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Hydrogeological and Hydrochemical Maps of Jima NB 37 – 1 Sheet
Explanatory Notes

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Extended Summary

The Jima area is located in Southeastern Ethiopia on the Jima map sheet (NB 37-1) at the scale of 1:250,000, covering an area of 18,287 km². The area is a part of the Oromia and Southern Nations, Nationality and People (SNNPR) regional states and is inhabited by 2,994,062 million people. A substantial part of the Jima area in the west is covered by forest and the eastern part is represented mainly by cultivated land.

The highest peak of the study area lies to the west of Ameya. Elevation ranges from 2,500 to 3,348 m a.s.l. in the area of Girawa. The dissected gorges represent areas between 1,000 and 2,000 m.a.s.l. The lowest area of the map sheet lies in the Omo river gorge, which lies at less than 1,000 m.a.s.l. The area is mainly part of the Omo-Gibe, but also Abay and Baro basins. The rainy season within the area passes from March to May and from July to October. The mean annual rainfall is from 1,600 to 2,000 mm. There are several permanent (Gojeb, Gilgel Gibe, Omo) and several intermittent rivers. Specific surface runoff was adopted as a value of 15 l/s.km². The adopted value of specific baseflow is 5. l/s.km², representing 30 and 10 % of precipitation. The area shows moderate drought probability throughout the year.

The aquifer system has been defined based on the hydrogeological characteristics of lithological units described by the geological maps and data from the field inventory and desk study. The characterization of the area shows the following aquifer/aquitard systems:

1. Extensive and moderately productive or locally developed and highly productive porous aquifers (T = 1.1–10 m²/d, q = 0.011–0.1 l/s.m, with spring and well yield Q = 0.51–5 l/s). The aquifers consist of Quaternary alluvial deposits and stratified tuffs.
2. Extensive and moderately productive fissured aquifer (T = 1.1–10 m²/d, q = 0.011–0.1 l/s.m, with Q = 0.51–5 l/s). The aquifers consist of basalts and trachyte.
3. Extensive and moderately or locally developed and highly productive mixed porous and fissured aquifers (T = 1.1–10 m²/d, q = 0.011–0.1 l/s.m, with spring and well yield Q = 0.51–5 l/s). The aquifers consist of volcanic, sedimentary and pyroclastic rocks.
4. Formation consisting of a minor fissured aquifer with local and limited groundwater resources – Aquitard. The formation consists of the trachyte plugs and phonolite.

The water balance, hydrograph separation and Kille methods show that the infiltration coefficient (recharge) varies by about 10 % of the total precipitation. A majority of the groundwater infiltrates directly from precipitation and groundwater flows laterally to local and/or regional drainage base levels represented by rivers in valleys or flows vertically recharging deeper aquifers. This type of frontal recharge occurs in the aquifers developed in unconsolidated sediments and volcanic rocks. The lateral discharge contributes to aquifers developed in unconsolidated sediments of grabens. The intermittent and ephemeral rivers and flood episodes of perennial rivers contribute significantly to the recharge of aquifers along river banks. Bank recharge provides a relatively large amount of good quality groundwater with low TDS for development in the alluvial aquifers.

The chemistry of groundwater in the Jima area reflects the hydrological (aquifer) system and system of groundwater circulation and its variability in the geology and hydrogeology of the area consists of different volcanic rocks partly intercalated with sedimentary and volcano-sedimentary rocks. The

dominant hydrochemical types of groundwater in the study area are calcium-magnesium-bicarbonate. The second most common chemical type is sodium-bicarbonate. Groundwater TDS varies from 100 mg/l to 200 mg/l and practically all water samples are convenient for drinking when compared to drinking water standards. The use of groundwater can be limited by pollution particularly of a human and animal origin and some samples show increased concentrations of nitrates in addition to high fluoride.

The total amount of water resources of the area has been assessed to be 8,656 Mm³/year. The use of surface water for irrigation is the most important development factor and some of the fresh surface water of the big rivers can be used for irrigation using dams of different scales.

The total volume of renewable groundwater resources of active aquifers in the area has been assessed to be 2,885 Mm³/year. Considering the total number of people living within the area is 2,994,062 million the need for water supply can be nearly 22 Mm³/year (20 l/c.d). The figure shows that recent demand represents less than 1 % of the renewable groundwater resources of active aquifers, meaning that aquifers can provide adequate drinking water even in the future considering the trends in population growth and can also be used for supplying areas adjacent to the Jima sheet.

Most of the people within the area live in towns of varying population and villages, which are mainly supplied from drilled wells. In addition to further development of dug wells, water supply based on drilled wells represents the most sanitary secure water and should be applied for towns as well as for rural inhabitants. Technically, it is recommended to drill wells as follows:

- In aquifers developed in volcanic rocks with a depth of about 40–150 m. Each of the wells can yield about 2 l/s (recent average) to 10 l/s. Each of these wells can provide 172,800 l/d to 86,400 l/d and can supply a town or group of villages with about 8,000 to more than 40,000 inhabitants considering a daily consumption of 20 l/c.d with good quality groundwater.
- In aquifers developed in alluvial rocks with a depth of about 50–100 m with very little drawdown. Each of the wells can yield about 2 l/s (expected average). Each of these wells can provide 172,800 l/d and can supply a small town or group of villages with about 8,640 inhabitants considering a daily consumption of 20 l/c.d with good quality groundwater.

Drilling should be done in sites without an adequate water supply, the quality of water at the existing water source is not safe for drinking purposes, and where groundwater resources exist but they are not effectively utilized. Drilling sites should be selected and tested by geophysical measurements (VES).

The minimum required distance of water supply wells and potential pollution sources should be maintained during the development of groundwater resources for towns and rural settlements. In addition to priority in development of groundwater for safe drinking water supply, it should be possible to select the most fertile soil to be developed by small scale irrigation and livestock watering based on groundwater to increase the stability of food supply in prolonged periods of drought in the Jima area.

Soil erosion and protection is one of the limiting factors of sustainable development of agriculture within the area and should be addressed in all development projects; however, soil erosion data for the area are scarce.

The work which is summarized in the presented explanatory notes shows the large water, agricultural, industrial and human potential of the Jima area.

Introduction

Background

Among the invaluable resources nature endowed us water is the most crucial for without it life cannot be sustained. Water can be abundant or scarce depending on the geological, climatic and topographic setting of a locality.

The area covered by the Jima map sheet is considered to be a moderate water scarce area in the southwestern part of the country. The topography coupled with increasing population aggravates environmental problems. It is therefore important to compile a map of water resources to be able to propose and implement appropriate protection measures during development efforts. In this context, a hydrogeological investigation was performed in the Jima sheet area in 2015 by the Geological Survey of Ethiopia. Publication of the project results was conducted in the framework of bilateral cooperation between the Czech and Ethiopian governments, where the participation of the Czech experts was financed by the Czech Development Agency in the framework of the Czech Republic Development Assistance Program. Participation of the Ethiopian professionals was financed by the Ethiopian government.

Objective and Scope of the work

The objectives of the hydrological and hydrochemical mapping of the Jima area (NB 37-1) at a scale of 1:250,000 with accompanying explanatory notes are to identify water bearing lithological units and their characteristics, indicate recharge and discharge areas and ground water flow direction, and categorize potential and quality variations. The main aims of this work are to define groundwater resources and their quality variations and to indicate the suitability of groundwater for different uses.

The desktop study and field work were carried out by a group of Ethiopian hydrogeologists. Final assessment and publication of the map were carried out by a joint Czech-Ethiopian team of professionals. The names of participating experts are shown in the following list.

Name	Institution	Participation filed
Jiri Sima	AQUATEST a.s.	Editor
Thomas Agezew	Geological Survey of Ethiopia	Hydrogeologist – group leader and the map compiler
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Romana Suranova	AQUATEST a.s.	Printing expert
Craig Hampson	AQUATEST a.s.	Language revision

1. Basic Characteristics of the Area

1.1 Location and Accessibility

The Jima map sheet (sheet No. NB 37-1, at a scale of 1:250 000) is located in the southwestern part of Ethiopia and covers about 18,000 km^2. The study area is located partly in the Oromia Regional State in the north and the Southern Nation Nationality People Regional State in the south. Geographically, the Jima map sheet area is located at a longitude of 36°00'00" and 37°30'00" east and a latitude of 7°00'00"and8°00'00" north. In general, the whole are of the Jima map sheet lies on the southwestern plateau of Ethiopia. The location of the map is illustrated in Fig. 1.1. The sheet is bounded by the NC 37- 13 Arjo sheet to the north, the NB 37 – 2 Hosaina sheet to the east, the NB 37 5 Dime sheet to the south and the NB 36-4 Jecha sheet to the west.

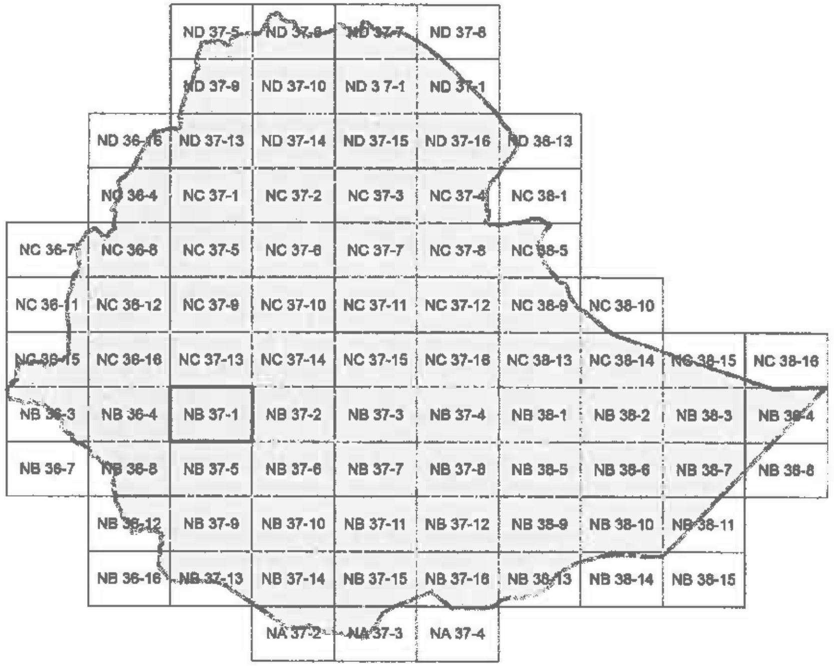


Fig. 1.1 Location map

The study area can be accessed by the roads connecting the capital city of Addis Ababa with the Sebeta — Tefki — Debre Genet — Dilela — Weliso — Tawla — Welkite — Kumbi — Sekoru - Jima asphalt road. There are many important all-weather and dry-weather gravel roads leading to different parts of the mapped area. Jima town, the capital of the Jima zone, is located 354 km away from Addis Ababa. The main accessible roads and settlements are shown in Fig. 1.2.

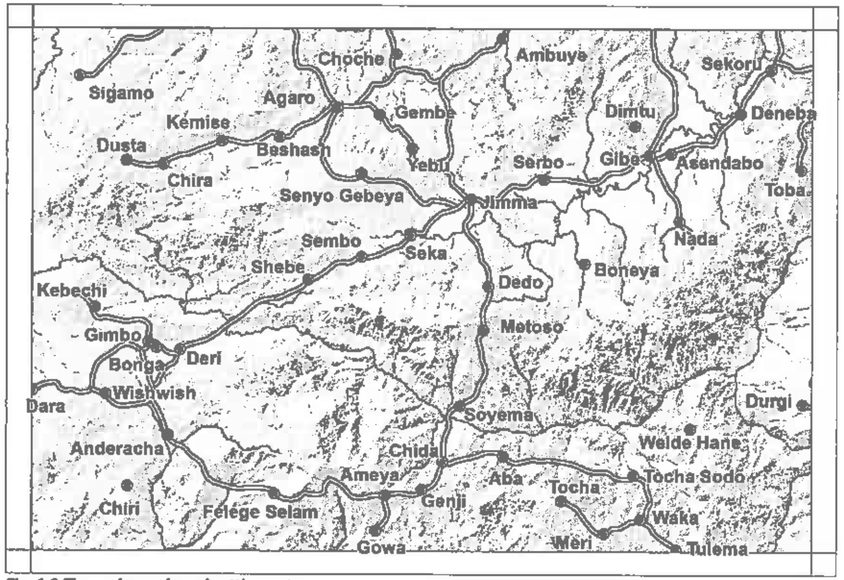


Fig. 1.2 The main roads and settlements

1.2 Population, Settlements and Health Status

The study area is administrated by two different regional states, the Oromia Regional State and the Southern Nation Nationality People Regional State. The Oromia Regional State (ORS) mostly covers the northeastern and northwestern parts of the map sheet and the people living there speak the Oromifa language. The Southern Nation Nationality People Regional State (SNNPRS) covers the southeastern and southwestern parts of the map sheet. The extent of this regional state is also reflected in its own culture and languages. Kaficho, Konta and Dawuro people live to the south of Gojeb. To the east of Omo the inhabitants are mainly Wolaita people. Kambata-Tambaro people live in the north and Yem people live in the northwestern part of the map.

The ORS is represented by the Jima Zone. The Kafa, Hadiya, Kembata Tembaro, Wollayita, Dawro Zone and Yewm special woredas belong to the SNNPRS. The study area consists of 7 zones and 39 Woredas. Most of the densely populated towns and villages are suited in the northern and southern parts of the plateau and Asendabo graben areas, and well known towns of Jima, Agaro, Asendabo and Bonga are also located there. According to the Federal Democratic Republic of Ethiopia Population Census (2007/2014) the population in the study area is 2,994,062 and detailed data are shown in Tab 1.1. and the location of the zones is shown in Fig. 1.3.

Tab. 1.1 Population in the study area

Region	Zone	Woreda	Woreda area in the mapped area		Total population	Assessed population in the mapped area
			[km²]	[%]		
Oromia	Jima	Agaro (1) town	8.18	100.00	37,447	37447
SNNP	Wolayita	Bolossa Bonibe (2)	4.90	18.03	2,021	364
SNNP	Keffa	Bonga Town (3)	1.36	100.00	39,837	39837
Oromia	Illu Aba B.	Dedesa (4)	0.37	0.44	104,786	461
Oromia	Jima	Dedo (5)	1515.89	100.00	352,497	352497
SNNP	Kefa	Decha (6)	971.66	32.84	152,128	49959
SNNP	Dawuro	Esira (7)	11.33	1.05	7,711	81
SNNP	Dawuro	Gena Bosa (8)	858.27	93.04	2,685	2498
Oromia	Jima	Gera (9)	1390.04	95.60	137,980	131909
SNNP	Keffa	Gewata (10)	379.31	41.87	84,285	35290
SNNP	Keffa	Gimbo (11)	817.83	99.23	110,558	109707
SNNP	Hadiya	Gombora (12)	19.28	4.17	106,912	4458
Oromia	Jima	Gomma (13)	780.77	90.29	262,462	236977
Oromia	Jima	Guma (14)	275.93	67.63	74,953	50691
SNNP	Keffa	Chena (15)	90.85	8.58	20,102	1725
SNNP	Keffa	Cheta (16)	113.17	16.50	38,569	6364
SNNP	Jima sp. z.	Jima Town (17)	50.52	100.00	177,943	177943
Oromia	Jima	Kerisa (18)	970.66	100.00	202,644	202644
SNNP	Wolaiyta	Kindo Koyisha (19)	42.07	7.99	125,052	9992
SNNP	Dawro	Konta Special (20)	701.04	29.44	110,600	32561
Oromia	Jima	Limu Kosa (21)	518.16	39.37	200,101	78780
SNNP	Hadiya	Loma (22)	33.12	2.83	137,687	3897
Oromia	Jima	Mana (23)	494.79	100.00	179,600	179600
SNNP	Dawro	Mareka (24)	327.40	70.07	158,959	111383
SNNP	Bench Maji	Meant Goldiya (25)	0.64	0.04	4,879	2
SNNP	Keffa	Menjiwo (26)	1056.80	99.11	5,479	5430
Oromia	Jima	Omonada (27)	1619.10	100.00	305,111	305111
SNNP	Keffa	Sayilem (28)	4.45	0.53	48,470	257
Oromia	Jima	Seka Chekorsa (29)	854.85	100.00	255,020	255020
Oromia	Jima	Sokoru (30)	383.35	38.15	9,169	3498
Oromia	Jima	Setema (31)	263.67	25.51	6,957	1775
Oromia	Jima	Shebe Senbo (32)	765.59	100.00	137,712	137712
Oromia	Jima	Sigmo (33)	453.52	64.53	113,742	73398
SNNP	Hadiya	Soro (34)	263.25	37.29	229,617	85624
SNNP	Kemb. Tibaro	Tibaro (35)	179.38	52.82	11,779	6222
Oromia	Jima	Tiro Afeta (36)	512.33	55.26	161,423	89202
SNNP	Dawro	Tocha (37)	721.46	94.44	123,099	116255
SNNP	Keffa	Tulo (38)	474.14	98.29	6,617	6504
SNNP	Yem	Yeme Special (39)	334.62	51.65	98,722	50990
Total						2,994,062

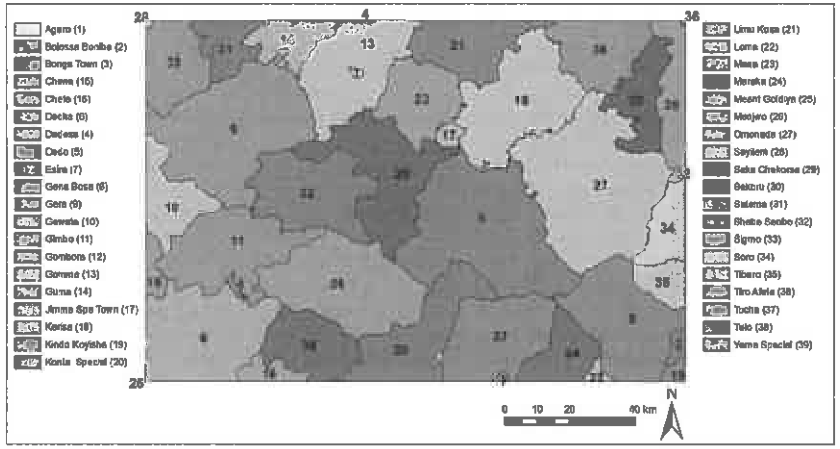


Fig. 1.3 Administrative zones (Woredas)

The rural population is mainly engaged in peasant farming with a mixed type of agricultural activity, including ploughing of cereal crops (for subsistence) and livestock breeding. They also breed horses, mules and donkeys. The urban population is mainly engaged in tertiary activity.

The major agriculture activity of the rural population of the Jima and Kafa zones is the plantation of coffee and these zones are among the best coffee producers in the country. Coffee is thought to have originated in this area, and the name coffee is derived from the local word Kafa. Agriculture in the other zones of the SNNPRS is subsistent and mainly involves the plantation of various types of fruit and vegetables.

Other activities performed throughout the study area include the keeping of bees, with beehives being common, as well as the plantation of enset, banana, sugar cane papaya and mango. Cereal crops such as maize teff, sorghum, barley and wheat are also known and local people also cultivate cabbage, beans, peas and lentils.

Access to safe drinking water is limited and some statistics suggest that only 15 % of the rural inhabitants have access to safe drinking water. The WHO (2006) statistics show that 31 % of the rural population has sustainable access to improved drinking water sources (96 % of the urban population). This low number is alarming because 70 % of contagious diseases are thought to be caused by contaminated water. This is a serious problem for Ethiopia in the effort to establish a strong agricultural community that will be able to safeguard the supply of food for the whole country. One of the priorities of government policy is therefore to provide safe drinking water to rural communities. To tackle the problem with safe water supply in towns and rural area three key ministries Health, Water Resources, Energy and Irrigation, and Education have joined to launch the National One WASH program, which provides a strategic framework for achieving a national vision for universal access to hygiene sanitation.

Ethiopia faces chronic problems with malaria (Fig. 1.4) which is endemic over 70 % of the country, and was once a scourge in areas below 1,500 m a.s.l. The western part of the the Jima sheet has a substantial malaria risk.

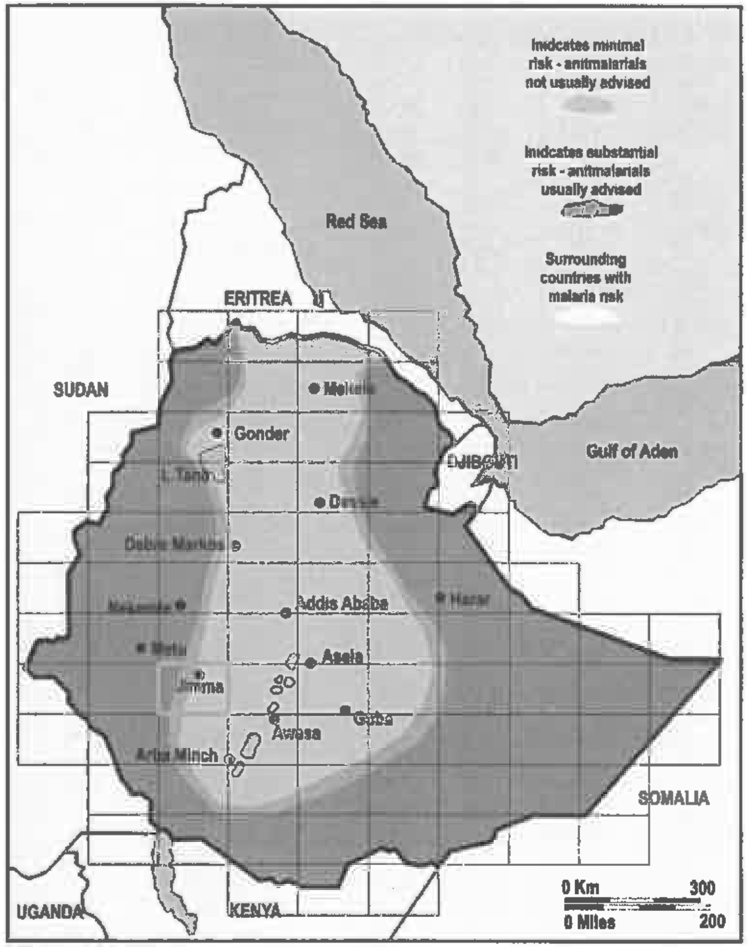


Fig. 1.4 Malaria risk in Ethiopia

1.3 Land Use and Land Cover

Poor land use practices, improper management systems and lack of appropriate soil conservation measures have played a major role in causing land degradation problems in the country. The land and water resources are in danger due to the rapid growth of the population, deforestation and overgrazing, soil erosion, sediment deposition, storage capacity reduction, drainage and water logging, flooding, and pollutant transport. In recent years, there has been an increased concern over climate change. A major effect of climate change is alterations in the hydrologic cycles and changes in water availability. Increased evaporation combined with changes in precipitation characteristics has the potential to affect runoff, frequency and intensity of floods and droughts, soil moisture, and water supplies for irrigation and generation of hydroelectric power.

Land cover includes cultivated land (large scale farms and family farms with different intensity of cultivation), vegetation (shrub lands, natural forest and grassland), manmade features (urban or built-up areas), small rocky outcrops and water bodies. Land cover is shown in Fig. 1.5. The land use is characterized according to FAO (2000) by the arrangements, activities and inputs people undertake in a certain land cover type to be used for production, change or maintain it. Land use information is derived from land cover maps and provides land use classes. It shows that substantial part of the Jima area in the west is covered by forest and the eastern part is represented mainly by cultivated land.

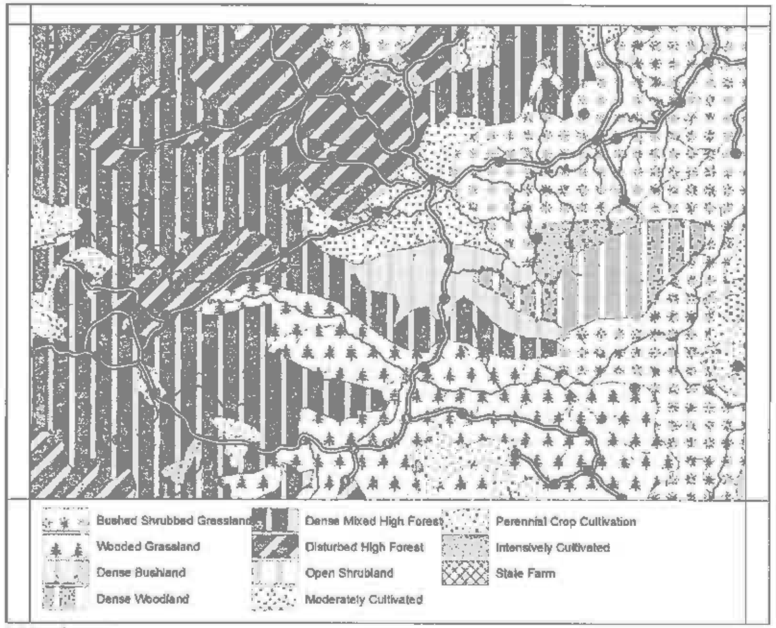


Fig. 1.5 Land cover

2. Selected Physical and Geographical Settings

The entire study area is located in the western part of the Ethiopian Plateau dissected by river valleys and modulated by grabens.

2.1 Geomorphology

The geomorphology of the area is highly variable and is generally the result of repeated volcanic and tectonic events with the associated erosion of volcanic rocks and deposition processes.

The tectonic activity and lithological variation in the area also partly or wholly control the drainage density and drainage pattern. Most of the river channels follow the young lineaments and grabens. The most distinct geomorphological units are shown in Fig. 2.1.

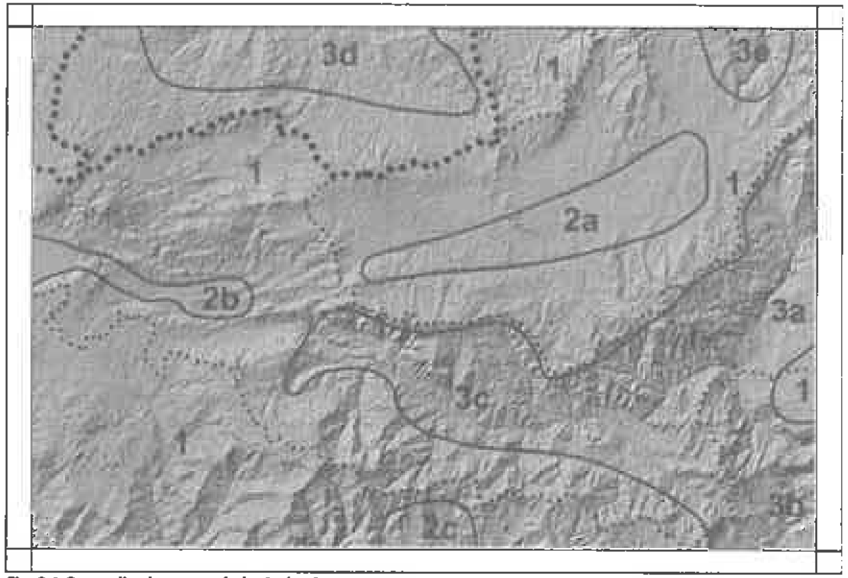


Fig. 2.1 Generalized geomorphological units

The highest peak of the study area lies to the west of Ameya. In the area of Girawa, elevation ranges from 2,500 to 3,348 m a.s.l. This area is covered by forests developed on the upper trachyte, which is deeply weathered. The plateau or the highland areas lie between 2,000 and 2,500 m a.s.l. These areas are also peaks with relatively moderate to steep slopes. The dissected gorges represent areas between 1,000 and 2,000 m.a.s.l. The lowest area of the map sheet lies in the Omo river gorge which is below

1,000 m. Here the slopes are very steep and the Omo River flows in deep gorges, but to the south outside the map area the river flows over a lowland plain.

The plateau (1) covers most of the sheet area and is generally characterized by a flat highland surface. The plateau is dissected by the deep gorges of the main rivers and in places is crowned by minor peaks. The rivers flow in valleys and are often lined by Quaternary alluvial deposits.

Deep gorges are developed along the main rivers: Gibe (3a), Omo (3b), Gojeb (3c), Didesa (3d) Gilgel Gibe (3e). They show steep slopes and cliffs along the valley sides. The terrain in this area is rugged and access is difficult. There is a high rate of erosion flow and alluvial deposits are less common. Some rivers have cut deep exposing the Precambrian rocks, but others drain Tertiary to Pliocene volcanic rocks.

Grabens formed by tectonic movements are developed in the plateau area.

The Asendabo graben (2a) forms the lowlands around Asendabo, from Deneba up to Jima. The area is a flat lowland and often contains smaller hills down-faulted from the uplands. The graben, which is asymmetrical, is formed by normal faults down thrown 700 m in places. The plain is filled by younger Quaternary tuffs and alluvium. The Gilgel-Gibe dam is located in this graben.

The Kishe graben (2b) is a westward extension of the Asendabo graben. This down-faulted area, occuring in the upper course of the Gojeb River, probably extends to the west into the Saja (Konda) area. The normal fault-produced narrow graben was filled with Quaternary alluvial deposits. The middle trachyte to the east of Kishe was down thrown more than 200 m to the west. Towards the lower course of the Gojeb, around Tarcha, there is a minor graben down throwing basalts of the TV5.

The Chebera-Churchura graben (2c) with the National Park of the same name is also a minor graben and occurs in the southeastern part of the map sheet.

2.2 Soil and Vegetation Cover

Soil and vegetation cover reflects the basic climatic conditions of the area as well as the regional and site specific hydrological, meteorological, geological, geomorphological and erosional characteristics.

Soil is important from a hydrogeological point of view because it stores rainwater in its pores before it infiltrates to greater depths and recharges the aquifer system. The hydrology of the soils is dependent on the texture of the rocks and the degree of weathering. According to the soil map provided by the Ministry of Agriculture, the study area is covered by five major types of soil as follows: Vetrisols, Cambisols, Nitosols, Lithosols, and Acrisols. The distribution of soil types is shown in Fig. 2.2. There are also some minor soil types in the area as follows: Glysols, Yemsols, Soloncak, Phaeozems, Xerosols and Leptosols.

Vertisols (Chromic vetrisols):- vetrisols are soils with a high content of expansive clay, which is known as montomorite, and which forms deep cracks during the dry season. Vetisols typically form from highly basic rock, such as basalts in a climate that is seasonally humid or subjected to erratic drought and flood or impeded drainage. Depending on the parent material and the climate they can range from grey or red to deep black. This soil type covers the Ansebo graben and the area around the shallow valley of the Gilgel Gibe River in the northeastern part of the Jima map sheet.

Cambisols (Distric cambisols):- cambisols are developed in medium- and fine-grained material derived from a wide range of rocks mostly in alluvial colluvial and aeolian deposits. They are widely distributed and mainly cover the western and southern parts of the study area.

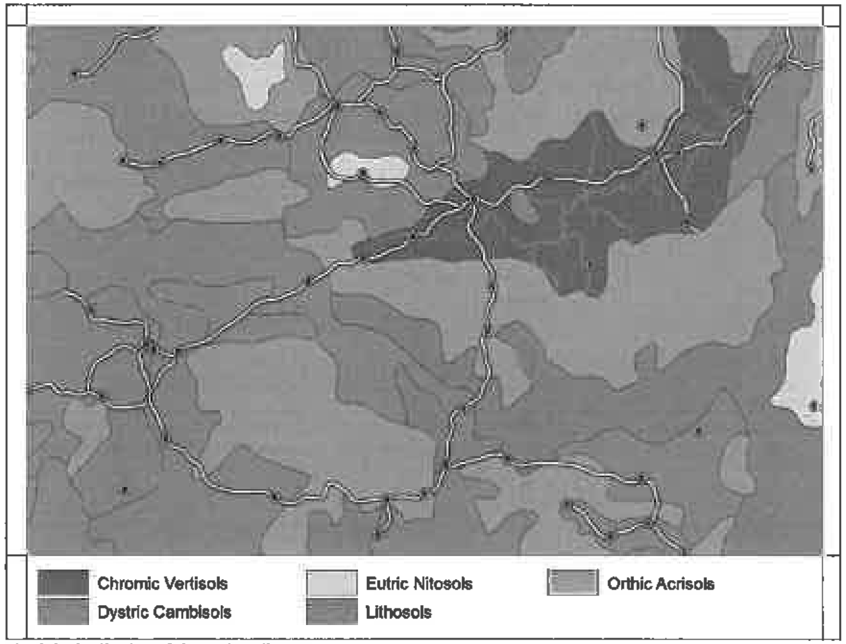


Fig. 2.2 Distribution of the main soil types

Nitosols (Eutic Nitosols):- are formed from the parent material, which is mainly as base rich as the soil itself, and are commonly found in sub-humid and semi-arid climates. They represent the youngest of the forest soil orders. Similar to fluvisols this soil also has two types: Dystic Nitosols and Eutic Nitosols. Dystic nitosols have a low content of unstable grains like feldspar and volcanic fragments and Eutic Nitosols are nitosols which have a high content of unstable grains. The nitosols cover small patches in the eastern and northern areas of the sheet.

Lithosols - Fluvisols (Dystic fluvisols and Eutic fluvisols):- are genetically young soils in alluvial deposits deposited (apart from river sediment) under natural conditions where periodic flooding is common. The soil has clear evidence of stratification. In the study area there are two types of fluvisols. Dyastic fluvisols, which have a low base status and low content of unstable grains like feldspar and volcanic fragments and Eutic fluvisols, which have a high base status and a high amount of feldspar and volcanic fragments. Lithosols are mainly developed in the deep valleys of the Gojeb, Gibe and Omo rivers.

Acrisols (Ortic acrisols) are clay-rich and are associated with humid, tropical climates. Their low fertility poses limitations their agricultural use, favoring silviculture, low intensity pastures and protected areas in many places. Crops that can be successfully cultivated, if the climate allows, include tea, coffee and sugar cane. They are widely distributed and mostly cover the eastern and southern parts of study area.

Vegetation

Vegetation is mainly found in woody forests along valleys and some mountain ranges. Tall and broad-leaved evergreens are characteristic for the regions of Jima, Kaficho, and Konta. Forest areas include the Belete forest, Wush Wush forest, Gera forest, Gojeb river forest, and Kulo Konta forest. Open grassland is common in places. The most typical vegetation in the Jima area includes coffee plants (see Fig 2.3)

Fig. 2.3 Coffee plants

Common woody vegetation includes Ficus gnaphalocarpa (oda), Syzygium guineense (dokima), Vernonia amygdalina (bisana), Olea africana (woira), Ekerbegia capensis (ononu), Ficus vasta (warka), Pygeum africanus (tikur inchet), Juniperus procera, Hagenia abyssinica (Koso) and Podacarpus grcilior (zigiba), Eritryna abyssinica (korch), with acacia (Acacia abyssinica) and bamboo trees being less common.

