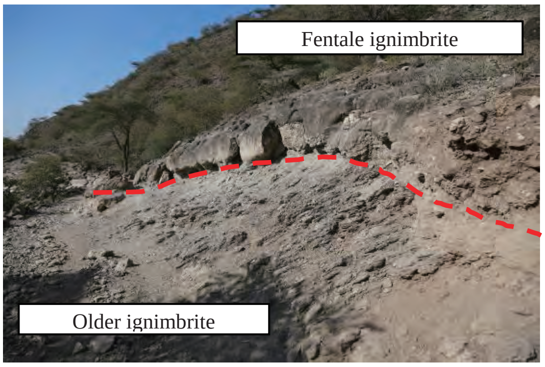
Source: the Project Team, Data: Result of geological survey in this Project

Figure 5.1.10: Outcrop photos of Birenti-Hada rhyolites

2) Older ignimbrite

This is widespread ignimbrite composed of greenish to greenish gray highly welded tuff to slightly welded tuff and pumice. In the detailed study area this geological unit outcrops in the NNE-SSW trending, east-facing fault escarpment (60 to 100 m in height) located at the northwest area of the detailed study area and is expanding out of the detailed study area further westwards. In the southwest part of the fault escarpment, it is observed that the Fentale ignimbrite overlie unconformably the fault slope formed by the old ignimbrite (L-BA04). The older ignimbrite are composed of several flow units with different welding grades. The characteristics of this welded tuff is similar to those of the Fentale ignimbrite and it is often difficult to distinguish. However, this unconformable contact between the two units allows them to be differentiated (photo).

This unit is correlated with welded tuffs of Nazret Group of Kazmin and Berhe (1978) which is widespread to the west of the detailed study area.



The Fentale ignimbrite unconformably overlie inclined welded tuff of the older ignimbrite (Haro Gersa). L-BA04

A NNE-SSW trending fault escarpment on which the older ignimbrite are exposed (Haro Gersa). L-BA10

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

Figure 5.1.11: Outcrop photos of the older ignimbrite

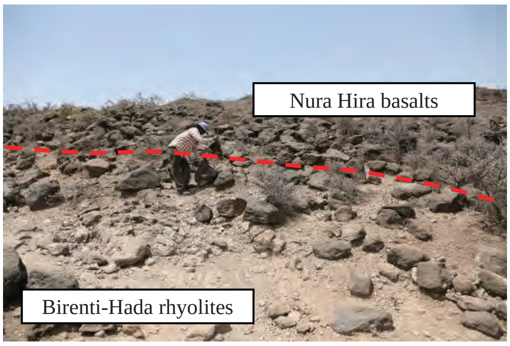
3) Nura Hira basalts

This unit is composed of black aphyric basalt lavas distributed around the north of Nura Hira farm. Although the area covered by these basalts was an extension of the Pleistocene to sub-recent basalts according to Kazmin and Berhe (1978), considering the characteristics of petrological characteristics, topography and stratigraphy, this unit was distinguished and newly named as Nura Hira basalts.

The topography formed by this unit is relatively flat and continuous and covered by relatively thicker shrubs. Most of the basalts of this unit are aphyric but sometimes pyroxene and plagioclase phenocrysts of about 1mm in size are observed. Olivine and pyroxene phenocrysts (about 0.5 mm in size) are included in the fine graind basalt distributed in some areas such as the north of Kubi Dimtu. The lava is usually vesicular near the surface.

It is observed that this unit overlies the Birenti-Hada rhyolites unconformably at the south foot of Mt. Hada (L-BA03) and is overlain by the Kone ignimbrite unconformably along the road connecting Nura Hira farm and Abadir farm (L-BA05).

Flat plain formed by the Nura Hira basalts (northwest of the Nura Hira farm).



The Birenti-Hada rhyolites unconformably overlain by the Nura Hira basalts (southern foot of Mt. Hada). L-BA03

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

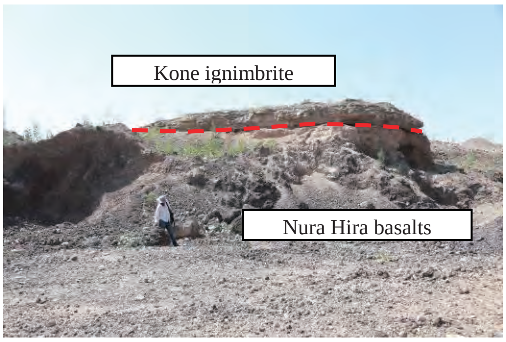
Figure 5.1.12: Outcrop photos of the Nura Hira basalts

4) Dino ignimbrite

This unit is an extension of the widely distributed welded tuff (Dino ignimbrite, Kazmin and Berhe (1978)) mainly distributed southeast out of the detailed study area between the right bank of the Awash River and Arba River. In the detailed study area, it is thinly (maximum about 5 m thick) distributed at the southwest of Lake Beseka in a limited area. It forms relatively flat topography. The tuff is greenish gray colored and weakly welded. It includes hornblende. The rock facies of this unit resembles that of Kone ignimbrite and Fentale ignimbrite, but they are separated due to discontinuity of distribution and topography.

It is observed that this unit overlays the Nura Hira basalts along the road connecting Nura Hira farm and Abadir farm. (L-BA05)

Dino ignimbrite exposed along the irrigation channel at the north of Nura Hira farm. L-BA11



Nura Hira basalts overlain by the Kone ignimbrite. L-BA05

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

Figure 5.1.13: Outcrop photo of Dino ignimbrite

5) Sobebor volcanic sand beds

This unit is represented by the Sobebor hill (L-BA12) located at the southern part of the Alaka plain and observed at only three locations such as Sobebor hill, Dinbiba (L-BA13) on the southern foot of Mt. Fentale and Boru Arole hill (L-BA14) about 6 km westwards from Sobebor. This unit forms an independent hill (tuff ring) at each location and three locations are arranged so as to draw a gentle arc shape. The size of the hills is vast and they have big craters with a diameter of 0.5 to 1 km at the center, which makes the appearance different from other scoria cones.

This unit is composed of thick layers of yellowish brown volcanic sand and silt with lamina with a thickness of 2 to 10 cm. Sometimes lapilli and boulders with a diameter of 1 to 30 cm are also included. The lamina inclines towards the outside from the center 20 to 30 degrees. At Dinbiba, some parts of the crater rim have remained and fresh basalt lavas (recent basalts) spilled out from the center. Fresh basalts came out from a collapsed hillside at Boru Arole.

Previous reports such as Kazmin and Berhe (1978) and EIGS and ELC (1987) mentioned this unit as basaltic hyaloclastites. However, it seems that they were either confused with the cause of hyaloclastite or the definition of the term was different at that time. The term “hyaloclastite” is generally used for the pyroclastic rocks formed when magma gets into water and is crushed due to rapid cooling. There is no evidence of these causes in the sediment of this unit. Moreover, it does not include original magma fragments (direct products of magma) in the sediment unlike scoria and pumice, which indicates that this sediment could be the remnant of a continuous phreatic eruption.

This unit is overlain by the Fentale ignimbrite at Dinbiba (L-BA13).

Sobebor tuff ring from a distance.

Sand beds inclined towards outside of the hill (Sobebor).

Sedimentary structure (parallel lamina) in the sand beds (Sobebor)

Inside the Sobebor crater. L-BA12

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

Figure 5.1.14: Outcrop photos of Sobebor volcanic sand beds

6) Pleistocene basalts

This unit is composed of basalts and scoria distributed mainly in the west and partly in the east of Lake Beseka. Taking the rock type into consideration, it is divided into two parts; olivine-pyroxene basalts (a-type) and alteration between porphyritic pyroxene basalts and aphyric basalts (b-type).

Within the distribution area of this unit, a-type occupies most of the area. The basalts of a-type contain a lot of olivine and pyroxene phenocrysts with a size of 0.5 to 1 mm with black with fine grained matrix. The lava is very vesicular near the surface and often filled with the secondary mineral (zeolite). The lava is aa-type and it remains the original undulated topography of lava flow. Most of the scoria cones distributed in the detailed study area are located within the distribution area of this unit. In addition, with the analysis of topography and satellite images, it is observed that most Pleistocene basalts spouted out from these cones. Generally, a scoria cone was formed first and then, lava erupted from the center or the side of the cone. The scoria cones are aligned in an NNE-SSW direction which is the same as the Wonji fault trend. This indicates that the magma erupted along the weak zones of faults.

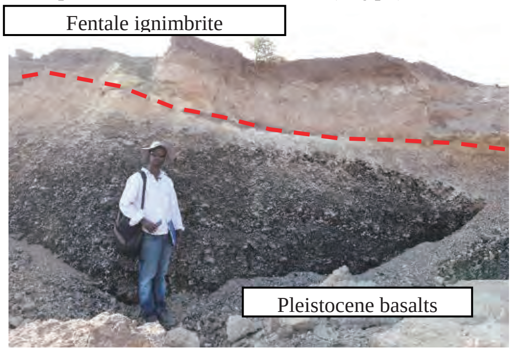
B-type basalts are distributed only in the west part of the detailed study area along the hills extending in a NNE-SSE direction between Dodote and Tututi about 6 km long and 0.5 to 1 km wide, and in the west of Alaka plain along a fault escarpment. The basalts of b-type are composed of porphyritic basalts and aphyric basalts. The former contains plagioclase phenocrysts with pyroxene reaching a prominent size of 5mm and olivine averaging a smaller size of 1 to 3 mm. Porphyritic basalts and aphyric basalts are distributed in the same area but the relationship of these two could not be observed directly.

Because a-type is distributed on a part of the hill formed by b-type, it is considered that a-type is younger than b-type.

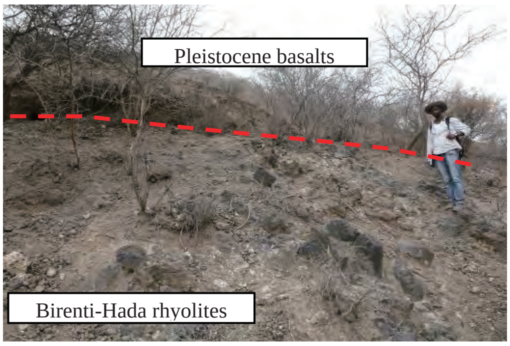
It is observed that this unit overlies Birenti-Hada rhyolites unconformably at the northeast of the Korke caldera (L-BA07) and is overlain by Fentale ignimbrite unconformably at the scoria cone (Ilala) located at the southwest foot of Mt. Fentale (L-BA06). Although a direct relationship between this unit and Kone ignimbrite was observed, this unit is considered younger than Kone ignimbrite from the view point of topography and distributional characteristics.

Olivine-pyroxene basalt exposed on the fault escarpment west of Lake Beseka (a-type). L-BA15

Porphyritic basalt exposed on the fault escarpment in the west of the Alaka plain (b-type). L-BA16



Scoria of the Pleistocene basalts (a-type) overlain by the Fentale ignimbrite (Ilala). L-BA06



The Birenti-Hada rhyolites overlain by scoria of the Pleistocene basatlt (a-type) (northeast of the Korke caldera). L-BA07

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

Figure 5.1.15: Outcrop photos of the Pleistocene basalts

7) Kone ignimbrite

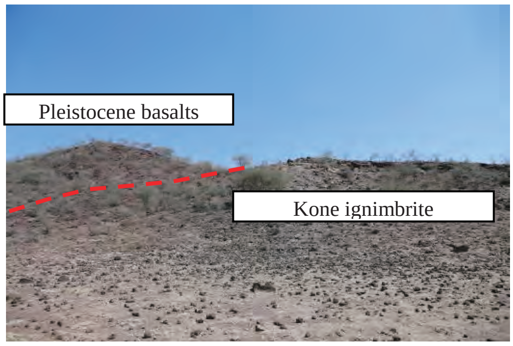
This unit is composed of greenish gray to gray colored highly welded tuff to unwelded tuff and pumice mainly distributed east of Kone caldera. The tuff contains relatively higher numbers of hornblendes 1 to 3 mm in size and foreign lapilli of up to several centimeters in size.

Continuous welded tuff with about 70 m in thickness forms a caldera wall on the south edge of the Korke caldera subordinately situated besides the Kone caldera. EIGS and ELC (1987) described several flow units of welded tuff on the wall of the Korke caldera. On the east wall of the Korke caldera, it is observed that several layers of unwelded pumice including obsidian lapilli 1 to 5 cm in size continue for about 20 m below the welded tuff.

The characteristics of the welded tuff of this unit is similar to the Fentale ignimbrite and Dino ignimbrite, which makes identification through facies difficult. Therefore, these units were distinguished from the view point of distributional continuation.

It is observed that this unit unconformably overlies Birenti-Hada rhyolites at the east wall of Korke caldera (L-BA01) and the Pleistocene basalts at the east of Kube (L-BA08).

The Kone ignimbrite exposed on the west wall of Korke caldera. L-BA17



Kone ignimbrite which overlay the Pleistocene basalts (east of Kube). L-BA08

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

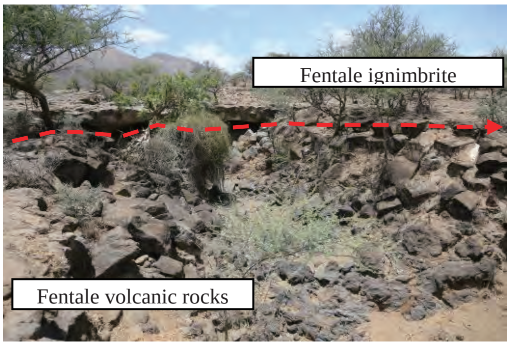
Figure 5.1.16: Outcrop photo of Kone ignimbrite

8) Fentale volcanic rocks

Mt. Fentale (2,007 m) is located just north of Lake Beseka and has an elevation gap of about 1,050 m between the surface of the lake. It has a caldera with a diameter of about 4 x 2.5 km on the top of the mountain. This unit is composed of acidic rocks which form the main body of Mt. Fentale.

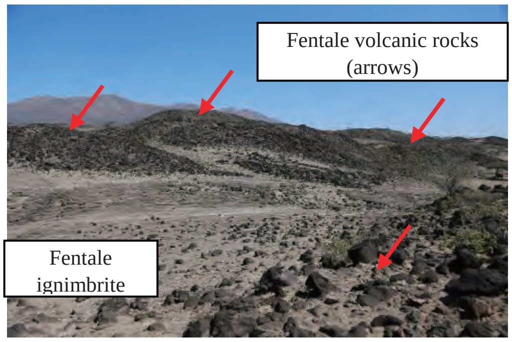
In the detailed study area, the west part of Mt. Fentale is included. Within the detailed study area, the volcano is composed of rhyolite and trachyte lavas in which phenocrysts of alkali feldspar and hornblende are scattered. The lava surface is block type with a diameter from several dozen cm to about 1 m. The lavas are generally very glassy and are black to deep green in color.

The lavas distributed on the foot of the mountain remain in the original topography of the lava flow and each lava flow can be distinguished through the analysis of satellite images and digital elevation model. However, since the characteristics of the lavas distributed in the detailed study area are almost similar to each other, they are grouped as the Fentale volcanic rocks in this report.



Trachyte of the Fentale volcanic rocks overlain by the Fentale ignimbrite (southern foot of Mt. Fentale). L-BA18

Block lava of glassy trachyte (south foot of Mt. Fentale). L-BA19



Glassy trachytes (arrow) exposed after the erosion of the Fentale ignimbrite (southern foot of Mt. Fentale). L-BA20

Glassy rhyolites exposed on the southern slope of Mt. Fentale. L-BA21

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

Figure 5.1.17: Outcrop photos of the Fentale volcanic rocks

9) Fentale ignimbrite

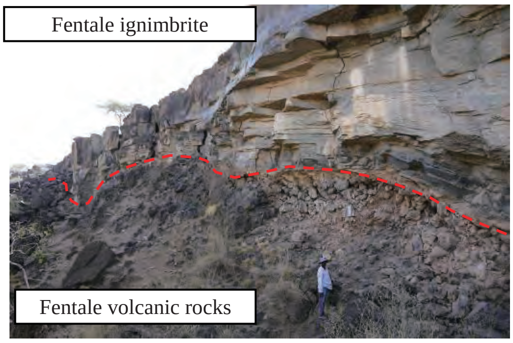
This unit is composed of greenish gray to whitish gray welded to unwelded tuff and pumice which erupted from Mt. Fentale. It is distributed at the slope of Mt. Fentale, foot of the mountain and widely around the surrounding area. It includes a lot of lapilli with a diameter of a few mm to several cm and develops glassy (obsidian) lens structure (fiamme). The size of the fiamme is variable from several mm to more than 50 cm. There is unwelded pumice at the bottom of the welded tuff.

This unit covers 15 to 18 km towards south to west directions from Mt. Fentale and more than 30 km towards east direction according to Kazmin and Berhe (1978). On the slope of Mt. Fentale, welded tuff thinly are deposited in the gentle valleys and plains (about 1m thick). At the southwestern to western side around the mountain peak of Mt. Fentale, it is observed that pumice and welded tuff are deposited from the top of the caldera wall towards the outside overlaying rhyolites of the Fentale volcanic rocks.

At the southern foot of Mt. Fentale, there is a thick deposit of pumice. This is considered the secondary sediment of collapsed pumice which originally was deposited on the mountain slope. This pumice is assumed to be a part of pyroclastic rocks of the Fentale ignimbrite. This pumice is covered by the Holocene basalts.

The maximum observed thickness of this unit is about 10m in the outcrops, but a borehole log record shows about 30 m of welded tuff for the horizon assumed as the Fentale ignimbrite (AW BH-5).

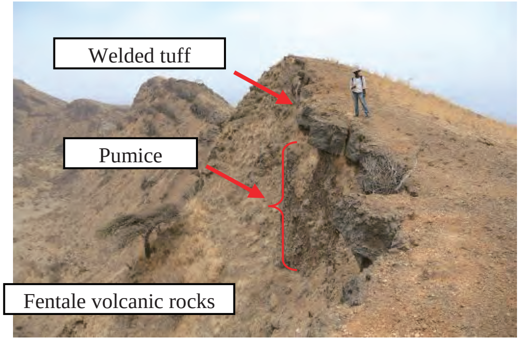
There is a report about the age of this unit as 1.1±0.1 Ma (Gibson (1970)). However, EIGS and ELC (1987) indicated a possibility of a much younger age for the unit due to its topographical characteristics.



The Fentale ignimbrite which overlies the trachyte of the Fentale volcanic rocks. (Southern foot of Mt. Fentale). L-BA22

Glassy lens structure (fiamme) of the Fentale ignimbrite.