The Quaternary alluvium is either bogy or characterized by grassland, but around the main rivers savanna grassland is common. Gojeb, Didesa, Gibe and Churchura are characterized by elephant grassland. Bamboo forests are common in the highlands and along minor rivers. Besides the natural vegetation, plantation of different trees is common in many localities. Juniperous procera and eucalyptus are common examples, as are coffee and false banana (enset) plantations. Bare lands are often reforested by planting various different types of vegetation.

Wildlife around Chebera - Churchura National Park (southeastern part of the map) includes elephants, lions, buffalos and deer. In many of the forests hyenas have also been observed. Apes and monkeys, including coulombs monkeys, are also common in places.

2.3 Climatic Characteristics

Climatically, the area is highly variable and is mainly characterized by the humid Dega and subtropical Weina Dega climatic zones on the highlands. The highest area of Girawa is characterized by sub-alpine Wurch and the bottoms of the Gibe and Omo river gorges are characterized by arid Kola climatic zones. The rainy season within the area passes from March to May and from July to October. The mean annual rainfall is from 1,600 to 2,000 mm. The mean annual temperature is from 20 to 25°C.

2.3.1 Climatic Zones and Measurements

The climatic conditions of Ethiopia are mostly dominated by elevation. According to Daniel Gamatchu (1977) there are wide varieties in climatic zones. The climatic zones defined by Javier Gozálbez and Dulce Cebrián (2006) and Tesfaye Chernet (1993) are shown in Tab. 2.1.

Tab. 2.1 Ethiopian climate classification

Name / Altitude / Mean annual temperature	Precipitation below 900 mm	Precipitation between 900 and 1,400 mm	Precipitation above 1,400 mm
High Wurch (Kur) above 3,700 m below 5 °C			**Afro-alpine** meadows of grazing land and steppes, no farming *Helichrysum, Lobelia*
Wurch (Kur) 3,700–3,200 m 5–10 °C		**Sub-afroalpine** barley *Erica, Hypericum*	**Sub-afroalpine** barley *Erica, Hypericum*
Dega 3,200–2,300 m 10–15 °C		**Afro-mountain** (temperate) forest – woodland barley, wheat, pulses *Juniperus, Hagenia, Podocarpus*	**Afro-mountain** (temperate) bamboo forest barley, wheat, nug, pulses *Juniperus, Hagenia, Podocarpu, bamboo*
Weina Dega 2,300–1,500 m 15–20 °C	**Savannah** (sub-tropical) wheat, teff, some corn acacia savannah	**Shrub-savannah** (sub-tropical) corn, sorghum, teff, enset, nug, wheat, barley *Acacia, Cordia, Ficus*	**Wooded savannah** (sub-tropical) corn, teff, nug, enset, barley *Acacia, Cordia, Ficus, bamboo*
Kolla 1,500–500 m above 30 °C	**Tropical** sorghum and teff acacia bushes	**Tropical** sorghum, teff, nug, peanuts *Acacia, Cordia, Ficus*	**Wet tropical** mango, sugar cane, corn, coffee, oranges *Cyathea, Albizia*
Bereha below 500 m above 40 °C	**Semi-desert and desert** crops only with irrigation thorny acacias, *Commiphora*		

Remark: after Javier Gozálbez and Dulce Cebrián (2006), Tesfaye Chernet (1993)

The climatic zones of the study area defined based on elevation and precipitation are shown in Fig. 2.4.

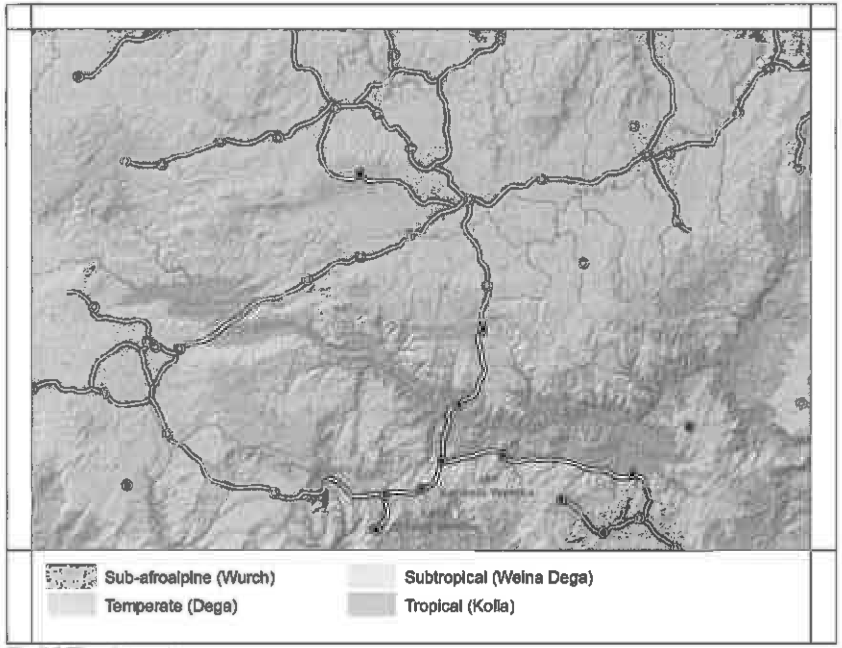


Fig. 2.4 Climatic zones

There are many meteorological stations operated by the National Meteorological Service Agency (NMSA) and WMO within the mapped area and several others are located in the near surroundings. The stations selected to evaluate the climatic data are characterized in Tab. 2.2 and shown in Fig. 2.5.

The data shows that rainfall increases to the west and the local maxima are related to topography and altitude. Average annual rainfall is in general higher than 1,500 mm in the western part and less than 1,500 mm in eastern part of the map sheet. The maximum annual average rainfall of 2,092 mm was measured in the Chira meteo-station (map ID 7) in the northern part of the Gojeb catchment. The minimum annual rainfall of 1,031 mm was measured in the Deneba meteo-station (map ID 9) in the central part of the Gilge-Gibe catchment.

An annual average rainfall of 1,500 mm was adopted for the Jima sheet and will be used in further calculations.

Tab. 2.2 Climatic stations of the Jima area

Map ID	Station	X_UTM	Y_UTM	Class	Altitude	Annual average [mm]	Sub basin
1	Gojeb	211100	820500	3	1250	1523	Gojeb
2	Ambay School	268500	881100	4	1700	1720	Tinishu Gibe
3	Asendabo	286700	858900	4	1740	1254	Gilgel-Gibe
4	Bonga	194400	798500	4	1650	1784	Omo
5	Chekorsa	249900	842500	4	1770	1614	Gilgel-Gibe
6	Chida	255100	792600	1	1640	1690	Gojeb
7	Chira	198400	857500	1/3	1900	2092	Gojeb
8	Dedo Sheki	264500	831300	3	2210	1898	Gilgel-Gibe
9	Deneba	322400	868700	4	1880	1031	Gilgel-Gibe
10	Agaro	235300	868300	1/3	2030	1527	Didessa
11	Gera	200300	861200	1	1640	1789	Didessa
12	Yebu	250000	859000	3	1800	1963	Didessa
13	Jima	260900	847900	1	1725	1495	Gilgel-Gibe
14	Metseso	266300	822100	4	2270	2106	Gojeb
15	Omonada	306900	844000	4	2400	1205	Gilgel-Gibe
16	Saja	323600	880800	¾	2100	1506	Gilgel-Gibe
17	Sekoru	323600	875300	1	2100	1430	Gilgel-Gibe
18	Serbo	277300	816500	4	1810	1318	Gojeb
19	Shebe	225900	831500	4	1635	1622	Gojeb
20	Wishwish	183400	809600	1//3/4	1950	1768	Omo
21	Woshi(o)	168700	807900	3	2300	1463	Omo
22	Dimtu	306600	777700	4	1000	1425	Gojeb

The mean annual ambient air temperature of Jima is 22.8 °C (Tab. 2.3). Minimum, maximum and mean temperatures were calculated from the original data supplied by NMSA. The minimum and maximum temperatures measured during 1980–2014 are 7.7 °C and 29.9 °C, respectively. The hottest and coldest months are March and December, respectively (Fig. 2.6).

Tab 2.3 Basic climatic data for Jima meteo-station (monthly mean)

Meteo-characteristic	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Max. temp	28.8	29.8	29.9	28.9	28.0	26.3	24.7	24.9	25.7	27.1	27.8	28.1
Min. temp	8.5	9.6	11.7	13.1	13.5	13.6	13.7	13.8	13.5	11.5	9.2	7.7
Mean temp	19.1	20.7	22.3	23.0	23.2	23.0	22.7	23.4	24.1	24.3	24.0	23.9
Sunshine	7.8	8	4.1	5.3	6.7	6.5	3.5	4.3	2.6	6.5	8.7	7.4
Wind	0.45	0.52	0.60	0.56	0.56	0.50	0.43	0.45	0.46	0.44	0.40	0.41
Relative Humidity	61.8	59	57.2	60.4	75.6	82.4	87.2	87.6	83.2	77.8	74	71.4

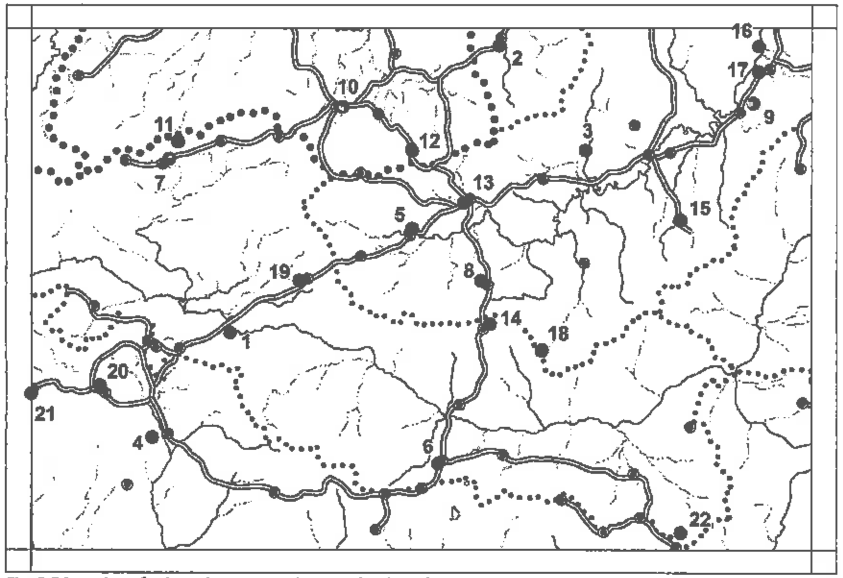


Fig. 2.5 Location of selected meteo-stations on the Jima sheet

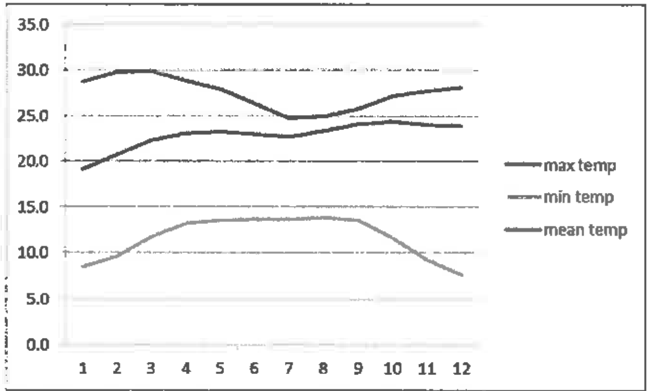


Fig. 2.6 Annual variation of temperature in °C (monthly mean)

Relative humidity (RH) determines the rate of evaporation as well as isotopic fractionation. RH was measured three times a day at a station in Jima town between 2006 and 2014. The mean monthly values of RH vary from 57.2 in March to 87.6 in August and are shown in Tab. 2.3 and Fig. 2.7.

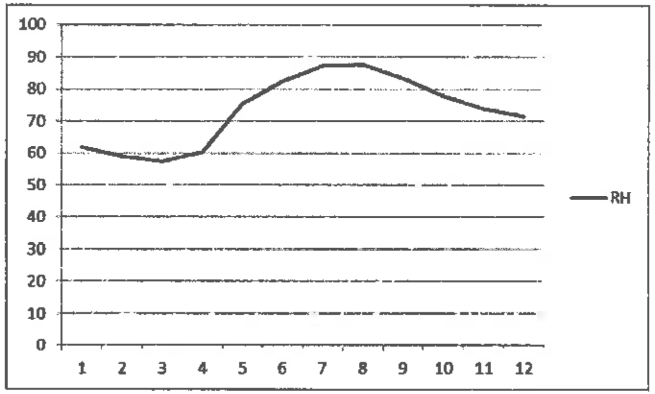


Fig. 2.7 Annual variation of Relative Humidity (RH) in % (monthly mean)

The total daily evapotranspiration rate is dependent on the total daily sunshine hours. It is clear that at the Jima station the mean maximum sunshine hours are recorded through November to February when there are approximately 8 hours of sunshine per day (period 1980 to 2014) as shown in Tab. 2.3 and Fig. 2.8. The mean minimum sunshine hours are registered in September when there are less than 3 hours of sunshine per day.

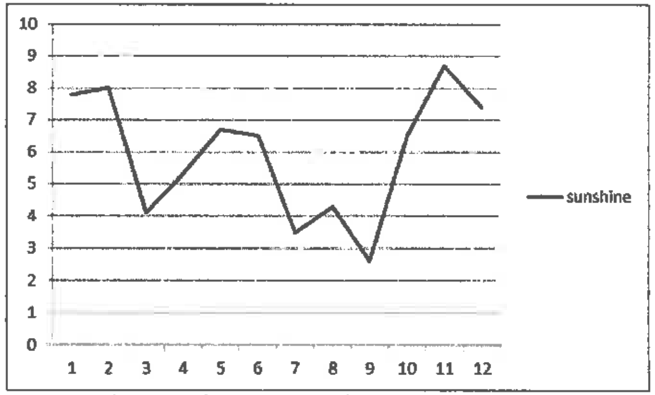


Fig. 2.8 Annual variation of sunshine in hours (monthly mean)

One factor which controls evaporation is wind speed, as saturated vapors concentrate in a limited space due to a lack of strong winds to carry them away, thereby decreasing the rate of evaporation. In the area of the Jima map sheet the wind speed is high from January to July and the lowest wind speed is recorded in October. The mean annual wind speed is given in Tab 2.3 and is shown in Fig 2.9.

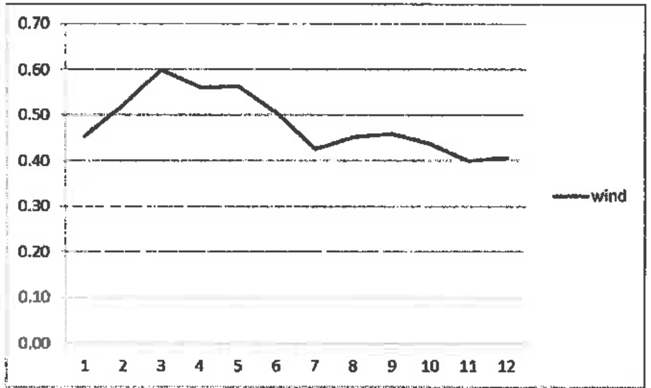


Fig. 2.9 Annual variation of wind speed in m/s (monthly mean)

2.3.1 Precipitation

The Ethiopian territory is divided into four zones marked as A, B, C, and D, each of them with different precipitation patterns. The seasonal classification and precipitation regimes of Ethiopia (after NMSA, 1996) are characterized in Tab. 2.4 and shown in Fig. 2.10.

Tab. 2.4 Characterization of the precipitation pattern in Ethiopia

Zone	Precipitation pattern
A	This region mainly covers the central and central eastern part of the country. It is characterized by three distinct seasons, and by bimodal precipitation patterns with small peaks in April and the main rainy season during mid-June to mid-September with peaks in July.
B	This region covers the western part of the country. It is characterized by a single precipitation peak. Two distinct seasons, one being wet and the other dry, are encountered in this region. The analysis of mean monthly precipitation patterns shows that this zone can be split into southwestern (b1) with the wet season during February/March to October/November, western (b2) with the wet season during April/May to October/ November, and northwestern (b3) with the wet season from June to September.
C	This region mainly covers the southern and southeastern parts of the country. It has two distinct precipitation peaks with a dry season between. The first wet season is from March to May and the second is from September to November.
D	The Red Sea region in the extreme northeastern part of the country receives diffused precipitation with no distinct pattern; however, precipitation occurs mainly during the winter.

The mapped area belongs to zone b1 which is characterized by two distinct seasons and by one precipitation season occurring from March to November. Precipitation patterns in selected stations are shown in Fig. 2.11 together with mean monthly precipitation data.

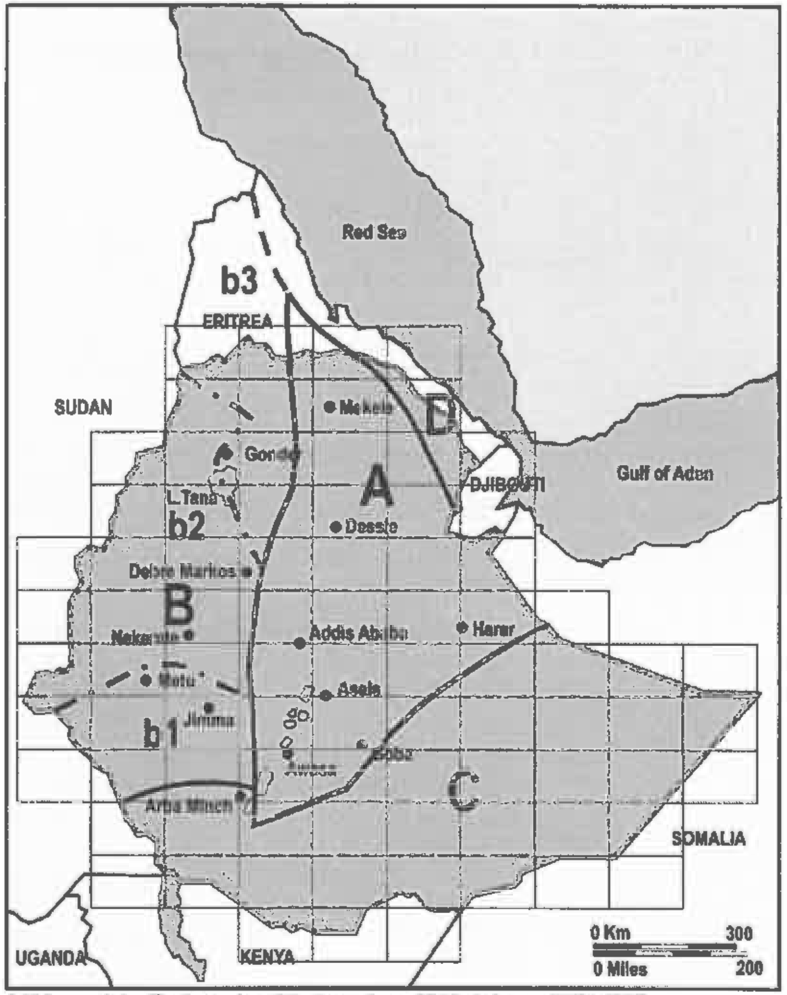
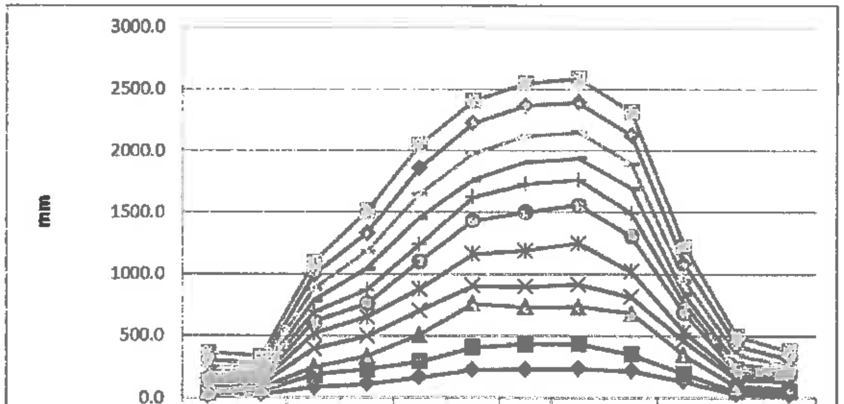


Fig. 2.10 Seasonal classification and precipitation regimes of Ethiopia (source NMSA, 1996)

Since 1955 there have been at least 10 rainfall stations in operation in the area of the Jima map sheet at any one time. Of these, Jima (with more than 35 years of record) and Bonga (with about the same) have good long term records. There are several other stations with over 10 years of records, although these records are not always continuous.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bonga	58.28	56.84	103.8	179.7	192.7	183.2	187.7	198.6	189.9	143.6	79.28	65.75
Chira	51.6	34.9	114.7	148.9	209.0	248.0	246.7	240.9	236.8	136.0	72.5	47.8
Jimma	36.0	34.6	88.8	135.7	188.7	215.1	207.4	212.0	193.6	110.0	66.4	37.6
Tercha	37.3	28.5	95.2	175.6	219.6	138.8	181.3	175.5	204.4	76.4	49.5	12.9
sekoru	31.9	22.6	79.0	109.5	135.0	190.0	226.4	203.8	185.8	73.3	21.3	23.5
Limu Genet	21.5	23.6	95.0	109.1	226.9	271.2	311.9	308.4	286.8	156.6	33.1	37.2
Dimtu	29.5	22.7	124.9	153.8	174.2	254.6	293.7	331.8	202.8	69.2	28.6	20.5
chida	49.0	30.0	147.0	161.4	197.2	144.7	162.7	182.7	133.1	114.7	60.4	50.8
Bedele	8.6	23.1	64.9	103.9	214.4	354.7	300.1	297.4	327.6	150.0	36.4	26.3
Assendabo	24.2	30.0	96.4	119.2	127.1	180.8	202.7	204.4	134.4	61.5	19.8	34.4
Agaro	18.4	30.2	87.7	113.3	167.1	227.2	231.2	233.6	220.3	135.3	32.1	22.1

Fig. 2.11 Precipitation pattern in meteo-stations of the Jima map sheet (including data in mm)

2.4 Hydrography and Hydrology of the Area

The area of the Jima map sheet is found mainly within the Omo-Gibe basin, but its northwestern part belongs to the Abay (Didesa River) and western part to the Baro river basin. The principal river basins and sub-basins of the area of the Jima map sheet are shown in Fig. 2.12.

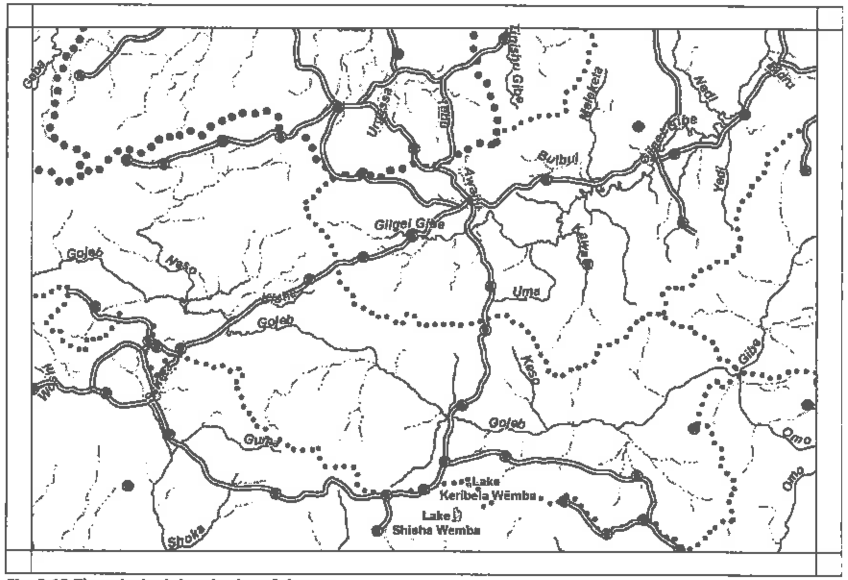


Fig. 2.12 The principal river basins of the area

2.4.1 Surface Water Network Development

The Jima topographic map sheet is divided by the main surface water divide and the largest part belongs to the Omo-Gibe basin and only a small part in the northwestern part of the sheet belongs to the Baro and Abay river basins

Omo-Ghibe basin occupies about 90% of the study area in the south, central and northeastern parts of the Jima map sheet. The major perennial rivers flowing in the Omo drainage basin are the Gilgel Gibe River and its tributaries from the center to the northeast, the Gibe River and its tributaries from the northeast and east, the Gojeb River and its tributaries from east to west and the Omo River from the southeast. The Gibe and Gojeb join to form the Omo River in the southeastern part of the map sheet. The drainage forms a parallel, dendritic to subparallel pattern.

Abay basin occupies the northeastern part of the study area. It is divided from the Omo drainage basin by the Sentema Highlands and N-S trending volcanic ridges. The Didessa River tributaries (Urgessa and Yebu) are the main perennial rivers in the northern part of the sheet. The drainage forms a sub parallel pattern mainly flowing towards the north.

Baro basin is located in the northwestern corner of the map sheet. The perennial N-S flowing Geba River flows through the Baro basin.

The Keribela and Shisha Wemba lakes are located in the southern part of the sheet to the east of Genji in Meda Yeja, at an elevation of 1,251 (1,450) m.a.s.l. The Shisha Wemba lake is also known as Womba Häyk', Lake Uombo and/or Womba Hayk'. Another lake will be formed by the Giglel-Gibe Dam III, which will cover an area of approximately 30 km².

2.4.2 River Flow Regime

There are a large number of river gauging stations within the Omo-Gibe and Baro basins. Some of them are operational but many of the stations have no data. On the Jima sheet there are 12 registered gauging stations (see Fig. 2.13). Other river gauging stations are within the neighboring sheets and data from these stations were also used for the assessment of surface as well as baseflow values and for comparing and correcting data from the Jima area. The selected river stations are summarized in Tab. 2.5.

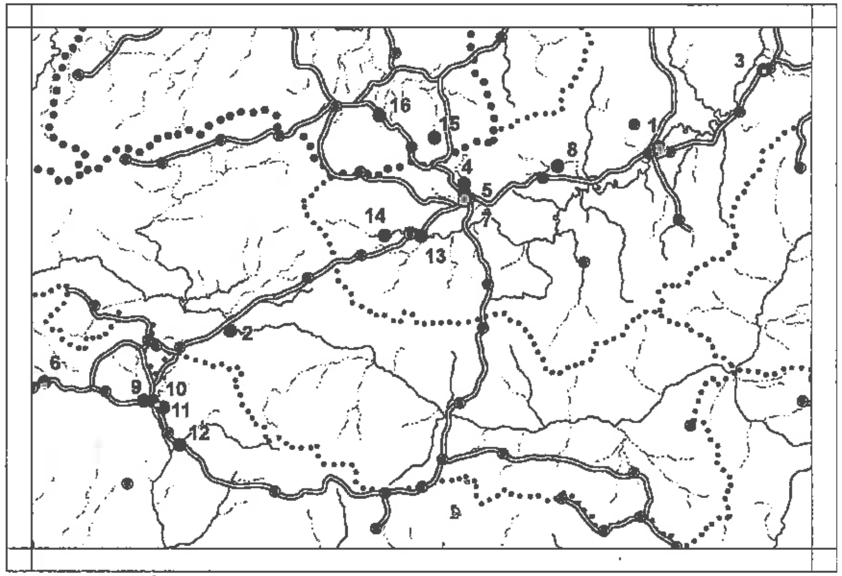


Fig. 2.13 Location of selected river gauging stations on the Jima sheet

Tab. 2.5 Data on the river gauging stations

Map ID	Station No	River	station	POINT_X	POINT_Y	Elevation	Area km²	Basin Sub
1	91008	Gilgel Gibe	Ansend	302158.49	859090.63	1679	2966	Gilgel-Gibe
2	91011(12)	Gojeb	Shebe	211057.49	820454.68	1300	3577	Gojeb
3	91019	Bidru Awana	Sokur	324515.28	875360.65	1817	41	Gilgel-Gibe
4	91023	Kito	Jima	260913.27	851530.83	1770	85	Gilgel-Gibe
5	91024	Awaitu	Jima	260903.93	849687.05	1739	72	Gilgel-Gibe
6	91025	Woshi	Dimbi	171449.59	809745.12	1791	47.5	Omo
7	91030	Awaitu	Babu	260894.62	847843.27	1717	36.5	Gilgel-Gibe
8	91032	Bulbul	Serbo	280745.84	855189.13	1740	526	Gilgel-Gibe
9	92002	Gecha	Bonga	192554.13	805810.03	1623	175	Omo
10	92003	Sheta	Bonga	194395.96	805798.71	1598	190.6	Omo
11	92004	Guma	Andar	200073.37	796401.13	1630	231.3	Omo
12	92005	Dincha	Bonga	196730.83	804330.27	1697	443.8	Omo
13		Ghibe	Seka	251658.93	840515.08	1735	280.4	Gilgel-Gibe
14	No data	Ghibe	Seka	243936.44	840632.57	1880	No data	Gilgel-Gibe
15	114008	Yebu	Yebu	254633.79	861270.66	1892	47	Abbay
16	114009	Urgessa	Gembe	242971.53	866087.70	1630	19	Abbay
	101010	U. Baro	Masha	302158.49	859090.63	1679	1653	Baro

Records from all of the stations reflect the fact that the river discharge is directly proportional to the intensity of rainfall within the basin. There is a high discharge fluctuation between the wet and dry seasons of the year. The rivers show only one high flow period which is usually from July to October and the peak flow for all of the rivers is usually recorded in August (see Fig. 2.17 for the Gilgel-Gibe River). The period from December to April is characterized by low flow when most of the smaller rivers are completely without water. The rivers in the western part of the sheet (the Bonga area) show a slight irregularity in high flow records, which can be seen in a break in the increasing limb of the mean flow graph during June (see e.g. Fig. 2.29 for the Dincha River). Runoff data are summarized in Tab. 2.6.

The data shows that specific runoff is higher (approximately 16 to 20 l/s/km²) in the western part of the area, which receives more rainfall, than the eastern part where specific runoff is about 12 to 14 l/s/km². The increase in specific runoff in the west is also documented by the value of 35 l/s/km² for the Upper Baro River. The extreme values of specific runoff in the Woshi River at Dimbi (92.2 l/s/km²), the Babu River at Awaitu (92.6 l/s/km²), and the Guma River in Andar (92.2 l/s/km²) are difficult to explain and doubt about the accuracy and representativeness of the measurements in these small catchment can be raised. Based on the data discussed above the ***adopted value of the specific runoff for the Jima sheet is in value of 15.5. l/s/km²***.

Tab. 2.6 Runoff data

Map ID	River	Station	Mean flow [m³/s]	Annual flow [mm]	Annual precip. [mm]	Area [km²]	Specific runoff [l/s.km²]	Dominant Aquifer
1	Gilgel Gibe	Ansendabo	40.07	426	1514	2966	13.5	Mixed
2	Gojeb	Shebe	57.04	503	1746	3577	15.9	Basalt+Mixed
3	Bidru Awana	Sokur	0.48	369	1031	41	11.7	Basalt

Map ID	River	Station	Mean flow [m³/s]	Annual flow [mm]	Annual precip. [mm]	Area [km²]	Specific runoff [l/s.km²]	Dominant Aquifer
4	Kito	Jima	1.16	431	1669	85	13.6	Basalt
5	Awaitu	Jima	2.00	877	1669	72	27.8	Basalt
6	Woshi	Dimbi	4.38	2910	1463	47.5	92.2	Basalt
7	Awaitu	Babu	3.38	2922	1669	36.5	92.6	Basalt
8	Bulbul	Serbo	8.83	530	1495	526	16.8	Basalt
9	Gecha	Bonga	5.03	907	1776	175	28.7	Basalt
10	Sheta	Bonga	3.84	636	1776	190.6	20.1	Basalt
11	Guma	Andaracha	13.54	1847	1776	231.3	58.5	Basalt
12	Dincha	Bonga	8.75	622	1776	443.8	19.7	Basalt
13	Ghibe	Seka	4.05	546	1614	280.4	14.4	Basalt
15	Yebu	at Yebu	0.16	107	1963	47	3.4	Basalt
16	Urgessa	near Gembe	0.81	1345	1745	19	42.6	Mixed
	Upper Baro	near Masha	58.08	1109		1653	35.1	

Measured discharge of the Gilgel-Gibe River at the Asendabo river gauge in the period from 1982 to 2013 is shown in Fig. 2.14. The figure shows that the flow is relatively regular (22 to 60 m^3/s); however, the total value of annual flow and particularly maximal monthly flow can vary substantially from year to year. The river was not flowing in March and April 1992 and the highest daily discharge of 256.844 m^3/s (27th of July, 1994) was recorded at the river gauge. The calculated mean annual flow of 40.07 m^3/s for the Ansendabo station represents flow generated mainly in the western highlands where the Gilge-Gibe River rises (originates) and which receives the highest precipitation within the basin. Annual variability of the mean annual flow of the Gilgel-Gibe River at the Asendabo river gauge is shown in Fig. 2.15. Annual variability of average, average of minimal monthly and minimum of minimal monthly discharge is shown in Fig. 2.16 and Fig. 2.17.