Welded tuff of the Fentale ignimbrite which cover the southern slope of Mt. Fentale. Black oval patterns are fiammes seen from above. L-BA23



Pumice and welded tuff deposited out of the caldera rim of Mt. Fentale. L-BA24

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

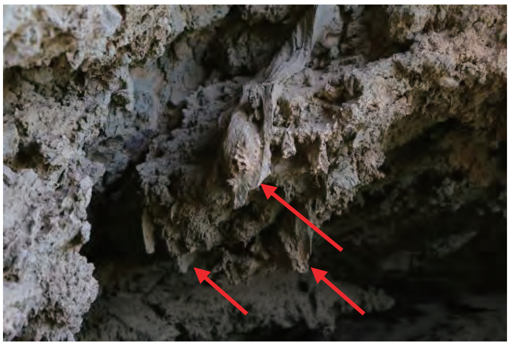
Figure 5.1.18: Outcrop photos of the Fentale ignimbrite

There is a remarkable topographic feature on the surface of the Fentale ignimbrite that is called “Blister”. The blister is a small rise of welded tuff surface forming a conical shape. The existence of the blisters is limited to an area near Mt. Fentale (within about 10 km) and many of them can be observed especially in the west and the south of Mt. Fentale where there is a flat plain. The size of a blister is normally from 5 to 30 m in diameter and reaches up to 100 m when a couple of blisters are combined. Relatively larger blisters tend to have been collapsed at the center and only their rims have remained.

Blisters are considered to have been formed by the presence of steam pockets which caused a bulge to the surficial portion of the still hot and plastic material (EIGS and ELC, 1987). To support this idea, the inside of a blister is hollow and it is observed that half melted material is hanging down from the ceiling made of welded tuff, and then cooled and consolidated. In addition, the cracks developing on the surface of the blister do not reach deep inside (photo).

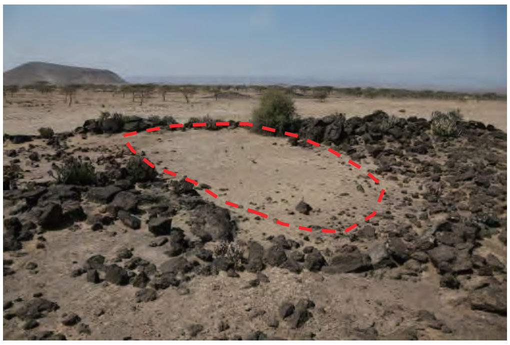
EIGS and ELC (1987) mentions the cause of the blister as steam produced by the sudden vaporization of water from swampy areas or shallow lakes trapped beneath the flow at the moment of deposition. However, blisters are observed on the lava plateau formed by the trachyte block lava of the Fentale volcanic rocks and sometimes on the slope of the plateau edge. It is difficult to assume that these places were all swamps or lakes. Moreover, there is no trace of lake deposits beneath the Fentale ignimbrite and the tuff deposited on water would be cooled rapidly so that it cannot be welded strongly. Generally pyroclastic flow contains a large volume of volatiles and degassing structures are observed in the unwelded deposits. Probably the volatiles included in the original pyroclastic flow deposits of the Fentale ignimbrite lost a way out for degassing due to welding of the deposits, and then they gathered and combined at certain places increasing the volume. At last, the shape of present blisters was formed.

A blister with its original cavity remaining without collapsing (southern foot of Mt. Fentale). L-BA25



Ceiling of the cavity of a Blister. Melted parts of the welded tuff are hanging down like stalactite (southern foot of Mt. Fentale).

Cracks observed on the surface do not reach the inside (southern foot of Mt. Fentale)



Remnant of a collapsed blister (a diameter of about 20m) (southern foot of Mt. Fentale)

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

Figure 5.1.19: Outcrop photos of the blisters of the Fentale ignimbrite

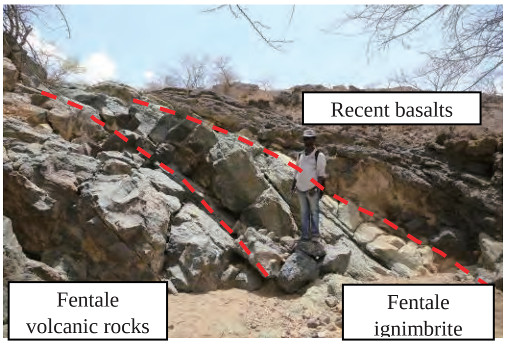
10) Recent basalts

This unit distributed in the detailed study area is black vesicular aphyric basalt and it is the youngest volcanic ejecta in the area (1810 to 1830, Buxton (1949)). It is located at the southern foot of Mt. Fentale and the southern tip of the lava reaches Lake Beseka. Since it is a very recent basalt, there is little vegetation on the lava and the lava flow maintains its original shape without weathering or erosion. The viscosity of the lava is very low and spatter cones and lava tunnels are developed and a few ropy structures are observed near the eruption center. These characteristics of pahoehoe lava turn into those of aa lava after some distance from the eruption center. There are several eruption centers along the faults (in and out of the tuff ring of the Sobebor sand beds and at the southern foot of Mt. Fentale)

Since there is little vegetation and soil developed on these lavas, their distribution is clearly demarcated from other units. Many other recent basalts are distributed west of the detailed study area at Boru Arole, Kube, Korke and Kokoro, etc. At all these locations, the basalts generally contain olivine and pyroxene. Most of them are aa lava but the basalt distributed at Boru Alole shows pahoehoe characteristics such as lava tunnels and ropy structures. The mineral composition of these basalts are different from that of the detailed study area, they are considered to be the basalts of a similar age due to the freshness of their surface.

Lava tunnel observed near the eruption center of the recent basalt lava (Dinbiba). L-BA26

Spatter cone developed at the spout of the recent basalt lava (Dinbiba). L-BA26



The recent basalts over the Fentale ignimbrite and the Fentale volcanic rocks. L-BA27

The recent basalts reaching Lake Beseka. L-BA28

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

Figure 5.1.20: Outcrop photos of the recent basalts

11) Alluvial deposits

This unit is mainly a flood plain deposit of the Awash River and is composed of sand and silt. Most of the area is now utilized for sugar plantations. In addition, alluvial deposits are distributed at the Alaka plain on the west of Mt. Fentale and eastern foot of Mt. Bilenti.

Alluvial plain utilized for a sugar plantation (Abadir farm). L-BA29

Section of alluvial deposits (northeast of Mt. Bilenti)

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

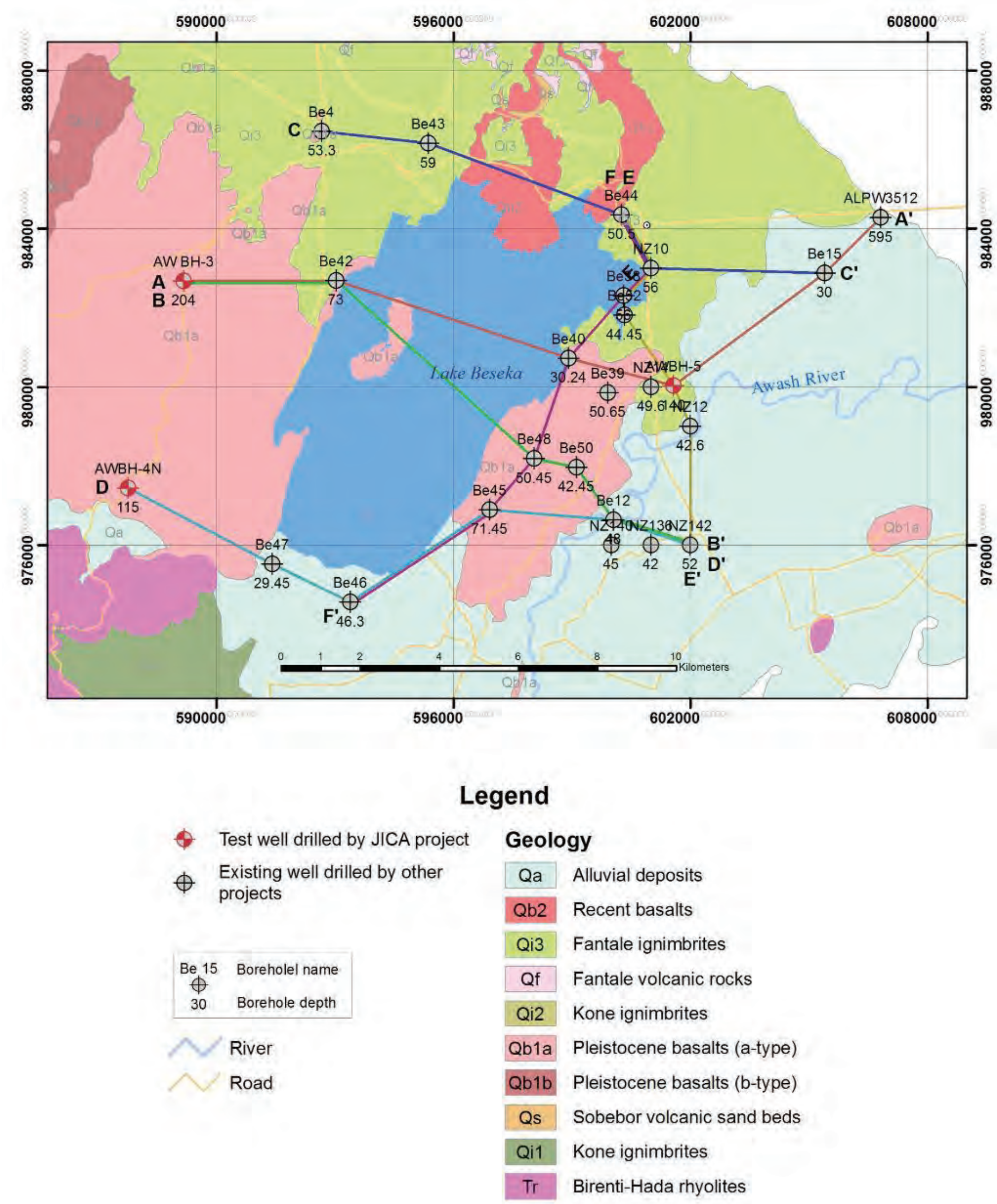
Figure 5.1.21: Photos of alluvial plains and deposits

b. Borehole log analysis

The geological log information of 22 existing wells and three observation wells constructed through this project around Lake Beseka were examined to analyze the correlation of geology and thickness of each geological unit. Most of the existing wells are relatively shallow (40 to 73 m) but the geological information of the deep part was compensated by the three observation wells of this project (114 to 204 m) and a deep well (595 m) constructed by MoWIE for irrigation purposes 6km east of Metehara Town, in 2014 . The results of analysis of those geological logs was almost consistent with the result of the field work. When a large gap of geological unit is observed within adjacent wells, effects of previous topographical features or displacement by fault activity were considered although a description error cannot be completely ruled out.

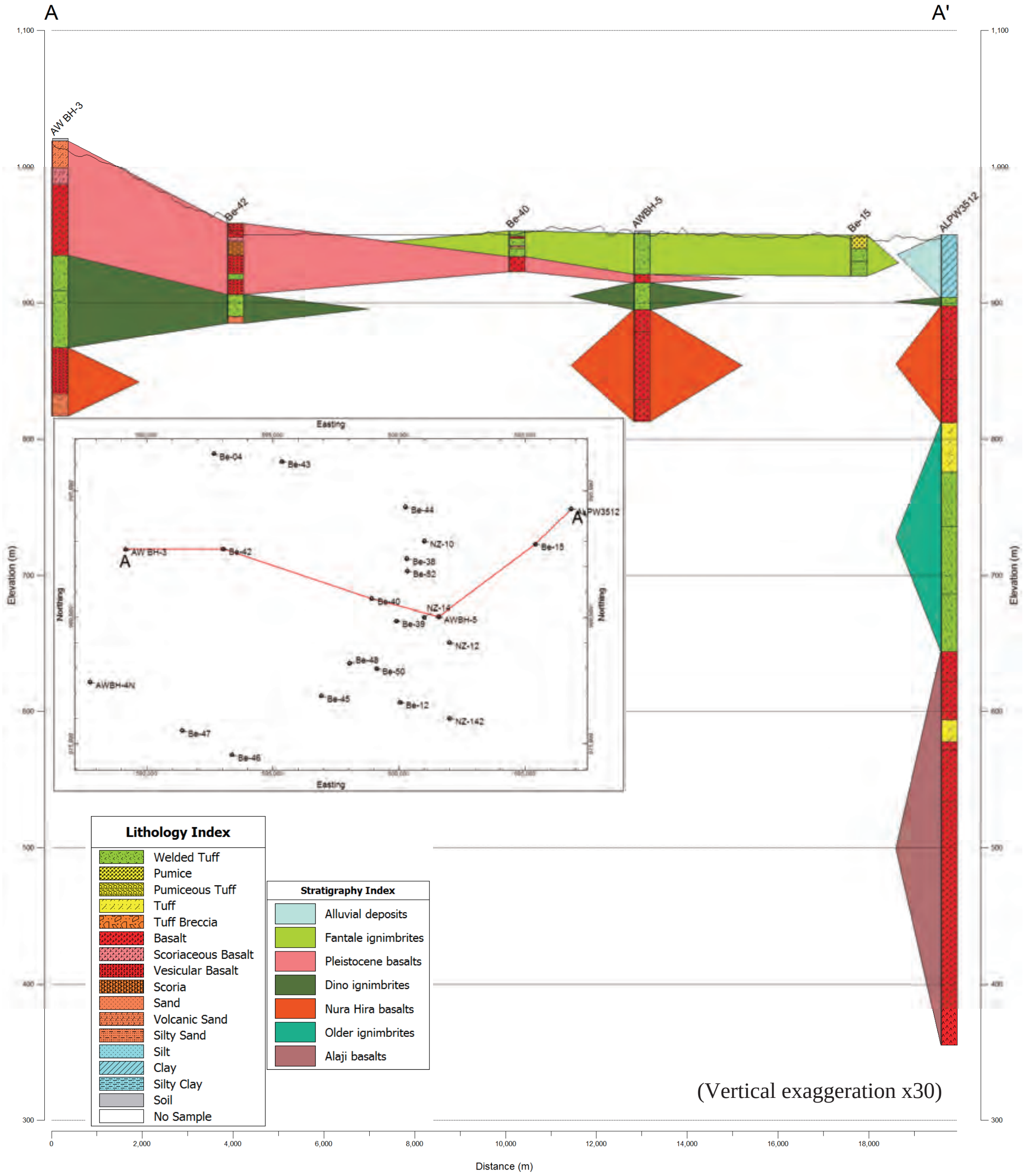
In each profile section the position of wells are arranged according to the ground elevation of the wells and the continuation of each horizon is schematically shown.

The location of the existing wells and observation wells and profile lines are shown in Figure 5.1.22, and profile sections are shown in Figure 5.1.23, Figure 5.1.24, Figure 5.1.25, Figure 5.1.26, Figure 5.1.27, Figure 5.1.28. The results of this analysis are reflected in the attached geological section (Figure 5.1.9).



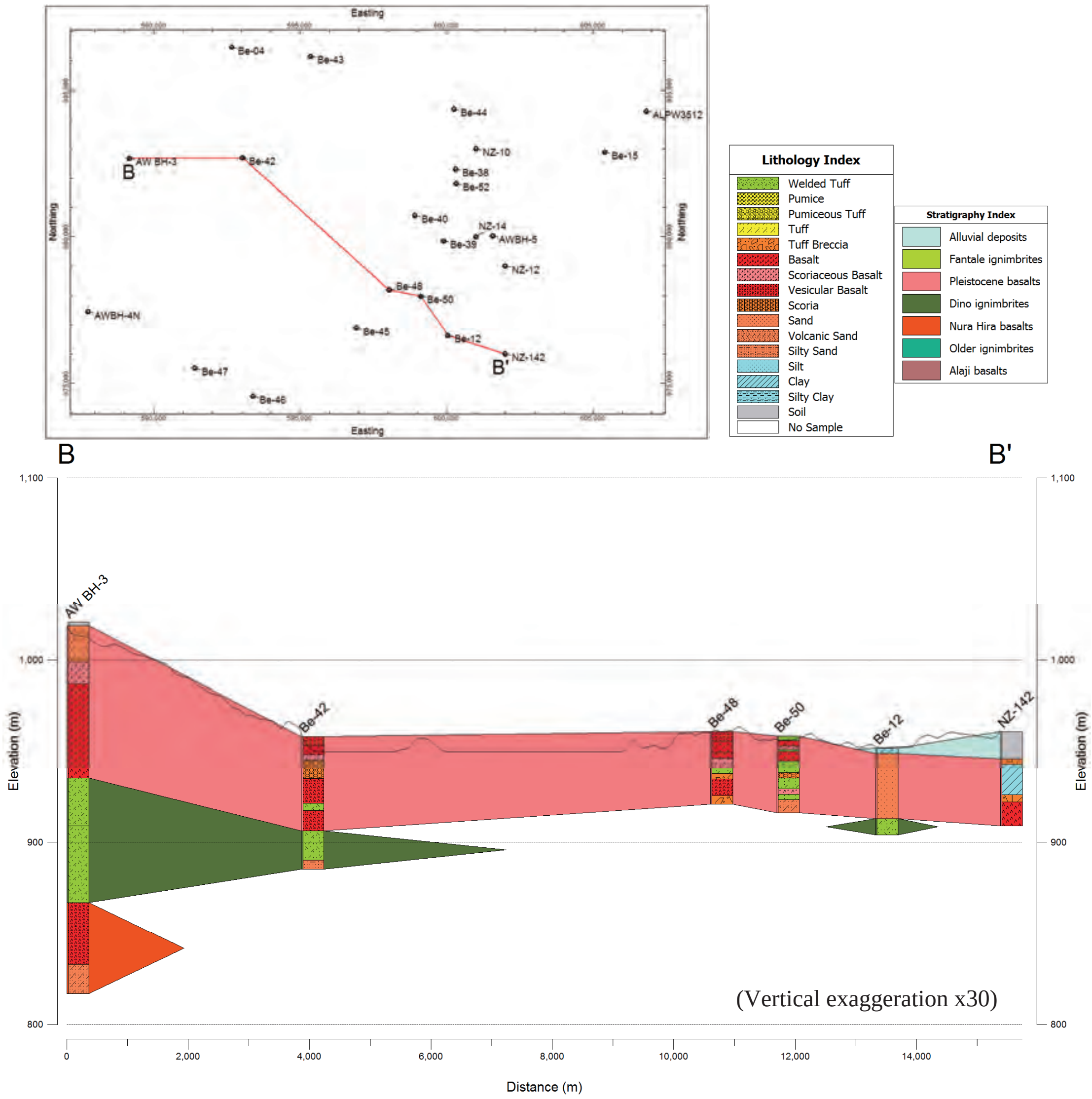
Source: the Project Team, Data: Result of geological survey in this Project

Figure 5.1.22: Location of existing wells and observation wells constructed by this project and profile lines around Lake Beseka



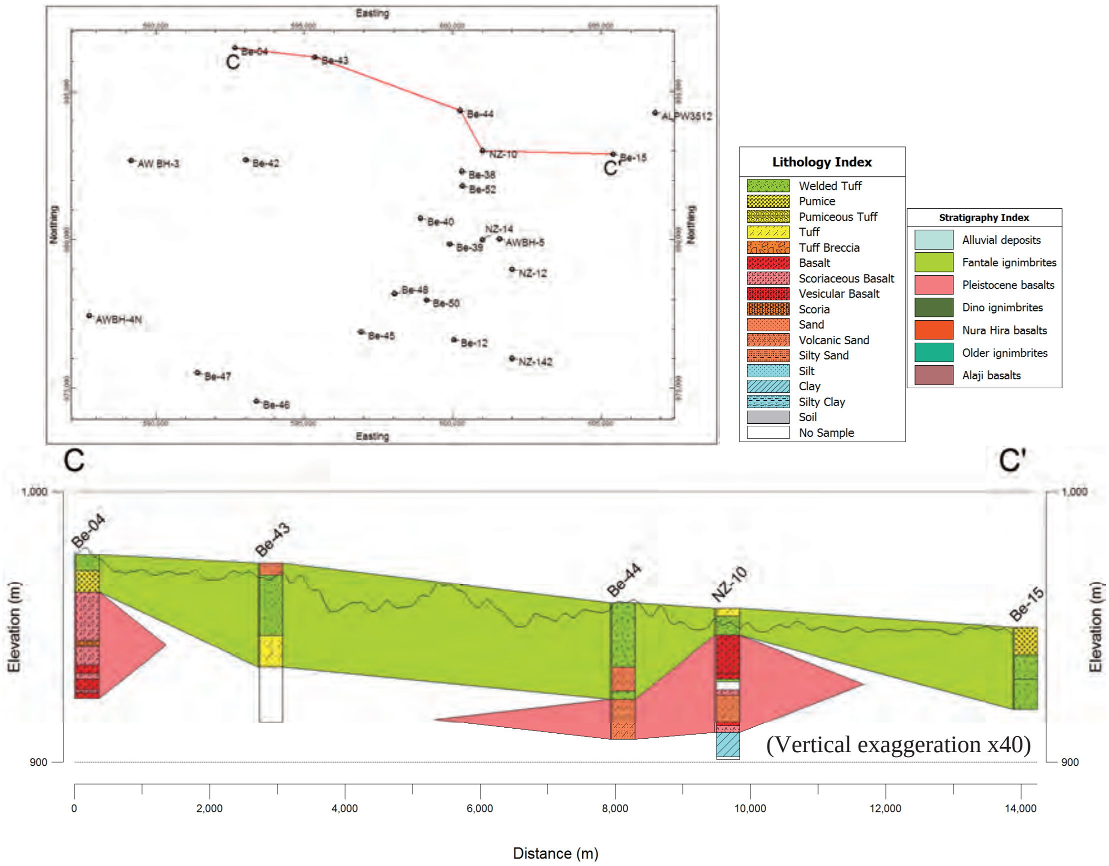
Source: the Project Team, Data: Result of geological survey in this Project

Figure 5.1.23: Borehole log profile A-A' section



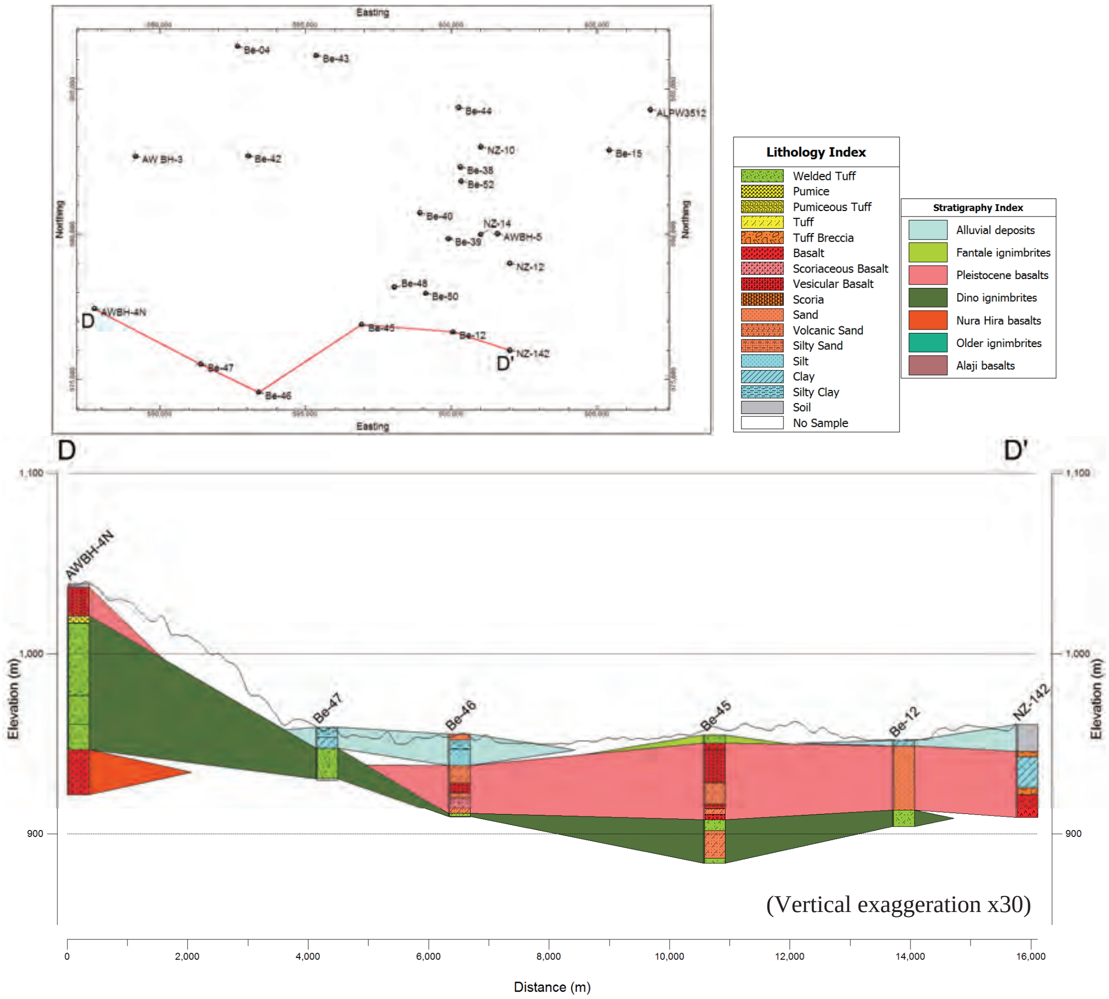
Source: the Project Team, Data: Result of geological survey in this Project

Figure 5.1.24: Borehole log profile B-B' section



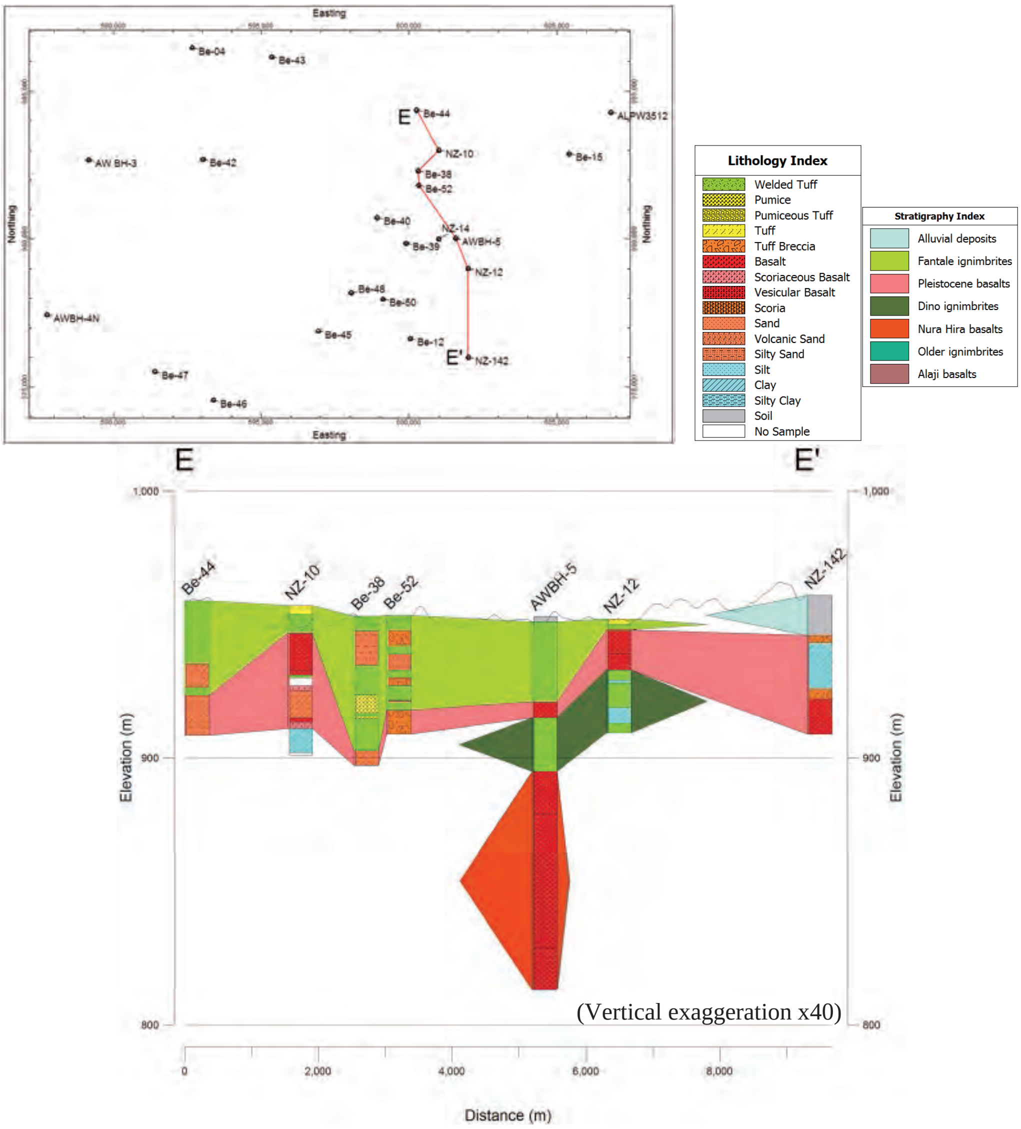
Source: the Project Team, Data: Result of geological survey in this Project

Figure 5.1.25: Borehole log profile C-C' section



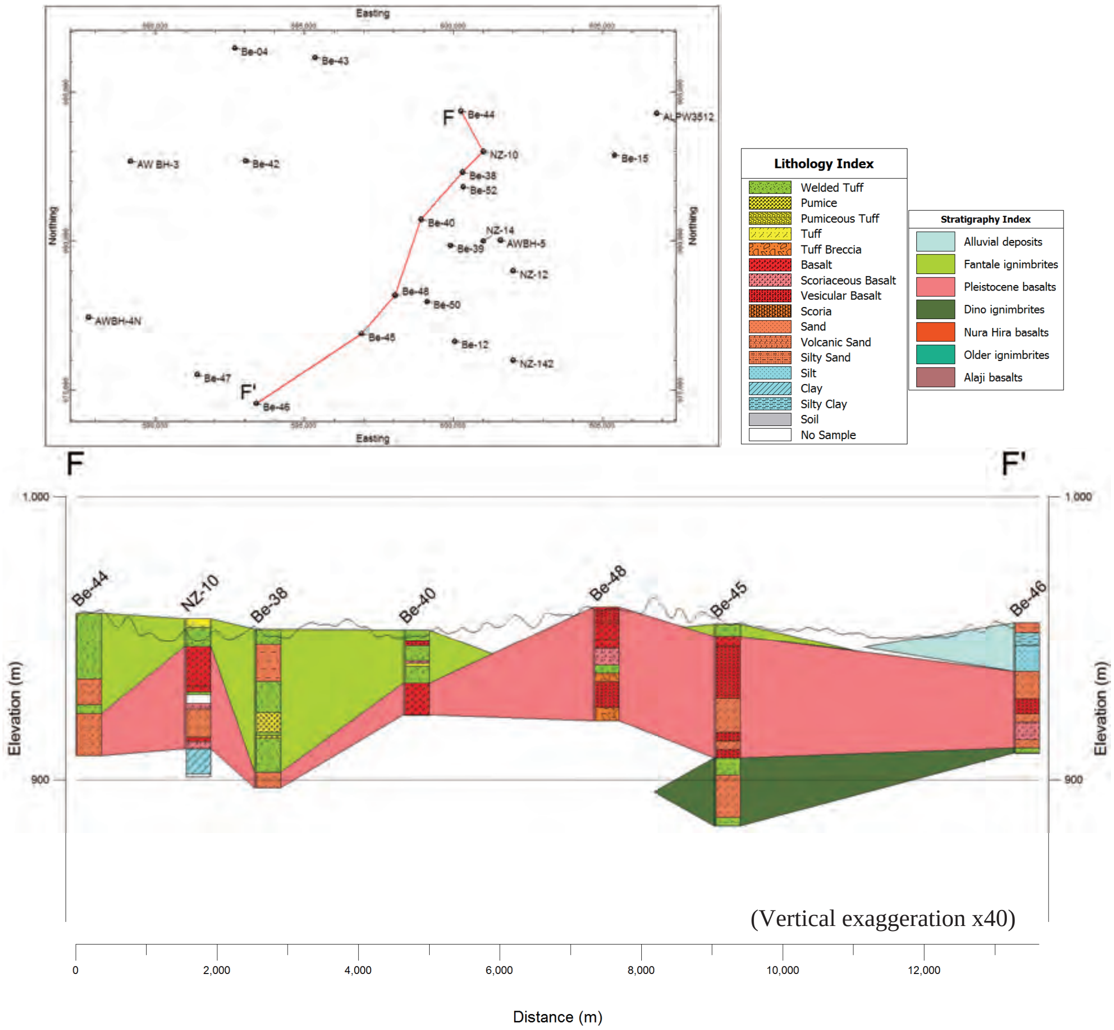
Source: the Project Team, Data: Result of geological survey in this Project

Figure 5.1.26: Borehole log profile D-D' section



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

Figure 5.1.27: Borehole log profile E-E' section



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

Figure 5.1.28: Borehole log profile F-F' section

c. Stratigraphy

A stratigraphy of the detailed study area and correlation with other areas as a result of field survey and borehole log analysis is summarized in Table 5.1.2.

Table 5.1.2: Geological stratigraphy around Lake Beseka and correlation with other areas

Age			Stratigraphy	Legend	Kazmin and Berhe (1978)	Dating
Cenozoic	Quaternary	Holocene	Alluvial deposits	Qa	Alluvium	
Cenozoic	Quaternary	Holocene	Recent basalts	Qb2	Recent aphyric basalts	Between 1810 and 1830 (Buxton, 1949)
Cenozoic	Quaternary	Pleistocene	Fentale ignimbrite	Qi2	Young ignimbrite of Fentale	1.1±0.1Ma (Gibson 1970)
Cenozoic	Quaternary	Pleistocene	Fentale volcanic rocks	Qf	Pantelleritic volcanics of Fentale rhyolites, trachytes, tuffs and agglomerates	
Cenozoic	Quaternary	Pleistocene	Kone ignimbrite	Qi2		
Cenozoic	Quaternary	Pleistocene	Pleistocene basalts	Qb1a Qb1b	Pleistocene-subrecent basalts	
Cenozoic	Quaternary	Pleistocene	Sobebor volcanic sand beds	Qs	Basaltic hyaloclastites	
Cenozoic	Quaternary	Pleistocene	Dino ignimbrite	Qi1	Dino ignimbrite	1.51Ma (Kazmin and Berhe (1978))
Cenozoic	Tertiary	Pliocene	Nura Hira basalts	Tb	Bofa basalts	
Cenozoic	Tertiary	Pliocene	Older ignimbrite	Ti	Nazret Group	
Cenozoic	Tertiary	Pliocene	Birenti-Hada rhyolites	Tr	Older alkaline and paralkaline rhyolitic domes and flows	

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

5.1.3 Geological structure

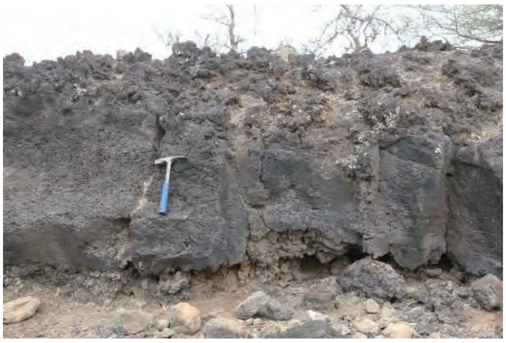
The vicinity around Lake Beseka is located at the very center of Main Ethiopian Rift and the geological structure is dominated by the Quaternary still active NNE-SSW trending normal faults (Wonji Fault Belt, Mohr (1960)). The faults distributed in the detailed study area are divided into two segments; one is the area around Kone caldera and the other is around Lake Beseka (EIGS and ELC (1987)). From the view point of topography and geological structure, since the area around Lake Beseka is located in the lower position of the rift, it may indicate that the active center has shifted from the Kone caldera area to the Lake Beseka area. The youngest fault in the detailed study area is observed on the recent basalt (1810 to 1830, Buxton (1949) north of Lake Beseka (L-BA31).

Although the displacement of the normal faults observed in the detailed study area is relatively small, mostly less than 10 m, the displacement gap becomes larger when the faults get closer to the main fault escarpment of MER (NE-SW trend). The largest displacement is observed at the Haro Gersa area for about 100 m. The inclination angle of the faults observed in the field is almost vertical.

In addition, some of the normal faults show open cracks within the dFetailed study area. A relatively long extending normal fault passing through the northeast of Mt. Fentale up to Lake Beseka has an open crack with a width of about 10 m in addition to the 10m displacement about 2 km north of the lake (L-BA30).

Open crack with a width of more than 10 m at 2 km north of Lake Beseka. L-BA30

A normal fault extending from Lake Beseka towards Mt. Fentale



Recent basalt lava section cut by a fault. L-BA31

NNE-SSW trending fault escarpment at the western part of the detailed study area (Haro Gersa)

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

Figure 5.1.29: Outcrop photos of faults distributed in the detailed study area

5.2 Hydrogeology

5.2.1 Aquifer classification and groundwater flow

As mentioned in Chapter 4, the existing wells data around Lake Beseka was mainly collected from the following reports.