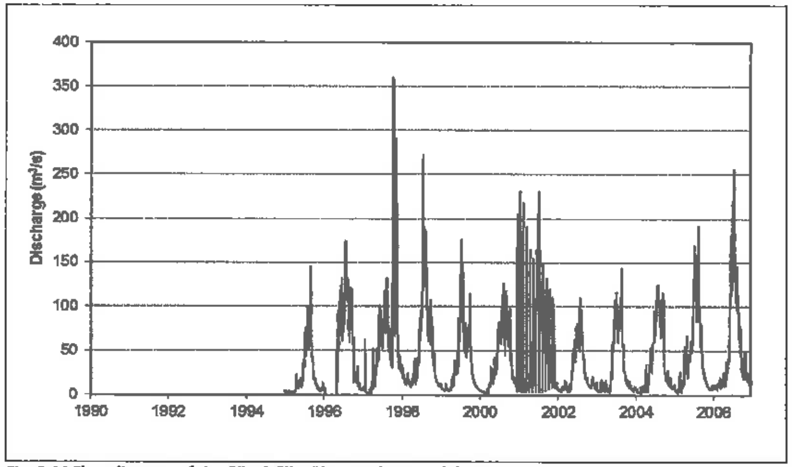


Fig. 2.14 Flow diagram of the Gilgel-Gibe River at the Asendabo river gauge

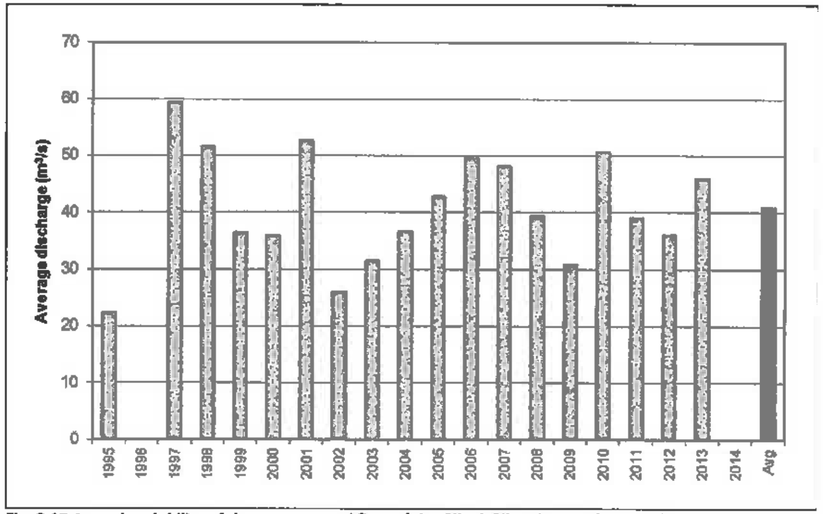


Fig. 2.15 Annual variability of the mean annual flow of the Gilgel-Gibe River at the Asendabo river gauge

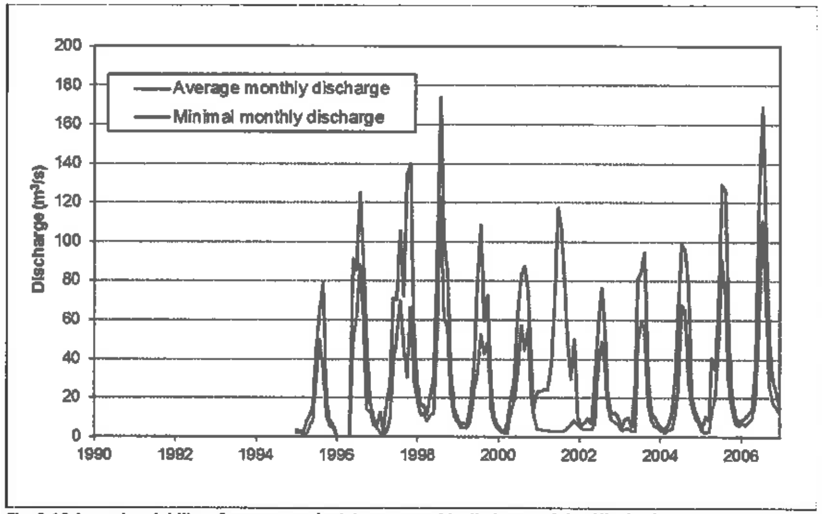


Fig. 2.16 Annual variability of average and minimum monthly discharge of the Gilgel-Gibe River at the Asendabo river gauge

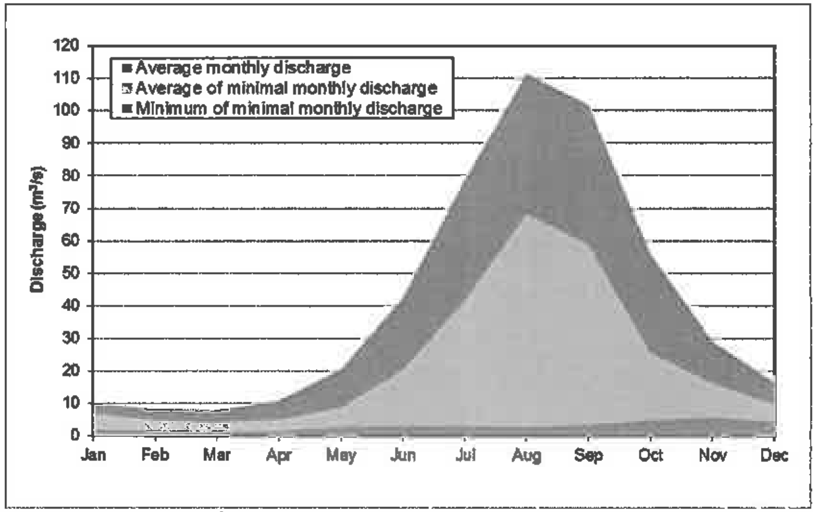


Fig. 2.17 Annual variability of average monthly, average of minimal montly and minimum of minimum monthly discharge values of the Gilgel-Gibe River at the Asendabo river gauge

Measured discharge of the Gojeb River at the Shebe river gauge in the period from 1971 to 2004 is shown in Fig. 2.18. The figure shows that the flow is relatively regular; however, the total value of annual flow and particularly maximal monthly flow can vary substantially from year to year (from 40 to 90 m^3/s). The lowest daily discharge of 0.122 m^3/s (February, March and April 1999) and the highest daily discharge of 551.873 m^3/s (18th of September, 1983x) were recorded at the river gauge. The calculated mean annual flow of 57.04 m^3/s for the Shebe station represents flow generated mainly in the western highlands where the Gojeb River rises (originates) and which receives the highest precipitation within the basin. Annual variability of the mean flow of the Gojeb River at the Shebe river gauge is shown in Fig. 2.19. Annual variability of average, average of minimal monthly and minimum of minimal monthly discharge is shown in Fig.2.20 and Fig. 2.21

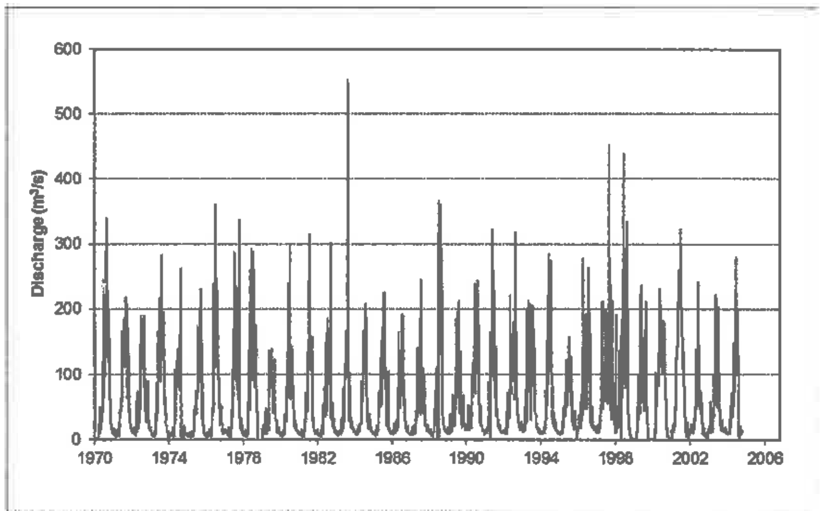


Fig. 2.18 Flow diagram of the Gojeb River at the Shebe river gauge

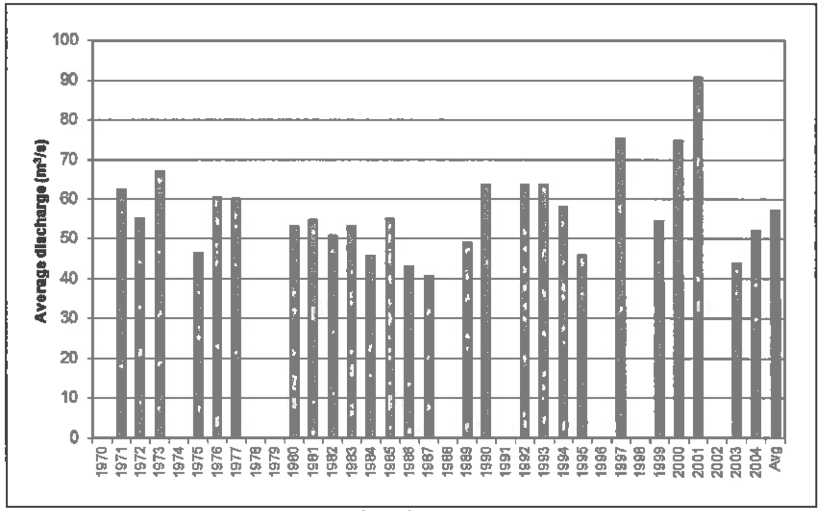


Fig. 2.19 Annual variability of the mean annual flow of the Gojeb River at the Shebe river gauge

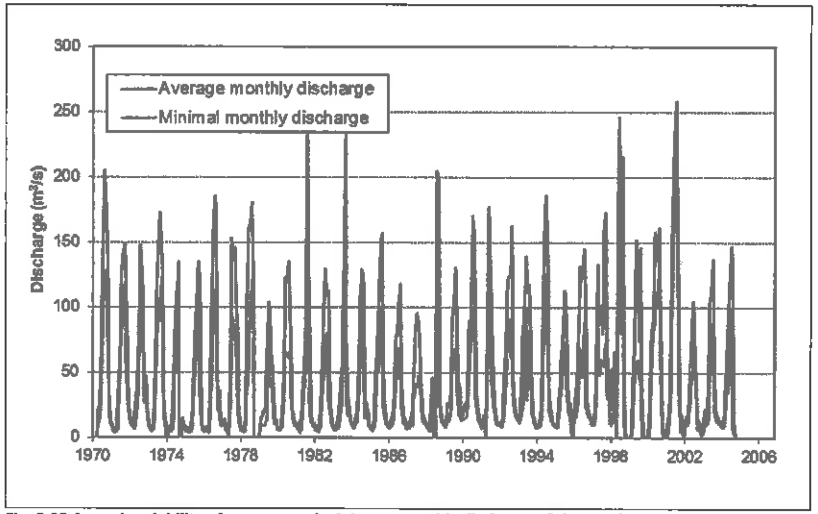


Fig. 2.20 Annual variability of average and minimum monthly discharge of the Gojeb River at the Shebe river gauge

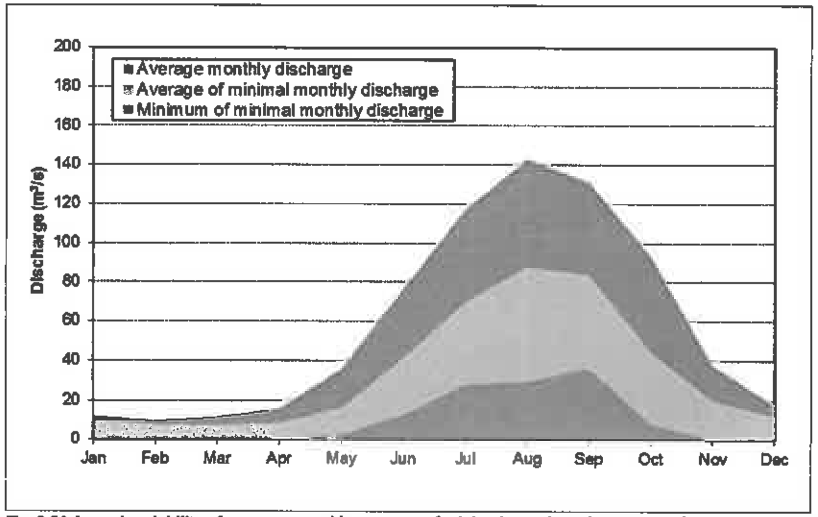


Fig. 2.21 Annual variability of average monthly, average of minimal montly and minimum of minimum monthly discharge values of the Gojeb River at the Shebe river gauge

Measured discharge of the Bulbul River at the Serbo river gauge in the period from 1986 to 2005 is shown in Fig. 2.22. The figure shows that the flow is relatively regular in period of 1986 to 2000;after this period the flow increases significantly and the total value of annual flow and particularly maximal monthly flow can vary substantially from year to year (from 2.5 to 16 m^3/s). The river was not flowing several times (1988, 1989, 1990), but the longest period without flow is from February to August 1991 and the highest daily discharge of 141.043 m^3/s (26[th] of September, 2005) was recorded at the river gauge. The calculated mean annual flow of 8.83 m^3/s for the Serbo station represents flow generated mainly in the western highlands where the Bulbul River rises (originates) and which receives the highest precipitation within the basin. Annual variability of the mean flow of the Bulbul River at the Serbo river gauge is shown in Fig. 2.23. Annual variability of average, average of minimal monthly and minimum of minimal monthly discharge is shown in Fig. 2.24 and Fig. 2.25

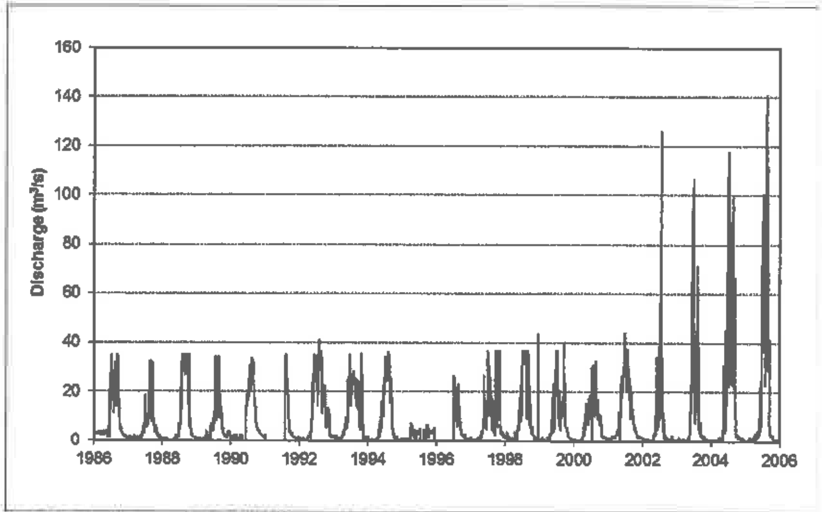


Fig. 2.22 Flow diagram of the Bulbul River at the Serbo river gauge

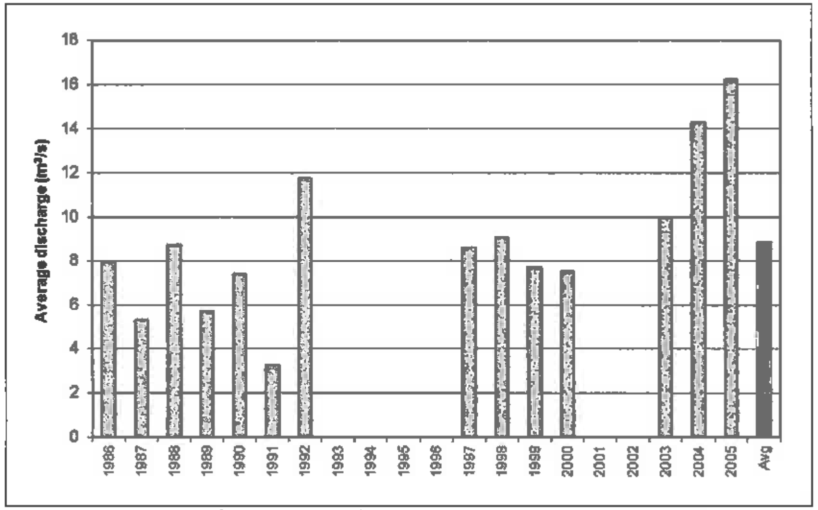


Fig. 2.23 Annual variability of the mean annual flow of the Bulbul River at the Serbo river gauge

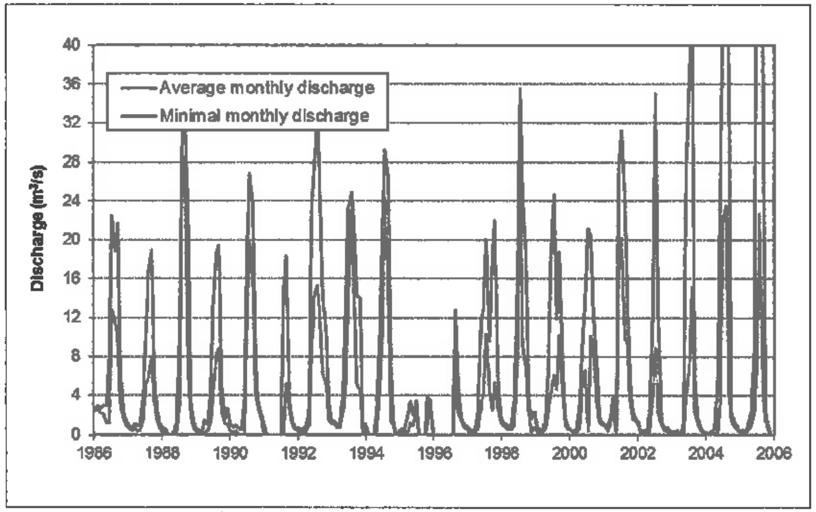


Fig. 2.24 Annual variability of average and minimum monthly discharge of the Bulbul River at the Serbo river gauge

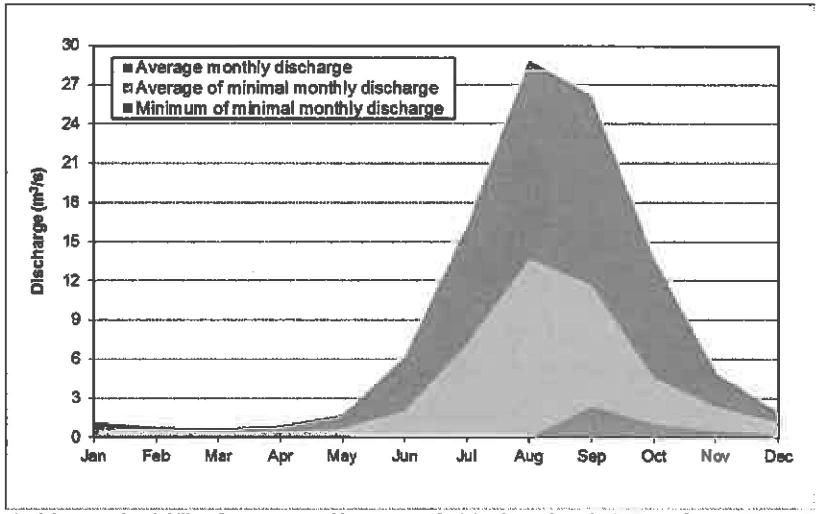


Fig. 2.25 Annual variability of average monthly, average of minimal montly and minimum of minimum monthly discharge values of the Bulbul River at the Serbo river gauge

Measured discharge of the Dincha River at the Bonga river gauge in the period from 1983 to 2007 is shown in Fig. 2.26. The figure shows that the flow is relatively regular; however, the total value of annual flow and particularly maximal monthly flow can vary substantially from year to year (from 4.5 to 16 m^3/s). The lowest daily discharge of 0.017 m^3/s (25th February 1984 and 24th March 1988) and the highest daily discharge of 104.081 m^3/s (29th of October, 1997) were recorded at the river gauge. The calculated mean annual flow of 8.75 m^3/s for the Bonga station represents flow generated mainly in the western highlands where the Dincha River rises (originates) and which receives the highest precipitation within the basin. Annual variability of the mean annual flow of the Dincha River at the Bonga river gauge is shown in Fig. 2.27. Annual variability of average, average of minimal monthly and minimum of minimal monthly discharge is shown in Fig. 2.28 and Fig. 2.29.

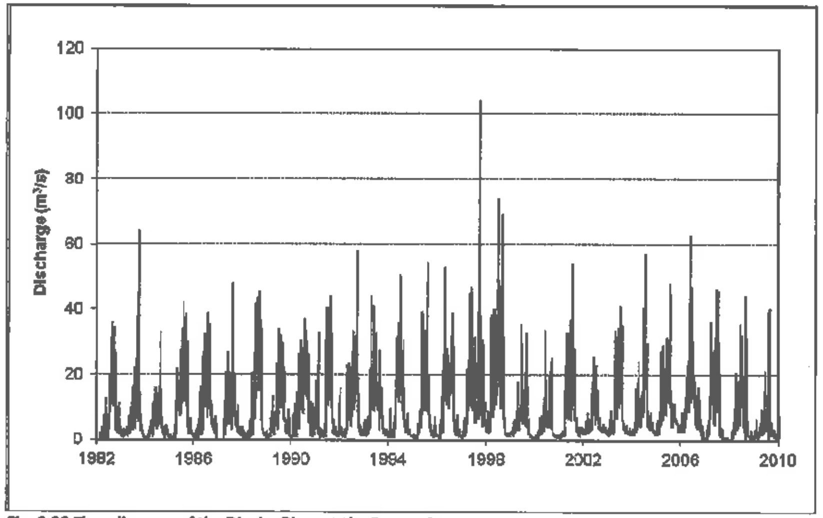


Fig. 2.26 Flow diagram of the Dincha River at the Bonga river gauge

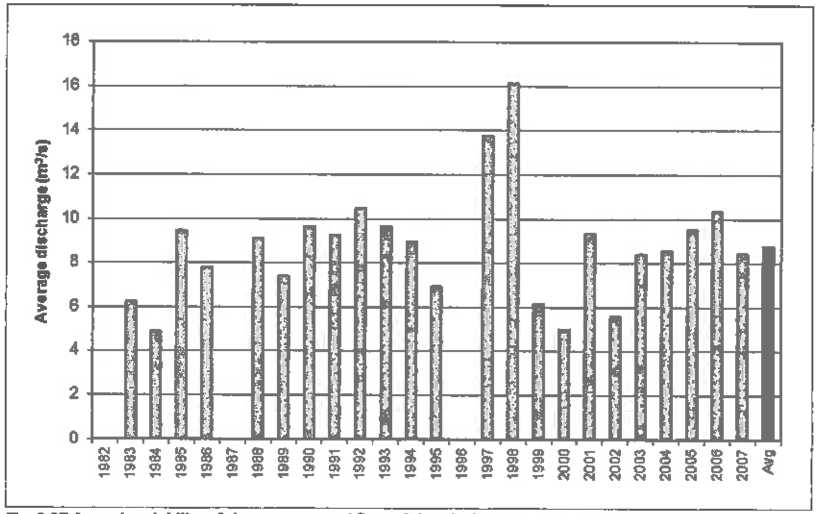


Fig. 2.27 Annual variability of the mean annual flow of the Dincha River at the Bonga river gauge

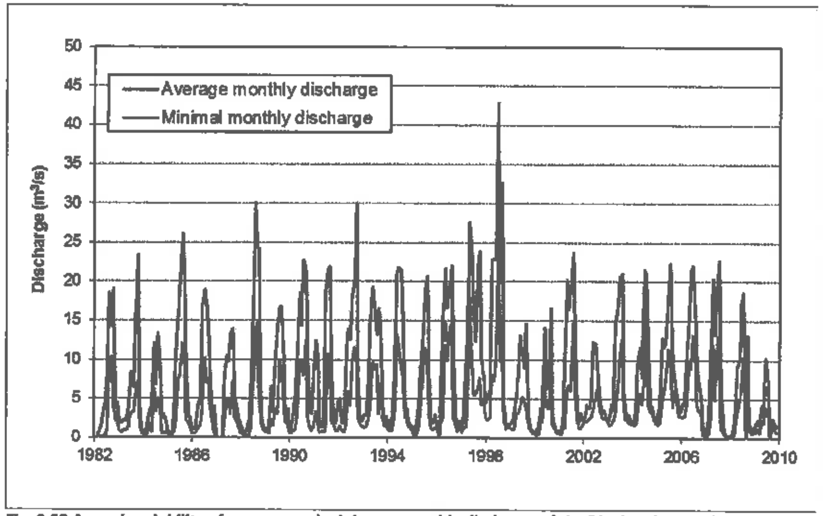


Fig. 2.28 Annual variability of average and minimum monthly discharge of the Dincha River at the Bonga river gauge

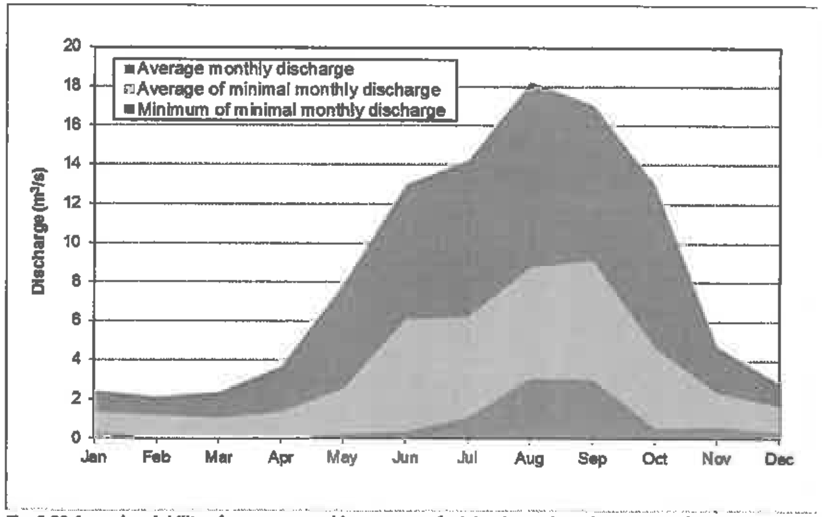


Fig. 2.29 Annual variability of average monthly, average of minimal montly and minimum of minimum monthly discharge values of the Dincha River at the Bonga river gauge

Measured discharge of the Gibe River at the Seka river gauge in the period from 1990 to 2005 is shown in Fig. 2.30. The figure shows that the flow is regular; however, the total value of annual flow and particularly maximal monthly flow can slightly vary from year to year (from 4.8 to 5.9 m^3/s). The lowest daily discharge of 0.017 m^3/s (25th February 1984 and 24th March 1988) and the highest daily discharge of 25.226 m^3/s (1st and 12th of August, 2005) were recorded at the river gauge. The calculated mean annual flow of 4.05 m^3/s for the Seka station represents flow generated mainly in the western highlands where the Gibe River rises (originates) and which receives the highest precipitation within the basin. Annual variability of the mean annual flow of the Gibe River at the Seka river gauge is shown in Fig. 2.31. Annual variability of average, average of minimal monthly and minimum of minimal monthly discharge is shown in Fig. 2.32 and Fig. 2.33.

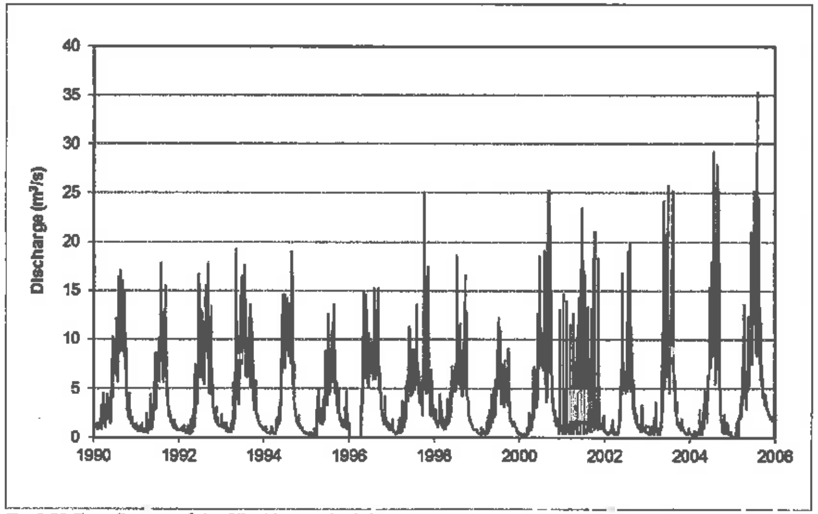


Fig. 2.30 Flow diagram of the Gibe River at the Seka river gauge

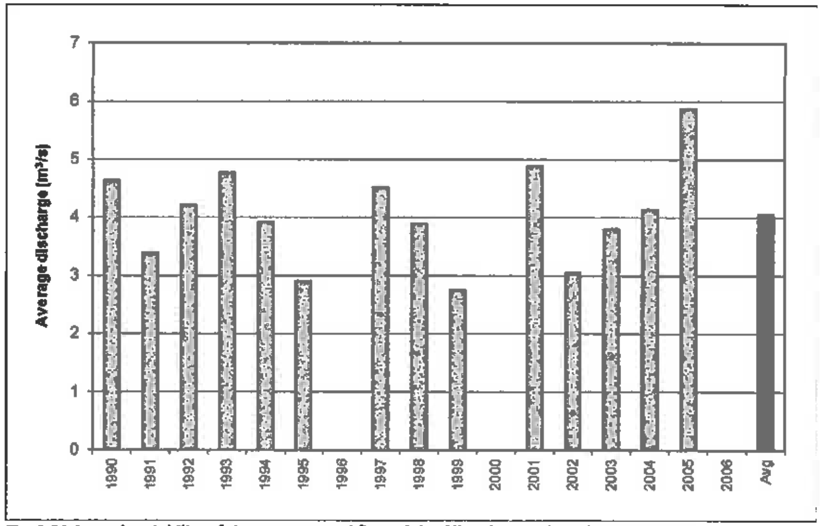


Fig. 2.31 Annual variability of the mean annual flow of the Gibe River at the Seka river gauge

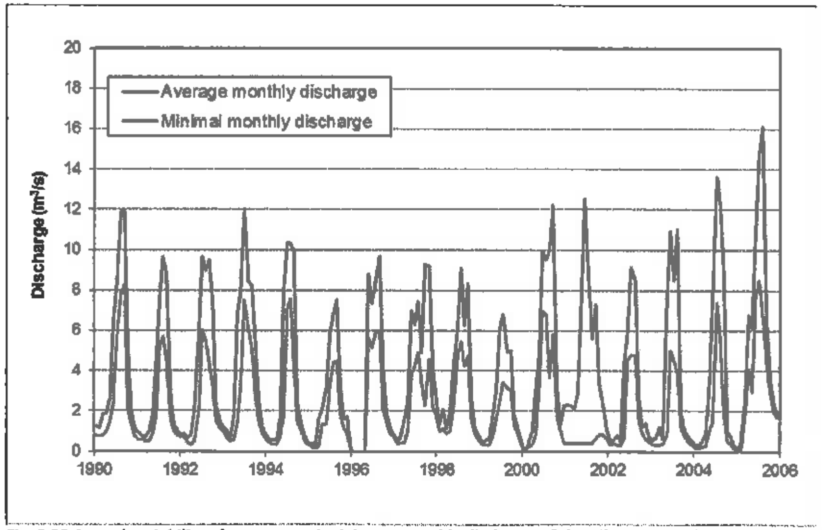


Fig. 2.32 Annual variability of average and minimum monthly discharge of the Gibe River at the Seka river gauge

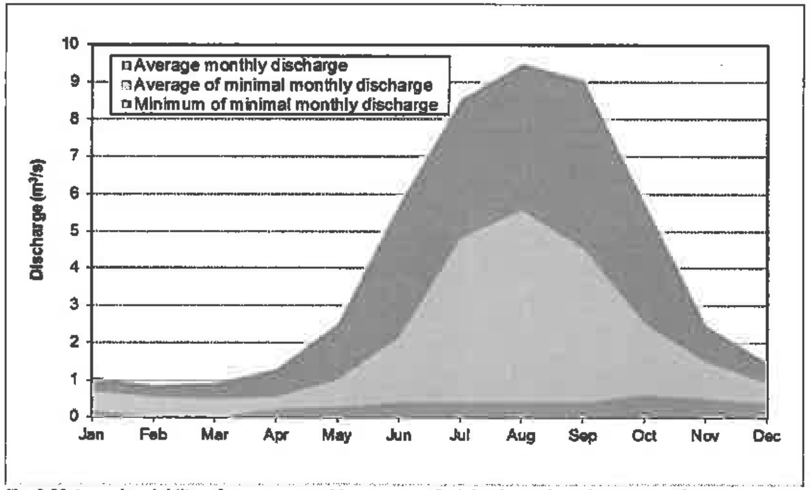


Fig. 2.33 Annual variability of average monthly, average of minimal montly and minimum of minimum monthly discharge values of the Gibe River at the Seka river gauge

2.4.3 Baseflow

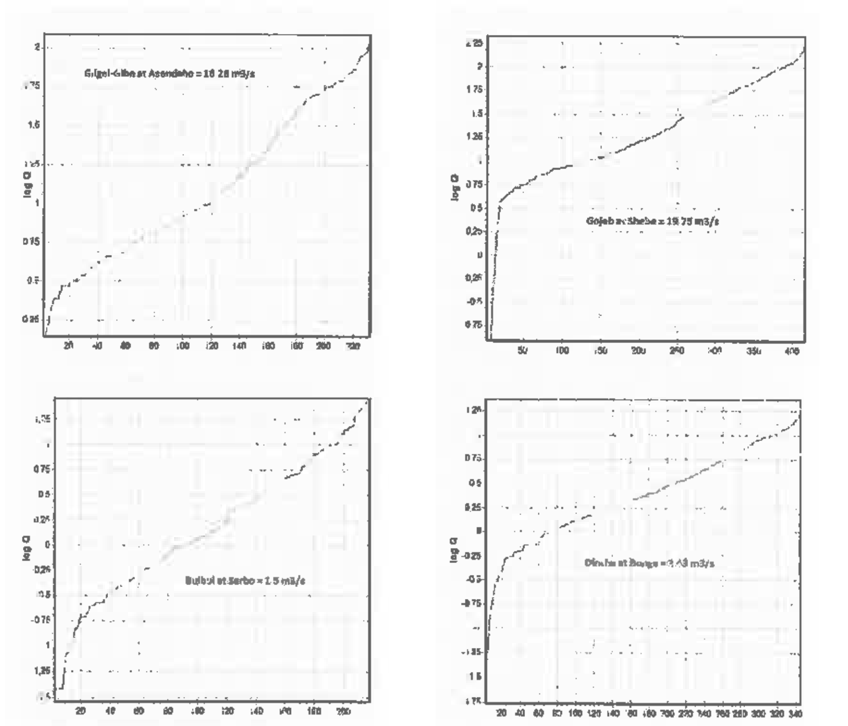
Baseflow represents one of the most important types of information on groundwater resources in the Jima map sheet area. The methods were analyzed by Bogena et al. (2005) and it was found by means of a correlation analysis that the appropriate baseflow values can be determined on the basis of daily river discharge data. Hydrograph separation and the Kille method were used for the baseflow separation. Results of baseflow assessed by the Kille method are shown in Fig. 2.34 and data in Tab. 2.8 together with baseflow data assessed by the hydrograph separation method. Separation of hydrograph and results of separation are shown in Fig. 2.35. A comparison of the assessment of baseflow using the Kille method and hydrograph separation is shown in Tab. 2.20. Results show very small differences between the assessment of baseflow using the Kille method and hydrograph separation.

The assessment of specific runoff based on data from flow measurements and calculated specific runoff in the gauging stations and the appropriate area of the pertinent river basin within the Jima map sheet area considering the elevation and rock composition of the area are shown in Tab. 2.7.