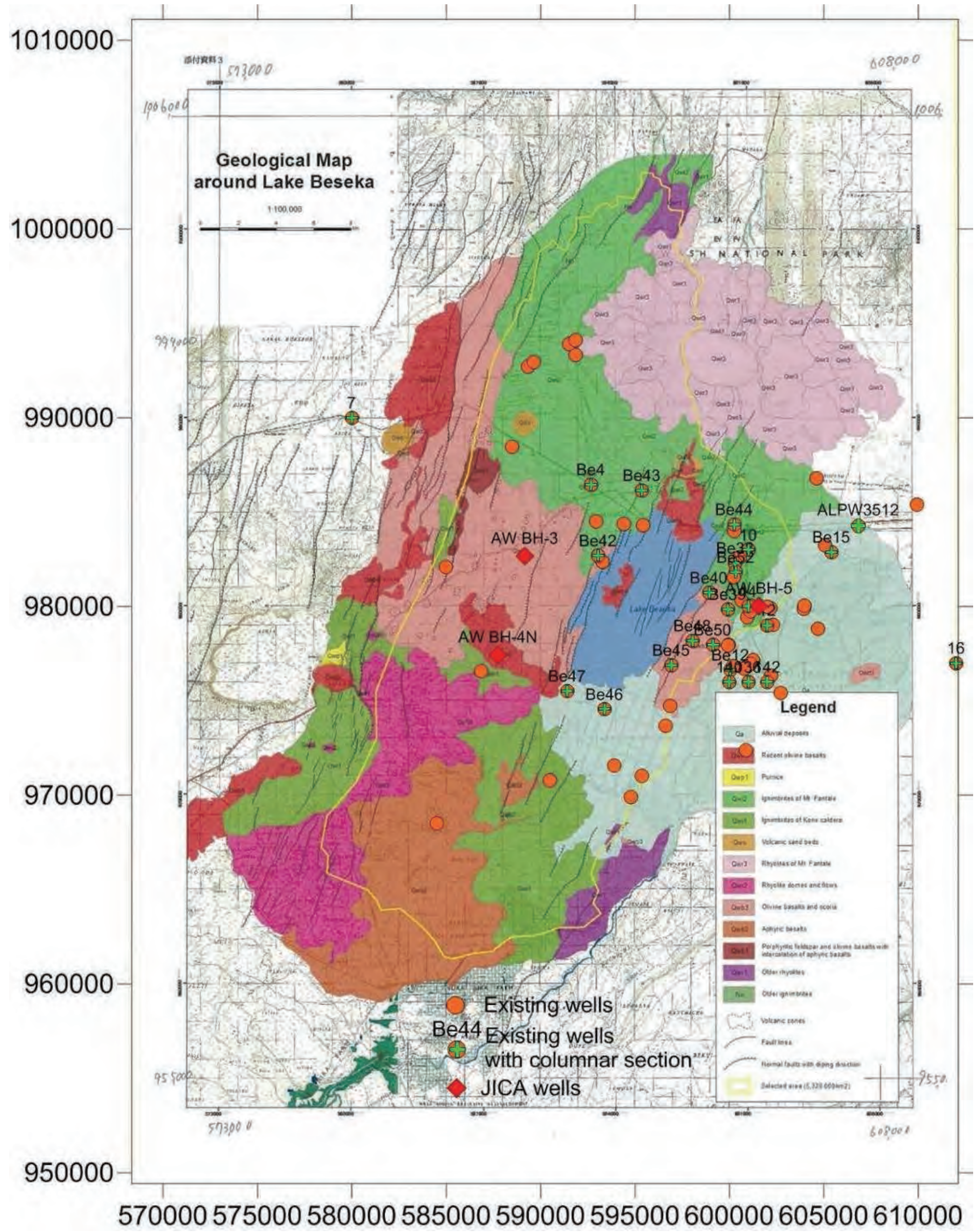
- Hydrogeology (Map) of the Nazret, EIGS, 1985
- Study and design of Lake Beseka level rise project II, WWDSE, planned by MoWE, 2011

All existing wells around Lake Beseka, were plotted on the geological map created after making P/R2 around Lake Beseka (refer to Figure 5.2.1). Lithological conditions of JICA wells were clarified by the chip sampling of drilling, so the columnar sections of JICA wells are able to correlate with the geology around Lake Beseka (refer to Figure 5.2.2 to Figure 5.2.4). Table 5.2.1 shows the results of geological interpretation for each existing well by using the geological map and the columnar section for each of the existing wells.

The depth of almost all existing wells around Lake Beseka was less than 70 m; the geological conditions of these existing wells can be correlated with the geology of JICA wells with depths less than 100 m. The geology of JICA wells more than 100 m deep was correlated with the results of a geological survey and geological map. Transmissivity and Specific capacity are shown in Table 5.2.1. The aquifer of each existing well is estimated in reference to the groundwater level and the depth of screen.

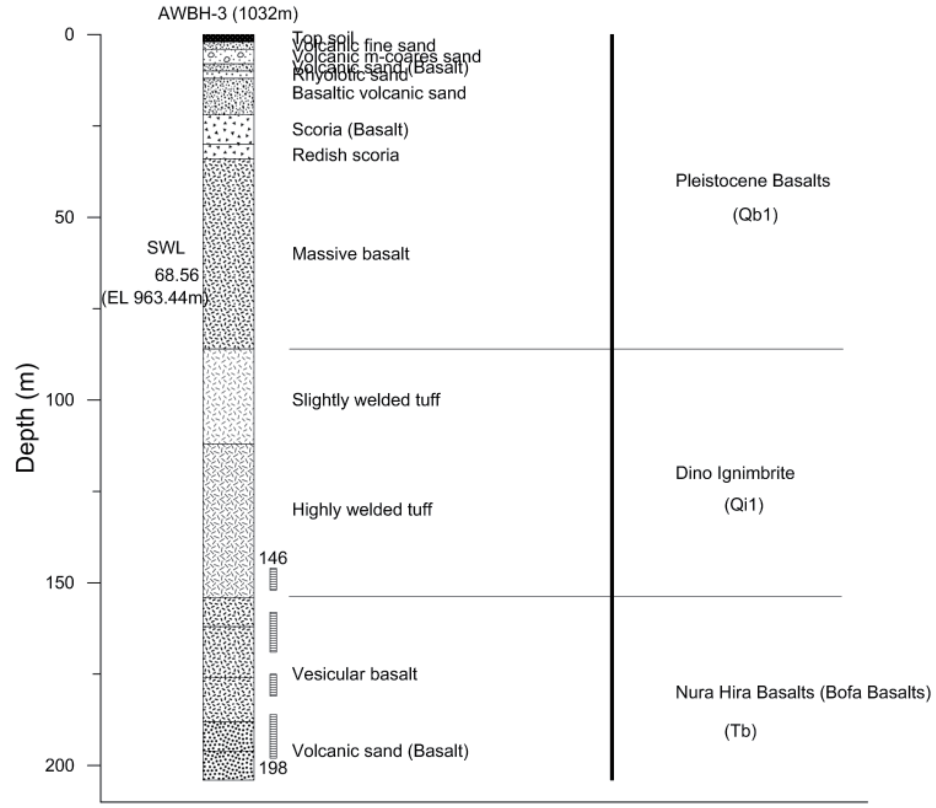
The groundwater flow was discussed around Lake Beseka by the two categories, using the existing wells of less than 100 m deep or more than 100 m deep because of the differences of groundwater level by the geology and depth of aquifer speculated. Figure 5.2.5 shows the groundwater level contour map for existing wells less than 100 m deep, and Figure 5.2.6 shows that of wells more than 100 m deep. The former shows a SW to NE flow direction, and the latter shows a south to north flow direction. There is a difference of groundwater flow by the aquifer depth. The aquifers are classified by the correlation with each geological layer, and the classification of aquifers was conducted and is shown in Table 5.2.2 in accordance with the Table 5.2.1.

As mentioned in Chapter 3, fluoride concentration in the water around Lake Beseka is high and exceeds the Ethiopian standard. There is no correlation between fluoride concentration and depth as Figure 5.2.7 shows.



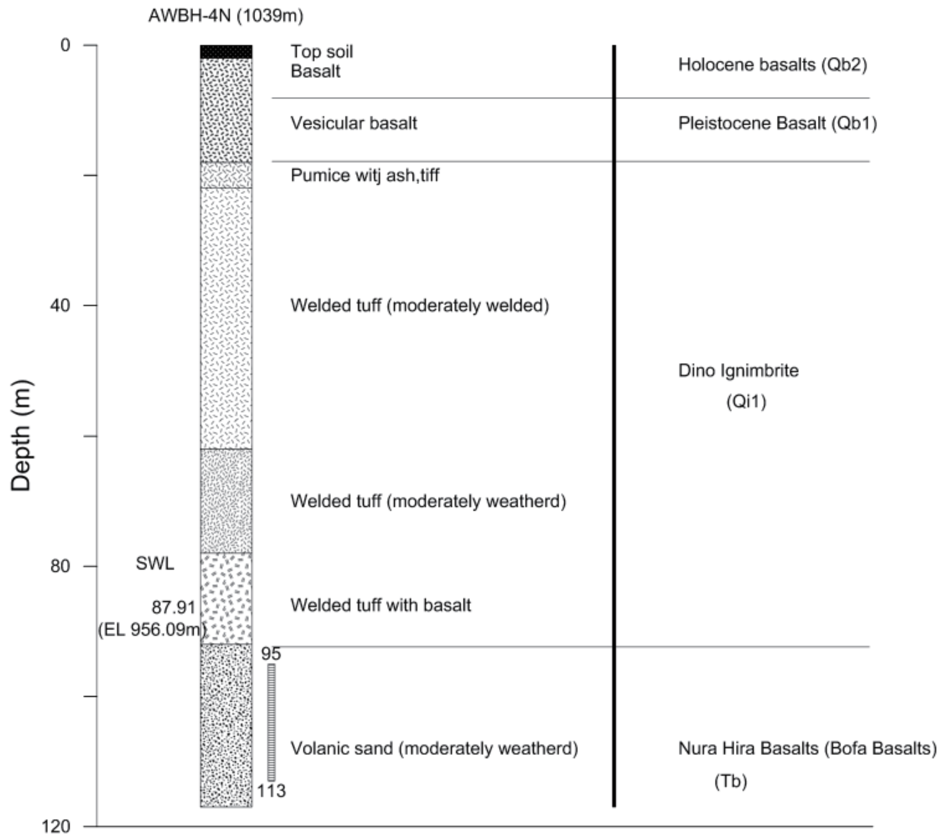
Source: the Project Team, Data: reference 1) & 4) of ① and ④

Figure 5.2.1: Geological Map, Existing Wells and JICA Wells around Lake Beseka



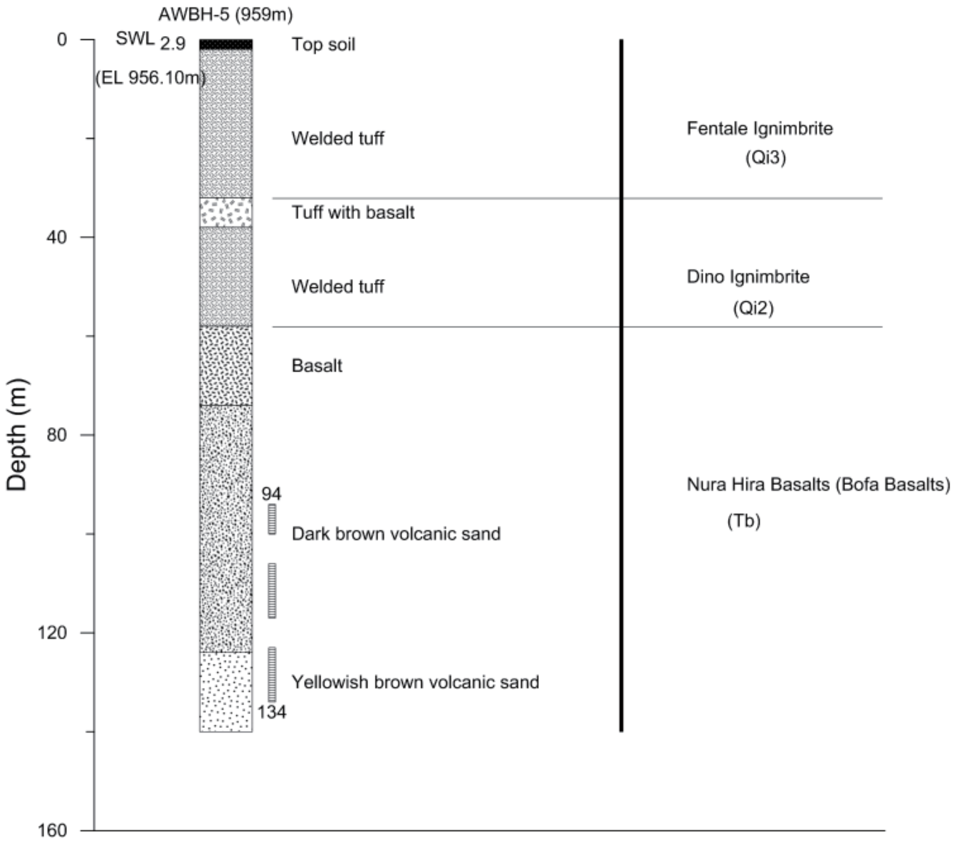
Source: the Project Team, Data: reference ④

Figure 5.2.2: Columnar Section of JICA Well (AW BH-3) and Geological Correlation



Source: the Project Team, Data: reference ④

Figure 5.2.3: Columnar Section of JICA Well (AW BH-4N) and Geological Correlation



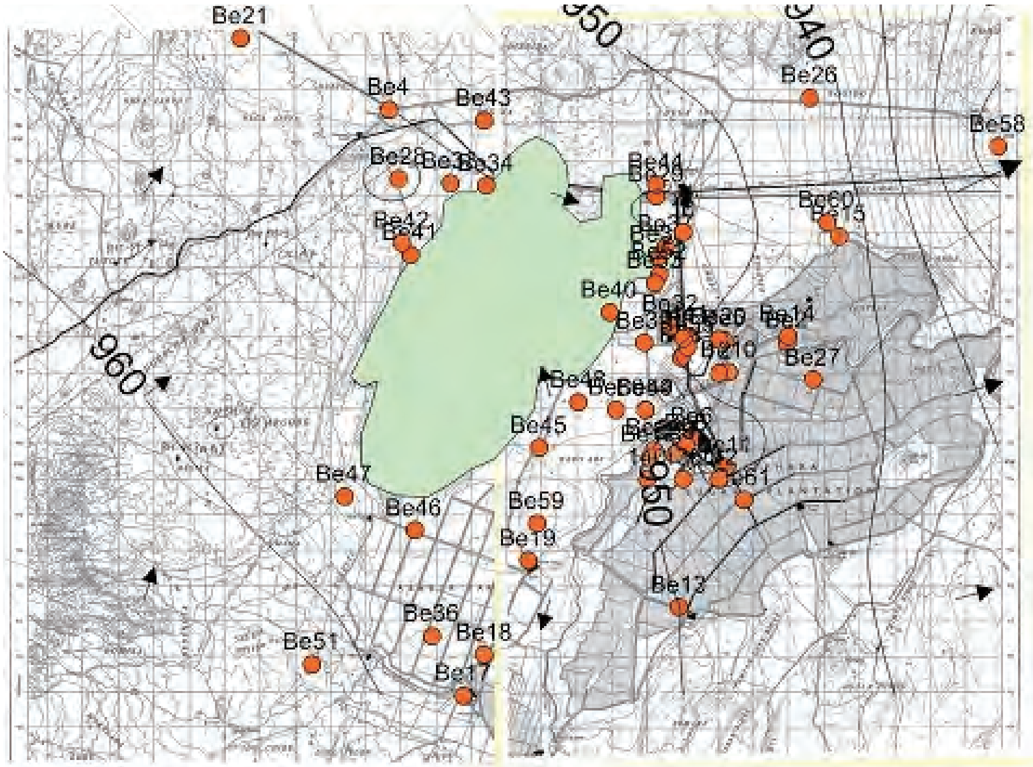
Source: the Project Team, Data: reference ④

Figure 5.2.4: Columnar Section of JICA Well (AW BH-5) and Geological Correlation

Table 5.2.1: Existing Wells and JICA Wells with Columnar Section around Lake Beseka

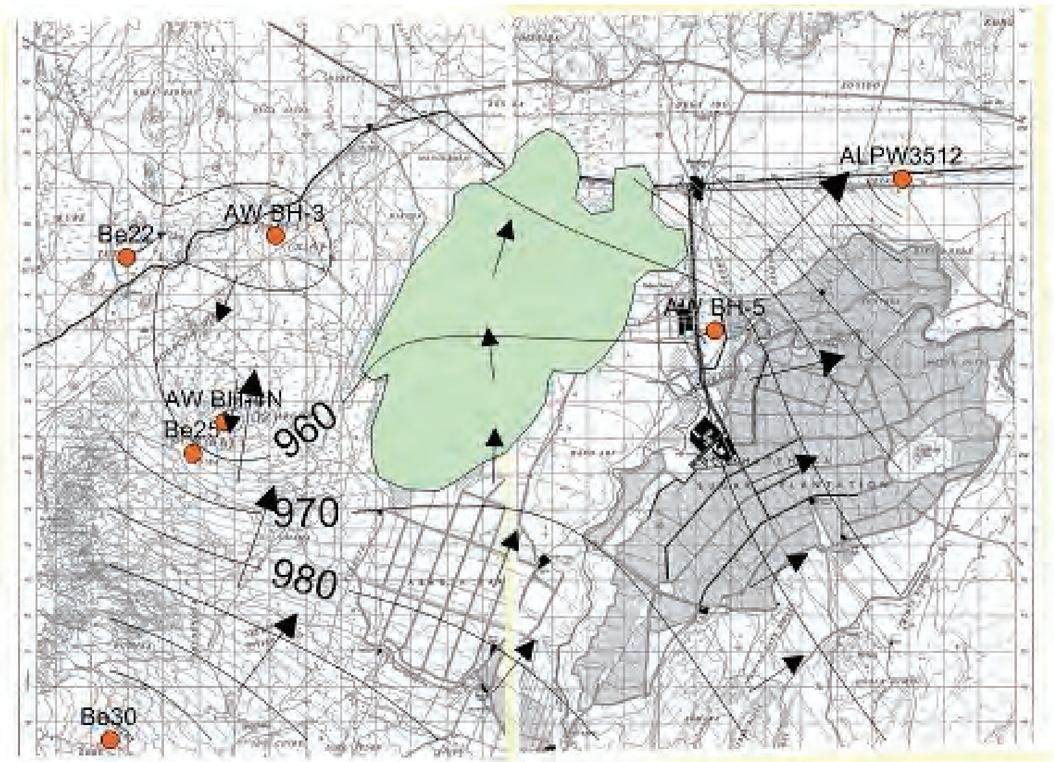
X	Y	No	H	SWL	GWL	GWL2010	Total D (m)	Q(L/sec)	Existing name	Top of Screen(m)	Top of Screen (Elevation)	T (m2/day)	Geology	Aquifer
592664	986463	Be4	981.29	30.94	950.35	953.09	53.3	-	BHI-02	29.3	951.99	8088	Geological map: Fentale Ignimbrite (Qi3), Lower part: Pleistocene basalt(Qb1)	Qb1
600048	976634	Be12	959	15.32	943.68	955.36	48	6.5	BHMR-20	12	947	965	Geological map: Alluvium, Lower part: Fentale Ignimbrite(Qi3)	Alluvium sand
605405	982881	Be15	949.8	6.15	943.65	945	30	4	BHG-32	15	934.8	60.4	Geological map: Alluvium, Lower part: Fentale Ignimbrite(Qi3)	Qi3
600305	982301	Be38	953.21	3.7	949.51	951.31	56	-	BH-59	-	-	-	Geological map: Alluvium, Lower part: Fentale Ignimbrite(Qi3)	Alluvium sand
599903	979853	Be39	953.93	4.43	949.5	951.3	50.65	-	BH-23	18.65	935.28	2681	Geological map: Fentale Ignimbrite(Qi3)	Qi3
598914	980723	Be40	953.02	3.24	949.78	951.58	30.24	-	BH-37	11	942.02	502	Geological map: Between Holocene basalt(Qb2) and Fentale Ignimbrite(Qi3), Columnar section: Fentale(Qi3)+Pleistocene basalt(Qb1)	Qi3
593035	982691	Be42	958.32	8.18	950.14	952.88	73	-	BH-50B	17.25	941.07	-	Geological map: Basalt & Scoria (Qb1), Lower part: Tuff (from 50m deep).Tuff belongs to Dino Ignimbrite(Qi1)	Qb1
595362	986153	Be43	973.83	23.16	950.67	953.42	59	-	BH-57	24	949.83	217.8	Geological map: FentaleIgnimbrite (Qi3). Columnar section is same lithology.	Qi3
600252	984352	Be44	958.93	8.62	950.31	951.91	50.5	-	BH-58	-	-	-	Geological map: Fentale Ignimbrite (Qi3)	Qi3
596921	976889	Be45	955.14	4.2	950.94	953.44	71.45	-	BH-63	-	-	-	Geological map: Basalt & Scoria (Qb1), Lower part: Tuff (from 50m deep).	Qb1
593389	974555	Be46	955.53	4.54	950.99	954.79	46.3	-	BH-62	-	-	-	Geological map: Alluvium (Depth to 17m), Lower part: Scoria, Basalt(Qb1), Tuff (from about 44m deep)	Qb1
591413	975520	Be47	959.35	7.7	951.65	955.35	29.45	-	BH-60	-	-	728	Geological map: Alluvium (Depth to 12m), Lower part: Tuff(Qi2)	Qi2(Fissure)
598043	978183	Be48	965.16	14.25	950.91	953.42	50.45	-	BH-66	28.75	936.41	189	Geological map: Basalt and Scoria (Qb1), to about 40m depth	Qb1
599118	977968	Be50	958.64	8.08	950.56	952.36	42.45	-	BH-64	-	-	-	Geological map: Basalt and Scoria (Qb1), and many tuff layers (Dino ignimbrite (Qi1) from 14m deep)	Qi1
600331	981811	Be52	953.42	3.65	949.77	951.57	44.45	-	BH-05	23	930.42	996	Geological map: Fentale Ignimbrite(Qi3)	Qi3のBreccia
580000	990000	7	1000	25	975	975	50.6	6.7	-	25	975	-	Geolgical map: Kone Ignimbrite (Qi2)	Qi2(Fissure)
601000	983000	10	1000	13.6	986.4	986.4	56	12	-	-	-	-	Geological map: Fentale Ignimbrite (Qi3), Depth to about 10m, Lower part: Basalt(Qb1)	Qb1
602000	979000	12	950	8.8	941.2	941.2	42.6	12	-	-	-	-	Geologicalmap: Alluvium deposit, Basalt(Holocene basalt)(Qb2), Lower part: Fentale Ignimbrite(Qi3)	Breccia (Qi3, fissure)
601000	980000	14	950	11.19	938.81	938.81	49.6	7	-	-	-	Sc: 3.1(l/sec/m)	Fentale Ignimbrite	Qi3
601000	976000	136	960	20.6	939.4	939.4	42	6	-	32	928	Sc: 0.6	Geological map: Alluvium, Lower part: Basalt(Qb1).	Qa
600000	976000	140	960	25.6	934.4	934.4	45	8	-	24.5	935.5	Sc: 2.3	Geological map: Alluvium, Lower part: Basalt(Qb1).	Qa
602000	976000	142	966	42.8	923.2	923.2	52	8	-	30	936	Sc: 4.7	Geological map: Alluvium, Lower part: Basalt(Qb1).	Qa+Qb1
606822	984277	ALPW3512	942	46.65	895.35	895.35	595	100	-	111.41	830.59	703, Sc:6.5	Qi3, Pleistocene basalt(Qb1), Dino Ignimbrite (Qi1), Bofa basalts (Tb3), Nazret G (Ti3), Alaji Basalt (Tb1)	Qi1, Basalt(Tb1)
589168	982673	AW BH-3	1032	68.56	963.44	963.44	204	6.3	-	158	874	-	Qb1(Pleistocene Basalt), Dino Ignimbrite, Bofa besalts	Bofa(Tb3)
587744	977436	AW BH-4N	1044	87.91	956.09	956.09	117	4.43	-	96	948	3.52	Qb2(Recent Basalt), Qb1, Dino Ignimbrite, Bofa basalts	Bofa (Tb3)
601567	980025	AW BH-5	959	2.90	956.10	956.10	140	7.6	-	94	865	-	Fentale Ignimbrite, Dino Ignimbrite, Bofa basalts	Bofa (Tb3)

Source: the Project Team, Data: reference 1), 4) of ①, 5) of ②and ④



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

Figure 5.2.5: Groundwater Level Contour Map around Lake Beseka (Less than 100 m depth of Existing Wells)



Source: the Project Team, Data: reference 1), 4) of ①, 5) of ②and ④

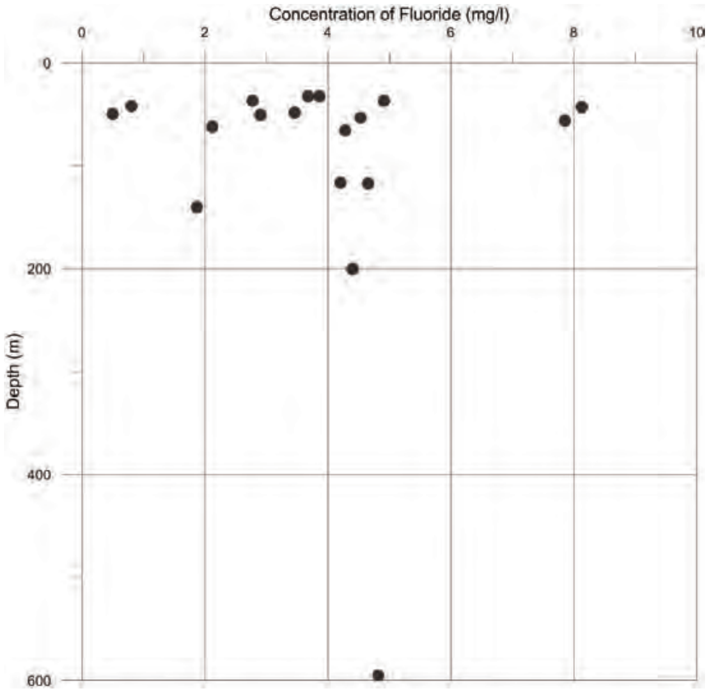
Figure 5.2.6: Groundwater Level Contour Map around Lake Beseka (More than 100 m depth of Existing Wells)

Table 5.2.2: Aquifer Unit Classification and Characteristics around Lake Beseka

Geologic age	Aquifer unit name	Code	Hydrogeological characteristics
Quaternary Pleistocene -Holocene	Holocene deposits	Qal (including Lacustrine deposits)	• Along the Awash River, alluvial sediment covers a small area. • The Alluvium around Lake Beseka consists of sand, mud and gravel, and the thickness of alluvium reaches about 11-40 m. Most of the boreholes in these areas have yield from 3 to7 L/sec.
	Recent Basalts	Qb2	• They are products of fissure eruption • They are highly vesicular, and can store an appreciable quantity (amount) of groundwater. • They are considered to have a high permeability. However it is difficult to predict whether or not an impermeable layer exists below.
	Fentale Ignimbrite	Qi3	• "Fentale Group of Ignimbrites (Qwi2)" shows different hydrogeological characteristics in different areas. • To the west and south of the Fentale volcano, this welded tuff is greyish green, fresh, columnar jointed with blisters and crevasses. So these fractures act as groundwater conducts, some existing boreholes have a yield of 7 L/sec. Such layers in this area have high permeability. • Depth of existing boreholes is 30-60 m. Although the yield data are limited, there is a record of 7 L/sec.
	Pleistocene Basalts	Qb1	• They are vertically and horizontally jointed. • Drawdown is small by the existing borehole and specific capacity is more than 7 L/sec/m in some areas. Other yields are 1.4 and 1.6 L/sec respectively. • The basalt layer occurs at 50 m to 70 m depth of the existing wells around Lake Beseka. The record of yield is sparse, but there are partial records of 8 to 12 L/sec. • Therefore, these groups of basalt are considered to have moderate permeability.
	Dino Ignimbrite	Qi1	• "Dino Ignimbrites (Qwi)" corresponded to this layer are jointed and faulted. • Yield data from existing boreholes are limited around Lake Beseka. • Although there is a layer correlate with Dino in JICA well, the groundwater was taken from the lower layers. • According to the information in other area, the average of specific capacity of the existing well gives 2.2 L/sec/m. It is grouped as moderately permeable formation. The average of the yield indicates more than 6 L/sec.
Tertiary Pliocene	Nura Hira Basalts	Tb (correlate with Bofa baslts)	• Columnar jointing is very well developed with openings of 2-3 cm joints and a distance of 1 m between joints in the outcrop. • There are no outcrops around Lake Beseka, but JICA wells correlated with the Bofa horizon, the yield ranges from 6 to 11 L/sec and specific capacity is 0.15 to 9.3 L/sec/m. • In general Bofa basalts are expected to have high to medium permeability.
	Older Ignimbrite	Ti (correlate with upper Naret Pyroclastic deposits)	• "Nazret Group of Ignimbrites (Nn)" shows variable permeability in different areas. • Geology consists of Ignimbrites, welded tuffs, ash flows, rhyolites and tuffs. • The group to the northeast of Melka Jilo and north of Kone Caldera is jointed and faulted and a borehole drilled in this formation has a yield of 6.7 L/sec. • The average yield is 15 L/sec as a whole, specific capacity is more than 2 L/sec/m. There are highly productive areas in the Study

Geologic age	Aquifer unit name	Code	Hydrogeological characteristics
			area. • In the other areas, they predominantly consist of ash flow and tuff, and bore holes drilled in this formation have low yields according to the information.
	Birenti-Hada Rhyolites	Tr (correlate with Pliocene rhyolite)	• Mainly consists of rhyolites with pumice tuff. • They are generally grouped as formations of middle permeability by fractured aspects.

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



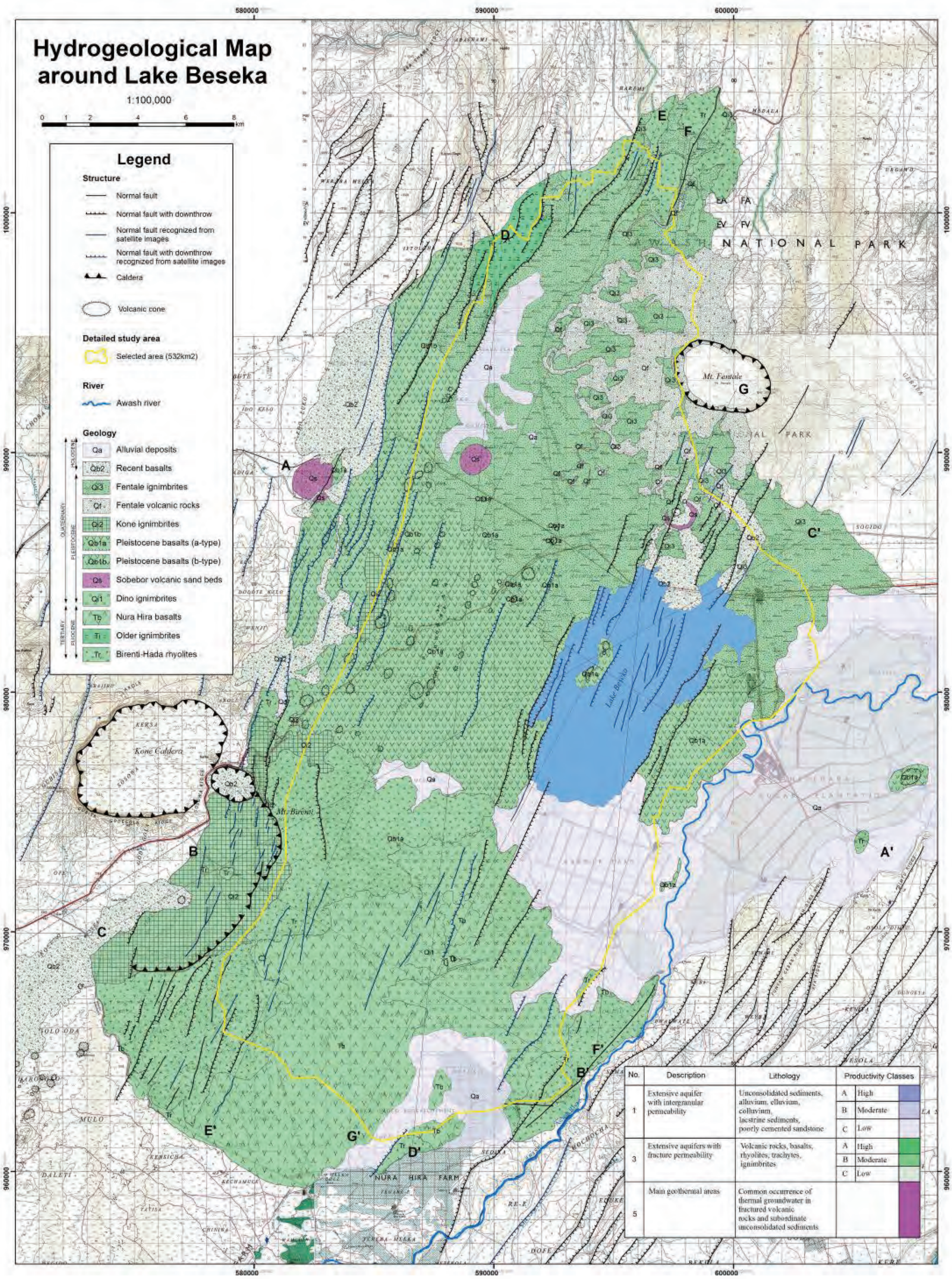
Source: the Project Team, Data: reference 1), 4) of ①, 5) of ②and ④

Figure 5.2.7: Well Depth and Fluoride Concentration around Lake Beseka

5.2.2 Hydrogeological map and cross-sections

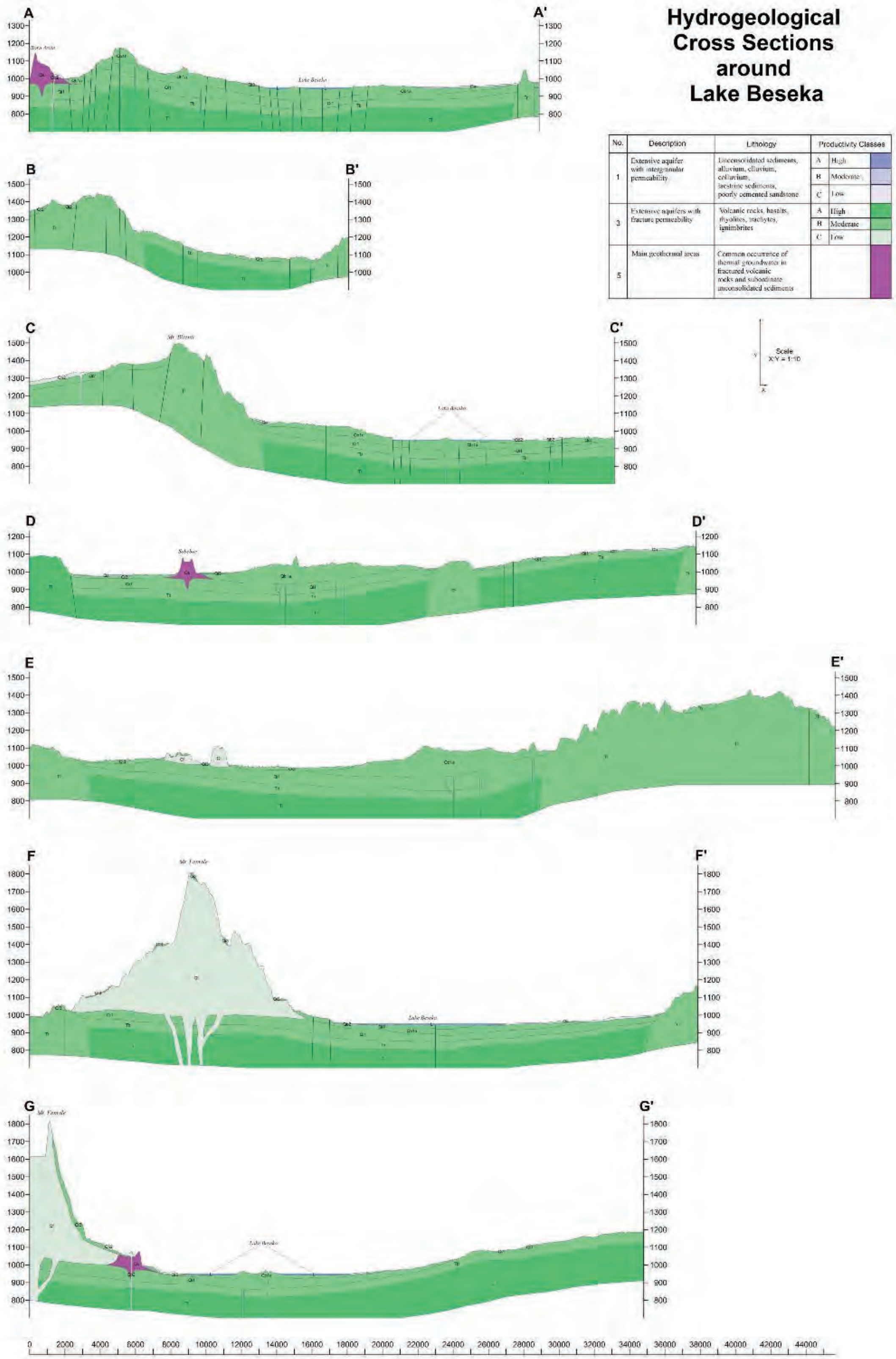
Aquifer units in the Middle Awash river basin were classified based on the existing information in Ethiopia such as a hydrogeological map with scale of 1:2,000,000 prepared by GSE (aquifer unit classification and definitions). The productivity of aquifer units were estimated through the aquifer information obtained on the hydrogeological survey in this Project. Based on these units, a hydrogeological map and cross-sections were prepared for the Middle Awash river basin. The hydrogeological map and cross-sections for the Lake Beseka area were then prepared referring to the geological survey results for the Lake Beseka area as shown in Figure 5.2.8and Figure 5.2.9 below.