Tab. 2.7 A comparison of the assessment of baseflow using the Kille method and hydrograph separation

Map ID	River	Station	Area [km²]	Kile method [m³/s]	Hydrograph separation [m³/s]	Specific baseflow [l/s.km²]	Dominant Aquifer
1	Gilgel Gibe	Ansendabo	2966	10.26	17.27	3.46/5.82	Mixed
2	Gojeb	Shebe	3577	19.75	22.89 (1999)	5.52/6.40	Basalt+Mixed
3	Bidru Awana	Sokur	41	0.12	0.13 (2004)	2.93/3.17	Basalt
4	Kito	Jima	85	0.55	0.59 (2003)	6.47/6.94	Basalt

Map ID	River	Station	Area [km²]	Kile method [m³/s]	Hydrograph separation [m³/s]	Specific baseflow [l/s.km²]	Dominant Aquifer
5	Awaitu	Jima	72	0.20	0.74 (1993)	2.78/10.28	Basalt
6	Woshi	Dimbi	47.5	0.93	2.18 (1993)	19.58/45.89	Basalt
7	Awaitu	Babu	36.5	0.72	1.78 (2001)	19.73/48.77	Basalt
8	Bulbul	Serbo	526	1.50	2.62 (1987)	2.85/4.98	Basalt
9	Gecha	Bonga	175	1.09	1.62 (1997)	6.23/9.26	Basalt
10	Sheta	Bonga	190.6	0.79	1.44 (2008)	4.14/7.56	Basalt
11	Guma	Andaracha	231.3	1.83	3.76 (2003)	7.91/16.26	Basalt
12	Dincha	Bonga	443.8	2.42	4.21 (2003)	5.45/9.49	Basalt
13	Ghibe	Seka	280.4	1.23	1.66 (2003)	4.39/5.92	Basalt
15	Yebu	Yebu	47	0.05	0.1 (1998)	1.06/2.13	Basalt
16	Urgessa	Gembe	19	0.27	0.37 (2003)	14.21/19.47	Mixed
	U. Baro	Masha	1653	16.82	18.25 (2004)	10.18/11.04	



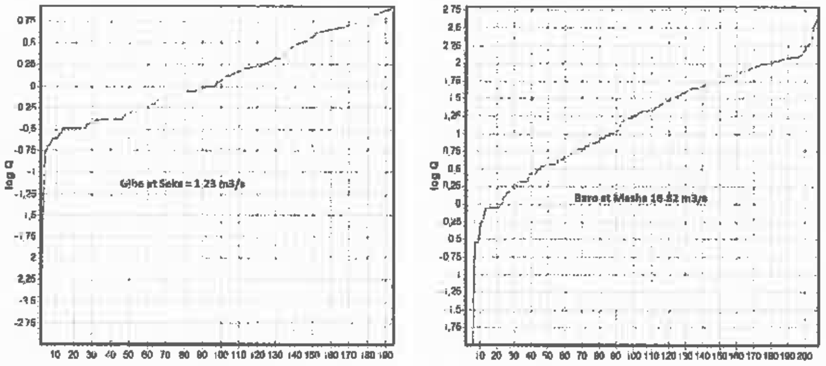
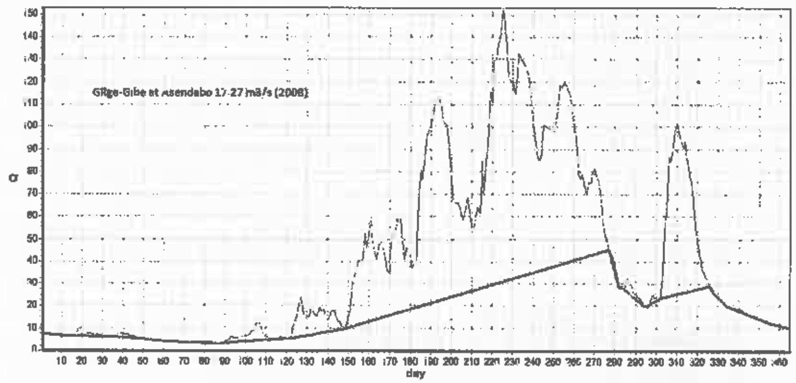
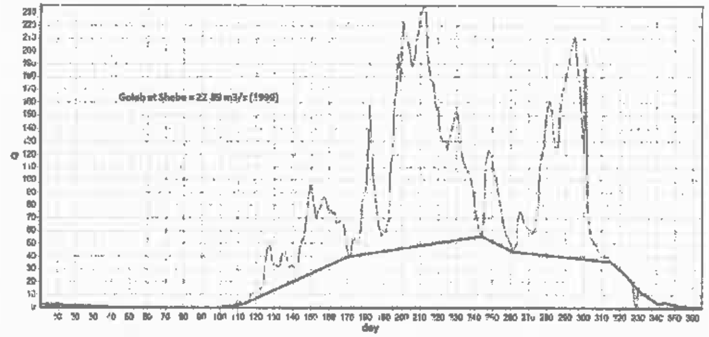
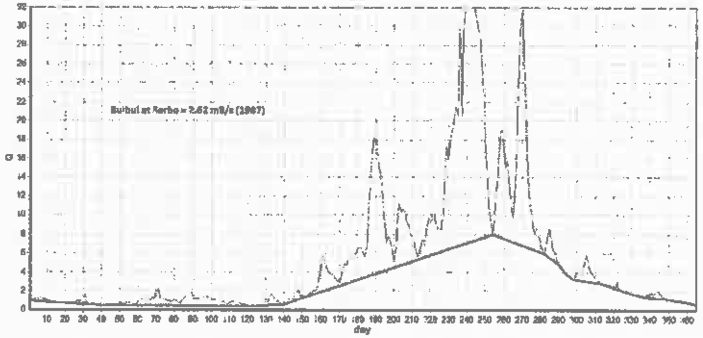
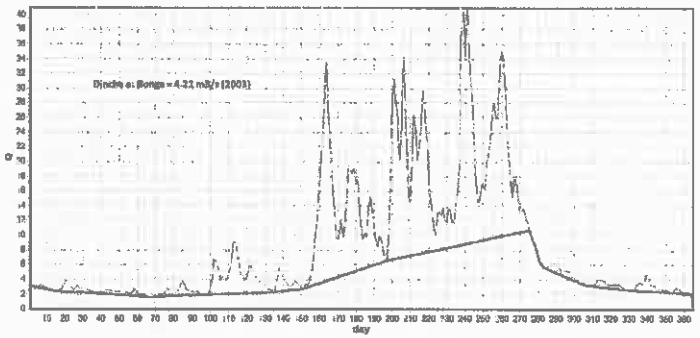


Fig. 2.34 Kille baseflow separation (Part 1and2)









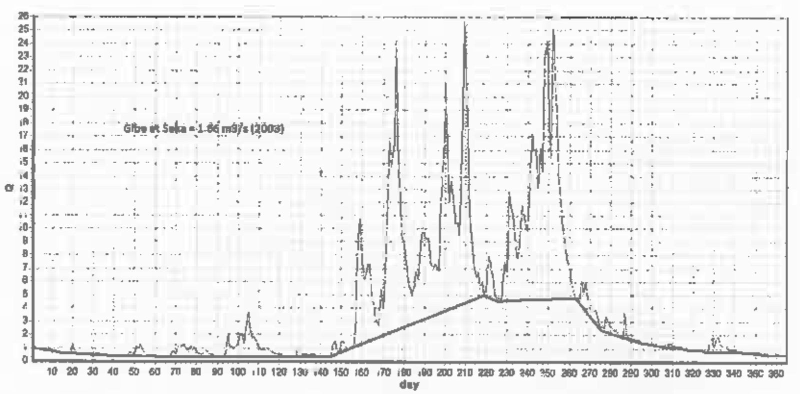


Fig. 2.35 Hydrograph of baseflow separation (Part 1 and 2)

The assessment of specific baseflow is based on data from hydrograph separation and using the Kille method. ***The specific baseflow is assessed for the Jima sheet based on data from the river gauges shown in Tab. 2.20, and is 5 l/s.km²***.

2.4.4 Sediments load

Sediment yields from river catchments were estimated by Richard Woodroof and Associates (1995-6) and the results obtained show a negative correlation between river flow and sediment concentrations. Such a negative correlation, where sediment concentrations diminish with increasing flow, is definitely discernible for the Great Gibe Station 91001. This negative correlation is in place of the expected positive correlation between river flow and sediment concentrations, and is more or less clearly evident in the results from all six stations in the Omo-Gibe basin. Apparently, the early rains that signal the end of a long dry season are effective in causing sediment discharge, but after vegetation in the catchment is reestablished, the sediment discharge is very much reduced. This corresponds with experimental data showing the important effect of vegetative cover in reducing the impact force of raindrops that in turn is a major cause of soil break-up and erosion. This same pattern is evident for the Great Gibe and Gilgel Gibe, which carry normal sediment loads, the Wabe and Walga with much higher sediment concentrations and also for the Gojeb and Guma, which both carry very low sediment loads. For the Great Gibe the average sediment concentration over the sampling period was 582 mg/l. The mean annual discharge is 156 m^3/sec. An estimate of annual sediment discharge was made by combining these values to give an annual amount of 2.9 million tons. This is equivalent to an average of 181 t/km^2/year over a catchment of 15 807 km^2.

2.5 Water Balance

The water balance was calculated by Richard Woodroof and Associates (1995-6) by the simple empirical formula: Rf = Ea + Ro + s. According to the calculated data, the distribution of potential evapotranspiration (PET) in the north and northeastern highlands of the Omo-Gibe basin is about 960 mm/yr. The water balance technique, as employed by Richard Woodroof and Associates (1995-6) and without considering soil moisture accretion, indicates that there is $10x10^9$ m^3 (10,084 MCM) of recharge to groundwater systems throughout the Omo-Gibe basin. For various reasons the entire recharge estimated above cannot be abstracted for supply purposes. It is particularly important to sustain the water resource rather than deplete it steadily by abstracting more than the annual recharge. In addition, there will be economic and technical constraints related to pumping (which in turn is related to water level drawdown), water quality and accessibility of the most favorable abstraction points. Consequently, only a small percentage of the available recharge can be abstracted. Assuming arbitrarily that about 10% of the available recharge can be abstracted, then the total groundwater resource that may be developed is estimated to be $1.0x10^9$ m^3/year (1,000 MCM/year). The results are shown for selected sub-catchments of the basin that are partly covered by the Jima sheet in Tab. 2.8

Tab. 2.8 Water balance of selected sub-catchments

Sub-Basin	Area (km^2)	Precipitation (mm/yr)	PET (mm/yr)	Runoff (mm/yr)	Recharge (MCM/yr)
Gibe-Tunjo	1,309	1,346	1,165	321	(-)183
Gilgel Gibe	5,152	1,276	1,033	323	(-)412
Gojeb	6,932	1,598	1,154	439	(+)35
Omo-Deme	1,971	1,338	1,148	199	(-)18
Mansa	1,053	1,606	1,154	334	(+)124
Zinga	1,232	1,574	1,305	304	(-)43
Denchiya	3,563	1,738	1,016	304	(+)1489
Sherma	4,166	1,649	1,012	377	(+)1083

2.6 Drought and Climate Changes

Drought

The whole Ethiopian territory is often affected by reoccurring droughts causing famine. The impact of drought is severe both in the arid lowlands as well as the highlands of Ethiopia. The existence of drought and desertification is well known from geological and archeological evidence as well as from historical documents and on-going measurements. It is a matter of fact that the center of the Ethiopian civilization was shifted about 1,000 km from Axum in the dry north to Addis Ababa located in the more humid center of the current (modern) Ethiopia over the last 2,000 years. The northern and eastern parts of the country appeared to be highly vulnerable to reoccurring drought and famine.

Despite to the fact that southwestern Ethiopia is not considered as a drought prone region (see Fig. 2.36) the area can be classified as an areas of high variability of rainfall and considered these areas as being drought prone.

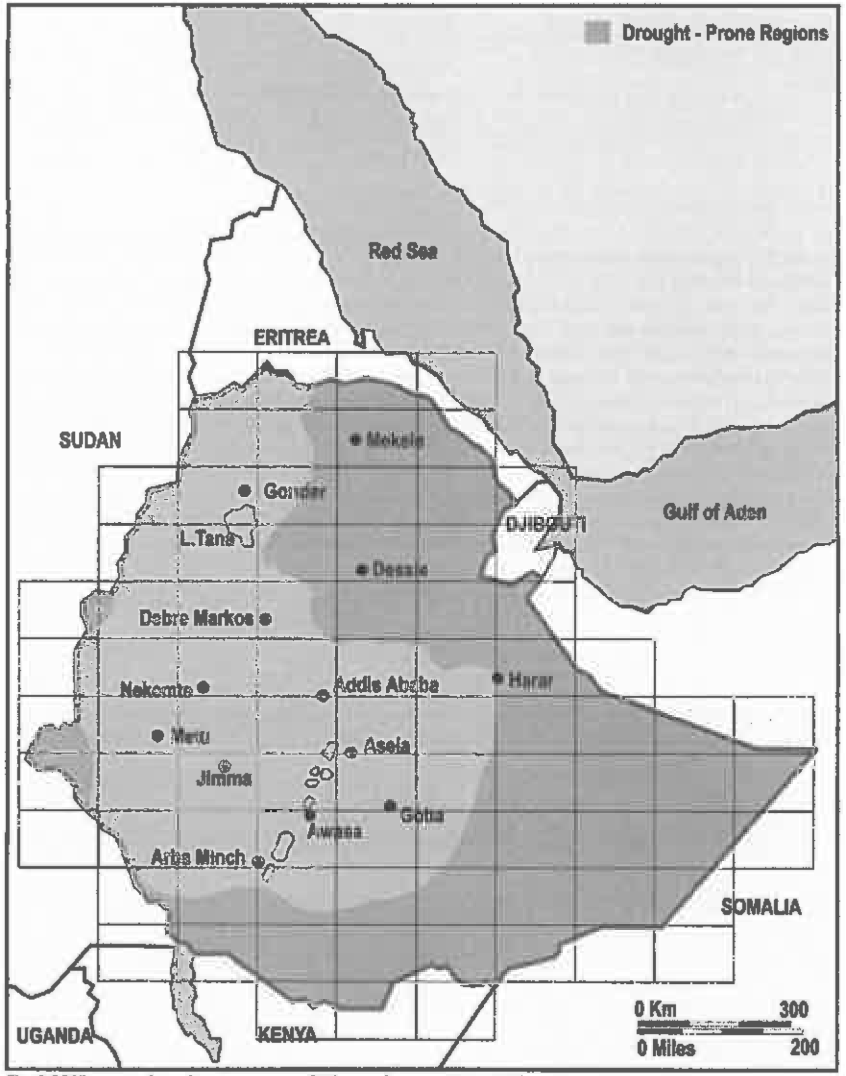


Fig. 2.36 The most drought prone areas of Ethiopia (source: RRC, 1985)

Climate Change

Current climate change poses a significant challenge to Ethiopia by affecting food security, water and energy supply, poverty reduction and sustainable development efforts, as well as by causing natural resource degradation and natural disasters. For example the impacts of past droughts such as those of 1972/73, 1984 and 2002/03 are still fresh in the memories of many Ethiopians. Floods in 2006 caused substantial loss to human life and property in many parts of the country. In this context, planning and implementing climate change adaptation polices, measures and strategies in Ethiopia will be necessary.

The agricultural sector is the most vulnerable to climate variability and change. In terms of livelihoods, small scale rain-fed subsistence farmers and pastoralists are the most vulnerable.

The major adverse impacts of climate variability in Ethiopia include:

- Food insecurity arising from the occurrence of droughts and floods.
- Outbreaks of diseases such as malaria, dengue fever, water borne diseases (such as cholera, dysentery) associated with floods and respiratory diseases associated with droughts.
- Heavy rainfalls which tend to accelerate land degradation.
- Damage to communication, road and other infrastructure by floods.

Major floods occurred in different parts of the country in 1988, 1993, 1994, 1995, 1996 and 2006. All of them caused loss of life and property. The DPPA estimate is about 199,000 critically affected people due to the flood in the country. It is known that 2006 flooding caused the following disasters (NMA, 2006) and more than 364 fatalities in Southern Omo and more than 6,000 (updated to 8,350 after August 15) people were displaced, where around 14 villages were flooded. More than 900 livestock drowned over the South Omo area. In addition, 2,700 heads of cattle and 760 traditional silos were washed away (WFP).

3. Geological Settings

The study area (37-2) covers a large part of the western plateau. The Jima map sheet is covered mainly by Tertiary volcanic flows, pyroclastic flows, pyroclatic fall-outs, ash-flows and to a lesser extent by Quaternary ash-falls and Quaternary alluvial deposits.

3.1 Previous Work

Concise and General Geology of Ethiopia was written by Mohr (1963) and was later modified by Kazmin (1972). Davidson et al. (1976) and (1983) worked on the geology and geochemistry of the southwestern part of the map area, although systematic mapping is lacking. Their map depicts the main volcanic sequence for Jima and the surrounding region, which is Eocene to Oligocene and consists of basalt, rhyolite, trachyte, tuff and ignimbrite.

Merla et al. (1979) mapped Ethiopia as a whole, but the map is rather generalized. The whole area of Jima to Kaficho was mapped simply as Jima volcanites. Jima volcanites are Oligocene to Miocene in age and consists of rhyolites and trachy-basalts. To the northeast of the map area, the Jima volcanics are overlain by Wollega basalts and cover the plateau to the north of Sekoru. They are Miocene to Pliocene in age and consist of basalts with lesser acidic tuffs. The northern part of the Jima sheet i.e. the Arjo map sheet was regionally mapped by the Regional Geology and Geochemistry Department and compiled by Tadesse (1995 E.C). The whole descriptive geology of Ethiopia was compiled by Mengesha et.al. (1996). According to their work, the geology of the area comprises Cenozoic volcanics of early Tertiary rocks. These include lower Jima volcanics and upper Jima volcanics together with the Nazret series. The lower Jima volcanics are mainly basalt flows, whereas the upper Jima volcanics are mainly silicic flows.

For the purpose of oil shale and coal exploration, Miniyie (1992) reported the occurrence of the Eocene rift to the south of Jima. This older rift is supposed to posses a different lacustrine and fluvial environment, in which the oil shale, mudstone, siltstone as well as coal beds were deposited. He further noted that this fault is branched from Lake Turkana and is in line with the rift formed in the Tana Graben. Discontinuous lacustrine basins of similar facies deposits were reported. But this notion is not conclusive because the supposed lacustrine/fluvial deposits are interbedded within middle trachyte, which was not affected by the fault. The minor graben occurring around Tarcha has a different altitude.

The following description of the stratigraphy, lithology and geological development is based on the report by Workneh Haro at al. (2012).

3.2 Stratigraphy

A general stratigraphy scheme of the area with the age and generalized lithological description of the formations is shown in Tab. 3.1. The thickness of individual formations is not known.

The older units encountered are Omo trachyte flows (TV1), Lower basalt flows (TV2), Lower trachyte flows (TV3), Lower pyroclastic deposits (TV4). These are assumed to be the older volcanics of the area and can be correlated to the Ashanghi Formation. The next volcanic rocks are Middle basalt flows (TV5) and Middle trachyte flows (TV6). These are assumed to be a fissural eruption and can be correlated to

the Aiba Formation. The younger units are Upper basalt flows (TV7), Upper trachyte flows (TV8), Upper rhyolite flows (TV9) and Upper pyroclastic rocks (TV10). These cover the highlands in the area and on the lithological basis can be correlated to the Alajae Formation. After rifting and graben formation the Kobech phonolite (TV11), Trachyte plugs (TV12) and the Sentema basalts (TV13) were formed through a central type of eruption. During the Quaternary major volcanic activity is confided to the graben area and to low lying plateau areas. Quaternary stratified tuffs (Qt1) were deposited in the Asendabo graben, and Quaternary alluvial deposits (Qal2) were deposited in the graben of the area and on the valley floors of the main rivers.

Tab. 3.1 Lithostratigraphy of the area

Age				Lithological Unit	Description
Quaternary				Alluvium deposit (Qal2)	Composed of silt and clay which often changes to marsh bogs.
				Stratified tuff (Qt1)	Loosely patched stratified tuff, lose or very slightly compacted.
Cenozoic era	Upper Tertiary	Miocene - Pliocene	(Central vol.	Sentema basalt (TV13)	Medium to coarse grained, massive hard and compacted rock composed mainly of pyroxene, olivine and plagioclase.
				Trachyte plugs (TV12)	Plugs are massive to columnar jointed, the rock is fine to medium grained containing sanidine crystals.
				Kobech phonolite (TV11)	The rock often contains sanidine phenocryst and mafic minerals.
			(Alaje F.)	Upper pyroclastic (TV10)	Composed mainly of ignimbrite, coarse grained and shows columnar jointing.
				Rhyolite flows (TV9)	Mainly rhyolite intercalated with tuff, coarse grained, the rock is often layered but mainly massive.
				Upper trachyte flows (TV8)	The trachyte is deeply weathered and light grey to pinkish in color.
				Upper basalt flows (TV7)	The basalt is mainly aphanatic, fine grained and shows horizontal stratification (around Saja).
		Oligocen	(Aiba F.)	Middle trachyte flows (TV6)	Mainly trachyte intercalate with ignimbrite, rarely basalt, the rock is often massive but shows fractures in places.
				Middle basalt flows (TV5)	Mainly basalt with rare occurrences of intercalation of trachyte showing various grain sizes.
	Lower Tertiary	Pre-Oligocene (Ashangi F.)		Lower pyroclastic (TV4)	Mainly ignimbrite with stratified and lithic tuff, the ignimbrite is medium to coarse grained, massive compacted and dense and contains fragments of tuff, pumice and filammes, the lithic tuff is pinched out to the west up to the scarp of the Omo Valley.
				Lower trachyte flow (TV3)	Mainly ignimbrite with stratified and lithic tuff, the ignimbrite is weathered and medium grained; it shows layering and often tilts to the east due to probable faulting.
				Lower basalt flows (TV2)	Fine grained, often scoriaceous and slightly weathered, contains basaltic pyroclastic rocks.
				Omo Trachyte flows (TV1)	Fine to medium grained and contains weathered sanidine, but can also be massive.

Omo trachyte flows (TV1)
This is exposed in the valley of the Omo River in the southeast part of the map area. The trachyte forms steep slopes to cliffs along the course of the river. It is fine to medium grained and contains weathered sanidine. It is pinkish to light grey and forms thick massive flows. The contact with the overlying lower basalt is not exposed. Omo trachyte covers an approximate area of 106 km^2.

Lower basalt flows (TV2)
TV2 also contains basaltic pyroclastics especially in the valley of the Omo River to the east and west lying on the trachte. The basalts in this area are fine grained, dark grey and slightly weathered, and are 6 to 7 meters thick with sharp contact forming successions of 12 layers. The pyroclastic rocks are topped by a fine grained layer of basalt. TV2 often grades to scoriaceous basalt. The scoria is vesicular and has a sieve-like texture with rock fragments of scoria and basalt. It shows heterogeneous mixtures of rock fragments cemented by lesser sized fragments. The lower basalt covers an area of 746 km^2.

Lower trachyte flows (TV3)
These are mainly exposed in the valley of the Gojeb River, around Chebera-Churchura National Park, south of Felege Selam, to the southwest of the map area and also in the Wukiro-Gera lowlands. Their stratification is exposed on the road to Waka, east of Tarcha. Here the 10 to 15 meter thick trachyte flows are often separated by paleosoil. They are light grey when weathered and when fresh they are dark grey with secondary zeolite and primary sanidine. To the northwest of Chida the unit is intercalated with coal beds. The coal beds are horizontal and often friable. The lower trachyte covers an approximate area of 2,197 km^2.

Lower pyroclastic deposits (TV4)
TV4 is exposed in the eastern part of the map area around the Gilgel Gibe dam in the lowlands of Deneba and around Dimtu town continuing to the west. It is also exposed to the southwest of Nada and south of Ale. In these areas the major pyroclast is ignimbrite. There are also tuffs and lithic tuffs as well as trachytic obsidian lenses. The deposits are more than 100m thick and continue up to the confluence of the Gojeb and Gibe. TV4 has an approximate area of 795 km^2.

Middle basalt flows (TV5)
To the east of Gibe, this unit directly overlies the lower pyroclastic rocks. In this area fine grained, dark grey basalts are separated by paleosoil. Horizontally layered basalts form 5 (five) lava layers. Intercalation of basaltic pyroclasts occurs in places. The pyroclasts contain boulders, blocks, cobbles and gravel cemented by fine grained material. Some of the fragments are scoriaceous basalts. They represent near-source facies. These are exposed in the valley of the Warwarsa River and they are often cut by basalt dikes. The middle basalt has an area of 3,109 km^2.

Middle trachyte flows (TV6)
The middle trachyte covers many areas of the map sheet. It is exposed to the west of Agaro, northeast of Jima, southeast of Jima, in most areas of Gera and Belete Chaka, south of Bonga and Delbi Moye to Debo. It also forms the highlands of Waka and Wolde Hane, and to the extreme northeast, east of Deneba and north of the Gilgel Gibe dam site. In Kishe, the units are intercalated with ignimbrite and are separated by 30 to 50 cm of paleosoil. The trachyte is associated with coal beds. The Delbi Moye coal mine is situated within this trachyte. The top and bottom of the coal bed is trachyte. The coal is horizontally stratified in discontinuous beds (1.7m). It is soft friable and black. In many areas, fault breccias are observed. The middle trachyte covers a wide area of about 5,750 km^2.

Upper basalt flows (TV7)
TV7 is exposed around Sekoru, to the north of Gilagel Gibe, Dedo, Kusaie, on a slope to the west of Ameya, south of Bonga and to the northwest of Gera up to Gatira. The upper basalt is a continuation of the plateau basalt of Central Ethiopia. It represents a fissure eruption covering vast areas. Similar rock units form minor hill tops in places. The basalt is interlayered with thin trachyte flows and lesser pyroclasts (subaerial tuffs) and ash flow tuffs in places. Around Genji it is underlain by horizontally stratified lahar with a thickness of approximately 15m. TV7 has an area of 2,565 km^2.

Upper trachyte flows (TV8)
The upper trachyte is exposed at higher altitudes to the north of Felege Selam and east of Bonga. The exposure is rare due to thick saprolite and dense vegetation cover. The trachyte has deeply weathered to a light grey to pinkish color. The rock is exposed at an elevation of 2,700 to over 3,300 m.a.s.l. It covers an area of 716 km^2.

Rhyolite flows (TV9)
Rhyolite forms the high mountain ranges of Woserbi to the east of Nada. This occurs to the northeast of the map area. The rhyolitic ignimbrite is a pyroclastic flow containing rock fragments of pumice and trachyte gravels. The rock is often layered, but is mainly massive. This type is exposed forming Mt. Meda Bora. The rhyolite covers an approximate area of 625 km^2.

Upper pyroclastics (TV10)
The upper pyroclastics (pyroclastic flow) is exposed in the northeastern part of the map, northwest of Dimtu town. It is exposed on the stratigraphic highlands of the summit of Mt. Geshe. It is more than 100m thick and lies on the upper basalt flows (TV7) forming high northwest trending peaks. The upper pyroclastic rocks cover an approximate area of 44 km^2.

Kobech phonolite (TV11)
Towards the western part of the Jima map sheet there is a mountain range which is densely forested. The mountain is known as Kobech and is located to the west of Kobech town. The phonolite lies on TV5 (middle basalt flows) but its contact is not exposed due to deep weathering developed in the soil. The phonolite is light grey, massive and slightly fractured, which implies that it is of central eruption type with the mountain root being the source. Kobech phonolite covers an area of 135 km^2.

Trachyte plugs (TV12)
Trachyte plugs are exposed in the southern part of the map sheet to the south of Chida on the way to Ameya. These plugs are associated with TV6 and are about four in number. The trachyte plugs form subcircular outlines of bare rocky surfaces. The plugs are massive to columnar and form steep sided rocky surfaces devoid of soil or vegetation. They often rise above the ground by 50 to 70 meters. The plugs are rare and only cover an approximate area of 11 km^2.

Sentema basalt (TV13)
Sentema is a highland area between Agaro and Jima. It rises to 2100-2400 meter a.m.s.l. It is sub circular outline on Dem and also shows different tone on Landsat image. This feature differentiates the exposure from other lithologies. Due to deep decomposition the contact with the underlying rock is not exposed. Sentema basalt covers an approximate area of 561 km^2.

Quaternary stratified tuffs (Qt1)

Qt1 is exposed on Mt. Goro, to the east of Asendabo in the Bishike river valley. Different horizontally layered tuffs 10 to 15 meters thick make a total thickness of 50 meters. The color of the tuffs is grey to light grey and they are loose or very slightly compacted in places. The tuff beds are separated by paleosoils. Alluvial channel deposits containing 30 cm of sand were also observed between the tuff layers. Near Ale village an old channel deposit containing sands, gravels, pebbles, cobbles and boulders cemented by finer materials is overlain by loose tuff of the same genetic origin. This unit covers an area of 244 km^2.

Quaternary alluvial deposits (Qal2, Qal1)

Alluvial deposits (Qal2) are exposed along major rivers, Asendabo Graben, near Jima town, Kishe Graben, Konda lowlands, and Kemise lowlands. A minor unmappable Quaternary deposit also occurs on the low flat highlands. The deposits are mostly light grey, often bogy with soft clayey soil forming loose thick soil of unconsolidated clayey-silty material in places. They are covered with grass or low vegetation such as reeds. Most of the Quaternary exposure is swampy and occurs in meandering wide flat valleys. Minor lake sediments (Qal1) also occur around Lake Womba in the south of the map.

Minor inner grabens containing Quaternary transported soil occur in Asendabo Graben The inner graben forms flat wide valleys vegetated with grass. These areas are mostly used for pasture. Unmappable Quaternary alluvial deposits occur to the west of Tarcha in Tarcha Graben. Here channel deposits, slope deposits, alluvial fans and minor Quaternary tuffs occur in the lowlands of Gojeb. Quaternary alluvial deposits cover an area of 642 km^2.

3.3 Structures

The geological structures are primary structures such as columnar joints in basalts and flow bands in trachyte and rhyolites. Many types of basalts are massive, but older flows show layering.

Secondary structures are common in the area. The major faults in the area show an ENE-WSW trend. These structures control the position of local grabens in the area. These grabens are formed by normal faults and are asymmetrical. The following grabens are located in the map area:
1. Asendabo graben,
2. Kishe graben,
3. Minor grabens around Tarcha and Chebera-Churchura areas and also to the west and northwest with Quaternary alluvial and tuff deposits.

There are also NW and NE trending faults, some of which produced fault breccia and mylonitic rocks, due to vertical and lateral (strike-slip) movement. A gravity survey conducted during the field work revealed gravity values similar to the MER in certain areas. This finding further proves the occurrence of rifts in this area.

The Sentema central eruption occurring to the west of Jima represents rift shoulder volcanic centers similar to Chilalo and some ignimbrite and rhyolite composed mountains on the Hosaina map sheet as well as some of the trachytic mountains on the Dila map sheets.

3.4 Geological History

Uplift in the lower Tertiary (Eocene) produced a fracture system, which shows a meridional to sub meridional trend. The fracture systems developed into main faults, resulting in fissures through which volcanic eruptions took place.

The Pre-Oligocene lower volcanic rocks of the area are the earliest formed rocks. The first volcanic manifestation began with the Omo trachyte flows (TV1) followed by layered lower basalt flows (TV2), which are covered by minor basic pyroclastic flows.

This episode was followed by lower trachyte flows (TV3) which cover most of the Gojeb gorge and the southwestern part of the map area. There are many paleosoils in between the trachyte flows, which indicate a hiatus in volcanism. There are coal deposits on many of the stratigraphic levels. TV3 is related to fissure eruption at various stages and was followed by the lower pyroclastic rocks (TV4).

Quiescence of volcanism was later followed by Oligocene fissural basalt flows (TV5), followed by middle trachyte flows (TV6). These cover a substantial part of the study area. The presence of coal deposits (Delbi) indicates a hiatus between the eruptions.

A new period of basaltic magmatic activity took place during the Miocene and outpouring of the (upper) plateau basalts (TV7), covering the summits of most of the highlands areas. This event was followed by central-type upper trachyte flows (TV8), which may correspond in time with the eruption of the rhyolite flows (TV9). The event was commenced by the upper pyroclastic ignimbrite rocks (TV10) and by intrusion of trachytic plugs (TV12)

The Tarcha, Chebera-Churchura, Asebo, Kishe and other minor grabens in the central part of the study area were formed during the upper Miocene rifting related to the development of the MER.

4. Hydrogeology

Hydrogeology of the Jima map sheet is based on the assessment of data collected from existing reports and maps and during field work. Some previous hydrogeological work at a scale of 1:250,000 exists; however, data for the area of the map sheet are scarce. Habteab (1988) has produced a more comprehensive hydrogeological report and map of the Jima area (Map Sheet NB 37-1).

The sheets of Hoseina (Kefale Tilahun, Jiri Sima, 2013) to the east, Beseka Akaki (Bereket Fenatw, 2011) to the north, Dila (Thomas Agezew, Jiri Sima, 2014) to the southeast and Nazret (Getahun Kebede, 1980) to the northeast of the Jima map sheet have been compiled by GSE.

The fissured aquifers developed in volcanic rocks of the Hosaina sheet were characterized as follows:

- Extensive and moderately productive fissured aquifers (T = 1.1–10 m^2/d, q =0.011–0.1 l/s.m, with Q = 0.51–5 l/s). The aquifers consist of basalts of the rift floor, and ignimbrite, rhyolite and trachyte of the highlands and escarpment.
- Extensive and moderately or locally developed and highly productive mixed porous and fissured aquifers (T = 1.1–10 m^2/d, q = 0.011–0.1 l/s.m, with spring and well yield Q = 0.51–5 l/s). The aquifers consist of volcanic, sedimentary and pyroclastic rocks of the Central volcanic complexes and pumiceous pyroclastic rocks of the Dino formation and the lower part of the Nazret group.

The hydrogeological map of Ethiopia at a scale of 1:2,000,000 was published by Tesfaye Chernet(1993). He classified the geological units of Ethiopia into four major groups depending on the type of permeability and the extent of the aquifer. This hydrogeological map was the basic documents used for preparation of the field work. Tesfaye (1993) identified the following units (for the highlands):

- Other sedimentary and volcanic rocks along rivers and plain areas with fissured porosity classified as moderately or low productive aquifers; the specific yield of wells was estimated to be in the interval 0.05–1.1 l/s.m and total yield of wells with 20 m of drawdown varies in the interval 0.45–9.9 l/s in moderately productive aquifers.
- Recharge and discharge characteristics were derived as 150–250 mm for the highlands.
- The highlands were classified as an area with major water resources. These were assessed to be widespread and moderate to large in quantity. Groundwater and surface water are of good chemical quality (TDS less than 500 mg/l). Most of the streams are perennial; there are many cold springs, and the groundwater level is between 0 and 100 m and can be exploited in low relief areas (valleys).
- Groundwater chemistry is characterized as being bicarbonate (HCO3) in the highlands.

The hydrogeology of Jima town was published by (Ketema, 1975) who described the groundwater conditions in and around the town and almost all water supply sources in the town were recorded including data on the hydrochemistry.

An unpublished report by Eccleston (1977) also describes the extent of groundwater use in Western Ethiopia. Boreholes that supply community centers in the northern part of the Omo-Gibe Basin have been recorded with some hydraulic details.

A complex hydrogeological assessment, including a water point inventory, as well as hydrological and climatic characterization was performed by Richard Woodroof and Associates (1995-6) in "Omo-Ghibe River Basin Integrated Development Master Plan Study", providing a statistic assessment of boreholes and spring yield.

Flood Basalts (Pv) are characterized by low run-off and high infiltration, and give rise to many springs that form the head waters of the major perennial streams in the basin. Deep wells drilled in the basalts have also provided a very high amount of water with discharges of about 4 l/s, and a calculated formation transmissivity of about 25 m^2/day (high permeable). Makonnen Basalts (Pom) are in many places covered with the top soil which reaches 20 - 50 m in thickness. Springs, hand dug wells and deep boreholes sunk in these basalts have yielded 0.5 to 5.0 l/s of good quality water. Transmissivity values range 0.67-54 m^2/day (high permeable).

The Lower Felsic Volcanic and Sedimentary Formation (Transitional volcanic flows; PNv1) consists dominantly of trachy-basalts overlying welded tuffs (or ignimbrites), with basalts at the base. In some cases, discontinuous intercalations of palaeosols, including lacustrine sediments, clay, shale, lignite and coal, are encountered. Springs are reported to have discharge rates between 0.1 and 0.2 l/s. Shallow hand dug wells sunk to depths of 10 to 20 meters have similar yields. Some of the boreholes drilled in Jima town have static groundwater levelat an average depth of 70 meters below ground level and yields in the range of 0.3 to 3 l/s with an average formation transmissivity of about 3 m^2/day (moderate permeability). Sedimentary layers create artesian or sub-artesian conditions in boreholes.

Upper Felsic Volcanics (PNv2) are relatively fresh, jointed, fractured and faulted trachytes, rhyolites and ignimbrites that have a domed and high rugged topography. The density of spring distribution is very low in fault zones and the yield ranges between 0.05 and 0.3 l/s, thus demonstrating the low aquifer potential of this unit. (low permeability). However, thermal springs such as the Bilbo geyser in the Daramalo area (Maze river catchment – out of the map sheet), discharge 50-60 l/s suggest that some fault zones could tap deep groundwater.

The Nazareth Formation (NMn) consists of silicic rocks including trachyte, rhyolite, ignimbrite, tuff, with minor basic basalt flows. Borehole logs indicate that volcanic sand layers (pyroclastics, including volcanic sand) intercalated with the lava flows are responsible for the high yields (up to 10 l/s) with transmissivity of 18-40 m^2/day(high permeability).

Plugs and Dykes (NMh) are located close to structural intersections and are dominantly composed of felsite, phonolite and trachyte. It is suggested that drilling sites should be chosen close to these features but on their upstream sides with respect to the groundwater flow direction.

Quaternary trachy-rhyolite, ash and tuff in the upper part and basalt in the lower part (Qv1, Qv2, QHn). Damota, Humbo and other eruptive centers. Borehole logs show that sandy pyroclastic sediments interbedded with massive trachy-rhyolite horizons are the primary aquifers. The well yields are high (up to 10 l/s) but because of low aquifer transmissivity (1.3 m^2/day in some cases) the drawdown during pumping can be very high i.e. in the order of 60 m. (Moderate permeability)

Quaternary sediments are: alluvium (e.g. alluvial fans), lacustrine silt and clay, and fluvial sand and silt. Eastern Alluvial/Colluvial Plain Deposits (Q3). This refers to alluvial and colluvial deposits that overlie early flood basalts in the narrow tectonic grabens in the area between Sawla and Sodo. The unit consists of several cycles of fine to coarse sediments of basaltic origin down to at least 80 m.b.g.l. Danan plain, several sandy gravel aquifers could be encountered with increased depth of drilling giving at least 4 l/s of excellent quality groundwater with a drawdown of about only 4m during pumping. Northern Alluvial/Colluvial Deposits (Q4) represent deposition of materials derived from the erosion of silicic rocks such as rhyolite and ignimbrite in the Gojeb and Gibe river catchments. The sediments are dominantly clayey with intercalations of several volcanic sand beds. A borehole at Serbo, in the Gibe River Basin, shows that these sediments extend to about 50 m.b.g.l and that sand beds, which are the main water bearing horizon, are encountered below 35 m.b.g.l. Discharges vary between 1 and 3 l/s, with transmissivity of 0.6-2.2 m^2/day.

The dominant water type, in almost 84% of spring waters, is calcium-magnesium/carbonate-bicarbonate.

A large number of local studies and drilling reports describing lithology and hydrogeological characteristics of individual wells were collected during the field work.

4.1 Water Point Inventory, Methodology and Procedures

The overall hydrogeological study has three different phases, namely pre-field work, field work and post field work, and used different types of equipment in order to achieve its objective with the available resource and within the allotted time. The list of equipment and different tasks in each phase are discuses below:

Phase 1 pre field work:- prior to the field work the relevant material is collected from the Basic Geosciences Mapping and Geo-information Center of the Geological Survey of Ethiopia. Topographic map are purchased from the Ethiopian mapping agency. A semi hydrogeological map is also produced and an identification of gap made.

Phase 2 field work:-The field work is performed as soon as the necessary desk study (pre-field work) has completed spring, dug well and borehole inventories based on the ENGDA format, which includes several parameter characterizing each water point i.e. yield, lithology, static water level etc.. The respective water samples are taken wherever possible. Field pH and EC measurements, geological and hydrogeological observations, environmental condition assessments and the relevant data from water bureaus at federal, regional, zone and district levels as well as private sources are collected.

Phase 3 post field work: - The main task of this phase is based on detailed field observation, yield measurements of water points, chemical results of the water samples to produce a hydrogeological report and hydrogeological map. Data are processed with the help of software such as Global Mapper-8, DEM, ArcGIS-10.0, Surfer-8, Aquachem-4 and Excel. Based on the detailed field observation, yield measurements of water points, chemical analysis of the water samples aquifer classification and identification of productivity geological unit and recharge condition are made. In general, the main task is to use the data collected during the above two phase to produce the hydrogeological report and hydrogeological map. A list of materials used during the study is shown in Tab. 4.1.

Tab 4.1 List of materials used during the study

No	List of material	Purpose
1	Topographic and Geological map of scale 1:250,000	base map for hydro geological map
2	GPS	Acquiring position
3	pH and EC meter	For field measurement of pH and EC
4	Solution such as pH (4.7 and 9) and dissolved salt (kcl)	For calibration of pH and EC meter
5	Distilled water	Washing pH and EC
6	Plastic sample bottles	To store representative sample
7	Camera	To take photos
8	Stationary material	For field and office work
9	Computer and various software applications	For report writing
10	Field car	Transport

During the field investigation, 211 water points were thoroughly inventoried and 153 water samples were collected (see Tab. 4.2). The static water level of open dug wells was also measured using electrical sounding instruments wherever possible (two water points are outside of the map sheet). Other important hydrogeological data were collected from drilling reports provided by various organizations in the studied area.

Tab. 4.2 Summary of field inventory

Water point type	Number of inventory	Sampled
Borehole (BH)	86 (119)	61
Dug well (DW)	8	8
Spring (CS)	76	76
Surface water (RW)	6 (7)	6 (7)
Rain water (RAIN)	1	1
Total	178 (211)	153

4.2 Hydrogeological Classification/Characterization

The qualitative division of lithological units is based on the hydrogeological characteristics of various rock types using water point inventory data and by analogy with surrounding map sheets and previous works. The lithological units were divided into groups with dominant porous and fissured permeability and mixed permeability. This division served for a definition of the basin's aquifer/aquiclude system. Since quantitative data such as permeability, aquifer thickness and yield are not adequate or evenly distributed enough to make a detailed quantitative potential classification; analogy was used for characterization of rocks without the adequate number of water points. Hence, the hydrogeological characterization of the study area reveals the following aquifer/aquiclude systems:

Units with porous permeability, where groundwater is accumulated in and flows through pores of an unconsolidated or semi-consolidated material. Porous materials of Quaternary age are represented either by lacustrine sediments with subordinate fluvial, colluvial and eluvial sediments developed in grabens and depressions of lakes and/or along valleys of former and existing rivers or by pyroclystic and unwelded tuff materials. The porous aquifers are widely developed over the study area. The aquifer with porous permeability forming aquifers is expressed on the hydrogeological map in blue.

Units with fissured permeability, where groundwater is accumulating in and flows through the weathered, jointed and fractured part of volcanic rocks. The porosity of lava flows may be high but the permeability is largely a function of a combination of the primary and secondary structures (joints and fissures) within the rock. In addition, the permeability of lava flows tends to decrease with geological time. The pyroclastic rocks between lava flows are generally porous but usually less permeable due to poor sorting. They can be represented by impermeable unwelded tuff in some part of the volcanic sequence. Hence, extensive volcanic ash beds may form semi-horizontal barriers to water movement (infiltration) resulting in lower productivity of basaltic units located at greater depth. Layers of paleosoil of various thicknesses in between lava flows are also less permeable and usually consist of clay material on the one hand, whereas layers of fluvial and lake sediments and pumiceous pyroclastic materials between various lava flows can enhance well yield on the other hand.

Tertiary volcanic formations represented by basalts, rhyolite, trachyte and ignimbrite form aquifers with good fissured porosity. The units with fissured permeability forming aquifers are expressed on the hydrogeological map in green.

Units with mixed fissured and porous permeability volcanic rocks are often mixed with sediments accumulated in between lava flows and or volcanic episodes in rivers and lakes including coal and/or relatively thick layers of unwelded tuffs, ash flows and pumiceous pyroclastic material. These intercalated porous materials do not act as independent aquifers but they form a mixed fissured and porous multilayered aquifer together with the volcanic rocks. Porous materials can significantly contribute to the safe yield of wells when they are developed together with volcanic rocks. The permeable porous sediments in between lava flows form a body that can accumulate large volumes of groundwater by draining the surrounding fissured aquifers and contribute to the yields of wells developing groundwater from this mixed aquifer, which is more productive than fresh basalt, ignimbrite, trachyte and rhyolite that are normally considered as rocks with moderate and/or low permeability. These porous materials are recharged indirectly by groundwater from the overlying aquifers developed in volcanic rocks. Groundwater is under watertable or semi-confined conditions.

Units with essentially no groundwater resources are units where groundwater is neither stored nor transmitted through the rock under ordinary hydraulic gradients. Groundwater development for limited individual water supply is very difficult and even impossible in places. These are groundwater resources with poor or no exploitation potential and are represented by trachyte and phonolite plugs.

4.3 Elements of the Hydrogeological System of the Area (Aquifers and Aquitards)

The hydrogeological map shows aquifers and aquitards (formations with local and limited groundwater resources) defined based on the character of the groundwater flow (pores, fissures), the yield of springs and the hydraulic characteristics of boreholes. The following aquifers and aquitards were defined:

1. ***Extensive (642 km^2) and moderately productive or locally developed and highly productive*** porous aquifers (T = 1.1–10 m2/d, q = 0.011–0.1 l/s.m, with spring and well yield Q = 0.51–5 l/s). The aquifers consist of Quaternary alluvial deposits (Qal). The aquifers are shown in light blue.
2. ***Extensive (6,822km^2) and moderately productive fissured aquifer*** (T = 1.1–10 m^2/d, q = 0.011–0.1 l/s.m, with Q = 0.51–5 l/s). The aquifers consist of basalts and trachyte (Tv1, Tv2, Tv5, Tv8 and Tv13). The aquifers are shown in light green.
3. ***Extensive (10,671 km^2) and moderately or locally developed and highly productive mixed porous and fissured aquifers*** (T = 1.1–10 m^2/d, q = 0.011–0.1 l/s.m, with spring and well yield Q

= 0.51–5 l/s). The aquifers consist of volcanic, sedimentary and pyroclastic rocks (Qt1, Tv3, Tv4, Tv6, Tv7, Tv9 and Tv10). The aquifers are shown in light green and light blue horizontal hatching.

4. ***Formation (152 km^2) consisting of a minor fissured aquifer with local and limited groundwater resources – Aquitard.*** The formation consists of the trachyte plugs and phonolite (Tv11 and Tv12). The rocks are shown in the hydrogeological map in light brown.

The following detailed hydrogeological characteristics of the aquifers and hydrogeological characteristics of the individual lithological units are described based on archive data and data collected during field observation in during field seasons of 2015. Hydraulic characteristics of wells taken from drilling reports are in the tables in Annex 1a.

4.3.1 Extensive and Moderately Productive Porous Aquifers

The porous aquifers altogether make up 642, km^2, accounting for about 4 % of the area and consist of alluvial sediments (Qal2) exposed along major rivers, Asendabo and Kishe Grabens, Konda and Kemise lowlands and lake sediments are exposed around Lake Womba (out of the map sheet). Colluvial and elluvial sediments and stratified tuffs of a Quaternary age also make up the porous aquifers of the map sheet. Quaternary stratified tuffs (Qt10) form an exposure in Mt. Goro, east of Asendabo in the Bishike river valley. Different horizontally layered tuffs, 10 to 15 meters thick, make a total of 50 meter thickness. Alluvial channel deposits containing sand of about 30 cm thick were also observed between the tuff layers, and an old channel deposit containing sands, gravels, pebbles, cobbles and boulders cemented by finer materials was observed near the village of Ale. Porous aquifers developed in porous media are shown in light blue in Fig. 4.1.

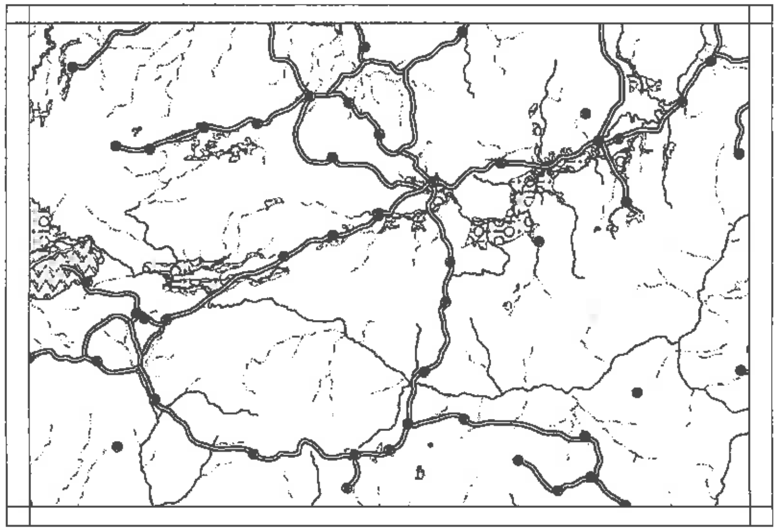


Fig. 4.1 Porous aquifers (light blue) and aquitards (light brown)

Volcanic sedimentary rocks are generally represented by volcanoclastic strata, associated with volcanic eruptions, which have the hydrogeological characteristics of sedimentary materials. These are dominated by clastic sediments of volcanic origin intermixed with lacustrine and/or fluvial units and tuff materials. There may be moderate yields locally where the aquifer provides important local supplies, but several wells drilled directly in tuff were totally without water and were abandoned.

There are three springs discharging groundwater from alluvial sediments with a yield varying from 0.4 to 4 l/s. Wells drilled in alluvial sediments are 60 to 100 m deep and their yield varies from 5 to 12.8 l/s. Alluvial sediments as well as volcano/sedimentary rocks are not monotonous, but they consist of alternating coarse and fine beds. In the grabens, large volumes of good quality water could be abstracted from a depth of 50-100 meters with very little drawdown.

4.3.2 Extensive and Moderately Productive Fissured Aquifers

The fissured aquifers of moderate productivity make up 6,822 km^2, accounting for 37 % of the area and consist dominantly of basalts with some trachyte and rhyolites in the eastern part of the sheet. These aquifers are characteristic for the western highlands. Their age and geomorphological setting dictate their hydrogeological characteristics, with fissure flow being dominant. Open faults and fault systems may also provide significant groundwater flow paths. Where these are extensive, they may allow regional transfer of groundwater. Fissured aquifers developed in fissured media are shown in Fig. 4.2.

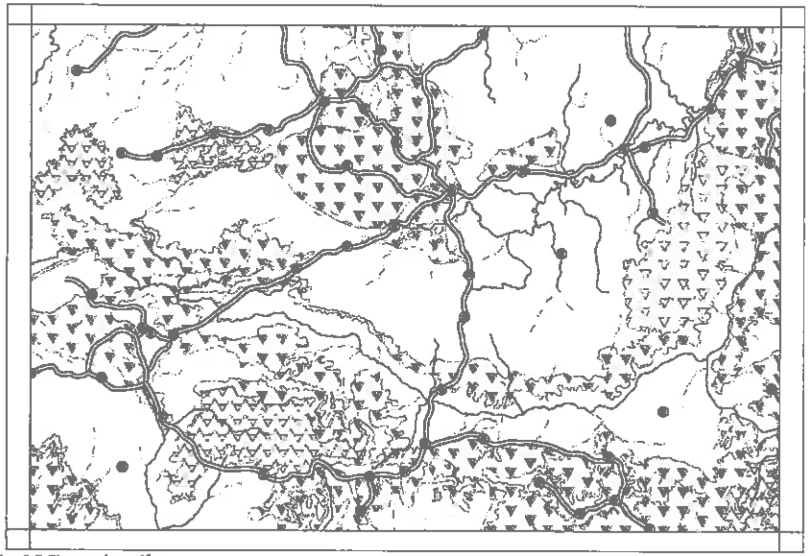


Fig. 4.2 Fissured aquifers

Basalts usually form less viscous thin lava flows and may be significantly affected by weathering, brecciation and may be interbedded with lacustrine or fluviatile deposits. Groundwater flows through joints, fractures, scoria intercalations and scoraceous horizons and interbedded sediments. The continuity of fractures in both horizontal and vertical planes provides the aquifers their hydraulic continuity with adjacent units and aquifers. The frequency of yield of water points from fissured aquifers hosted by various volcanic rocks are shown in Fig. 4.3 and basic statistics are given in Tab. 4.3.

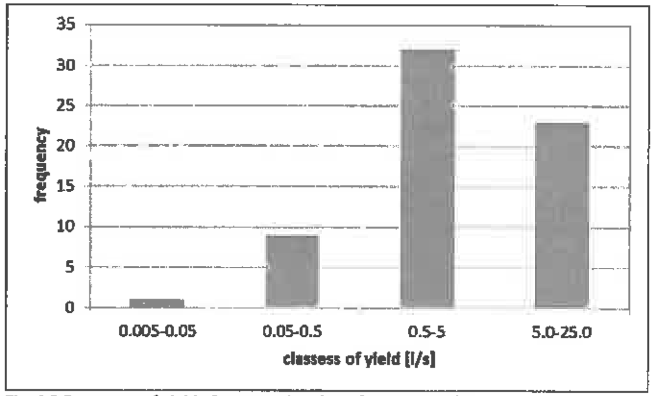


Fig. 4.3 Frequency of yield of water points from fissured aquifers

Tab. 4.3 Basic statistics of yield of water points from fissured aquifers in l/s

Number of data	Max	Min	Median	Average
65	15	0.01	4	4.5

Trachytic and rhyolitic lava flows are more viscous and are often thicker than basalts and less widespread, being located closer to the source volcano or extrusion. Jointing, fissures and regional faulting represents the major source of secondary porosity. Where these flows are extensive, springs may occur and aquifers have potentially high yields.

4.3.3 Extensive and Moderately Productive Mixed Porous and Fissured Aquifers

The mixed porous and fissured aquifers of moderate productivity make up 10,671 km^2, accounting for 58 % of the area and consist of dominant trachyte lava flows, some ignimbrites and rhyolite mixed (intercalated) with porous tuffs, pumice, river and lake sediments.

The aquifer consists of intergranular and fractured permeability. Mixed aquifers developed in porous and fissured rocks are shown in Fig. 4.5. The intercalated sediment does not act as an independent aquifer but rather contributes to the safe yield of the wells. The aquifers are recharged directly by percolating rain water as well as indirectly by overlaying aquifers. The average yield of the aquifer is about 4.5 l/s and median is 4 l/s. Aquifers show both unconfined and confined aquifer systems.

Frequency of yield of water points from mixed aquifers hosted by various volcanic rocks is shown in Fig. 4. and basic statistics are given in Tab. 4.4.

The ignimbrite formations are productive as a result of their secondary fracture porosity and permeability. Outcrops are mostly well jointed. Yields from both boreholes and springs may vary widely. Local investigations are essential to determine available yield and the extent and depth of the groundwater resource. The formation is often interbedded with volcanoclastic and even sedimentary materials.

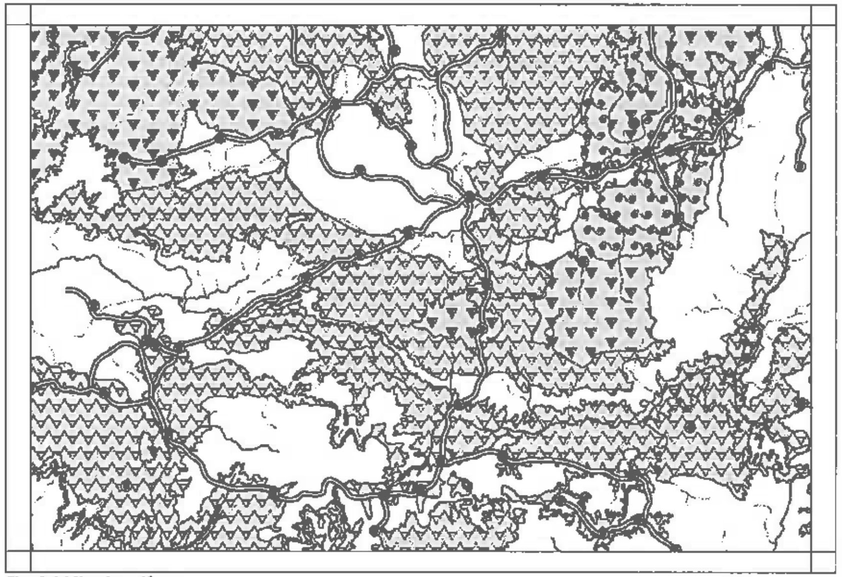


Fig. 4.4 Mixed aquifers

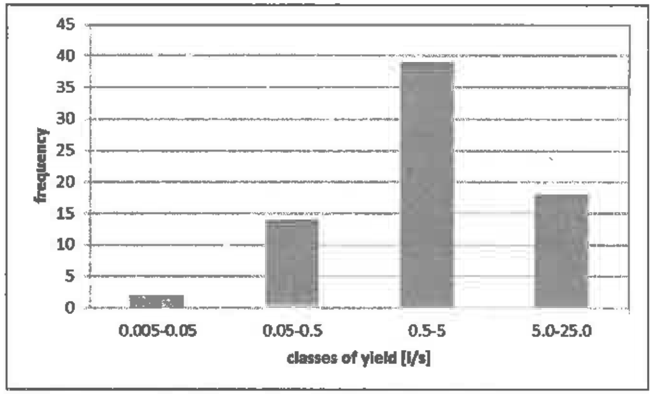


Fig. 4.5 Frequency of yield of water point from lacustrine sediments

Tab. 4.4Basic statistics of yield of water point from mixed aquifers in l/s

Number of data	Max	Min	Median	Average
73	15	0.01	2.0	3.2

4.3.4 Formation Consisting of a Minor Fissured Aquifer with Local and Limited Groundwater Resources – Aquitards

A minor formation (152 km^2) consisting of minor fissured aquifers with local and limited groundwater resources or aquitards of the Jima sheet consist of trachyte plugs and phonolite flows. The formation is shown in light brown. The extent and location of the aquitards is shown in Fig. 4.1.

Despite to the assessment of trachyte plugs and phonolite flows as aquifers with local and limited groundwater resources (aquitards) springs with discharge of springs can reach 7 l/s (CPS68 – Mareka); however, the main source of groundwater in the spring can be from adjacent aquifers.

4.4 Hydrogeological Conceptual Model

The general concept of infiltration and groundwater circulation in the Jima map sheet is divided into plateau sensu strictoand grabens inside of the plateau.

The western plateau is built by faulted basalts, trachyte, rhyolite and ignimbrite intercalated by volcano-clastic (tuff) and sedimentary rocks filling grabens. Rain water directly percolates into outcropping rock and infiltration is particularly good in areas where the plateau is covered by thick elluvial sediments. The thickness of lateritic soil is in some places assessed to be about 50 m. Aquifers outcropping on the plateau also feed deeper fissured aquifers developed in underlying volcanic rocks. Springs are relatively small in mountain areas in the west, along the surface water divide between the Abbay (Didessa) and Gojeb rivers and represent shallow local groundwater flow. Springs in deep river valleys (Gibe and Omo) are larger and represent deep local groundwater flow. The existence of deep regional groundwater flow is expected, however direct evidence in form of hot springs is missing in the sheet area. A conceptual hydrogeological model of the western plateau in the Jima area is shown in Fig. 4.6.

The principles of the general conceptual model of the Jima sheet are based on three main mechanisms of recharge as well as discharge as follows:

- direct recharge to outcropping aquifers
- vertical recharge from overlying aquifers into underlying aquifers
- horizontal recharge between aquifers and from rivers (during high waters)
- vertical as well as horizontal recharge of aquifers in grabens
- direct discharge by springs from outcropping aquifers in hill slopes, deep valley and along prominent faults
- direct discharge to rivers, indirect into aquifers of grabens
- indirect discharge from one aquifer to another (vertical as well as horizontal)

Groundwater is under watertable conditions; however, artesian conditions are also known, particularly from the mixed volcano sedimentary aquifers.

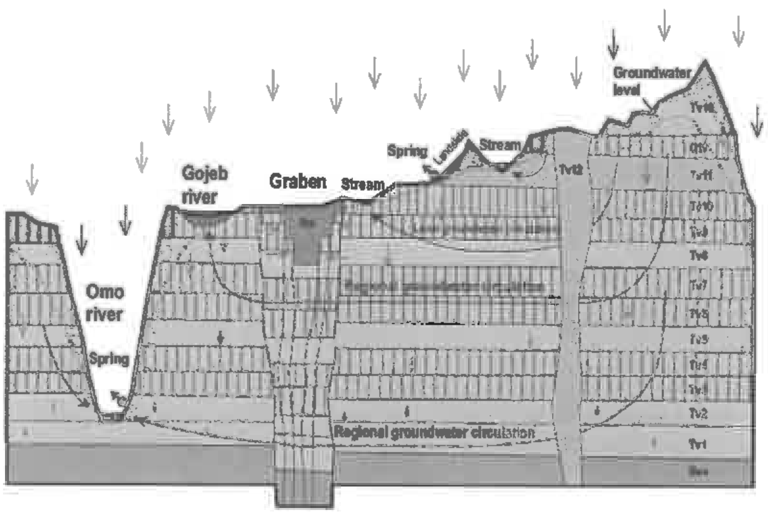


Fig. 4.6 Conceptual hydrogeological model of the western plateau in the Jima area

Groundwater flow is in general parallel with the surface water flow system and is from regional groundwater flow direction to north, west and south to the valleys of the main rivers.

Groundwater (boreholes and springs) remains the main source of water supply for towns and villages within the Jima map sheet.

4.5 Annual Recharge in the Area

There is large volume of data from different reports about the assessment of recharge; however, these data vary significantly. The regional mechanism of recharge of aquifers in the area has been described above. As is the case in other areas the groundwater is recharged from precipitation depending on its intensity and annual distribution, topographical gradient of the area, as well as the lithological composition (particularly in the vertical profile) of outcropping rocks and their tectonic disturbance. A substantial part of the groundwater is recharged from direct precipitation. There is also a seasonal but less significant amount of recharge to localized aquifers from most of the permanent as well as intermittent streams after rains when the level of water in rivers is above the groundwater level in the surrounding aquifers. Aquifers along the rivers are recharged by the surface water of streams as the flow of many streams is controlled by structures.

Recharge assessment was performed based on rainfall infiltration (recharge from rainfall) according to the rainfall infiltration factor (RIF) by WWDST (2003) to be about 6% for both alluvial sediments and volcanic rocks. The recharge area of outcrops of lithological units was considered only if the slope of the terrain is less than 20 %.

Tesfaye (1993) characterized recharge in the highlands to be between 100 to 250 mm on the western plateau.

The water balance technique used by Richard Woodroof and Associates (1995-6) without considering soil moisture accretion, indicates that there is $10x10^9$ m^3 (10,084 MCM or 1.5 $l/s/km^2$) of recharge to groundwater systems throughout the whole of the Omo-Gibe Basin (79 000 km^2) of 46.6 mm.

Recharge calculated from mean values of baseflow shows the possibility of recharge variability from 100 mm/year to 512 mm/year, having an average 200 to 300 mm/year and mean value of 234 mm/year depending on precipitation depth variations in different years. Compared to the adopted average depth of precipitation of 1,500 mm the calculated infiltration (recharge) can be assessed as being 10 % of the precipitation depth.

5. Hydrogeochemistry

One of the important tasks of the water point inventory and data collection was to study the groundwater chemistry and to assess the groundwater quality for its use within the mapped area. Therefore, a study of the groundwater quality was carried out on the different aquifers (geological formations) of the area as well as various parts of the water circulation system (rain and surface water, as well as groundwater). The results of the hydrochemical study can help to understand the groundwater circulation within the aquifers in addition to comparing the water quality with various standards.

Tesfaye Chernet (1993) identified the hydrochemical characteristics of the natural waters, which were collected from different sources and the recharge/discharge conditions of the groundwater. According to Tesfaye Chernet:

- the water resources consist of cold groundwater with TDS below 1,000 mg/l,
- the groundwater chemistry is characterized as being dominantly calcium-bicarbonate or calcium-magnesium-bicarbonate types of water. Some of the groundwater (particularly from lacustrine sediments) has a high fluoride content.

Hydrochemical characterization assessed by Richard Woodroof and Associates (1995-6) shows that the dominant water type is calcium-magnesium/carbonate-bicarbonate; although in most cases neither calcium nor magnesium is dominant, several samples are dominated by magnesium. The second water type is sodium-potassium/carbonate-bicarbonate.

Observation and assessment by the mapping group are similar to the previous finding done by Tesfaye Chernet (1993) and by Richard Woodroof and Associates (1995-6).

5.1 Sampling and Analysis

A total of 153 water samples were collected from boreholes (61), dug wells (8), springs (76), surface water (7) and rain water (1) in the study area and data on an additional 10 water analyses were collected from different basin study and drilling reports. All of the water samples collected for laboratory analysis were submitted to the central laboratory of GSE and analyzed for chemical composition. The chemistry of the water obtained from the samples is shown in Annex 2. Chemical analysis of the major constituents (Mg, Ca, Na, HCO_3, SO_4, Cl) and secondary constituents (K, NO_3, F, HBO_2, CO_2, SiO_2), and measurements of electrical conductivity (EC) and pH at room temperature were performed in the laboratory. Field measurements of pH, temperature and electrical conductivity were made at the time of sampling. The analytical results were presented graphically on a hydrochemical map to facilitate visualization of the water type and their relationships. Suitability of groundwater for drinking, industrial and agricultural purposes is assessed based on the pertinent quality standards.

Reliability of the analyses was assessed using the cation-anion balance. The assessment showed that none of the samples exceeded the reliability level of 10 %. The frequency of the level of balance is shown in Tab. 5.1 and Fig. 5.1.

Tab. 5.1 Level of balance

Level of balance [%]	Frequency	Cumulative frequency [%]
Less than 5	83	55.0
5–10	38	80.1
10–15	21	94.0
15–20	4	96.7
20–25	2	98.0
More than 25	3	100.0

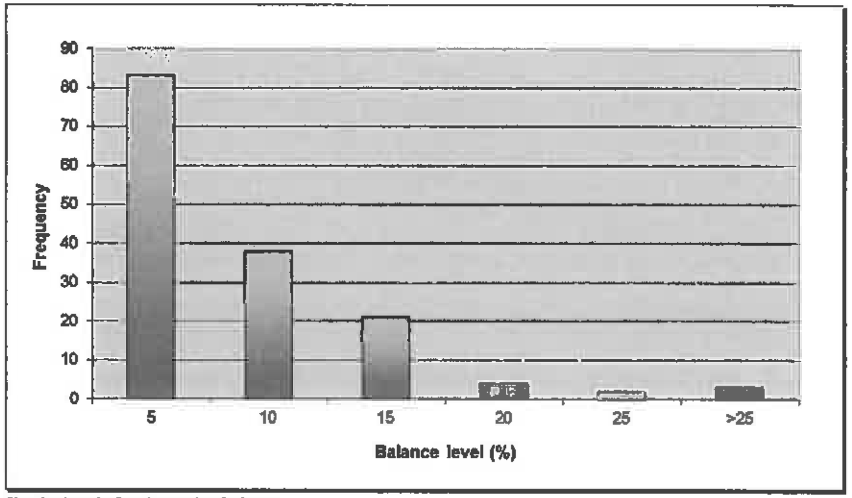


Fig. 5.1 Level of cation-anion balance

5.2 Classification of Natural Waters

Classification of natural water was used to express the groundwater chemistry on the hydrochemical map. Hydrochemical types are classified based on the Meq% representation of the main cations and anions by implementing the following scheme:

- Basic hydrochemical type, where the content of the main cation and anion is higher than 50 Meq%. This chemical type is expressed on the hydrochemical map by a solid color.
- Transitional hydrochemical type, where the content of the main cation and anion ranges between 35 and 50 Meq%, or exceeds 50 % for one ion only. A dominant ion combination is expressed on the hydrogeological map by the relevant colored horizontal hatching. The secondary ion within the type is expressed by an index (e.g. Mg^{2+}).

- Mixed hydrochemical type, where the content of cations and anions is not above 50 Meq% and only one ion has a concentration over 35 Meq%. This type is expressed on the hydrogeological map by the relevant colored vertical hatching.

The chemistry of groundwater in the Jima area reflects the hydrological (aquifer) system and system of groundwater circulation and its variability in the geology and hydrogeology of the area consisting of different volcanic rocks partly intercalated with sedimentary and volcano-sedimentary rocks. The dominant hydrochemical types of groundwater in the study area are calcium-magnesium-bicarbonate (see Tab. 5.2). The second most common chemical type is sodium-bicarbonate. These two types are represented mainly by transitional types where sodium is mainly developed in the northeast and calcium type is mainly developed in the southwest.

The low TDS and dominant calcium-bicarbonate type of groundwater indicate the fast hydrogeological regime of the area receiving a relatively high volume of precipitation where groundwater flows in fractured volcanic rocks of plateaus, which are also the main sources of aquifer recharge.