Most of the aquifer units distributed in the surface area, except for the surrounding area of the Mt. Fentale, are considered to have medium permeability, and these reach up to around 150 m in depth. In the deeper area than this, pyroclastic deposits of Tertiary Pliocene are distributed and the aquifer unit in this area is considered to have high productivity.



Source: the Project Team, Data: reference 1), 4) of ①, ④and⑬

Figure 5.2.8: Hydrogeological Map around Lake Beseka



Source: the Project Team, Data: reference 1), 4) of ①, ④and⑬

Figure 5.2.9: Hydrogeological Section around Lake Beseka

5.2.3 Results of water quality testing

The water quality testing around Lake Beseka was carried out for the purpose of understanding the recent inflow conditions from the surrounding area to Lake Beseka. The testing involved comparing the water quality of Lake Beseka with that of wells, springs, and river & irrigation water. As mentioned in the second phase, the water quality of water resources around Lake Beseka have specific properties compared to the other areas in terms of the main seven ions and fluoride concentration. The sampling points around Lake Beseka conducted by the Study team are shown in Table 5.2.3. Moreover, the existing water quality data around Lake Beseka is utilized as the reference data (refer to Table 5.2.4).

Table 5.2.3: List of Sampling Points around Lake Beseka

Zone or Region	Detailed Place	Type of Water Sources	Number of Sampling Points		SL. No.	Location ID (Sample ID)	Reference Coordinate		Remarks
			For Physio-chemical Analysis	For Isotope Analysis			Easting	Northing	
East Shewa	Around Lake Besaka	Awash River Water	1	0		B1-2R	587,951	968,181	From BH-53 to River/Canal
		Existing Well	1	0		B1-4	604,677	978,810	From BHM-12 to R28
		Existing Well	1	0		B1-5	604,309	975,247	From BH-41to M21
		Existing Well	1	0		B1-6	601,234	972,270	From BH-64 to L11
	Near the Tone spring	Spring	1	0		B1-7	591,607	979,363	Lake water?
	Spring of Southwest Side of Lake Besaka	Spring	1	0		B1-8	591,608	976,552	
	North-western part of the Lake Besaka	Lake Besaka Water	1	0		B1-9	594,960	984,098	
	South-eastern part of the Lake Besaka	Lake Besaka Water	1	0		B1-10	595,100	977,400	Same point with suggestion
	South-western part of the Lake Besaka	Lake Besaka Water	1	0		B1-11	592,000	977,900	Same point with suggestion
	Central-western part of the Lake Besaka	Lake Besaka Water	1	0		B1-12	593,000	981,600	Same point with suggestion
	Drainage Channel of Lake Besaka	Lake Besaka Water	1	0		B1-13	600,905	982,406	Lake outlet
	Along Wast of Lake Beseka	Spring	1	1		B1-14	592,612	981,509	
	In Metehara Plantation	Awash River Water	1	1		B1-15	598,077	972,974	
	From Nura Hera Farm	Awash River Water	1	1		B1-16	592,729	967,092	Irrigation water
	Middle Awash River	Awash River Water	1	1		B1-17	596,078	965,762	River intake point
	Metehara SP	Awash River Water	1	1		B1-18	601,502	978,505	
	South of Lake Besaka	Lake Besaka Water	1	1		B1-19	595,246	975,723	
	Tone Spring	Spring	1	1		B1-20	591,674	978,734	
	Around Lake Besaka (AW BH-3)	New Well	1	1		E1-1	589,167	982,682	
	Around Lake Besaka (AW BH-4N)	New Well	1	1		E1-2	587,754	977,437	
	Around Lake Besaka (AW BH-5)	New Well	1	1		E1-3	601,565	980,024	
	West of Lake Beseka	Lake Water	1	1		B1-21	592,146	980,409	
	West of Lake Beseka	Spring	1	1		B1-22	591,536	979,199	
	West of Lake Beseka	Lake Water	1	1		B1-23	591,532	979,193	
	South of Lake Beseka	Lake Water	1	1		B1-24	593,045	975,249	
	South of Lake Beseka	Lake Water+Irrigation	1	1		B1-25	593,044	975,228	
	South of Lake Beseka	Lake Water	1	1		B1-26	594,247	974,998	
	South of Lake Beseka	Irrigation Water	1	1		B1-27	593,243	972,517	
	East of Lake Beseka	Lake Water	1	1		B1-28	598,897	980,437	
	East of Lake Beseka	Lake Water	1	1		B1-29	596,741	978,173	
	East of Lake Beseka	Lake Water	1	1		B1-30	598,698	984,130	
			31	**20**					

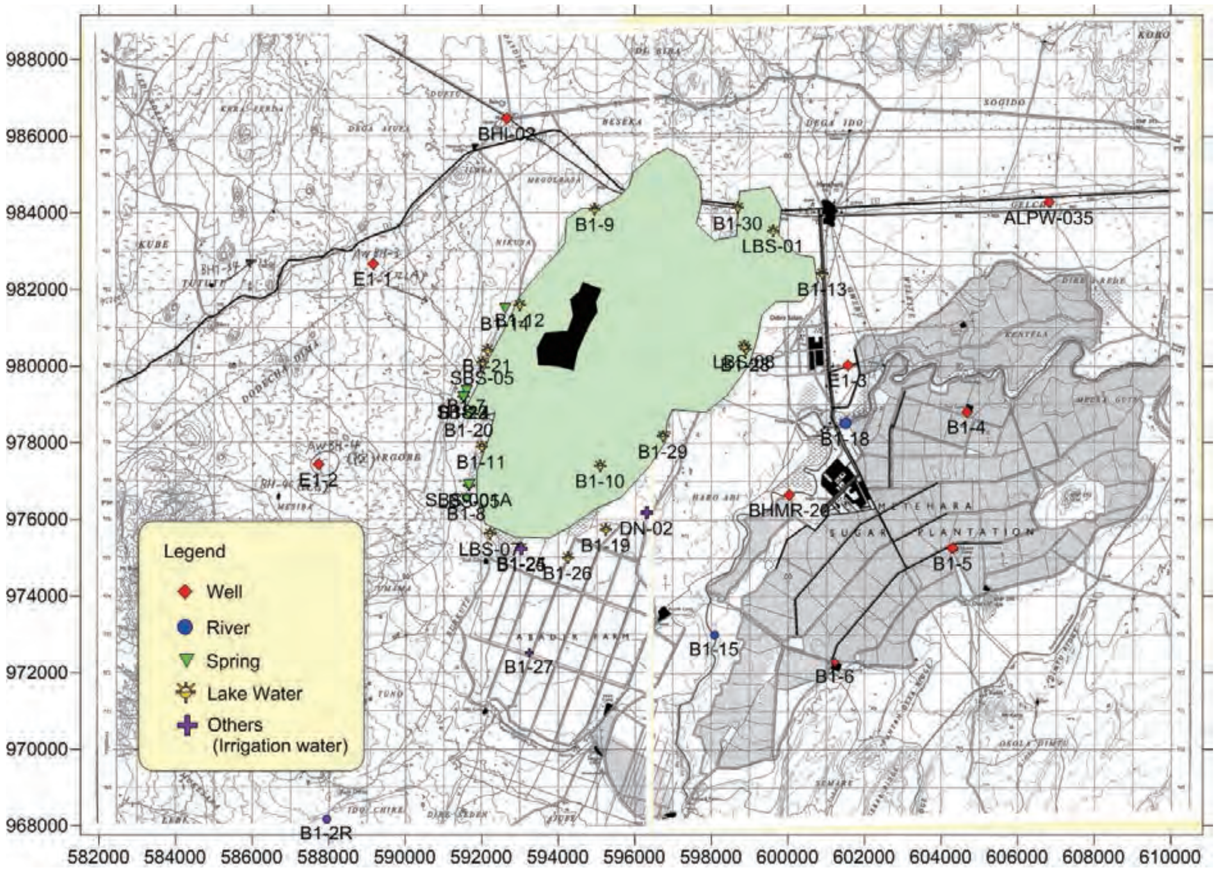
Source: the Project Team, Data: reference ④

Table 5.2.4: List of Existing Water Quality Data (around Lake Beseka)

Code	Easting	Northing	Resource	Remarks
LBS-01	599,618	983,534	Lake water	North East of Lake Beseka
LBS-08	598,860	980,515	Lake water	East of Lake Beseka
DN-02	596,308	976,168	Irrigation	South East of Lake Beseka
LBS-07	592,218	975,624	Lake water	South of Lake Beseka
LBS-05	591,670	976,881	Lake water	South West of Lake Beseka
SBS-4	591,533	979,204	Hot spring	West of Lake Beseka
SBS-05	592,019	980,096	Lake water	West of Lake Beseka
SBS-001A	591,669	976,913	Hot spring	South West of Lake Beseka
ALPW-035	606,822	984,277	Existing well	Depth; 595m (WWDSE,2015)
BHMR-20	600,048	976,634	Existing well	Same to Be12, Depth;48m
BHI-02	592,664	986,463	Existing well	Same to Be4, Depth; 53m

Source: the Project Team, Data: reference 4) of ①, 5) of ②

The sampling points and existing water quality testing points are shown in Figure 5.2.10.



Source: the Project Team, Data: reference ④

Figure 5.2.10: Location Map of Water Quality Testing Points around Lake Beseka

a. Characteristic of water quality by Trilinear Diagram

The results of the water quality testing around Lake Beseka are seen in the annex of this chapter. The Trilinear Diagram is shown in Figure 5.2.11 using the main ions. Figure 5.2.11 shows the following results and interpretations.

- The river and irrigation water (this canal water is classed as “others”) belong to the

$CaHCO_3$ type of water quality, and shows the same behaviour as surface water. Irrigation water sampled near Lake Beseka indicates a $NaHCO_3$ type due to the effects of Lake water.

- Both existing and JICA wells around Lake Beseka have been located in the west and east of Lake Beseka, and the depth of each well is different. However, with the exception of a few wells, those wells belong to the $NaHCO_3$ type of retarded deep groundwater. In the Trilinear Diagram, one well is plotted at a range of shallow groundwater by the effect of the shallow well, and a well belong to the $NaSO_4$ type containing the SO_4 and Cl ions. The water quality of the groundwater of each well is not affected by Lake Beseka's water because the water quality of both existing and JICA wells do not change as a whole even if the location of each well is different.

- The (hot) springs are located in the west and south west of Lake Beseka. It is difficult to find out the accurate points of the springs in the current situation because the springs have been submerged under the Lake. However it can be assumed to spring the groundwater along the flow line from the west and south west of Lake Beseka based on the groundwater level contour map as mentioned above. The characteristic of the springs belongs to the same type of both existing and JICA wells plotted in the $NaHCO_3$ type.

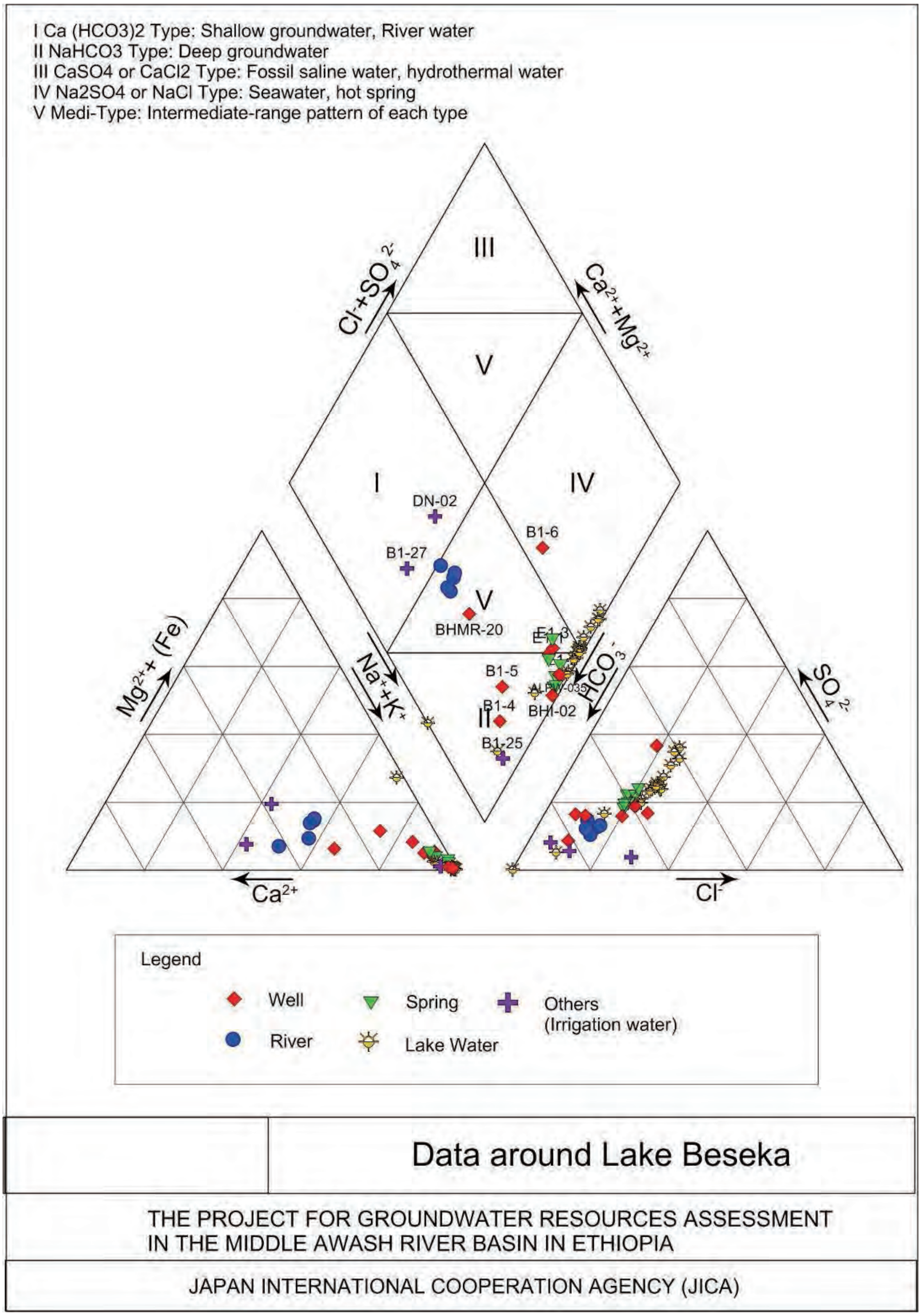
- The lake water shows the $NaHCO_3$ and Na_2SO_4 or NaCl types in the Trilinear Diagram, and the water quality of the lake water has the retarded deep groundwater characteristics as well as hot spring characteristics (near the component of the sea water). The lake water is affected by the spring, clearly having the same component. In other words, according to the assortment of the main ions, the water quality of the lake water is directly affected by the groundwater and spring.

- The change of anion and cation appears like the trace below in response to the retarded time and flow distance of the groundwater. This is generally called "the water quality evolution of the groundwater".

  Anion: $HCO_3^- \rightarrow HCO_3^- + SO_4^{2-} \rightarrow SO_4^{2-} + HCO_3^- \rightarrow SO_4^{2-} + Cl^- \rightarrow Cl^- + SO_4^{2-} \rightarrow Cl^-$

  Cation: $Ca^{2+} \rightarrow Ca^{2+} + Na^+ \rightarrow Na^+$

  In the Trilinear Diagram, the type of the water quality is changed from I to II and IV. This is the change of the water quality of the groundwater in accordance with the retarded time, and Figure 5.2.11 shows the change of ion from river water to spring and lake water. The river water is plotted near I type, the groundwater and spring is plotted in II type and almost all of the lake water belongs to the IV type. In other words, the lake water is strongly affected by the water quality of the groundwater and spring compared to that of river and irrigation water.