Tab. 5.2 Summary of hydrochemical types

Hydrochemistry	Type	Number of cases	Percentage
$Ca-HCO_3$	Basic	36	23.8
$Na-HCO_3$	Basic	15	9.9
$Ca-HCO_3$	Trans	52	34.4
$Ca-Mg-HCO_3$	Trans	4	2.6
$Ca-Na-HCO_3$	Trans	8	5.3
$Mg-HCO_3$	Trans	3	2.0
Na-Cl	Trans	1	0.7
$Na-HCO_3$	Trans	10	6.6
Ca-Cl	Mixed	1	0.7
$Ca-HCO_3$	Mixed	1	0.7
$Mg-SO_4$	Trans	1	0.7
$Ca-HCO_3-SO_4$	Basic	1	0.7
$Na-Ca-HCO_3$	Trans	7	4.6
Ca-Cl	Trans	1	0.7
$Mg-HCO_3$	Mixed	1	0.7
Na-SO4	Trans	1	0.7
$Na-HCO_3$	Mixed	2	1.3
Na-Cl	Mixed	1	0.7
$Ca-HCO_3-Cl$	Trans	1	0.7
Ca-Na-Cl	Trans	1	0.7
$Ca-HCO_3-SO_4$	Trans	3	2.0

The hydrochemistry of groundwater of the area is expressed on the hydrochemical map by the relevant colored hatching (for transitional and mixed types). To facilitate the visualization of the classification of water types the percentage of the major cations and anions of the analyzed samples is plotted on the Piper diagram as shown in Fig. 5.2.

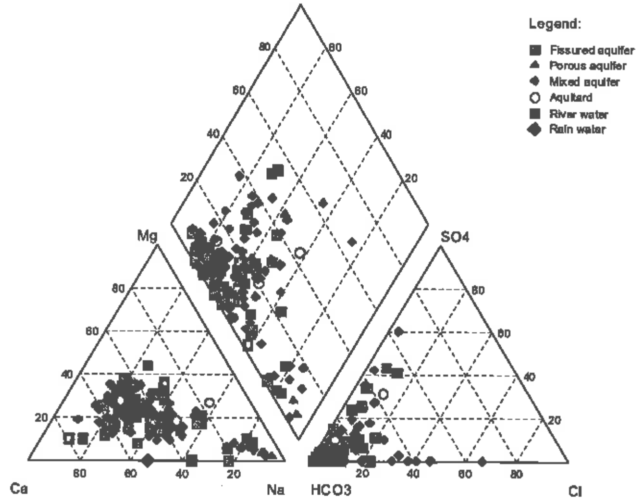


Fig. 5.2 Piper diagram for the classification of natural waters of various aquifers

The basic statistical data for values of electric conductivity (EC), total dissolved solids (TDS) and concentration of chloride (Cl) are shown in Tab. 5.3.

Tab. 5.3 Groundwater descriptive statistics of TDS, EC and Cl values

	TDS [mg/l]	EC [µS/cm]	Cl [mg/l]
Average	211	205	3.1
Median	151	151	1.46
Minimum	15	19	0.57
Maximum	1245	1313	40.55
Count	153	153	153

Groundwater residence time along flow paths, length of water-rock interaction, lithology, ionic exchange, and evaporation play a significant role in the increment TDS and formation of groundwater composition. Major changes in the chemical composition of groundwater occur firstly in the soil zone during the concentration of salts by evaporation and evapotranspiration. A high rate of evaporation and low rainfall concentrates the salts in the soil and when high rainfall occurs it leaches the salts in the soil and moves dissolved solids downwards towards the aquifers saturated by groundwater. The second most important reaction is a result of the contact of water with carbon dioxide. This mechanism is believed to form the sodium bicarbonate groundwater chemistry of the majority of the groundwater.

The development in TDS, which shows no trend, and the relatively uniform hydrochemistry and dominant calcium-magnesium-bicarbonate type of the groundwater indicate the dynamic hydrogeological regime in the western highlands and their structures, including grabens. Groundwater mainly infiltrates into aquifers in the highlands with a cold climate receiving a high volume of precipitation and flows in all directions to the drainage areas formed by the rivers and grabens of the highlands. It flows into lithologicaly homogeneous fissured aquifers developed in various Tertiary volcanic rocks, as well as lithologicaly inhomogeneous fissured and mixed aquifers developed in various volcanic and volcano-clastic-sedimentary rocks, and unconsolidated Quaternary lacustrine sediments in grabens. The gradual development in TDS follows the surface water drainage system. This variability in TDS is shown by idealized isosalinity lines on the hydrochemical map.

5.2.1 Rain Water

The hydrochemistry of rain water in the area is not known in detail; however, the chemical composition of a sample taken in Jima town is shown in Tab. 5.4. The difference in the ion (cation and anion) balance of 25 % shows that the reliability of the analysis is not very high. The water chemistry can be classified as transitional Ca-Na-HCO_3 type.

Tab. 5.4 Chemical composition of rain water [mg/l]

HCO_3	Cl	SO_4	F	NO_3	Na	K	Ca	Mg	SiO_2	pH	TDS
9.76	0.71	0.1	0.62	1.33	1.13	0.35	1.22	0.2	0.21	6.25	15.63

The hydrochemistry of rain water is shown on the hydrochemical map by a pie chart.

5.2.2 Surface Water

Samples taken from seven rivers are used to characterize the hydrochemistry of surface water. The composition of river water is relatively uniform and TDS varies insignificantly from 52 to 124 mg/l, based on the character of the river and the main source of water in the river. The surface water chemistry of these rivers is of transitional calcium – sodium - bicarbonate type and represents mainly groundwater drained by the Limukosa at Gebe, Mana at Arengama, Gera at Hota, Tirowfeta at Gilgel Gibe, Dencha at Dincha, and Mareka at Keerti. The hydrochemistry of surface water is shown on the hydrochemical map by a pie chart.

5.2.3 Groundwater

Groundwater from aquifers hosted in volcanic, volcano-clastic, volcano-sedimentary and alluvial and minor lacustrine sediments is of calcium-bicarbonate type in the southwestern and sodium-bicarbonate type in the northeastern part of the sheet. The types of groundwater are not dependent on the morphological position of the aquifer on the plateau, the type of aquifers (fissured, mixed or porous) or rock type (basalt, trachyte, alluvial sediments) as shown in Fig. 5.3.

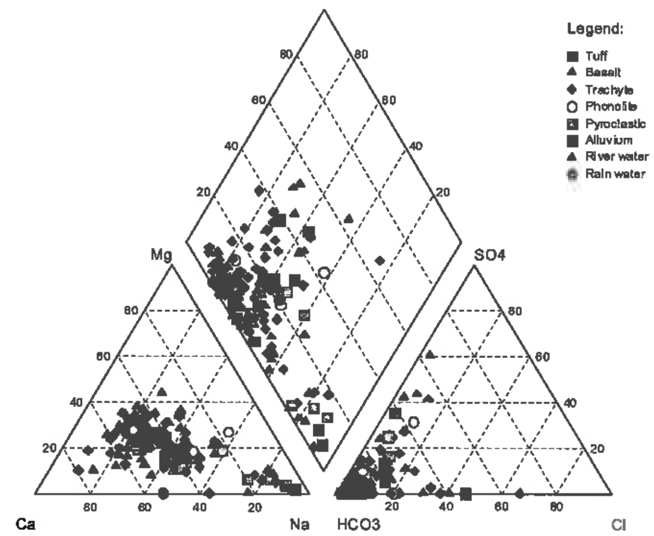


Fig. 5.3 Piper diagram for the classification of natural waters of various rock types

Plateau groundwater is characterized by low TDS, which varies from 100 to 300 mg/l; however, higher or lower TDS can be found randomly.

The hydrochemistry of groundwater is expressed on the hydrochemical map by a solid color for the basic type and by the relevant colored horizontal hatching for transitional types.

5.3 Water Quality

The water quality in the mapped area was assessed from the point of view of drinking, agriculture and industrial use.

5.3.1 Domestic Use

To assess the suitability of water for drinking purposes, the results of the chemical analyses were compared with the Ethiopian standards for drinking water (see Tab. 5.5.) published in the Negarit Gazeta No. 12/1990 and The Guidelines of Ministry of Water Resources (MoWR, 2002).

Tab. 5.5 shows that groundwater in the mapped area is convenient for drinking. This situation reflects the fact that the groundwater dissolves solids from volcanic and mixed volcano-sedimentary aquifers and is in contact with the geothermal systems of the rift valley floor. The groundwater of the highlands only requires fixing of pH by simple water treatment and removal of fluorides in several cases.

Tab. 5.5 Groundwater chemistry compared to drinking water standards and guidelines

Property	Range (min–max) [mg/l]	Ethiopian standards (1) and MoWR Guidelines (2) [mg/l]		Number of exceeding values	
		Highest desirable level	Maximum permissible level	Highest desirable level	Maximum permissible level
Na (2)	1.13-0		358		0
Ca (1)	1.22-48.55	75	200	0	0
Cl (1)	0.57-40.55	200	600	0	0
Cl (2)	0.57-40.55		533		0
HBO_2	0-0		0.3		0
(free) ammonia		0.05	0.1		
Fe (1)		0.1	1		
Fe (2)		0.4			
Mg (1)	0.2-25	50	150	0	0
Mn (1)		0.05	0.5		
Mn (2)			0.5		
SO_4 (1)	0.04-28.29	200	400	0	0
SO_4 (2)	0.04-28.29		483		0
TDS (1)	15.63-1245	500	1500	5	0
pH (1)	5.22-9.64	7.0 - 8.5	6.5 - 9.2	90	59
pH (2)	5.22-9.64		6.5 - 8.5		61
NO_3 (1)	0.44-68.65	10	45	30	2
NO_3 (2)	0.44-68.65		50		2
F (1)	0.1-10.4	1	1.5	15	9
F (2)	0.1-10.4		3		4

Particular interest was paid to the content of nitrates in groundwater. The content of nitrates is not related to the rock composition (type) but it reflects pollution of groundwater by human and/or animal waste. The background content of nitrates in groundwater is about 5 to 10 mg/l depending on the relevant land cover. In forest areas it can be even higher because of the decomposition of various plants and other organic material. The nitrate content in the Jima area varies from 0.44 mg/l to 69 mg/l (Fig. 5.4).

Water samples (30 out of 152 or 20 %) with a nitrate content of above 10 mg/l show that the first (shallow) aquifers are polluted by human activity. The value of 10 mg/l is considered as the natural content of nitrates in the groundwater. The content of nitrates in 2 water points exceeds 50 mg/l (68.65 mg/l in samples BH48 and DW4) showing higher local pollution by nitrates. This pollution is an important factor particularly in vulnerable groundwater resources. This fact also has to be considered when planning for the future development and protection of groundwater resources in the area. Proper location of water points and suitable protective measures should be applied to boreholes, springs and dug wells used for human water supply.

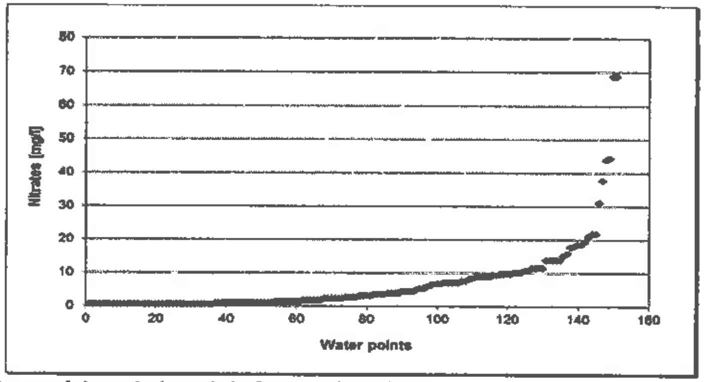


Fig. 5.4 Content of nitrates in the analysis of water in the study area

5.3.2 Irrigation and Livestock Watering Use

Agricultural standards for the quality of groundwater used for irrigation purposes are determined based on the Sodium Adsorption Ratio (SAR), total dissolved solids and United States Salinity Criteria (USSC). The Sodium Adsorption Ratio (SAR) is used to study the suitability of groundwater for irrigation purposes. It is defined by $SAR = Na/[(Ca+Mg)/2]$ where all concentrations are expressed in mg/l.

Tab. 5.6 Suitability of water for irrigation

Value of SAR	Water class	Number of samples in the range
< 10	Excellent	135
10–18	Good	3
18–26	Fair	4
> 26	Poor	9

The majority (94%) of the water samples (see Tab. 5.6) from the study area were found to be suitable for irrigation since they show the SAR value within the water quality class of excellent and/or good for agricultural purposes. Most of water types having sodium (Na) as the dominant cation also have good water quality for irrigation because of a relatively low content of sodium. Application of the United States Salinity Criteria (USSC) revealed that only 2 samples have medium high salinity but are still satisfactory for some irrigation (see Tab. 5.7).

Tab. 5.7 Salinity criteria for irrigation

EC values [µS/cm]	Class	Remarks	Number of cases
< 250	Low salinity	Good	110
250–750	Moderate	Good for soils of medium permeability for most plants	40
750–2,250	Medium high	Satisfactory for plants having moderate salt tolerance, on soils of moderate permeability with leaching	2
2,250–4,000	High	Satisfactory for salt tolerant crops on soils of good permeability with special leaching	0
> 4,000	Excessive	Not fit for irrigation	0

The criteria for livestock watering mainly based on the value of total dissolved solids (TDS) are shown in Tab. 5.8 using the Criteria of the Department of Agriculture, Western Australia (1950) and Raghunath (1987). All of the tested water resources can be used for livestock watering.

Tab. 5.8 Suitability of water for livestock watering

Animals	Upper limit of TDS [mg/l]	Number of samples exceeding the limit
Poultry	2,860	0
Pigs	4,290	0
Horses	6,435	0
Cattle (dairy)	7,150	0
Cattle (beef)	10,000	0
Adult sheep	12,900	0

6.3.3 Industrial Use

Industrial water criteria establish the requirements for the quality of water to be used for industrial processes that vary widely. Thus, the composition of water for high pressure boilers must meet extremely strict criteria, whereas water of low quality can be used for cooling of condensers. The suitability of water for use in industry is shown in Tab. 5.9.

Tab. 5.9 Suitability of water for use in industry

Industry or use	Solids (TDS) [mg/l]	pH	Chlorides as Cl [mg/l]	Sulfates as SO_4 [mg/l]	Number of samples in the range
Brewing	500–1,500	6.5–7.0	60–100		0
Carbonated beverages	< 850		< 250	< 250	148
Confectionary	50–100	> 7.0			9
Dairy	< 500		< 30	< 60	143
Food canning and freezing	< 850	> 7.0			67
Food equipment washing	< 850		< 250		148
Food processing general	< 850				148
Ice manufacture	170–1,300				69
Laundering		6.0–6.5			27
Paper and pulp fine	< 200				90
Paper groundwood	< 500		< 75		145
Paper bleached cardboard	< 300		< 200		116
Paper unbleached cardboard	< 500		< 200		145
Paper soda and sulfate pulps	< 250		< 75		104
Rayon and acetate fiber pulp production	<100				44
Rayon manufacture		7.8–8.3			16
Sugar	< 100		< 20	< 20	43
Tanning		6.0–8.0			107
Textile			< 100	< 100	150

Remark: Sugar requirements for TDS are in general low

Of almost equal importance for industry as the quality of the water used is the relative time constancy in the concentration of various components. As a result, adequate groundwater quality often becomes a primary consideration in selecting a new industrial plant location. Groundwater from the mapped area can be used for industry in general, but some specific technologies require water treatment before it can be used in the technology.

Incrustation hazard is important for the design of various pipes as well as technological processes. Incrustation occurs if concentrations exceed the limits shown in Tab. 5.10. Corrosion hazard occurs if concentrations exceed the limits shown in Tab. 5.11.

Tab. 5.10 Concentration limits for incrustation

Component	Concentration [mg/l]	Number of sample in the range
Bicarbonates (HCO_3^-)	> 400	152
Sulfates (SO_4^{2-})	> 100	152
Silicon (Si)	> 40	71
Iron (total)	> 2	Not analyzed
Manganese (total)	> 1	Not analyzed
Hydrogen sulfide (H_2S)	> 1	Not analyzed
Total hardness (TH as $CaCO_3$)	> 200	Not calculated

Tab. 5.11 Concentration limits for corrosion

Component	Concentration and/or value	Number of sample in the range
pH	< 7	69
EC	> 1,500 µS/cm	151
Chloride (Cl^-)	> 500 mg/l	151
Hydrogen sulfide (H_2S)	> 1 mg/l	Not analyzed
CO_2	> 50 mg/l	Not analyzed
Dissolved oxygen (O_2)	> 2 mg/l	Not analyzed
Total hardness (TH as $CaCO_3$)	< 100 mg/l	Not calculated

There is a low threat of incrustation or corrosion when such groundwater is used in pipes for public water supply or for delivery of water for industry or agriculture. The value of pH should be balanced in any case for both industrial as well as drinking water.

6. Natural Resources of the Area

Natural resources of the Jima area vary in origin relating to the geological composition, soil conditions, water, wind and solar radiation, as well as human resources.

6.1 Energy Potential

The energy potential of the Omo-Gibe basin is high and arises from the combination of large river flow volumes and a topography offering both deep and confined areas for potential dam storage and high water head providing a good potential for turbines.

Geothermal resources are not big as in the Main Rift Valley; however, fumaroles occurring in the Bitno River indicate that geothermal activity exists in this area. Further study may prove possible economic geothermal power occurrences.

The Gilgel Gibe I Dam is a rock-filled embankment dam located about 57 km northeast of Jima in the Oromia Region. The primary purpose of the dam is hydroelectric power production and it diverts water through a 9.2 km long tunnel to an underground power station downstream. It has an installed capacity of 184 MW. The dam is 1,700 m long and 40 m tall. Construction on the dam began in 1998 and the power station was commissioned in 2004.

The Gilgel Gibe II Power Station is a hydroelectric power station located about 80 km east of Jima in the Oromia Region. The power station receives water from a tunnel. It has an installed capacity of 420 MW and was inaugurated in 2010.

The 1,870MW Gilgel Gibe III (Gibe III) hydroelectric power project is being constructed on the Omo River in the Southern Nations, Nationalities, and People's Region State (SNNPRS). It is expected to be one of the largest hydroelectric power plants in Ethiopia and will produce an estimated 6,500GWh of energy a year. The project will include a 243m roller compacted concrete dam, the first of its kind in Ethiopia and one of the tallest in the world. Gibe III was launched in July 2006, with the first unit starting its trial-running generation in September 2013. It is expected to be fully commissioned by 2016. The Gibe III dam would be part of the Gibe cascade, a series of dams including the above-mentioned Gibe I dam and Gibe II power station as well as the planned Gibe IV (1472 MW) and Gibe V (560 MW) dams.

6.2 Industrial Minerals

Building and construction materials are widely available throughout the study area, but are not widely used except around Jima, where there are several quarries producing a wide range of materials. The economic potential of the Jima map area is mainly in terms of the available construction material. There are immense basalt and trachyte resources. Basalts, scoria, trachytes and sands are common. Basalts and trachytes are used for the foundations of buildings and road construction. They may be important also for cobble stone work. Ignimbrites can also be used for buildings and cobble stone work and scoria can also be used as pavement material. The in-situ weathered lava flows of the area, the saprolite, are also used for road construction.

Quaternary deposits and laterite soil are used for agriculture and brick work as well as pottery work.

Tertiary volcanic rocks in the Jima area contain sedimentary horizons with coal, lignite and oil shale deposits. These have been investigated as a potential source of domestic and industrial fuel. The largest of these deposits is at Delbi-Moye and contains an estimated 70 million tons of coal and 100 million tons of oil shale. There are many other localities with coal occurrences in the present work. The coal is used for fertilizer and industrial works.

Finally, the Tertiary basalts contain many silicified amygdaloidal flows. In some places these contain large geodes lined with amethyst and rock crystal, or filled with chalcedony and agate. The felsic volcanics are reported to contain zones of secondary silicification with opal and chalcedony.

6.3 Agricultural Potential

Most of the area is suitable for agricultural activity like the planting of wheat, barley, bean and pea crops as well as for wood production. The main crops cultivated in the rift floor are maize, vegetables and fruits. Traditional farming methods prevail; however, green houses are becoming more common and irrigation agriculture is being partly developed.

Coffee is commercially planted around Jima and Kaficho. Tea (Wush-Wush) is also commercially cultivated towards the south of the Jima map sheet. Bee keeping is common in the area due to dense forest cover and existence of perennial rivers. Both old and modern methods of bee keeping are common.

6.4 Water Resources

Previous studies were also made of the dry season recession flow of the gauged rivers in the whole basin, and the relevant recession coefficients obtained. Typically, the monthly runoff is about 5% of the mean annual runoff when recession flow begins. It is estimated that about 7% of the mean annual runoff is in groundwater storage in the upper Omo-Gibe Basin at the end of the rainy season. As an example, this groundwater storage amounts to some 350 million cubic meters for the Gibe River at Abelti.

The average annual outflow from the Omo-Gibe Basin into Lake Turkana is 16 600 Mm^3/year, corresponding to approximately 225 mm over the basin or 18% of the rainfall on the basin as a whole.

Water resources of the studied area depend mainly on rainfall and other climatic characteristics, as well as the hydrological, geological and topographical settings of the study area. The ultimate source of all natural potable water is rain, but in a place where it is rarely present other means have to be devised to meet public demand. There are many meteorological stations operated by the Meteorological Institute in the mapped area. Selected meteorological stations with long-term measurements were used to assess precipitation depth. ***The long-term mean annual rainfall of the area has been assessed to be about 1,500 mm/year.***

The area of the map was calculated from a 1:250,000 hydrogeological map and an area of ***18,287 km^2 is used for further calculation.***

The areas of active aquifers that have the ability to store and transmit water were calculated based on the hydrogeological map. The active aquifers (Tab. 6.1) of porous, mixed and fissured permeability cover an area of 18,135 km^2.

Tab. 6.1 Aquifers of the study area

Aquifers	Area [km^2]
Porous aquifers	642
Fissured aquifers in volcanic rocks	6,822
Mixed aquifer in volcanic and sedimentary rocks	10,671
Aquitards	152
Total of the area	18,287

The runoff characteristics vary widely because of the variability in climatic conditions and hydrogeological characteristics between different observation points.

Surface river flow measurements are performed in many gauging stations in the Jima area and river flow measurements were considered in the assessment of surface and baseflow values. The surface flow-baseflow assessment is highly affected by the quality of flow measurements, the effect of bank groundwater storage, difficulties in flow measurements of the wide and unstable river channel and unknown groundwater flow beneath the gauging stations. ***For further calculations, the value of specific surface runoff of 15.0 l/s.km² and specific baseflow of 5.0 l/s.km² for areas containing active aquifers in the Jima sheet.*** The assessed water resources of the Jima area are shown in Tab. 6.2.

Tab. 6.2 Assessment of water resources of the Jima area

	Input	Area [km^2]	Resources total	Remark
Precipitation	1,500 mm	18,287	27,431 Mm^3/year	
Total water resources – map	15 l/s.km^2	18,287	8,656 Mm^3/year	30 % rainfall
Renewable groundwater resources active aquifers	5 l/s.km^2	17,493	2,885 Mm^3/year	10 % rainfall
Static groundwater resources of fissured and mixed aquifers	5 % porosity 100 m thickness	17,331	86,655 Mm^3	Not proved
Static groundwater resources porous aquifers	15% porosity 100 m thickness	642	9,630 Mm^3	Not proved

Water resources of the area are huge; however future utilization of water resources within the area depends on changes in the climate, human demands for water, and water resource management practices. Groundwater resources of the highlands which represent the open hydrogeological system are flexible in use with appropriate water management.

6.4.1 Surface Water Resources Development

Despite the fact that river gauge measurements show relatively moderate, but logical, evapotranspiration when nearly 30 % of precipitation is drained as total runoff from the area, there are good water resources to be used for irrigation, as well as for drinking water supply of people living within the area. The total water resources of the area have been assessed to be 8,656 Mm^3/year.

The surface water of the area should be primarily used for irrigation as well as for large and small scale electricity generation in the highlands. The irrigation plans and an assessment of potential and environmental impacts are discussed in detail by Richard Woodroof and Associates (1995-6) in "Omo-Ghibe River Basin Integrated Development Master Plan Study", and by various other specific studies.

6.4.2 Groundwater Resources Development

The river gauge measurements show that nearly 30 % of precipitation is drained as total runoff from the area and about 10 % of precipitation infiltrates and appears as baseflow. There are good groundwater resources to be used for the supply of drinking water to people living within the area. There is also the potential to use groundwater of the area to support irrigation as well as drinking water of people living outside of the mapped area. The total volume of renewable groundwater resources of active aquifers in the area has been assessed to be 2,885 Mm^3/year.

Considering the fact that the total number of people living within the area is 2,994,062 (Tab. 1.1) the need for water supply can be nearly 22 Mm^3/year. Assessment of drinking water demand was based on a calculation of 20 l/c.d (15 l/c.d rural and 22.5 l/c.d for towns with less than 15,000 inhabitants). The figure shows that recent demand represents less than 1 % of the renewable groundwater resources of active aquifers i.e. aquifers can provide adequate drinking water even in the future considering the trends in population growth.

Tesfay (2001) describes water supply issues and predicts that a large number of areas fall into the category of "water scarcity" areas because of an increase in population and in demands for more water for agriculture, industry and the community. This situation will be even worse in 2025 based on the trends in population growth. He defined "water scarcity" and "water stress" as cases where less than 1,000 m^3/year and less than 500 m^3/year are available annually per capita, respectively. These limits represent about 2,994 and 1,497 Mm^3/year; however, they are not supposed to be covered only from groundwater. Comparing these limits to the overall water resources of the area of 8,656 Mm3/year, the scarcity limit represents is exceeded and the stress limit is about 30 % of the overall water resources of the sheet. It is necessary to state that the limits are based on the idea of massive human, agriculture and industrial development in the area over the next 15 years.

Most of the people within the area live in large or small towns and villages, which are supplied from springs, drilled and dug wells. In addition to the further development of dug wells, the water supply based on drilled wells represents the most sanitary secure water and should be applied for small towns as well as for rural inhabitants.

To select appropriate areas, data from regional as well as detailed surveys have been evaluated, and a strategy chosen which consists in siting of the hydrogeological wells for the supply to population on the following basis:

1. Groundwater accumulated in the clastic volcano-sedimentary materials (tuff) may contain increased concentrations of fluorine and groundwater from poorly sanitized water points may contain nitrates, which can overreach standards for potable water some cases.
2. Basalts, trachyte, ignimbrites and alluvial sediments contain groundwater, the quality of which mostly corresponds with the standards for potable water.
3. The yields of the wells, which penetrate basalts, trachyte, ignimbrite and alluvial sediments fluctuate between 2 and 10 l/s, and they are sufficient for the supply for as many as 8,000 to 40,000 inhabitants, the consumption of per person being 20 l/day.

Within the area, the main prospective regions are considered for groundwater development by various methods:

- The high mountains areas occupied by the Makonnen Basalt in the north-west and the degraded part of the 'Flood Basalts' in the southeastern parts of the Omo/Gibe basin. In the former, very good quality ground water could be obtained by drilling moderately deep boreholes (40 to 100 m deep). In the latter, drilling in intermountain valleys or spring capture from the highlands could provide large quantities of groundwater.
- The alluvial plains along in Gojeb and Gilgel Gibe valleys as well as in the tectonic grabens. In the grabens, large volumes of good quality water could be abstracted from a depth of 50-100 meters with very little drawdown. In the Gojeb and Gilgel Gibe valleys, though not as much as in the former area, significant groundwater yields could be obtained from a shallow depth of 50 meters, but since this area is susceptible to environmental pollution care should be taken in the design of boreholes and hand dug wells.
- The eastern piedmont plains. These areas are generally covered by silicic volcanics interbedded by highly permeable pyroclastic sands of the Nazareth Group (NMh). Since the groundwater table is generally deep (>60m), boreholes may need to be deep (100-150m); however, a large groundwater potential exists.

The proposed depth of boreholes sited in the study area should be designed based on the optimum cost and yield of individual wells. During the final siting of each well it is necessary to consider that the final depth of the proposed wells is governed by the level of groundwater which is given by the drainage level (spring altitude, surface water level in river or lake) and surface level of the site selected for well drilling. The drainage level (groundwater level) for each specific site should be derived from the nearby spring and/or surface water level in the river (particularly in case that deep river canyon is nearby) and should be confronted with the site specific surface level of the drilling site and wells drilled before in the vicinity of the proposed well.

The most difficult question will be supply to rural areas with a widely spread population. This should be done from local centers where water wells will be drilled and connected to places of water use with relatively long distribution pipes. Effectiveness and cost of water supply systems for the rural population should be studied as a site specific problem in the future. Springs that emerge from the volcanic formations, especially from the western highland, have high discharge. Developing springs discharging an adequate volume of water is the best method for secured water supply in this area.

Potential groundwater resources existing in the highland areas surpass the current needs of people living in these areas. They even surpass the potential demand of water when agriculture, living standards and industry will be developed in the future in the area. Groundwater is generally of good quality and a minimum number of samples are not convenient for drinking. The groundwater from sampled points can be used for drinking purposes after the supply system is secured by chlorination. There is a chance to use the groundwater of the highlands for water supplies of the adjacent Rift Valley where there is a problem with water scarcity and quality, particularly high fluoride content.

Some of the existing water points do not represent safe water supplies as they show an increasing content of nitrates in shallow water supply systems. Deeper wells currently represent a safe type of water supply; however, they have to be protected against pollution from local sources like human and animal waste (sources of pathogens and nitrates) as well as from potential industry (tanneries, textile industry, flower plantations, etc.). The minimum required distance of water supply wells and potential pollution sources should be maintained during water resource development in towns and villages. The same level of interest should also be applied to the development and protection of groundwater resources for rural communities. It should be necessary to start with relatively concentrated communities where the feasibility and impact of developed schemes will be most significant.

In addition to priority in development of groundwater for safe drinking water supply, it should be possible to select the most fertile soil nearby human settlements and adequate water resources to be developed for irrigation based on groundwater to increase the stability of food supply in prolonged periods of drought. The problem was discussed by Tsur and Issar (1998) who stated that if, as it commonly found in reality, the supply of surface water is uncertain then groundwater plays a role in addition to that of increased water supply: the role of a buffer that mitigates the undesired effects of uncertainty in supply of surface water.

Development and protection of the water resources of the area and the environment as a whole have a principal importance for the development of the infrastructure with subsequent impacts upon the eradication of poverty (development of irrigated agriculture, maintaining livestock during drought). Access to safe drinking water improves the health level of the population (statistics show that 40 % of child death rates are related to water born diseases). About 15 % of the rural population has access to safe drinking water in the area and about 70 % of infections are related to contaminated water resources. This is a serious problem for the creation of strong farm and pastoral as well as industrial communities capable of full time engagement in working activity. It is therefore important to provide safe drinking water to communities. Protection of the environment, particularly prevention of soil erosion and degradation leading to food and water scarcity, is an important development aspect within the area. This aspect is based on the importance of water retention which is of primary importance with regard to the increase in population numbers, bringing with it an increase in demands on soil use. The water potential of the area requires feasible and environmentally sound water management.

Another important task for the future development is knowledge about the groundwater resources of the area and monitoring of their fluctuations in groundwater levels and quality. No monitoring well was drilled within the aquifers for this purpose. It is recommended to drill several monitoring wells e.g. next to climatic stations and river gauging stations and conduct groundwater monitoring together with measurements of climate characteristics. Selection of monitoring points for observation of groundwater level (quantity) and quality fluctuations in lacustrine and volcanic aquifers should be discussed with the Woreda Water Offices and possibly Jima University.

6.5 Human and Land Use Resources and Development

There is a large human resource potential within the area. The total assessed population is 2,994,062 million and the average population growth in the region is 3 %. Taking this into account the population of the area will double in the next 20–25 years. This represents a large potential of manpower for agricultural production as well as for developing industry using the natural resources of the area as well as services. Agricultural irrigation should be practiced and livestock husbandry should use more effective methods of livestock breeding, but a key element for the development of the region is the fundamental development of industrial production and services.

Improvement of the health status of inhabitants using safe water supply systems, utilization of the remaining water resources for agricultural irrigation and for industry and services using other natural resources of the area will improve the standard of life and help to eradicate poverty within this part of Ethiopia.

6.6 Wind and Solar Energy Development

The area has a good potential for the development of solar and wind energy. It should be feasible to use the produced energy for local supply e.g. running pumps for groundwater development or for distribution of irrigation water. It could also be feasible to use this electricity for running local small businesses such as grain mills, coffee washers, food (milk, coffee, tea) processing and conservation industry etc.

6.7 Environmental Problems and their Control / Management

Attention is paid to the eradication of poverty, protection of the environment and natural resources as well as the increase in education in this field. The explanatory notes provide information for planning in sustainable economical development, other sectorial planning, management in the use of natural and human resources and protection against natural hazards. The text concentrates on the identification and protection of water resources, soil (particularly protection of soil against erosion), protection against natural hazards and the support of correct wastewater and solid waste management.

Protection of water resources should be concentrated on better practices in sanitation within small towns, villages and rural settlements following principles of WASH program. About 50 % of the surface and groundwater is fair in quality and can be used directly and/or after some treatment (chlorination) for drinking; agricultural and industrial purposes (see Chapter 5). The use of ponds for rain water harvesting is also common in some parts of the study area; however, this type of water resource can be very dangerous when used for human consumption. Indication of improper sanitation practices is reflected in the increase of nitrates from human and animal waste in the shallow groundwater that is used by dug wells. Water development practices should be based on basic principles of protection as follows:

1. The source of groundwater should not be drilled directly in the center of the village/town.
2. The final design of the well and distribution system should prevent direct percolation of water from the surroundings of the well along its casing to the groundwater.
3. A well should be designed upstream from the groundwater flow direction in respect to existing and potential pollution sources (village, industrial and other similar areas).

4. The required minimal protection zones should be respected by land use development in the vicinity of wells.
5. Regular monitoring of water levels and quality should be performed.
6. There should be improvements in the general application of sanitation and waste management practices, particularly by applying the principles of the WASH program.

Soil erosion and protection is one of the limiting factors of sustainable development of agriculture within the area. The prominent factors for soil degradation in Ethiopia are population pressure, deforestation, poor agricultural techniques, overgrazing and drought. Data about soil erosion in the area are scare. The human causes of soil erosion relate mainly to ploughing and seeding when the heaviest rainfall occur and when crop cover is limited. Another human factor which contributes to soil erosion is the short fallow period (one to four years). Soil burning which destroys the organic matter content of the soil is another adverse factor.

Anti-erosion measures consist of several techniques. Some of the most frequent techniques can be defined as follows:

1. The area of steep slopes along the deep gorges where reforestation is not possible can be terraced (similar to the Konso area and/or on the slopes in the northern part of the country).
2. Retention of water in the countryside–construction of small dams for irrigation can help not only for the accumulation of water for irrigation, but also to slow down runoff after heavy rains and the accumulation of suspended material (eroded soil) in small dams. The accumulated material can be subsequently excavated and used as a fertilizer for arable land.
3. Wicker fascine is a cheap and very simple anti-erosion measure that can be practiced in all parts of the area either separating agricultural fields of individual owners or implemented inside the field when the fields are big enough and highly prone to erosion.
4. Creation of shrubs/tree rows preventing wind erosion and slowing down surface runoff.
5. Covering artificial cuts (along roads and other constructions) by nets or geo-textile.
6. Other technical measures and agricultural practices.