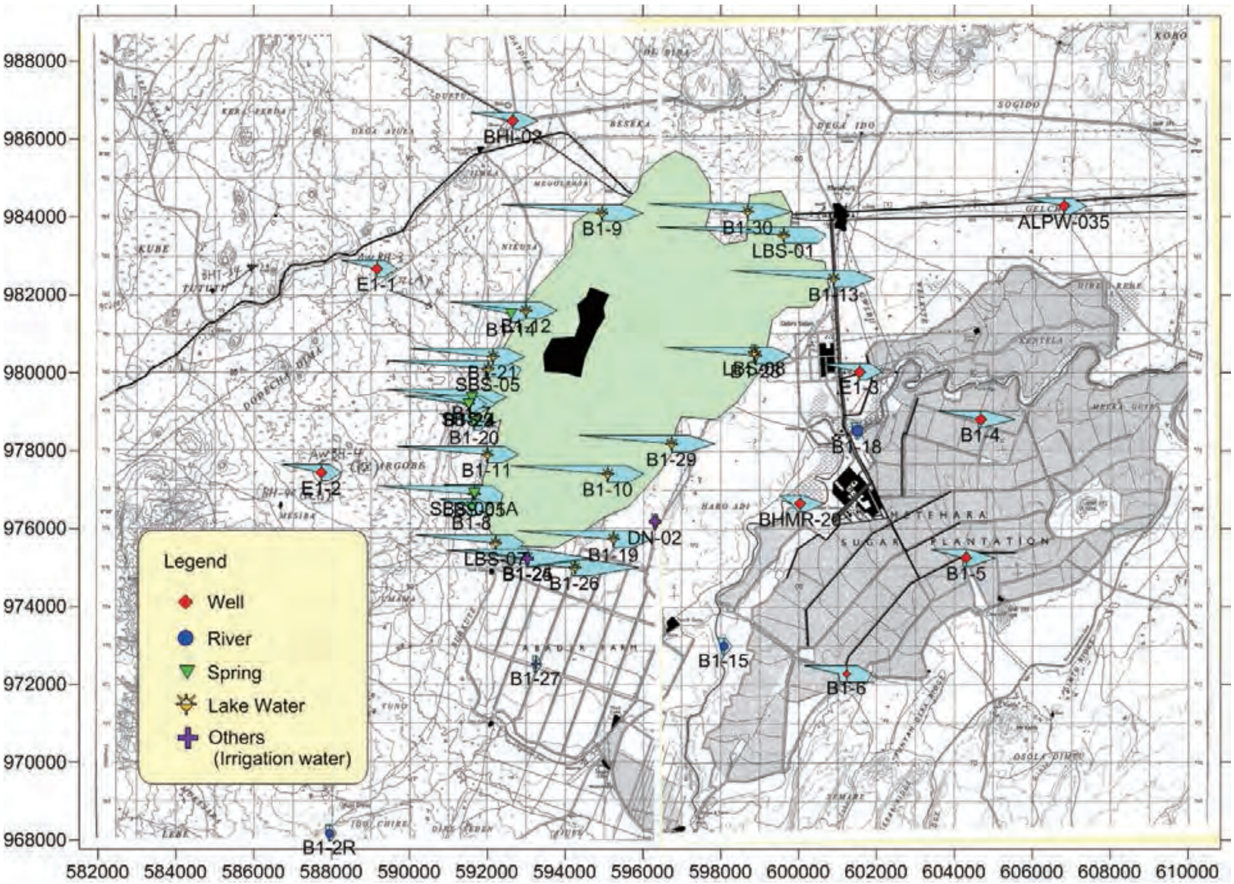


Source: the Project Team, Data: reference ④

Figure 5.2.11: Trilinear Diagram around Lake Beseka

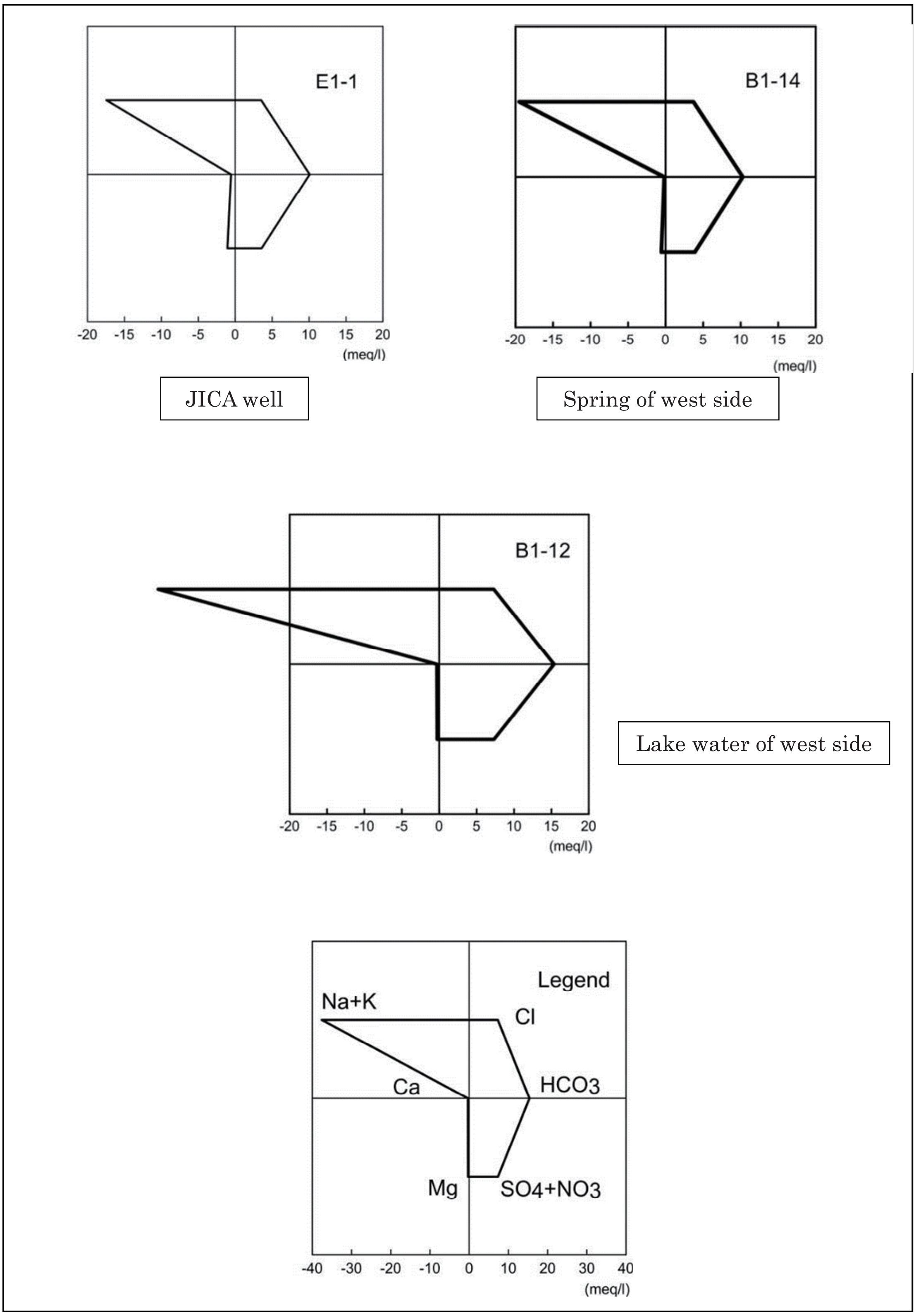
b. Characteristic of water quality by hexadiagram

The hexadiagram contains concentration information and total salinity weight, and can be used to represent water quality visually as mentioned in Chapter 2. The sampling points and existing data points with the hexadiagram are shown in Figure 5.2.12. The hexadiagrams at points of west to south west and south of Lake Beseka having possibilities for inflow into Lake Beseka from its surrounding area are shown in Figure 5.2.13, Figure 5.2.14 and Figure 5.2.15, respectively.



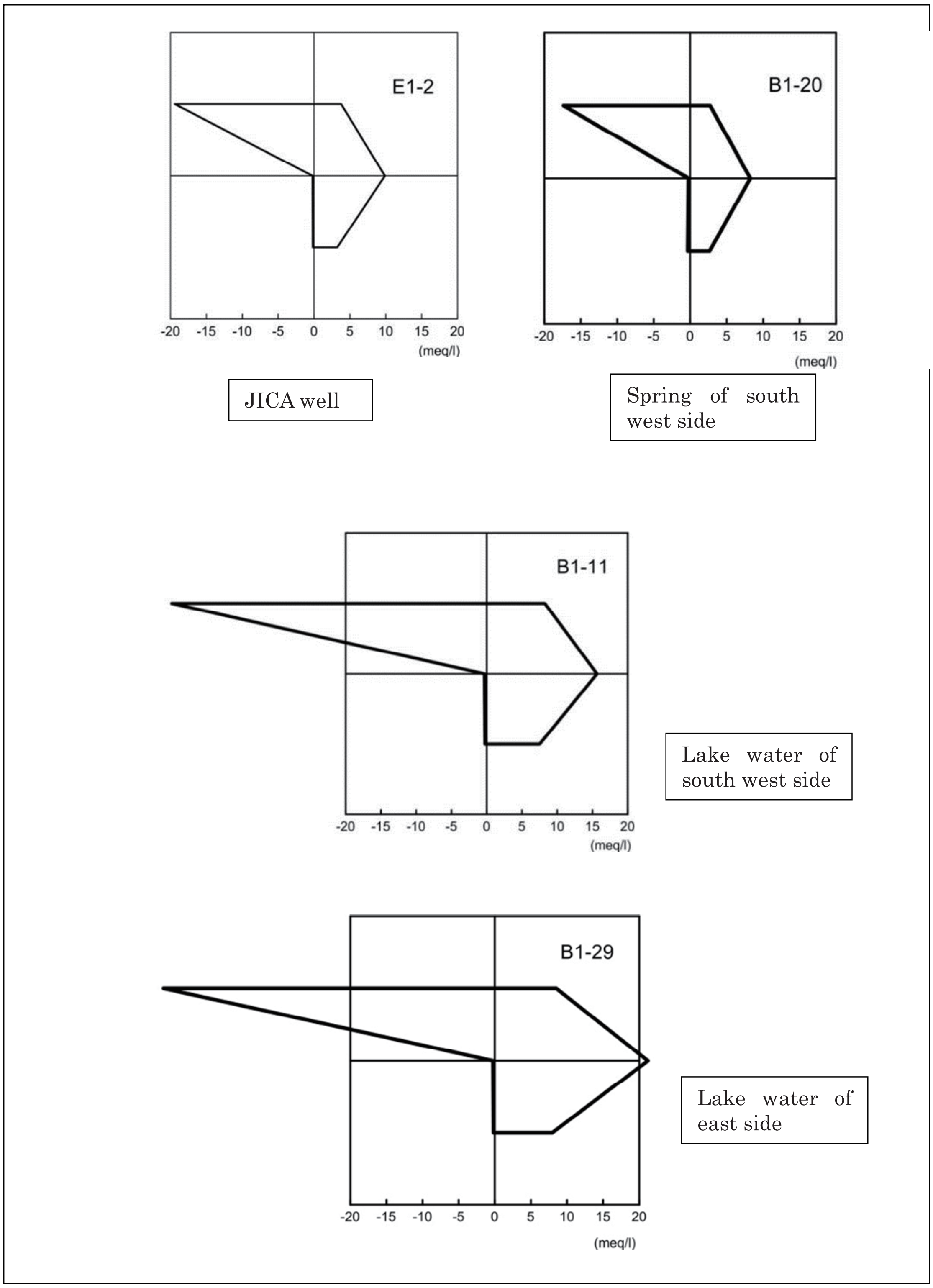
Source: the Project Team, Data: reference ④

Figure 5.2.12: Hexadiagram at Sampling Points around Lake Beseka



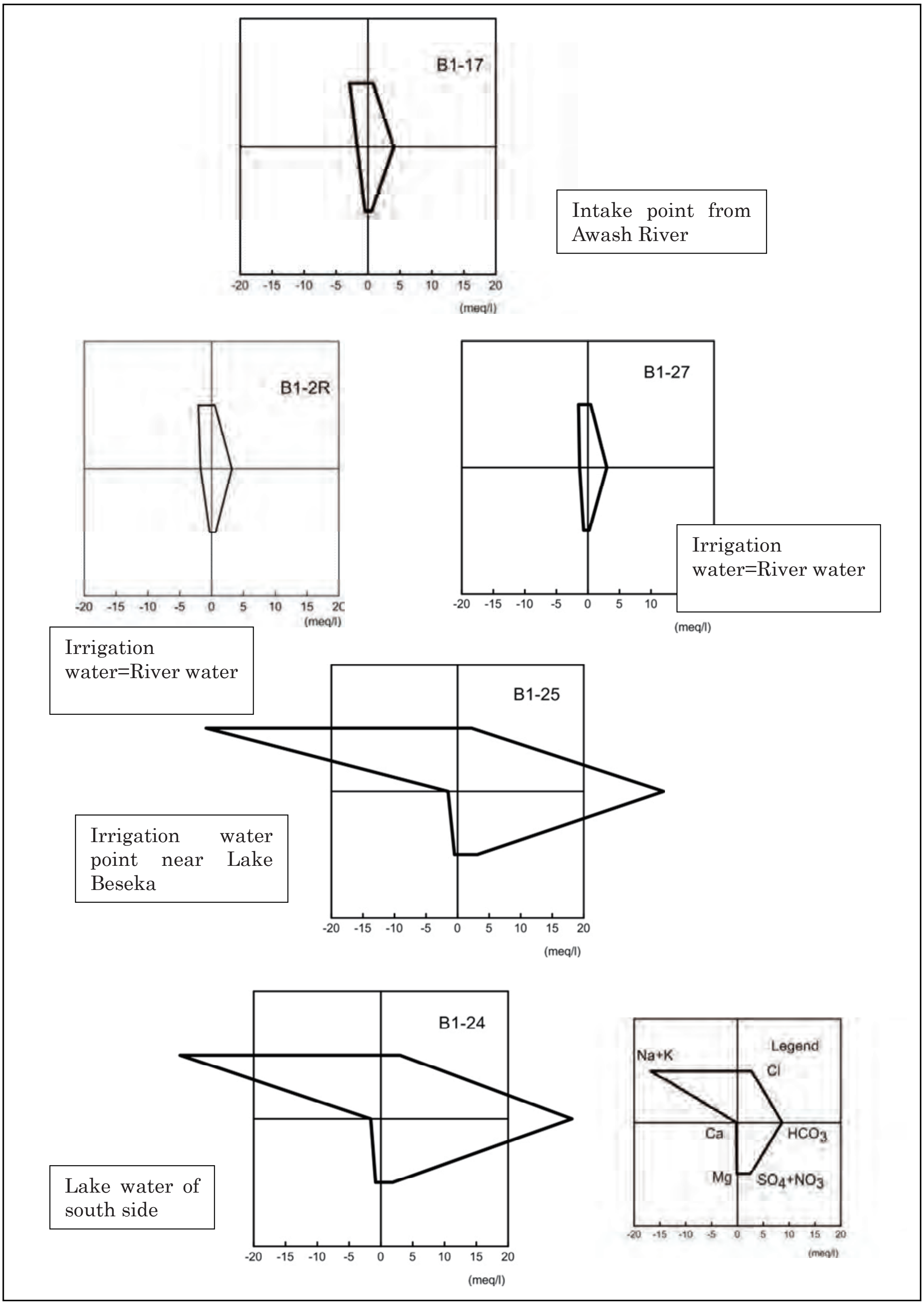
Source: the Project Team, Data: reference ④

Figure 5.2.13: Hexadiagram of Main Sampling Points at West of Lake Beseka



Source: the Project Team, Data: reference ④

Figure 5.2.14: Hexadiagram of Main Sampling Points at South West of Lake Beseka



Source: the Project Team, Data: reference ④

Figure 5.2.15: Hexadiagram of Main Sampling Points at South of Lake Beseka

These figures show the following results and hypotheses:

- The results of the hexadiagram for the groundwater from nine wells around Lake Beseka are shown in Figure 5.2.12. The water quality of these nine points belong to the

$NAHCO_3$ type. One point (B1-6) out of nine contains a high concentration of $Cl^-$and SO_4^{2-} ions compared to the that of other points. This point is plotted in the area of IV in the Trilinear Diagram and this is indicated by the effect deep groundwater. The depth of each well is 50 m to 595 m deep and there is considerable width. The main aquifer consists of basalt, and the groundwater of the each well indicates the retarded deep groundwater type. The river and irrigation water (this canal water is classed as “others”), belong to the $CaHCO_3$ type of water quality like the Trilinear Diagram, and the concentration is also thin compared to the other resource. The concentration and visual type of the spring are similar to that of the groundwater from wells. The type of the springs belongs to the retarded deep groundwater type, and the springs are affected by the groundwater from the west and south west of Lake Beseka. Figure 5.2.12 shows the lake water belongs to the Na-HCO_3 type and has a high concentration including high amounts of SO_4^{2-} and Cl^- ions,. As just described, the water quality of the lake water is affected by the inflow of the springs (groundwater), according to the hexadiagram. Generally, in the deep groundwater, the oxygen is consumed when the decay of organic matter and NO_3 and SO_4 disappear in the reductive environment. However, in the groundwater of wells around Lake Beseka, the NO_3 and SO_4 do not disappear. So the oxygenation may be slow (the retarded time is not so long).

- Figure 5.2.13 shows the hexadiagram of the groundwater of wells and springs around Lake Beseka as well as lake water. The hexadiagrams of the springs resemble the groundwater of wells in shape and concentration. The Na of springs increases a little bit because the springs retain the Na during the inflow of groundwater to springs because Na has a soluble aspect in water. The Na, SO_4, Cl and HCO_3 ions increase in the Lake water keeping the characteristic of the springs. In particular, the concentration of the HCO_3 ion increases in the Lake water due to carbon dioxide existing as the atmosphere in the air reacts with the water. Figure 5.2.14 also shows the same situation like Figure 5.2.13. In the east of Lake Beseka, HCO_3 and other anions also tend to increase because of the long retarded time in Lake Beseka.

- The change of the water quality in the lake water at the south area of Lake Beseka is shown in Figure 5.2.15. In this figure, the water quality among the river water, irrigation water, and lake water is compared. The water quality of the river water and irrigation water include the Ca ion compared to that of the groundwater, springs and lake water at the west and south-west of the Lake Beseka. Therefore, Ca is found in the Lake water and the water between the lake and the irrigation area (refer to the points of B1-24 and B1-25 belonged to the $NaHCO_3$ type). B1-25 was collected between the lake and the irrigation area, but the water quality of B1-25 is affected by that of the lake water. The HCO_3 has high values while SO_4 & Cl have low values at the south area of Lake Beseka. It is highly probable that it is affected by the vegetation of the sugar cane at the irrigation area of southern Lake Beseka.

- The lake water is affected in totality by the groundwater and springs according to the hexadiagram. On the other hand, lake water at the south area is affected by the river and irrigation water due to the existence of Ca ion. However, according to the hexadiagram, aside from the south area of Lake Beseka, the entire lake water is not affected by the river water because there is no Ca ion in the water throughout the whole of Lake Beseka.

- The component and visual type of the lake water is very similar to that of springs even if there is a difference of the concentration according to the hexadiagram. It is hypothesized that the springs are concentrated from evaporation and the concentration of the lake water is made in these environments. As mentioned above, the analysis results indicate the present lake water is not influenced by the river water regardless of the existence of Ca ion.

- Although this conclusion mentioned above cannot directly account for Lake Beseka's dramatic water rise, the water quality of almost all the lake water suggests the effect of the groundwater (springs) from the characteristic of the hexadiagram.

c. Isotope analysis

Isotope analysis was conducted by the IAEA in regard to the groundwater of JICA wells. On the contrary, isotope analysis of the river waters (including irrigation water), springs and lake waters around Lake Beseka were carried out in AAU and the analysis results were utilized for useful information for tracing the source of waters. The sampling points analysed and the results of the isotope analysis are shown in the Table 5.2.5.