A focus on soil conservation, particularly on sandy soil, is one of the most important factors for environmentally sound land use. Soil conservation contributes significantly to the food security in the area.

Natural hazard and protection against the consequences of earthquakes, landslides, rock falls and other hazards is important for the preservation of human lives, property and arable land.

Susceptibility to exogenous risks differs both in quantity and quality between the valley and plain engineering geological provinces. The following natural hazard potentials have been identified:

- Slopes of the deep erosion valleys in the highlands with repeated rockslides of all sizes and small to medium sized rock falls.
- Repeated rock falls along the upper rims of the deeply cut valley sides.
- River floodplains have been included into risk susceptible units because of the possibility of floods which can be very severe after torrential rains. The observed lithological-structural changes in cuts of alluvial soils indicate the occurrence of catastrophic floods carrying substantially increased volumes of coarse materials in sub-historical times.
- Soil erosion and protection has been addressed above so we can say that areas especially susceptible to erosion are on medium and low energy relief in residual and sandy soil units derived from

ignimbrite. Intensive deforestation and agricultural production in these areas will result in a further increase in the erosion susceptibility.

Wastewater and solid waste management is important for environmentally sound development of the area. Appropriate management in this field protects not only the environment and soil and water resources but also human health against exposure to harmful pathogens and chemicals.

Recent practice is to release wastewater from households as well as from small scale industrial and agro-industrial production directly to the environment. Wastewater is discharged directly to rivers and/or lakes without appropriate treatment. Wastewater is mixed with surface water and is used for irrigation as well as for drinking by people living downstream from wastewater discharge points. People use this polluted water from the river without any knowledge about the potential harm to their health. There is little chance to educate a large number of people about the possible adverse health impact of using polluted water and that is why the wastewater producers have the responsibility to treat the water to remove substances harmful for human health. Infiltration of polluted water to the groundwater threatens the groundwater resources in the area, which is very well documented by the increasing content of nitrates in groundwater.

Solid waste management is poorly practiced within the study area. Alarming is the location of a landfill near towns where all existing waste is piled without any sorting in an abandoned quarry in permeable volcanic rocks.

Increasing environmental care and protection of natural resources will contribute to better living standards of the people living within the area and also to an increase in their working output leading to an increase in food security.

6.8 Touristic Potential of the Area

Jima town itself with about 140,000 inhabitants is 1,763 m above sea level; it has a pleasant climate and also is in a beautiful location nearby coffee and tea plantations. Jima town is a good starting point for longer trips to the lower Omo areas and Chebera Churchura National Park.

There is relatively good touristic potential. Chebera Churchura National Park is found within the western side of the central Omo-Gibe basin, in between Dawro zone and Konta Special Woreda of the Southern Nations, Nationalities and Peoples Regional State of Ethiopia. The Omo River provides the boundary in the south and the west. The natural vegetation of the park is diverse. There are montane forests in the eastern and northwestern highlands, riparian forests along the rivers, and woodland vegetation is found in the southern part of the Park. Activities include bird watching, tourism and experiencing the cultural variety of the area. Ready to consume tourist products seems to be the birds. . Endemic birds are also recorded among these species.

7. Conclusions

Over the past 40 years natural disasters on the Ethiopian territory have increased both in frequency and intensity and have led to severe social impacts, particularly in the southeastern part of the country. Evidence has long suggested that disaster risk reduction has a high cost-benefit ratio. Disasters also divert a substantial amount of national resources from development to relief, recovery and reconstruction, depriving the poor of the resources needed to escape poverty. Disasters cannot be avoided but there are ways to reduce risks and to limit their impacts.

These explanatory notes to the hydrogeological and hydrochemical map of the Jima area provide the results of the joint Czech-Ethiopian projects. The mapping activity was carried out by field groups of hydrogeologists of the GSE in framework of the project joint project in 2015. The mapped area covers 18,287 km^2 and is inhabited by 2,994,062 million people.
There is a good potential for development of surface water for small-scale irrigation and electricity generation in the area because of large rivers in the highlands (Gilgel Gibe cascade) however construction of dams and other water management structures should carefully considered in plans for development and environmental protection.

Groundwater accumulates in relatively porous aquifers developed mainly in alluvial sediments and in fissures and mixed aquifers developed in volcanic and mixed sediment-volcanic rocks. Aquitards of the area consist of trachyte plugs and phonolite.

Using this detailed information, coupled with geographical, climatic, geological and hydrogeological information, three prospective regions for the development of ground water have been identified.

- The high volcanic mountains composed of basic volcanic rocks which form double permeability aquifer systems; good quality water could be obtained from moderately deep boreholes.
- The alluvial plains where intergranular, sedimentary aquifers occur; both shallow and deep ground water resource could be developed with relatively small drawdowns.
- The eastern piedmont plains composed of silicic igneous rocks with interbedded, permeable pyroclastic sands, which may require deep boreholes.

Groundwater is of good quality and practically all of the groundwater resources can be directly used for drinking, industrial as well as agricultural purposes. Groundwater should be primarily used for drinking water supply; it should be also used for irrigation but there should be clear evidence that pumping for irrigation does not lead to over pumping of the groundwater resources and cause degradation of the aquifer. Should the aquifer be used for irrigation, monitoring wells are recommended to be drilled together with the production wells for systematic observation of changes in groundwater levels, quality of pumped water and optimization of the pumping system.

The water types in the study area are dominantly $Ca–HCO_3$ and $Na–HCO_3$ types with low TDS of groundwater. Local pollution of groundwater by nitrates occurs in rural as well as urban areas due to a lack of protection of water sources. In the case of developed springs their surroundings should be protected against pollution because most of the springs (except hot springs) have shallow groundwater circulation and human as well as animal waste (problem of watering animals directly from the spring) can easily and quickly penetrate the groundwater resources. Springs should be developed by a solid concrete box and it is preferable that the water will flow from the spring by a tube and distributed to people 10–20 m from the spring (lower position of water distribution point). The area of the protection box should be protected against the entry of people and animals; in particular animals should be completely prevented entry. The water distribution systems (bono) should preferably be equipped with a system minimizing discharge of water when it is filled into containers. In the case that water is used for animal watering it should be transported by a tube and distributed to the animals about 20–30 m from the well (lower position of water distribution point – cattle bin). The area of the well head should be protected against accumulation of surface water by drainage ditches and the entrance of animals to the well's surroundings should be completely eliminated.

It is advisable to use geophysical investigation to select locations for siting of wells where the regolith is thick and volcanic rocks are deeply weathered and soft. Groundwater can be totally missing when the regional groundwater table in the aquifer is not reached and/or in cases where the drilled part of the basalt is massive without joints and fissures.

Due to the hydrogeological properties of the study area, water supply programs should consider the exploitation of water supply resources through springs, drilled and hand-dug wells depending on position of development site.

Reasons for springs and dug wells are: easy to implement, cost effective, easy to maintain by local communities, the aquifer is shallow and is recharged by infiltrated rainwater as well as river water which is relatively fresh after rainfall episodes (in case that dud well is in aquifer which is connected to the river).

Drilling of boreholes should be concentrated to aquifers developed in volcanic rocks and thick alluvial sediments developed in grabens. Groundwater accumulated in clastic volcano-sedimentary materials contains groundwater of the quality of which mostly corresponds with the standards for potable water.

The proposed development should take into consideration the protection and conservation of the natural resources of the area. Particular interest should be paid to soil conservation and groundwater protection using the appropriate agricultural methods to decrease soil erosion and to the implementation of water resource protection to protect groundwater against pollution and over pumping, particularly in rural and urban settlements where pollution by nitrates is increasing. Monitoring of environmental components, particularly surface water flow and sediment load, in gauging stations in the lower reaches of the river should be enhanced. Recent inappropriate wastewater and solid waste management has to be considerably improved.

Despite some local and regional environmental problems the Jima area provides very good potential for feasible and environmentally sound natural and human resource management.

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ANNEX 1 Wells

Site ID	Woreda/locality	X UTM	Y UTM	Elevation [m a.s.l]	Depth [m]	SWL [m]	DWL [m]	TDD [m]	Yield [l/s]	T [m2/day]	symbol	lithology	HG Code
BH1	Omo Nada ,Nada	307215	844803	1814	60						Qt1	Quaternary stratified tuffs	B9
BH10	Goma,	239755	878021	1523	225						Tv6	Middle trachyte flows	B9
BH11	Goma,Kombie	242672	870139	1559	45						Tv6	Middle trachyte flows	B9
BH12	Goma,Chochia	242909	873305	1499	96.5	11			5		Tv6	Middle trachyte flows	B9
BH13	Limu kosa , Misreta	262112	879090	2001	55				>3		Tv6	Middle trachyte flows	B9
BH14	Limu kosa , Sonto	276766	894362	1645									
BH15	Manna,Bilida	257655	862114	1930	129.26	11.5	88.5	48.5	4.49	10.80	Tv5	Middle basalt flows	B4
BH16	Manna, Seye	251244	868755	1654							Tv5	Middle basalt flows	B4
BH17	Mana, Yebu(Doha)	258801	863961	1754	106	30.25		4.65	7.5		Tv5	Middle basalt flows	B4
BH18	Gera,Gena Chore	189621	855942	2286							Tv7	Upper basalt flows	B9
BH19	Gera,Ono kilo	193869	856486	2096	57				<1.5		Tv7	Upper basalt flows	B9
BH2	Omo Nada ,Jarso	302828	842179	1812					5		Qt1	Quaternary stratified tuffs	B9
BH20	Gera,Yukuro	208092	861457	2926	60				>5		Qal	Quaternary alluvial deposit	B2
BH21	Gera,Loya	214653	861118	1925	46						Tv8	Upper trachyte flows	B4
BH22	Goma, Beshasha	221428	862313	2050	147.84	58.21		13	5.7	18.70	Tv7	Upper basalt flows	B9
BH23	Gera, Gera(Chira)	197869	855213	1973	52						Tv7	Upper basalt flows	B9
BH24	Goma, Kechene	231654	880536	1550	50						Tv6	Middle trachyte flows	B9
BH25	Tirwafeta, Kegelo	303715	865608	1749	75						Tv4	Lower pyroclastics	B9
BH26	Tirwafeta,Decha Neie	306692	871531	1773							Tv4	Lower pyroclastics	B9
BH27	Tirwafeta,Bederu	301205	884160	2043	45						Tv7	Upper basalt flows	B9
BH28	Tirwafeta,Busa	302169	879019	1919	132						Tv7	Upper basalt flows	B9
BH29	Tirwafeta,Haro	309926	869796	1715	95	11	33.04		12.8	50.20	Qal	Quaternary alluvial deposit	B2
BH3	Omo Nada ,Sekela	298760	843865	1854	50						Qt1	Quaternary stratified tuffs	B9
BH30	Yem, Gishe 1	330116	871843	2091							Tv5	Middle basalt flows	B4
BH31	Yem, Gishe 2	330795	866393	2496	14						Tv5	Middle basalt flows	B4
BH32	Yem, Debrebore	330976	863371	2498	66						Tv5	Middle basalt flows	B4
BH33	Yem, Saja	328450	882548	1902	120						Tv5	Middle basalt flows	B4
BH34	Sekoru,Bidru(sekoro)	325421	875421	1811	104						Tv5	Middle basalt flows	B4
BH35	Sekoru,Dendeba	320364	867759	1732	40						Tv5	Middle basalt flows	B4
BH36	Sekoru,Bore	315933	858493	1680							Dam	Gilgel Gibe Dam	B9
BH37	Omo nada, Goroseden	306898	852258	1751	75						Qt1	Quaternary stratified tuffs	B9
BH38	Omo nada,Shone	305522	849409	1710							Qal	Quaternary alluvial deposit	B2
BH39	Kersa,Merwa	269020	849955	1783							Tv6	Middle trachyte flows	B9
BH4	Omo Nada ,Harsu	296394	843685	1784	47	4					Qt1	Quaternary stratified tuffs	B9
BH40	Kersa,Serbo	277619	854177	1746	160						Tv2	Lower basalt flows	B4
BH41	Kersa,Bulbulo	289670	852876	1788	144						Qal	Quaternary alluvial deposit	B2
BH42	OmoNada ,Asendabo	302341	859016	1678							Tv4	Lower pyroclastics	B9
BH43	OmoNada ,Waktola	302103	855526	1724	80						Tv4	Lower pyroclastics	B9
BH44	Gimbo,Shomba	204584	815598	1434	11						Tv5	Middle basalt flows	B4
BH45	Gimbo,Gojeb	210083	820679	1281	125						Tv3	Lower trachyte flows	B9
BH46	Shebe sombo,Shebe	225932	830183	1742							Tv6	Middle trachyte flows	B9

Site ID	Woreda/locality	X UTM	Y UTM	Elevation [m a.s.l]	Depth [m]	SWL [m]	DWL [m]	TDD [m]	Yield [l/s]	T [m2/day]	symbol	lithology	HG Code
BH47	Shebe sombo,Sombo	237578	835899	1744							Qal	Quaternary alluvial deposit	B2
BH48	Shebesombo,Sombo	237719	836111	1750	12.5						Qal	Quaternary alluvial deposit	B2
BH49	Seka chokorsa,Seka	247828	841610	1777	106				4.5		Tv13	Sentema basalt	B4
BH5	Omo Nada ,Ale	294284	843412	1798	80						Qt1	Quaternary stratified tuffs	B9
BH50	Sigmo,Jimate	185078	878891	2184	12						Tv7	Upper basalt flows	B9
BH51	Setema,Gateria	189678	883641	2206							Tv7	Upper basalt flows	B9
BH52	Goma,Simbero	229045	876650	1620	48						Tv6	Middle trachyte flows	B9
BH53	Decha,Chiri	189728	788413	2025	96						Tv6	Middle trachyte flows	B9
BH54	Decha,Beha	193265	793501	1848	84						Tv6	Middle trachyte flows	B9
BH55	Bonga,Bandira	195040	802749	1586							Tv5	Middle basalt flows	B4
BH56	Gimbo,wushwush	185311	808323	1878							Tv6	Middle trachyte flows	B9
BH57	Goma,Agaro	232338	870147	1599	155				5		Tv6	Middle trachyte flows	B9
BH58	Goma,Bulbulo	238689	869434	1591	114				7		Tv2	Lower basalt flows	B4
BH59	Goma,Gimbo	241227	869331	1559	50				7		Tv6	Middle trachyte flows	B9
BH6	Omo Nada ,Dinko	288134	844750	1440	60						Tv4	Lower pyroclastics	B9
BH60	Tercha,Tercha	297057	790198	1301	240	16.5	71.2	114.65	6.5		Tv3	Lower trachyte flows	B9
BH61	Maraka,Mari	289126	777216	2279	100	7			7		Tv5	Middle basalt flows	B4
BH62	Gesha chire,Gesha chire	309197	775672	2227		0.2		36.94	4		Tv5	Middle basalt flows	B4
BH63	Dedo, Dedo	267029	829899	2187							Tv6	Middle trachyte flows	B9
BH64	Jimma university	262919	849361	1743							Qal	Quaternary alluvial deposit	B2
BH65	Jimma university	259009	850654	1725							Tv5	Middle basalt flows	B4
BH66	Gimbo,Gimbo	194630	819101	1755							Tv6	Middle trachyte flows	B9
BH7	Omo Nada ,Burka	286093	841897	1749	62						Tv4	Lower pyroclastics	B9
BH8	Omo Nada ,Boniya	285679	834268	1762							Tv7	Upper basalt flows	B9
BH9				1865							Tv7	Upper basalt flows	B9
BHI1	Omonada,Ale	305362	842718	1792							Qt1	Quaternary stratified tuffs	B9
BHI10	Gera,Saja	329394	881573	1964							Tv5	Middle basalt flows	B4
BHI11	Omonada,Seyo	305728	867887	1756							Tv4	Lower pyroclastics	B9
BHI12	Kersa,Gelo	293847	854726	1712							Qal	Quaternary alluvial deposit	B2
BHI13	Kersa,Gilgelgibe	300319	858242	1681							Tv4	Lower pyroclastics	B9
BHI14	Sigmo,Sigmo	181486	875425	2195	117				8		Tv7	Upper basalt flows	B9
BHI15	Mareka,Waka	297326	779328	2367							Tv6	Middle trachyte flows	B9
BHI16	Konta,Chida	259209	793480	1399							Tv3	Lower trachyte flows	B9
BHI17	Gimbo,Kise	211814	823943	1314							Qal	Quaternary alluvial deposit	B2
BHI18	Gomma,Kemisse	235417	883244	1627							Tv6	Middle trachyte flows	B9
BHI19	Gomma,Deye Kechine	233279	882390	1644							Tv6	Middle trachyte flows	B9
BHI2	Goma,Sekoru	246398	887095	1483									
BHI3	Limukosa,Gibe	269344	884627	1641							Tv6	Middle trachyte flows	B9
BHI4	Limukosa, Dembibeskoka	271812	886065	1632									
BHI5	Mana,Atro	255955	866965	1760							Tv5	Middle basalt flows	B4
BHI6	Sekachokorsa, Sentema	243961	854156	2460							Tv13	Sentema basalt	B4
BHI7	Mana,Tela	252350	847836	1907							Tv13	Sentema basalt	B4

Site ID	Woreda/locality	X UTM	Y UTM	Elevation [m a.s.l]	Depth [m]	SWL [m]	DWL [m]	TDD {m]	Yield [l/s]	T [m2/day]	symbol	lithology	HG Code
BHI8	Gera,Chira	198087	855419	1954	110	3.6		10.75	7	44.50	Tv7	Upper basalt flows	B9
BHI9	Gera,Bogie	213908	868036	2394							Tv7	Upper basalt flows	B9
ABH2	Angecha	239755	878021	1457	100	8.36			8	97.70	Tv5	Middle basalt flows	B4
ABH3	Bululo	242672	870139	1780	114	4.45			10	41.73	Tv5	Middle basalt flows	B4
ABH4	Kentiri	242909	873305	1780	143	4.6			6	18.35	Tv5	Middle basalt flows	B4
ABH5	Mero-chisa	262112	879090	1417	155				dry	Dry			
ABH6	Mecha	276766	894362	1605	107	3.6			7	0.89			
ABH7	Mecha-kara	257655	862114	1662	107	12.45			7	117.00			
ABH8	Bore	251244	868755	1682	150	4.1			8	8.66	Dam	Gilgel Gibe Dam	B9
ABH9	Daka Gangalata	258801	863961	1922	145	49.3			8	12.32	Tv5	Middle basalt flows	B4
ABH10	Ashe	189621	855942	1898	52	15					Tv5	Middle basalt flows	B4
ABH11	Ashe	193869	856486	1898	49	15					Tv5	Middle basalt flows	B4
ABH12	Kesheli	302828	842179	2527	79	47.2					Tv5	Middle basalt flows	B4
ABH13	Gesi Tena Kela	208092	861457	2076	46	23.5					Tv5	Middle basalt flows	B4
ABH14	Nuba	214653	861118	2510	46	24.8					Tv5	Middle basalt flows	B4
ABH15	Gesi	221428	862313	2135	52	4.7					Tv5	Middle basalt flows	B4
ABH16	Tigir Timirt Bet	197869	855213	2298	64	31					Tv5	Middle basalt flows	B4
ABH17	Tigir	231654	880536	2259	82	56.7					Nnp	Nazreth group	B9
ABH18	Deri	303715	865608	2183	55	2							
ABH19	Goreminan Gari	306692	871531	2389	82	25							
ABH20	Melka	301205	884160	2299	64	20.2							
ABH21	Gembe	302169	879019	1559	50	2.75			7	41.08	Tv6	Middle trachyte flows	B9
ABH22	Limushaye	309926	869796	1711	200				dry	Dry	Tv5	Middle basalt flows	B4
ABH23	Sedi	298760	843865	2030	108	3.7		16.8	6		Tv7	Upper basalt flows	B9
ABH24	Ambuye	330116	871843	1634	246	0	22.34	22.34	15	75.82	Tv6	Middle trachyte flows	B9
ABH25	Raga Siba 1	330795	866393		60								
ABH26	Raga Siba 2	330976	863371		115								
ABH27	Nuba	328450	882548	2510	45	24.8					Tv5	Middle basalt flows	B4
ABH28	Gise 2	325421	875421	2076	46	23.5					Tv5	Middle basalt flows	B4
ABH29	Gise 1	320364	867759	2135	52	4.7					Tv5	Middle basalt flows	B4
ABH30	Keshelo	315933	858493	2527	79	42.5					Tv5	Middle basalt flows	B4
ABH31	Teger	306898	852258	2259	82	56.7					Nnp	Nazreth group	B9
ABH32	Teger School	305522	849409	2298	64	31					Tv5	Middle basalt flows	B4
ABH33	Ashe	269020	849955	1898	49	15					Tv5	Middle basalt flows	B4
ABH34	Guremina Angari	296394	843685	1898	82	25					Tv5	Middle basalt flows	B4

ANNEX 1 springs

Site ID	Woreda/locality	X UTM	Y UTM	Elevation [m a.s.l]	Yield [l/s]	Field conductivity [µS/cm]	symbol	lithology	HG_Code
CSP1	Omonada,Melkibelo	312322	840984	2072	3	0.05	Tv9	Rhyolite Flows	B4
CSP10	Limu kosa,3kuter	265869	880408	1733	>5	49.5	Tv6	Middle trachyte Flows	B9
CSP11	Limu kosa,Kemise	268980	876526	1717	0.5	78.3	Tv6	Middle trachyte Flows	B9
CSP12	Limu kosa,Ambuye	269089	883078	1634	7	32	Tv6	Middle trachyte Flows	B9
CSP13	Limu kosa,Babo	256496	874789	1736	0.5	34.6	Tv6	Middle trachyte Flows	B9
CSP14	Manna,Kintere	256858	871038	1723	0.3	64.1	Tv5	Middle Basalt Flows	B4
CSP15	Manna,Atro	256750	866891	1816		44.6	Tv5	Middle Basalt Flows	B4
CSP16	Manna,Oto	245534	868961	1555	2	126.5	Tv6	Middle trachyte Flows	B9
CSP17	Manna,kewa	244417	862981	1748	3	66.1	Tv13	Sentema Basalt	B4
CSP18	Manna,waraba	243464	858275	2208	1	82.6	Tv13	Sentema Basalt	B4
CSP19	Manna,Tibo Wacho	239665	852972	217	4	217	Tv13	Sentema Basalt	B4
CSP2	Omonada,Egu	307804	842305	1851	1	0.04	Tv4	Lower Pyroclasitc Flows	B9
CSP20	Manna,Adamose	245964	853356	2245	1	58.8	Tv13	Sentema Basalt	B4
CSP21	Manna,Seye	251495	868405	1676	0.5	45.7	Tv5	Middle Basalt Flows	B4
CSP22	Goma,Terami	228975	866565	1806	0.5	60.7	Tv6	Middle trachyte Flows	B9
CSP23	Manna,Boto	225306	859084	1977	0.3	50	Tv13	Sentema Basalt	B4
CSP24	Goma,Shashemene	227385	862302	1984	0.3	62.4	Tv7	Upper Basalt Flows	B9
CSP25	Goma,Kedo	230155	860798	1999	1	65.4	Tv13	Sentema Basalt	B4
CSP26	Seka,Geshi	234375	853854	2420	5	89.6	Tv13	Sentema Basalt	B4
CSP27	Gera,Timbashele	184921	861148	2457	0.5	48.6	Tv7	Upper Basalt Flows	B9
CSP28	Gera,Dusta	190039	857633	2305	2	182	Tv7	Upper Basalt Flows	B9
CSP29	Gera,Secha	184690	854703	2440	4	90	Tv8	Upper Trachyte flows	B4
CSP3	Goma,Chidaro	236866	871480	1545	1.5	156.2	Tv2	Lower Basalt Flows	B4
CSP30	Gera,Kecho Andaracha	202026	859129	1901	0.4	37.9	Tv8	Upper Trachyte flows	B4
CSP31	Gera,Afelo	193780	845131	1805	0.33	72.5	Tv6	Middle trachyte Flows	B9
CSP32	Gera,Welega	195959	851039	1926	0.3	164	Tv6	Middle trachyte Flows	B9
CSP33	Gera,Boge	212974	867358	2401	0.01	41	Tv7	Upper Basalt Flows	B9
CSP34	Gera,Dedo	211546	870330	2182	0.3	52.4	Tv7	Upper Basalt Flows	B9
CSP35	Goma,Huri	238875	884230	1416	0.01	131.7	Tv2	Lower Basalt Flows	B4
CSP36	Goma,Dayekechene	232291	882052	1584	0.5	122.3	Tv6	Middle trachyte Flows	B9
CSP37	Kersa,Degoso	303645	863796	1707	0.5	80	Tv4	Lower Pyroclasitc Flows	B9
CSP38	Yem,Shosher	333087	860883	2601	0.3	45.3	Tv5	Upper Basalt Flows	B4
CSP39	Yem,Toba	332460	855004	2509	1	25.4	Tv5	Upper Basalt Flows	B4
CSP4	Goma,Adamosi	239755	878021	1523	0.5	95.4	Tv6	Middle trachyte Flows	B9
CSP40	Sekoru,Bidru	325700	875882	1864	1	106.5	Tv5	Upper Basalt Flows	B4
CSP41	Kersa,Doyu	284858	858001	1715	0.5	23.1	Tv2	Lower Basalt Flows	B4
CSP42	Kersa,Hore	285692	865340	1759	1	39.6	Qal	Quaternary alluvial Deposits	B2
CSP43	Kersa,Aleltu	281091	860509	1738		25.3	Tv6	Middle trachyte Flows	B9
CSP44	Yimbo,4Kutir	201069	817725	1594	2	189.3	Tv6	Middle trachyte Flows	B9
CSP45	Shebesombo,Sego	218040	827540	1424	4	188.7	Qal	Quaternary alluvial Deposits	B2

Site ID	Woreda/locality	X UTM	Y UTM	Elevation [m a.s.l]	Yield [l/s]	Field conductivity [µS/cm]	symbol	lithology	HG_Code
CSP46	Shebe ,Sembo	232244	834342	2120		368	Tv6	Middle trachyte Flows	B9
CSP47	Gumay,Gindabele	221359	886940	1678		149			
CSP48	Gumay,Dekie	225357	882174	1729	3	122.3	Tv6	Middle trachyte Flows	B9
CSP49	Toba,Yachi	225804	879857	1695	3	86.6	Tv6	Middle trachyte Flows	B9
CSP5	Goma,Kombie	243294	870188	1533	0.66	67.4	Tv6	Middle trachyte Flows	B9
CSP50	Gimbo,Deree	200448	816342	1733	0.3	176	Tv6	Middle trachyte Flows	B9
CSP51	Decha,Ufa	190222	783122	1966	1.5	222	Tv6	Middle trachyte Flows	B9
CSP52	Decha,Ermo	192224	792406	1933	2	71.1	Tv6	Middle trachyte Flows	B9
CSP53	Decha,Chapa	193519	800628	1902	1.5	94.4	Tv6	Middle trachyte Flows	B9
CSP54	Telo,Felege Selam	221309	787461	2265	3	51.8	Tv3	Upper Trachyte flows	B9
CSP55	Telo,Shada	214065	787896	1830	0.8	249	Tv3	Lower Trachyte Flows	B9
CSP56	Telo,Bega	208488	788648	1831	0.05	46.5	Tv3	Lower Trachyte Flows	B9
CSP57	Telo,	205308	792338	2301	3	28.8	Tv8	Upper Trachyte flows	B4
CSP58	Bonga,Astatabi	196442	802989	1810	0.7	156.6	Tv5	Middle Basalt Flows	B4
CSP59	Bechana,Gatana	171076	811688	1884	4	57.3	Tv6	Middle trachyte Flows	B9
CSP6	Goma,Meto	244752	873040	1477	0.4	86.5	Tv6	Middle trachyte Flows	B9
CSP60	Getawa,Saja	176232	830731	2157	0.8	63.5	Tv11	Kobech Phenolite	B6
CSP61	Getawa,Mashaber	182502	827367	1812	2	48.1	Tv11	Kobech Phenolite	B6
CSP62	Gimbo,Muniya	189305	823155	1810	1	46.7	Tv6	Middle trachyte Flows	B9
CSP63	Gimbo,Getiya	194713	822726	1793	1.2	71.6	Tv6	Middle trachyte Flows	B9
CSP64	Tocha,Aba Diya	268573	794901	1616	2	374	Tv5	Middle Basalt Flows	B4
CSP65	Torcha,Gorkabersa	276531	792832	1491	7	223	Tv5	Lower Trachyte Flows	B4
CSP66	Torcha,Worama	283357	793056	1499	2	211	Tv3	Lower Trachyte Flows	B9
CSP67	Torcha,Kidanemihret	283241	784623	2622	1.5	63.3	Tv8	Upper Trachyte flows	B4
CSP68	Mareka,Waka	297326	781252	2367	7	128.4	Tv6	Middle trachyte Flows	B9
CSP69	Loma,Edget	305437	775737	2326	2	162.4	Tv5	Middle Basalt Flows	B4
CSP7	Goma,Kiltuwolka	246711	876610	1534	0.27	88	Tv5	Middle Basalt Flows	B4
CSP70	Mareka,Gobosha	300899	778213	2345	0.3	95.8	Tv6	Middle trachyte Flows	B9
CSP71	Konta,Amaya	245878	786222	1988	14.5	257	Tv6	Middle trachyte Flows	B9
CSP72	Konta,Genji	251420	786459	2230	7	188.8	Tv12	Trachyte Plug	B6
CSP73	Amaya,Kerara	263630	808652	1588	2.5	424	Tv5	Middle trachyte Flows	B4
CSP74	Dedo,Dilbi	264312	816930	2217	0.8	92.5	Tv7	Upper Basalt Flows	B9
CSP75	Dedo,Miteso	264176	820603	2268	2.5	37.2	Tv7	Upper Basalt Flows	B9
CSP76	Dedo,Dedo	262919	849361	1743	0.4	121	Qal	Quaternary alluvial Deposits	B2
CSP8	Goma,Loko	247414	878054	1665	0.2	84.7	Tv5	Middle Basalt Flows	B4
CSP9	Goma,Limushay	245370	883436	1711	0.3	195.9	Tv5	Middle Basalt Flows	B4

ANNEX 1 Dug wells

Site ID	Woreda/locality	X UTM	Y UTM	Elevation [m a.s.l]	Depth [m]	Lithology (inventory)	Symbol geology	HG Code	Field pH	Field EC [µS/cm]
HDW1	Omonada,Sekela	299174	843724	1869	10	Quaternary Stratified Tuffs	Qal1	B9	5.8	
HDW2	Omonada, Chefebele	286735	836445	1812	12	Upper Basalt Flows	Tv7	B9	5.45	0.02
HDW3	Goma,Chiracha	225046	864570	2034	15	Upper Basalt Flows	Tv7	B9	6	130.3
HDW4	Sigmo,Sigmo	180034	875337	2257	5	Upper Basalt Flows	Tv7	B9	5.4	254
HDW5	Decha, Modiogombora	201325	796568	1710	4	Middle Trachyte Flows	Tv6	B9	5.4	64.8
HDW6	Gimbo,Agama	185784	806169	1931	10	Middle Trachyte Flows	Tv6	B9	5.6	165.4
HDW7	Getawa,Sajo	176448	830633	2190	12.3	Kobech Phenolite	Tv11	B6	6.1	39.8
HDW8	Goma,Berachi	241036	869437	1567	12	Middle Trachyte Flows	Tv6	B9	5.5	77.7

ANNEX 1 Rivers

Site ID	Woreda/locality	X UTM	Y UTM	Elevatoion [m a.s.l]	Field pH	Field conductivity [µS/cm]
River 1	Limukosa,Gebe	269780	884584	1641	7.3	78.8
River 2	Mana,Arengama	255669	876449	1621	7.8	109
River 3	Gera,Hota	198036	855599	1971	8	119.5
River 4	Tirowfeta,Gilgel Gibe	314053	868085	1665	7.7	93.4
River 5	Dencha,Dincha	195190	802760	1585	6.7	61.9
River 6	Mareka,Keerti	289173	777142	2265	6.8	31.8
River 7	Fuafuate 1	247583	841563	1780		

ANNEX 1a Well characteristics based on drilling reports

Site ID	Site name	X	Y	Z	Depth (m)	Aquifer (filter)	SWL (m)	Yield (l/s)	DD (m)	Spec q (l/s/m)	T pump. (m^2/d)	T rec. (m^2/d)	Yield recom. (l/s)	Geology	Remarks
JBH1	Tercha/Mareka Gena w./North Omo z.			1280	169		34.8	5.2	24.35	0.21			5.0	Ignimbrite, Clay, rhyolite	Geremew Gamie, 1991 Awassa
JBH2	Gesa Chere/Loma Bosa w./ North Omo			2060	103		0.2	4.7	36.94	0.13			4.5	Tuff, basalt	Geremew Gamie, 1991 EC Awassa
JBH3	Bale/Essera w. Dawro y.	283860E	760880N	2170	116	65-113	38.5	7.6	7.4	1.03	295.2		20.0	Basalt (clay before)	Million Tarekegn, 2011 SWWCE
JBH4	Angecha	214167	831851	1457	100	42.3-94.2	8.0	8.0	3.49	2.29	97.78	97.63	12.0	basalt	Brotherhood ate well drilling and construction DTH
JBH5	Limusha				200								dry	Basalt, tuff, rhyolite	DTH
JBH6	Kentiri	255870	866752	1780	143	23.45-143.15	3.0	6.0	21.0	0.29	18.35		10.0	basalt	DTH
JBH7	Chira	198087	855419	1954	110	23.65-100.6	3.6	7.0	10.75	0.65	44.5		12.0	basalt	DTH
JBH8	Mecha	284966	910598	1605	170	27.1-141.7	1.1	2.0	100.2	0.02	0.89		2.0	Ignimbrite some basalt	DTH
JBH9	Tercha 2				167	53-149	8.4	4.5	96.6	0.05	2.3		3.99	Alluvial sed. And basalts	Nadeshewara, 2010
JBH10	Mareka (Mari)	28904	77700	2275	100	55-94	52.9	7.0	0.64	10.94	1022.4		10.0	rhyolite	Million Tarekegn SWWCE, 2011
JBH11	Tercha 1				185	111-189	27.37	2.5	114.65	0.02	1.0		1.39	Ignimbrite, agglomerate alluvial sed.	Nadeshewara, 2010
JBH12	Tercha -Dawuro				146		45.2		15.1	0.00			10		
JBH13	Zima Waruma				116	61-88	67.8	2.9	5.9	0.49				basalt, sand, gravel	
JBH14	Loma Bossa (Catolic Church)				121	40-115	18.05	3.5	16.09	0.22				Gravel, sand	
JBH15	Bacho				114	21-110	14.08	4.28	65.95	0.06				Basalt, sandy gravel	
JBH16	Aba Mila				69	38-66								Ignimbrite, basalt	
JBH17	Sardo				42	19-39	5.0							Basalt	
JBH18	Babo				59	22-56								Rhyolite	