Table 5.2.5: Results and List of Isotope Analysis

Detailed Place	Type of Water Sources	Location ID (Sample ID)	Reference Coordinate		Date of Sampling	$\delta\,^2$H (‰)	$\delta\,^{18}$O (‰)
			Easting	Northing			
Around Ombole (Hombole)	Awash River Water	A1-1(D)	475,873	925,842	2015/1/16	-2.69	-1.31
Around North of Gefersa	Awash River Water	A1-2(D)	525,365	937,096	2015/1/10	5.81	-0.16
Around Awash Melkasa	Awash River Water	A1-3(D)	536,207	927,203	2015/1/10	9.11	0.35
Around Doni	Awash River Water	A1-4(D)	562,223	940,652	2015/1/15	8.43	-0.07
East of Metehara Sugar Plantation	Awash River Water	A1-5(D)	611,191	977,348	2015/1/15	15.39	1.89
Lake Koka	Mojo River Water	A1-7(D)	506,888	929,588	2015/1/16	6.08	0.36
Along Wast of Lake Beseka	Spring	B1-14	592,612	981,509	2014/7/7	-14.38	-2.76
In Metehara Plantation	Awash River Water	B1-15	598,077	972,974	2014/7/8	-12.78	-1.42
From Nura Hera Farm	Awash River Water	B1-16	592,729	967,092	2014/7/8	-11.22	-0.86
Middle Awash River	Awash River Water	B1-17	596,078	965,762	2014/7/8	-3.88	-1.06
Metehara SP	Awash River Water	B1-18	601,502	978,505	2014/7/9	-12.58	-1.02
South of Lake Besaka	Lake Besaka Water	B1-19	595,246	975,723	2014/7/9	31.64	3.29
Tone Spring	Spring	B1-20	591,674	978,734	2014/7/9	2.55	-1.74
West of Lake Beseka	Lake Water	B1-21(D)	592,146	980,409	2015/1/8	16.41	2.69
West of Lake Beseka	Spring	B1-22(D)	591,536	979,199	2015/1/8	-9.56	-2.68
West of Lake Beseka	Lake Water	B1-23(D)	591,532	979,193	2015/1/8	9.79	1.04
South of Lake Beseka	Lake Water	B1-24(D)	593,045	975,249	2015/1/9	25.55	2.97
South of Lake Beseka	Lake Water+Irrigation	B1-25(D)	593,044	975,228	2015/1/9	34.28	4.81
South of Lake Beseka	Lake Water	B1-26(D)	594,247	974,998	2015/1/9	21.64	2.94
South of Lake Beseka	Irrigation Water	B1-27(D)	593,243	972,517	2015/1/9	6.45	0.19
East of Lake Beseka	Lake Water	B1-28(D)	598,897	980,437	2015/1/9	25.77	4.55
East of Lake Beseka	Lake Water	B1-29(D)	596,741	978,173	2015/1/9	25.41	4.49
East of Lake Beseka	Lake Water	B1-30(D)	598,698	984,130	2015/1/9	26.26	4.44
Around Lake Besaka (AW BH-3)	New Well	E1-1	589,167	982,682	2014/8/9	-9.79	-2.65
Around Lake Besaka (AW BH-4N)	New Well	E1-2	587,754	977,437	2014/11/12	-9.75	-2.72
Around Lake Besaka (AW BH-5)	New Well	E1-3	601,565	980,024	2014/4/2	1.65	-1.08
Around Feto (AW BH-6)	New Well	E1-4	552,789	958,778	2015/8/11	-33.1	-6.24
Between Doni and Bofo (AW BH-9)	New Well	E1-6	555,025	936,983	2014/9/22	-12.87	-3.55
Around Sire (AW BH-11)	New Well	E3-2	553,313	916,009	2015/4/3	-12.2	-3.03
Around Balchi (AW BH-1)	New Well	E4-1	542,642	985,361	2015/4/8	-11.78	-3.11
Around Melka Jiro (AW BH-2)	New Well	E4-2	567,414	980,822	2015/7/21	-27.3	-6.10
Around Dehaye (AW BH-12)	New Well	E4-3	550,405	1,027,427	2014/10/20	-30.59	-5.41

*New wells were analyzed by IAEA

Source: the Project Team, Data: reference ④, analyzed by AAU and IAEA

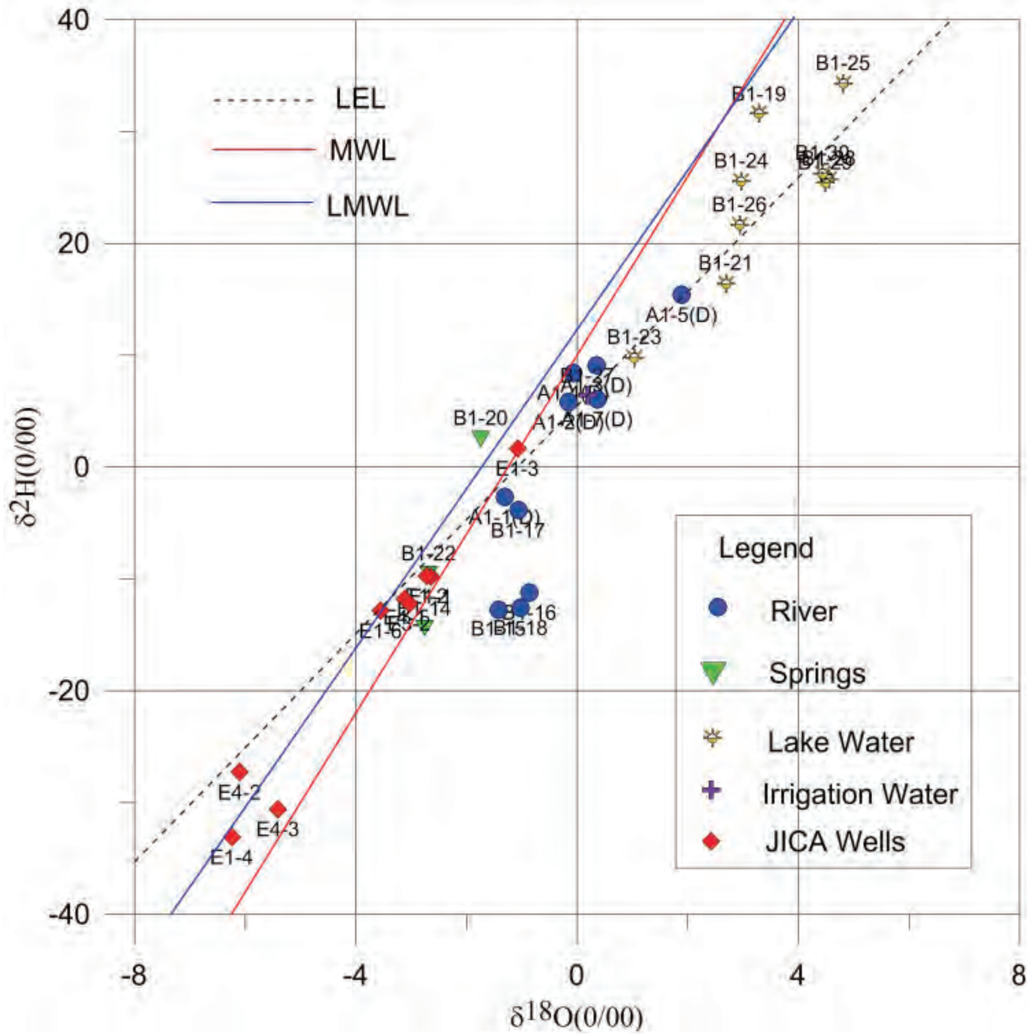
In stable isotopes in water, ^{2}H (D) of mass number 2, and ^{18}O of mass number 18 were used for the analysis. A water molecule consists of these atoms, and these are contained in the river and groundwater in high concentration (high compared to the other concentrated components). These isotope molecules are ideal tracers for the comprehension of groundwater flow in the hydrologic cycle because they do not have a chemical reaction with other matter like dissolved matter.

The results of the analysis for the stable isotopes are shown in Figure 5.2.16 as delta (δ) diagram. Generally, the straight line for precipitation and surface water is made using plotted points of precipitation around the world. This line is called the Meteoric Water Line (hereafter refer to as "MWL") as $\delta D = 8\delta^{18}O+10$.

As the formation temperature decreases and the latitude increases, the isotopic ratio of precipitation decreases along the MWL. This is called the temperature effect or latitude effect. Moreover, when the precipitation increases, the isotopic ratio decreases in what is called the precipitation effect. Isotopic ratio at higher elevations decreases or when the precipitation moves toward continental regions, isotopic ratio has a tendency to decrease. The former is called the altitude effect, and the latter is called the continental region effect.

Meteoric waters do not always plot on MWL, as they are affected by various local and regional factors such as source of moisture, extent of evaporation during rainfall, altitude, and so on. For instance, the line that is formed by plotting δ^2H and $\delta^{18}O$ for specific regions is called the Local Meteoric Water Line (hereafter referred to as "LMWL"). Records from 1964 to 2004 were used to establish the LMWL, and the line defined by the relation $\delta D = 7.12\delta^{18}O+12.3$ with a regression coefficient (r^2) of 0.93. Figure 5.2.16 includes MWL and LMWL.

The isotopic ratio of the precipitation or groundwater and river water derived from rainfall is plotted near the MWL. The δ value of the groundwater is similar to that of precipitation as the weighted mean near the point of groundwater. For the isotopic ratio of springs, one outcrop of groundwater was plotted near the LMWL. It is possible it was derived from the Addis Ababa rainfall in Figure 5.2.16. The isotopic ratio of river water can be plotted with three groups as a whole in Figure 5.2.16. The river waters marked by (D) including A1-5 (D) sample are plotted at a relatively high isotopic ratio. As these samples were collected in the dry season, it is possible to recognize the precipitation effect. Also, sample A1-5 (D) is influenced by the lake water because the sampling point of is located downstream of Lake Beseka. The low isotopic ratio group of the river waters is located below MWL. This group reflects the precipitation effect because of the sampling was done in the rainy season. The lake waters are plotted in the lower right below the MWL. The lake is characterized by an enriched composition compared to their inflows due to the isotopic fractionation during the evaporation process. Consequently, the isotopic ratio of evaporating lake plots below the MWL, along a line called Local Evaporation Line (hereafter referred to as "LEL"). The slope of LEL is found mainly from 3.5 to 6, and depends on local climate factors. The lake waters with some river waters plot along the LEL are defined by the relation $\delta D = 5.1\delta^{18}O+5.5$ in reference to Eleni, 2009. The LEL intersects the LMWL at the isotopic value of -3.40‰ in $\delta^{18}O$ and -11.84‰ in δ^2H (refer to Figure 5.2.16). As this isotopic value is comparable to the isotopic ratio of the groundwater in the up watershed, it was discussed in the flow system of the western part of the watershed. The average δ values of the groundwater in JICA wells (AW BH-1, 3, 4N, 9, and 11) taken in the western part of the watershed is characterized by an isotopic ratio of -3.01‰ in $\delta^{18}O$ and -11.28‰ in δ^2H (refer to Figure 5.2.16). This value is similar to that of the intersected point of LEL. This suggests that the inflow to Lake Beseka comes from the groundwater at the western and northwest part of the watershed. For example, Eleni, 2009 described the isotopic value of -2.8‰ in $\delta^{18}O$ and -10.7‰ in δ^2H as the average of the groundwater system in the western part of the lake watershed.



Source: the Project Team, Data: reference 5) of ①, and ④

Figure 5.2.16: Delta Diagram of Stable Isotope around Lake Beseka

d. Tritium Analysis

The results of the tritium analysis and sampling points are shown in Table 5.2.6 below. The sampling of groundwater with JICA wells will be carried out from now. A1-1 (D) to A1-7 (D) are samples from the Awash River, B1-21 to B1-30 are almost all lake waters and B1-22 and B1-27 are sampled from spring and irrigation water respectively.

Table 5.2.6: List of Points for Tritium Analysis

Detailed Place	Type of Water Sources	SL. No.	Location ID (Sample ID)	Reference Coordinate		Final Result TU±0.5σ
				Easting	Northing	
Around Ombole (Hombole)	Awash River Water	1	A1-1(D)	475,873	925,842	**2.33**
Around North of Gefersa	Awash River Water	2	A1-2(D)	525,365	937,096	**2.25**
Around Awash Melkasa	Awash River Water	3	A1-3(D)	536,207	927,203	**2.23**
Around Doni	Awash River Water	4	A1-4(D)	562,223	940,652	**2.17**
East of Metehara Sugar Plantation	Awash River Water	5	A1-5(D)	611,191	977,348	**2.19**
Lake Koka	Mojo River Water	6	A1-7(D)	506,888	929,588	**2.32**
West of Lake Beseka	Lake Water	7	B1-21	592,146	980,409	**2.21**
West of Lake Beseka	Spring	8	B1-22	591,536	979,199	**2.35**
West of Lake Beseka	Lake Water	9	B1-23	591,532	979,193	**2.30**
South of Lake Beseka	Lake Water	10	B1-24	593,045	975,249	**2.26**
South of Lake Beseka	Lake Water+Irrigation	11	B1-25	593,044	975,228	**2.14**
South of Lake Beseka	Lake Water	12	B1-26	594,247	974,998	**2.27**
South of Lake Beseka	Irrigation Water	13	B1-27	593,243	972,517	**2.25**
East of Lake Besek	Lake Water	14	B1-28	598,897	980,437	**2.13**
East of Lake Besek	Lake Water	15	B1-29	596,741	978,173	**2.36**
East of Lake Besek	Lake Water	16	B1-30	598,698	984,130	**2.29**
Around Lake Besaka (AW BH-3)	New Well	17	E1-1	589,167	982,682	-
Around Lake Besaka (AW BH-4N)	New Well	18	E1-2	587,754	977,437	-
Around Lake Besaka (AW BH-5)	New Well	19	E1-3	601,565	980,024	-
Around Feto (AW BH-6)	New Well	20	E1-4	552,789	958,778	**2.43**
Between Doni and Bofo (AW BH-9)	New Well	21	E1-6	555,025	936,983	-
Around Sire (AW BH-11)	New Well	22	E3-2	553,313	916,009	-
Around Balchi (AW BH-1)	New Well	23	E4-1	542,642	985,361	-
Around Melka Jiro (AW BH-2)	New Well	24	E4-2	567,414	980,822	**3.01**
Around Dehaye (AW BH-12)	New Well	25	E4-3	550,405	1,027,427	-

Source: the Project Team, Data: reference ④, analyzed by AAU and IAEA

Tritium (^{3}H) is a radioactive hydrogen isotope with a half-life of 12.43 years and changes to ^{3}He by beta-decay. The tritium concentrations are almost parallel in the vapor of the troposphere. The usual concentration in the mid-latitude rainfall was 10 tritium units (hereafter refer to as “TU”). However, following atmospheric detonation of thermonuclear bombs after 1952, a large amount of tritium, in particular, 1000 TU was released into the atmosphere in the peak period between 1963 to 1964,. After that, the tritium concentration was back to a natural level of 5 to 10 TU in 1990 due to decreasing tritium concentrations year on year after the experiments were finished. The tritium content of lake waters is 2.245 TU on average, that of river waters indicates 2.248 TU on average and that of springs is 2.35 TU for one point. Seifu Kebede, et al, 2008 says the tritium concentration of the groundwater around Lake Beseka is 1.5 and 5.8 TU, and that of a hot spring in the Fentale volcano is 0.7 TU. Eleni Ayalew Belay, 2009 shows the tritium content of the rainfall in Addis Ababa is transitional from 5 to 15 TU from1984 to 1997. The value of tritium contents in this Study indicates a mixture of recharge from sub-modern (prior to 1953) and modern (after 1953) meteoric waters.

References

① Data on existing wells presented in existing research papers

1) Hydrogeology (Map) of the Nazret, EIGS, 1985
2) Evaluation of water resources of the Ada'a and Becho plans groundwater basin for irrigation development project, WWDSE, planned by MoWR, 2009
3) Allaidege plain groundwater resources assessment project, WWDSE planned by MoWR, 2009
4) Study and design of Lake Besaka level rise project II, WWDSE, planned by MoWE, 2011
5) Growing lake with growing problems: integrated hydrogeological investigation on Lake Beseka, Ethiopia, ELENI AYALEW BELAY, 2009
6) Assessment and evaluation of causes for Beseka Lake level rise and design mitigation measures Part II: Study for medium and long term solutions (Main report final), MoWIE and OWWDSE, 2014

② Well development records, borehole logs and pumping test results

1) Existing well data (incl. borehole logs and pumping test results) from West Hararge Zone Water Office
2) Existing well data (incl. borehole logs and pumping test results) from Arsi Zone Water Office
3) Existing well data (incl. borehole logs and pumping test results) from East Shewa Zone Water Office
4) Well development records and individual well data in Arerti Woreda (Amhara Region) and Lomme Woreda (Oromia Region)
5) Data from irrigation well by WWDSE, 2014 (depth: 595 m)

③ Others

1) Hydrogeological map of Ethiopia (1:2,000,000) compiled by Tesfaye Chernet and the Regional Geology Department, EIGS, 1988

④ Data including photographs taken by the Project Team though field survey, analysis and interviews etc.

⑤ Study of Lake Beseka, Ministry of Water, 1999

⑥ Study and Design of Lake Beseka Level Rise Project II, WWDSE, planned by MoWIE, 2011

⑦ Irrigation Water Management: Irrigation Scheduling, 1989 (http://www.fao.org/docrep/t7202e/t7202e00.htm#Contents)

⑧ FAO Crop Water Information (http://www.fao.org/nr/water/cropinfo_sugarcane.html)

⑨ Manual for CROPWAT version 5.2. FAO, Rome. 45pp.

⑩ Growing Lake with Growing Problems: Integrated Hydrogeological Investigation on Lake Beseka, Ethiopia, Eleni Ayalew Belay, 2009

⑪ Buxton, D.R. (1949): "Travel in Ethiopia" – Centre national de la recherche scientifique (CNRS), France.

⑫ EIGS (Ethiopian Institute of Geological Survey) and ELC (Elc electroconsult milano and Geotermica italiana pisa, Italia) (1987): Geothermal reconnaissance study of selected sites of the Ethiopian rift system, Geotherm. Report, Milan, Italy.

⑬ Gibson I.L. (1970): "A pantelleritic welded ash-flow tuff from the Ethiopian Rift Valley" - Contr. Mineral and Petrol., 28, 89-111.

⑭ Kazmin, V. and Berhe, S. M. (1978): Geology and Development of the Nazret Area, Northern Ethiopian Rift, Ethiopian Institute of Geological Survey Report.

⑮ Mohr, P.A. (1960): Report on a geological excursion through southern Ethiopia. Geophys. Observatory of Addis Ababa Bull., 3, 9-20.