Site ID	Site name	X	Y	Z	Depth (m)	Aquifer (filter)	SWL (m)	Yield (l/s)	DD (m)	Spec q (l/s/m)	T pump. (m^2/d)	T rec. (m^2/d)	Yield recom. (l/s)	Geology	Remarks
JBH19	Sole				59	27-54								Rhyolite	
JBH20	Millenium Pa				90	39-84								Basalt, sand, gravel	
JBH21	Keshee 1				70	21-64	6	7.5	48.6	0.15	7.7			Basalt, Ash, Ignimbrite	
JBH22	Benja				130	17-127								Basalt	
JBH23	Shebe				124	42-120								Ignimbrite	
JBH24	Ambuye				246	58-234	0.0	15	22.34	0.67	87.41			Basalt	Brotherhood
JBH25	Kofea (Sadecha) Seka Chokorsa				57	39-54	17							Pyroclastic, ignimbrite	
JBH26	Migira / Chokorsa				62	38-59	8							Basalt	
JBH27	Hariri Kora				62	30-60	26							Basalt	
JBH28	Bumba Sefer				44	17-38	6.5							Basalt	
JBH29	Churchura / Sheba				53	20-50	6							Pyroclastic, ignimbrite, alluvial	
JBH30	Hulea / Omonada				58	10-52	3.0	1.5						Pyroclastic, basalt	KSR Infrastructures
JBH31	Harsu / Omonada				47	18.5-41	4.0	1.5						Pyroclastic, basalt	
JBH32	Odo / Omonada				56	22-50	3.5	1						Basalt, pyroclastic	
JBH33	Ano / Omonada				37.6	Dry								Ignimbrite, basalt	
JBH34	Kodo / Omonada				60	37-57	3.5	0.75						Pyroclastic, ignimbrite	
JBH35	Digo / Omonada				60	25-60	2.0	2						Ignimbrite, pyroclastic, basalt	
JBH36	Gura Bederu / Tiro Afeta				51	18-48								Basalt	Hard Rock Drilling
JBH37	Kenene / Tiro Afeta				51	9-45								Basalt	
JBH38	Nadi / Tiro Afeta				51	21-45								Basalt	
JBH39	Babo / Tiro Afeta				57	15-51								Pyroclastic	
JBH40	Medale / Tiro Afeta				63	dry								Pyroclastic	
JBH41	Akobo Badia 1 / Tiro Afeta				48	12-42								Pyroclastic, basalt	
JBH42	Ado Badia 2 / Tiro Afeta				51	9-45								Basalt	

Site ID	Site name	X	Y	Z	Depth (m)	Aquifer (filter)	SWL (m)	Yield (l/s)	DD (m)	Spec q (l/s/m)	T pump. (m^2/d)	T rec. (m^2/d)	Yield recom. (l/s)	Geology	Remarks
JBH43	Kiten Bile / Tiro Afeta				51	18-45								Pyroclastic, basalt	
JBH44	Bidaru / Tiro Afeta				45	12-39								Basalt	
JBH45	Kotecha Gebe / Tiro Afeta				54	18-48								Basalt	
JBH46	Sheki Dado				110	38-107	5.2	9.5	12	0.79	0.7			Basalt	OWWCE
JBH47	Raga Siba 3 / Tiro Afeta				95	52-92	11	12.8	22.04	0.58	9.72			Basalt	Nile Drilling
JBH48	Kuasmeda				59	25-56								Clay, basalt	Nandishewara
JBH49	Wersha				108	24-105	3.7	6	14.5	0.41				Basalt, sand	
JBH50	Beshasha / Goma				147.84	28-108	58.21	5.7	13	0.44	18.7	63.4		Basalt	Nile
JBH51	Dokonu				77	22-75	2	15						Basalt	
JBH52	Delame				59	34-57	26	2						Ignimbrite, basalt	
JBH53	Bureya				59	34-57	30	2						Basalt	
JBH54	Genda Santo school				59	43-57		1						Soil, ignimbrite	
JBH55	Eda				57	27-55	20							Basalt	
JBH56	Bechene/Murkuz				72									Basalt	
JBH57	Oso / Murkuz				70									Basalt	
JBH58	Genji				48	37-47	12							Basalt	
JBH59	Deresevoma				52	25-50								Basalt	
JBH60	Alka				59	28.5-57	18							Ignimbrite, diorite	
JBH61	Gebameda				59	30-50	30							Clay, basalt	
JBH62	Kelistu				68	23-65	22.6							Basalt	
JBH63	Kuasmeda				59	25-56	26							Clay, basalt	
JBH64	Sokoru no.2				104	16-96								Tuff, basalt	OWWCE T_3WIR
JBH65	Choche / Ana Gomma				96.5		11							Basalt	Myunsung
JBH66	Yebu				106	46-103	30.25	7.5	4.65	1.61	144			Basalt	Nile
JBH67	Bilida Mana				129.26	18-123	11.5	4.5	48.5	0.09	1.8			Basalt	Nile
JBH68	Chora Botor				150		19							Tuff, clay, gravel, sand	Myunsung
JBH69	Sigmo				117		artesian	2.4						Basalt	
JBH70	Kochole / Gomma Agaro				155		50	4.5						Basalt	Myunsung
JBH71	Chora				150	29-144	10.5	2.5						Sand, clay	
JBH72	Daka Gangalata	323116	872450	1922	145	44-129	49.3	5	19.55	0.26	9.67	14.97	8	Basalt	Brotherhood

Site ID	Site name	X	Y	Z	Depth (m)	Aquifer (filter)	SWL (m)	Yield (l/s)	DD (m)	Spec q (l/s/m)	T pump. (m^2/d)	T rec. (m^2/d)	Yield recom. (l/s)	Geology	Remarks
JBH73	Bore	315845	858271	1682	150	76-144	4.1	6	44.05	0.14	6.54	10.77	8	Basalt	
JBH74	Bulbulo	255870	866752	1780	114	34-112	9.45	7	8.75	0.80	9.59	73.87	10	Basalt	
JBH75	Mecha Kara	297670	925748	1662	107	62-98	12.45	7	4.25	1.65	54	180	10	Clay, basalt	
JBH76	Mero Chisa	262035	907946	1417	155									Basalt	abandoned
JBH77	Gembe				50	33-44	2.75	7	7.11	0.98	21.46	60.7	10	Clay, tuff	
JBH78	Tiro Afeta Ana				70	26-66.5								Basalt	Nile
JBH79	Jima Airport				170	24-162	3.8	3.5	65.85	0.05	2.8	0.08		Basalt	OWWCE
JBH80	Jima University no.3	258927	850438	1724	121.5	76-118.5	6.42	4.7	29.38	0.16	11.2	9.8	4.0	Ash, clay, basalt	OWWCE
JBH81	Jima University no.2	262907	849066	1741	187	118-166	7.0	1	119.73	0.01	0.4	0.5	0.3	Ignimbrite, tuff, clay	
JBH82	Jima University no.5 (Kito Furdisa campus)				165	60-144	1.15	1	122.4	0.01	1.5	1.5	0.3	Basalt	
JBH83	Jima University no.4 Kito Furdisa campus)				152	68-146	5.0	5	84.92	0.06	3.8		7.2	Basalt	
JBH84	Somodo / Mana	260160	856095		136	25-125	26.1	3.5	35.36	0.10	5.04		3.15	Basalt, rhyolite, granite	Madher Mehari Mesfin
JBH85	Limmu Sepa / Gomma	246281	886020		131	17-117	7.0	5.0	28.16	0.18	8.1		4.97	Basalt, rhyolite	
JBH86	Kishe Posta 1 and 2 / Sebi	211814	823943		200			Dry						Tuff,	
JBH87	Komma / Limmu Seka	263036	933934		121	39-113	7.15	5.0	34.15	0.15	7.2		4.57	Basalt	
JBH88	Beke Gundo / Seka Cheroksa	231501	844634		122.5	19-117	0.0	12.0	29.62	0.41	36.7		13.6	Basalt	
JBH89	Haro / Yebu	245475	863897		147.5	17-137	5.0	3.0	34.0	0.09	3.6		2.2	Basalt	
JBH90	Ketcho Tirtira / Limu Kosa	261952	882886		111	20-99	4.5	8.0	21.74	0.37	17.3		8.4	Basalt	
JBH91	Doyo / Sokoru				101	44-95	1.0	3.0	38.4	0.08	3.9		4.0	Basalt	
JBH92	Limmu Kossa /Limmu Genet				126	43-120	4.05	5.0	39.42	0.13	5.88		5.0	Basalt	
JBH93	Seka Twon / Seka Chekorsa	250172	839896		95	27-89	3.3	1.3	71.28	0.02	10.5		1.0	Ignimbrite, paleo soils	
JBH94	Tili Ilte	262408	856426		39		5.0							Basalt	proposal

Annex 2 Hydrochemistry

id	Na^+	K^+	Ca^{2+}	Mg^{2+}	CO^2_3	HCO_3	Cl	F	SO^2_4	NO_3	SiO_2	pH	EC.µS/Cm	TDS mg/l
Rain 1	1.13	0.35	1.22	0.20		9.76	0.71	0.10	0.62	1.33	0.21	6.25	18.90	15.63
River1	5.61	3.65	6.12	1.57	6.00	31.72	2.69	0.43	1.54	0.44	17.12	9.04	79.00	76.89
River2	5.18	4.03	10.84	2.91	7.20	50.02	1.91	0.28	16.67	0.44	20.12	9.48	112.00	119.60
River3	4.18	2.56	12.40	5.00	8.40	39.04	2.06	0.18	1.95	0.44	16.69	9.32	122.00	92.90
River4	5.44	2.70	9.76	2.88		37.00	5.25	0.19	26.38	0.44	34.24	6.94	105.00	124.28
River5	3.15	2.01	5.62	1.79		22.00	1.77	0.10	15.77	1.33	28.68	6.56	64.10	82.22
River	2.99	1.51	2.12	0.48		12.00	1.42	0.10	0.87	4.43	26.54	6.47	33.20	52.46
River7	5.62	2.75	9.24	3.10	26.40	1.22	2.76	0.16	0.10	1.33	22.26	9.64	105.00	74.94
BH1	21.34	7.91	18.50	4.12		154.94	0.99	0.86	0.10	2.22	71.08	7.49	240.00	282.06
BH10	74.40	4.34	11.55	3.35		235.46	0.71	9.45	5.38	0.88	49.22	7.86	413.00	394.74
BH12	38.65	2.86	26.35	8.75		256.20	1.77	0.83	0.10	0.44	62.92	7.94	368.00	398.87
BH13	3.02	0.46	19.34	3.20		80.52	3.76	0.21	0.10	7.53	26.11	7.09	143.00	144.25
BH14	24.60	11.93	16.02	2.78		145.18	0.71	0.69	0.10	4.87	74.90	7.60	236.00	281.78
BH15	11.94	2.04	20.58	10.22		152.50	0.71	0.37	0.10	1.77	49.68	7.70	249.00	249.91
BH16	17.20	6.74	36.75	12.05		234.24	0.71	0.38	0.10	4.43	69.76	7.91	381.00	382.36
BH17	49.60	3.62	18.75	7.55		236.68	0.92	0.94	0.10	0.88	74.47	7.63	370.00	393.51
BH18	3.34	1.32	12.00	4.38		70.76	2.13	0.98	0.10	3.99	35.95	7.08	128.00	134.95
BH19	1.59	0.89	8.38	2.45		36.60	0.71	0.65	0.10	0.89	31.24	7.44	76.00	83.50
BH2	18.28	8.55	32.12	8.90		202.52	1.63	1.90	4.90	0.44	88.17	8.05	321.00	367.41
BH20	9.44	3.47	12.66	4.50		93.94	0.71	0.76	0.10	0.44	48.36	7.69	151.00	174.38
BH21	4.88	2.29	18.54	5.20		104.92	0.71	0.48	0.10	1.33	44.51	6.90	167.00	182.96
BH22	7.22	4.40	25.38	8.02		168.60	0.71	0.39	0.10	3.54	61.20	7.55	255.00	279.56
BH23	7.24	3.24	22.24	8.26		136.64	0.71	0.36	0.10	0.89	59.06	7.93	219.00	238.74
BH24	68.90	3.80	13.05	3.60		250.10	5.17	1.70	0.10	0.86	51.36	7.83	389.00	398.64
BH25	25.30	3.87	27.55	6.05		176.90	3.69	0.61	4.62	10.19	57.35	7.02	312.00	316.13
BH26	8.82	3.17	18.02	4.32		90.28	3.76	0.54	0.04	2.66	36.81	6.80	176.00	168.42
BH27	45.00	1.75	40.00	5.00		214.72	0.71	0.97	0.10	0.44	66.77	8.02	321.00	375.46
BH28	27.70	3.70	31.35	12.50		244.00	1.06	0.53	0.10	0.44	42.80	8.10	356.00	364.18
BH29	33.95	7.45	37.75	13.75		280.60	0.71	0.81	0.77	0.88	49.65	7.89	439.00	426.32
BH3	10.72	6.38	30.12	11.60		183.00	0.85	0.86	0.10	0.88	69.34	7.19	301.00	313.85
BH30	14.95	3.41	35.85	15.75		219.60	0.71	0.40	0.10	3.54	53.93	7.17	350.00	348.24
BH31	11.32	3.28	26.90	8.40		162.04	0.71	0.40	2.56	0.44	43.66	6.98	250.00	259.71
BH32	69.95	4.79	17.05	3.05		244.00	0.85	0.49	0.10	0.44	32.96	8.00	380.00	373.68
BH33	34.75	6.39	29.45	15.05	4.80	237.90	0.71	0.79	0.10	0.44	55.21	8.47	372.00	385.59
BH34	26.25	3.98	48.55	19.25		329.40	1.56	0.51	7.69	0.44	48.79	8.15	488.00	486.42
BH35	13.05	4.95	41.50	12.90		235.46	0.71	0.63	0.10	0.44	50.93	8.25	371.00	360.67
BH36	147.00	9.79	18.20	5.50		390.04	7.73	1.24	22.52	13.73	37.24	8.19	701.00	652.99
BH37	15.10	7.39	17.16	4.60		123.22	0.71	1.11	0.10	0.88	83.03	7.49	209.00	253.30
BH38	24.60	8.01	26.35	6.75		185.44	1.13	1.48	15.48	0.44	73.62	6.94	305.00	343.30
BH39	17.25	6.15	42.90	17.50		240.34	2.20	0.76	1.28	0.44	49.65	7.62	425.00	378.47
BH4	10.08	3.32	21.42	5.64		119.56	1.13	0.41	0.10	0.77	80.46	6.98	203.00	242.89
BH40	46.40	6.75	20.05	7.75		229.36	1.91	1.16	5.13	8.86	36.81	7.43	366.00	364.18
BH41	82.20	11.81	6.30	1.95		248.80	5.46	2.23	2.31	8.86	57.88	7.90	410.00	427.80
BH42	87.25	7.49	6.25	1.90	33.60	179.34	9.00	2.46	10.19	0.44	35.95	9.35	427.00	373.87
BH43	11.56	4.68	25.16	5.70		136.64	1.21	1.34	0.10	0.44	57.35	6.69	230.00	244.18
BH44	19.05	1.75	48.35	14.55		244.00	10.78	0.70	0.10	3.10	56.49	6..65	435.00	398.87
BH45	93.80	10.73	10.05	2.50		258.64	14.68	3.08	19.23	0.88	62.06	7.45	505.00	475.65
BH48	18.54	6.12	18.08	5.10		12.20	40.55	0.25	0.10	68.65	15.41	5.50	291.00	185.00
BH49	31.90	23.45	16.05	8.75	52.80	97.60	1.21	0.92	8.97	0.44	54.78	9.45	321.00	296.87
BH5	10.42	5.29	19.84	4.90		120.78	0.71	0.97	0.10	0.88	100.58	7.29	202.00	264.47
BH50	3.49	1.14	12.41	4.54		58.56	1.46	0.37	0.10	11.52	32.10	6.19	125.00	125.69
BH51	7.82	2.99	21.98	8.02		140.30	1.42	0.28	4.38	0.44	40.66	7.23	233.00	228.29
BH52	71.55	6.31	17.25	3.00		12.41	6.38	4.70	0.10	0.44	47.50	6.86	418.00	169.64
BH53	9.82	3.32	23.70	2.90		103.70	6.03	0.30	3.59	6.65	23.11	7.13	199.00	183.12
BH54	11.02	7.18	19.98	6.44		112.24	0.71	0.24	13.88	0.44	75.76	7.21	228.00	247.89
BH55	21.55	7.65	26.40	7.70		156.16	3.26	0.24	17.25	0.44	74.90	6.96	307.00	315.55
BH56	8.80	2.06	28.90	9.40		136.64	1.42	0.17	19.07	1.77	54.78	6.89	247.00	263.01
BH57	72.90	6.44	29.05	17.40		363.56	9.57	0.19	2.13	0.44	78.32	7.39	602.00	580.00
BH58	256.60	12.11	29.10	18.10		840.58	12.76	0.37	0.10	4.87	70.19	7.67	1313.00	1244.78

id	Na^+	K^+	Ca^{2+}	Mg^{2+}	CO^{2}_{3}	HCO_3	Cl	F	SO^{2}_{4}	NO_3	SiO_2	pH	EC.µS/Cm	TDS mg/l
BH59	51.55	6.50	37.95	16.40		339.16	3.19	0.27	3.59	2.22	52.22	7.65	534.00	513.05
BH6	62.00	11.66	15.60	2.55		245.22	1.06	1.31	0.10	2.66	92.02	7.75	386.00	434.18
BH60	81.10	0.61	4.90	1.25	20.40	184.22	1.42	0.28	0.10	0.89	33.38	9.04	385.00	328.55
BH61	6.86	3.30	11.20	1.20		72.00	1.06	0.16	0.10	0.89	45.80	7.17	142.00	142.57
BH62	12.85	3.35	36.00	4.05		167.14	1.06	0.13	0.10	0.44	60.78	7.40	270.00	285.90
BH64	270.00	8.75	11.20	2.80		764.94	4.96	10.40	0.10	0.89	61.63	7.59	1244.00	1135.67
BH65	91.95	4.50	8.90	4.50		311.10	3.33	2.50	0.10	1.33	20.12	8.10	490.00	448.33
BH66	9.65	3.35	21.05	8.80		143.96	0.71	0.42	0.10	1.33	61.63	7.23	248.00	251.00
BH7	10.84	3.96	8.70	2.20		61.00	4.32	0.31	9.54	0.44	63.34	6.41	122.00	164.65
BH9	11.66	3.24	29.36	6.28		156.16	0.71	0.52	0.10	0.44	75.76	7.48	253.00	284.23
CPS50	8.58	2.05	14.96	4.74		26.84	18.22	0.22	2.22	37.66	35.10	5.77	182.00	150.59
CPS51	13.56	1.79	22.58	7.66		122.00	1.84	0.23	9.87	1.77	48.79	6.91	224.00	230.09
CPS52	5.16	2.85	5.93	1.43		30.50	2.27	0.19	0.10	6.20	45.79	5.91	75.00	100.42
CPS53	7.26	4.04	6.96	1.84		43.92	1.91	0.18	2.19	5.32	55.64	5.76	96.00	129.26
CPS 54	3.17	2.08	4.12	1.44		19.52	1.20	0.14	4.25	9.75	21.83	5.54	53.00	67.50
CSP55	3.00	1.02	4.00	2.00		18.30	0.71	0.15	3.61	2.22	58.64	5.51	51.00	93.65
CSP56	10.00	0.84	13.00	7.00		115.00	0.71	0.16	5.63	0.44	39.80	7.02	254.00	192.58
CSP57	1.83	0.96	2.70	0.94		17.00	0.71	0.14	5.19	0.44	14.98	6.50	47.00	44.89
CSP58	9.04	7.62	12.42	3.24		54.90	6.24	0.15	6.87	13.73	74.90	6.02	160.00	189.11
CSP59	2.05	0.39	5.56	1.35		18.00	2.91	0.12	3.20	10.63	25.68	5.41	57.00	69.89
CSP60	2.90	0.89	6.09	1.79		26.84	1.13	0.14	3.40	7.09	32.53	6.12	64.00	82.80
CSP61	4.18	1.56	3.15	0.91		13.42	2.34	0.11	0.10	6.65	38.95	5.24	49.00	71.37
CSP62	2.38	1.16	4.03	1.18		12.20	2.62	0.10	0.10	9.30	21.83	5.38	47.00	54.90
CSP63	3.68	1.13	10.15	2.22		31.72	3.33	0.10	0.20	13.73	39.38	5.97	93.00	105.64
CSP64	25.00	1.08	30.00	25.00		233.02	3.33	0.28	0.10	0.44	67.62	7.43	383.00	385.87
CSP65	19.84	2.23	19.88	5.28		136.64	0.78	0.36	18.60	0.44	38.95	7.53	238.00	243.00
CSP66	12.63	4.41	21.76	5.02		109.80	3.69	0.69	2.53	0.88	44.94	6.70	213.00	206.35
CSP67	3.92	3.51	4.69	0.96		14.64	5.03	0.10	0.40	15.06	14.98	5.24	64.00	63.29
CSP68	6.50	1.63	11.48	4.60		53.68	4.82	0.10	5.12	0.44	38.09	6.34	123.00	126.46
CSP69	6.46	4.90	13.66	6.54		79.30	3.26	0.10	2.29	10.19	45.79	6.51	163.00	172.49
CSP70	5.80	0.89	9.58	3.29		63.44	0.71	0.11	0.10	0.44	36.81	6.53	96.00	121.17
CSP71	10.44	3.61	23.40	12.34		156.16	0.85	0.10	0.08	9.75	57.35	7.08	258.00	274.08
CSP72	7.98	2.04	19.94	6.46		113.46	0.71	0.11	0.10	7.97	49.65	6.48	191.00	208.42
CSP73	36.45	1.29	35.40	17.65		295.24	0.71	0.11	0.10	0.44	59.92	7.50	426.00	447.31
CSP74	5.23	1.31	8.71	2.15		30.50	2.76	0.12	0.10	10.19	42.80	5.87	94.00	103.87
CSP75	3.77	2.04	2.01	0.72		12.20	0.71	0.11	21.02	3.54	32.53	5.22	37.00	78.65
CPS76	7.56	2.44	11.38	3.56		53.68	1.42	0.11	0.10	18.61	38.52	5.95	122.00	137.38
CSP1	5.13	3.31	4.37	1.04		36.60	0.71	0.22	2.40	1.77	38.95	6.62	66.00	94.50
CSP10	3.00	0.96	2.98	1.97		15.00	2.55	0.15	4.97	9.75	69.53	6.34	56.00	110.86
CSP11	4.96	3.01	6.70	1.40		15.86	3.89	0.10	1.82	21.71	41.52	6.08	80.00	100.97
CSP12	1.89	0.18	2.38	0.64		10.98	0.71	0.10	3.85	3.10	16.69	5.69	30.00	40.52
CSP13	2.71	2.21	1.84	0.30		19.52	0.71	0.15	0.10	1.33	2.57	6.04	35.00	31.44
CSP14	4.09	0.86	5.71	1.64		36.60	0.71	0.16	0.10	4.43	43.66	7.75	63.00	97.96
CSP15	2.97	0.59	6.20	1.37		32.94	0.71	0.10	0.10	9.75	25.25	7.35	62.00	79.98
CSP16	8.32	1.62	9.56	2.86		42.70	9.78	0.10	0.10	21.71	47.08	6.47	129.00	143.83
CSP17	3.82	2.44	4.81	1.17		18.30	0.71	0.10	0.10	13.73	38.52	6.25	66.00	83.70
CSP18	5.60	1.23	8.20	2.40		56.12	0.71	0.10	0.10	5.32	58.21	7.20	88.00	137.99
CSP19	7.45	2.21	18.70	9.95		134.20	0.71	0.10	0.10	7.09	47.08	7.40	222.00	227.59
CSP2	4.73	2.89	1.95	0.55		20.00	1.40	0.20	4.33	3.10	33.38	6.36	49.00	72.53
CSP20	2.81	0.69	5.06	1.53		23.18	0.71	0.10	0.10	8.86	34.67	6.30	59.00	77.71
CSP21	3.74	0.14	5.83	1.13		35.38	0.71	0.10	0.10	2.22	31.67	6.41	54.00	81.02
CSP22	4.37	3.11	3.70	0.81		23.18	2.13	0.10	0.10	8.86	38.52	6.08	60.00	84.88
CSP23	2.27	0.30	5.39	1.58		18.30	1.28	0.10	0.10	9.30	15.84	5.47	52.00	54.46
CSP24	3.01	0.84	6.69	1.56		24.40	2.76	0.10	0.10	15.95	25.25	5.72	71.00	80.66
CSP25	2.34	0.81	11.98	1.44		50.02	3.12	0.10	0.10	18.16	21.40	6.88	123.00	109.47
CSP26	3.48	1.11	7.24	2.76		52.46	0.71	0.10	0.10	3.99	35.95	6.92	91.00	107.90
CSP27	1.60	1.11	4.03	1.24		23.18	0.71	0.10	0.10	3.99	24.82	6.65	48.00	60.88
CSP28	5.55	1.11	19.15	8.45	24.00	31.72	4.61	0.10	0.10	2.66	47.94	9.39	176.00	145.39
CSP29	4.20	1.11	8.06	4.24		50.02	0.71	0.10	0.10	2.66	33.81	6.95	91.00	105.01
CSP3	7.87	2.02	13.10	4.50		67.10	3.89	0.18	1.81	18.60	62.92	6.81	161.00	181.99
CSP30	2.14	0.43	12.90	1.42		48.80	1.98	0.10	0.10	7.09	14.98	7.61	93.00	89.94
CSP31	2.88	0.55	7.04	1.98		29.00	1.63	0.20	0.10	7.53	28.68	6.65	76.00	79.59

id	Na^+	K^+	Ca^{2+}	Mg^{2+}	CO^2_3	HCO_3	Cl	F	SO^2_4	NO_3	SiO_2	pH	EC.µS/Cm	TDS mg/l
CSP32	5.00	1.24	16.70	6.80		102.48	3.19	0.30	0.10	7.09	50.07	7.25	172.00	192.97
CSP33	2.39	0.92	4.35	0.96		20.00	0.71	0.16	0.10	3.10	23.97	6.45	48.00	56.66
CSP34	2.16	0.33	4.73	1.74		25.62	0.71	0.12	0.10	7.09	23.54	6.67	53.00	66.14
CSP35	5.46	1.99	11.72	4.18		62.22	0.71	0.21	0.10	13.73	62.06	6.15	135.00	162.38
CSP36	10.16	4.99	7.08	1.74		13.42	8.86	0.15	5.44	31.01	51.36	5.30	124.00	134.21
CSP37	6.68	1.90	6.04	1.08		33.00	1.98	0.16	11.35	5.76	46.22	5.87	81.00	114.17
CSP38	3.93	1.87	3.80	0.74		22.00	0.71	0.16	10.17	1.33	30.82	6.58	50.00	75.53
CSP39	2.18	2.26	1.49	0.27		12.20	0.71	0.13	0.10	0.89	25.68	6.35	25.00	45.91
CSP4	5.56	2.04	6.92	1.98		31.00	3.26	0.18	3.77	17.72	46.22	6.44	96.00	118.65
CSP40	9.00	3.04	6.62	1.66		30.00	7.44	0.13	5.95	19.49	45.79	5.89	112.00	129.12
CSP41	3.70	1.09	3.15	0.73		17.08	0.71	0.11	0.10	6.65	29.96	6.54	48.00	63.28
CSP42	2.97	0.69	2.75	0.86		17.08	1.49	0.11	0.60	2.22	29.10	6.64	42.00	57.87
CSP43	2.23	0.87	1.75	0.59		18.30	0.71	0.12	0.25	0.89	27.39	7.08	28.00	53.10
CSP44	16.64	1.64	15.90	4.90		115.90	1.49	0.47	4.34	8.86	68.08	6.56	193.00	238.22
CSP45	13.76	4.11	16.08	2.60		54.90	7.02	0.32	13.14	44.30	47.94	6.40	193.00	204.17
CSP46	15.30	1.34	47.40	13.75		300.00	2.98	0.38	8.76	0.44	49.65	7.46	388.00	440.00
CSP47	5.00	3.00	7.00	0.10		78.08	2.62	0.29	6.16	4.43	44.08	6.81	153.00	150.76
CSP48	4.80	3.26	6.20	1.00		15.86	9.00	0.12	0.10	1.77	36.38	6.30	126.00	78.49
CSP49	5.55	1.07	8.19	2.18		37.82	3.05	0.16	0.10	1.77	25.68	6.01	89.00	85.57
CSP5	8.84	1.53	6.62	0.80		46.36	1.77	0.14	5.29	4.43	50.93	6.40	89.00	126.71
CSP6	6.40	1.49	6.52	1.98		47.00	2.13	0.12	3.44	3.99	41.52	6.39	88.00	114.59
CSP7	9.70	1.16	24.45	4.44		122.00	3.26	0.18	2.00	10.63	92.02	7.21	224.00	269.84
CSP8	2.82	1.57	3.14	2.18		35.38	2.41	0.14	4.43	11.52	41.52	6.24	89.00	105.11
CSP9	10.65	1.30	7.50	6.35		130.54	0.57	0.23	4.95	0.44	65.91	7.18	204.00	228.44
HDW1	6.81	2.52	11.64	2.50		59.78	1.42	0.34	28.29	2.22	52.22	7.10	116.00	167.74
HDW2	4.21	1.43	6.76	0.71		25.00	0.78	0.29	16.92	3.54	25.25	8.00	63.00	84.89
HDW3	2.80	7.80	11.92	2.65		34.16	11.13	0.26	0.10	11.52	18.40	6.55	120.00	100.74
HDW4	18.90	2.47	12.84	5.22		9.76	30.62	0.17	0.10	68.65	6.42	5.40	255.00	155.15
HDW5	2.70	2.19	6.77	1.73		21.00	2.48	0.19	10.11	8.42	22.68	5.60	66.50	78.27
HDW6	3.98	1.95	16.66	3.96		13.42	19.50	0.14	0.10	43.86	12.41	5.58	173.00	115.98
HDW7	2.49	3.05	1.26	1.35		5.00	1.42	0.13	6.63	11.52	10.70	6.00	41.20	43.55
HDW8	7.89	1.48	4.72	1.05		18.30	1.77	0.10	0.10	20.82	42.80	5.68	79.50	99.03

Hydrogeological and Hydrochemical Maps of Hagere Maryam NB 37 – 10 Sheet Explanatory Notes

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2015

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Extended Summary

The Hagere Maryam area is located in Southern Ethiopia on the Hagere Maryam map sheet (NB 37-10) at the scale of 1:250,000, covering an area of 18,145 km^2. The area is a part of the Oromia and Southern Nations, Nationality and People (SNNPR) regional states and is inhabited by 1.4 million people. A substantial part of the Hagere Maryam area is covered by pasture land in the south, forest in the northwest and agricultural land in the center.

The work which is summarized in the presented explanatory notes shows the large water, agricultural, industrial and human potential of the Hagere Maryam area.

The tectonic activity and lithological variation in the area partly or wholly control the drainage density and drainage pattern. Most of the river channels follow the Rift Valley structure and young lineaments.

An annual average rainfall value of 950 mm was adopted for the Hager Maryam sheet and was used in the calculations.

The area of the Hager Maryam map sheet is found within the Rift Valley Lakes basin in the western and the Genale - Dawa basin in the eastern part of the sheet. The principal river basins and sub-basins of the area of the Hagere Maryam map sheet are the Genale, Mormora, Awate, and Dawa in the eastern highlands and the Gelana and Sagen in the Rift Valley basin to the west. Lake Chamo is located in the northwestern corner of the map. Based on the data from river gauging stations the adopted value of the specific runoff for the Hagere Maryam sheet is 10. l/s/km^2 for the northeastern highlands and 2.5 10. l/s/km^2 for the rift floor (including escarpment areas, which are relatively small on the sheet) and practically the whole eastern part of the sheet and a value of 1 l/s/km^2 was adopted for the southeastern part of the sheet, resulting in a value of 4 l/s/km2 for the whole Hagere Maryam sheet.

The specific baseflow is assessed for the Hager Maryam sheet based on data from the river gauges, and is 3.5 l/s.km^2 for the northeastern highlands, 1.6 for the rift floor, and 0.9 l/s.km^2 for the southeastern lowlands. The Adopted value of the specific baseflow is 1. 9 l/s.km^2 for the whole Hagere Maryam sheet.

The hydrogeological map shows aquifers and aquitards (formations with local and limited groundwater resources) defined based on the character of the groundwater flow (pores, fissures), the yield of springs and the hydraulic characteristics of the boreholes. The following aquifers and aquitards were defined:

1. ***Extensive (2,670 km^2) and moderately productive or locally developed and highly productive*** porous aquifers (T = 1.1–10 m2/d, q = 0.011–0.1 l/s.m, with spring and well yield Q = 0.51–5 l/s). The aquifers consist of Quaternary alluvial, deluvial and mixed deposits (Q, Qa, Qe). The aquifers are shown on the map in light blue.
2. ***Extensive (4,461 km^2) and moderately or locally developed and highly productive fissured aquifer*** (T = 1.1–10 m^2/d, q = 0.011–0.1 l/s.m, with Q = 0.51–5 l/s). The aquifers consist of volcanic rocks (dominantly the Lower Basalts – Pgl). The aquifers are shown on the map in light green.
3. ***Extensive (11,014 km^2) and low productive*** **fissured aquifers** (T = 0.11–1 m^2/d, q = 0.0011 – 0.01 l/s.m, with spring and well yield Q = 0.051–0.5 l/s) developed in low and high grade metamorphic and intrusive rocks. The aquifers are shown on the map in red/brown.

The chemistry of groundwater in the Hagere Maryam area reflects the hydrological (aquifer) system and the system of groundwater circulation, and its variability in the geology and hydrogeology of the area, consisting of different volcanic rocks partly intercalated with sedimentary and volcano-sedimentary rocks, aquifers developed in superficial sediments and basement rocks. The dominant hydrochemical types of groundwater in the study area are basic and transitional calcium-bicarbonate. The second most common chemical type is sodium-bicarbonate. The sodium-bicarbonate type is mainly developed in the southwest and the calcium-bicarbonate type in the southwest.

The low TDS and dominant calcium-bicarbonate type of groundwater indicates the fast hydrogeological regime of the area, receiving a relatively high volume of precipitation where groundwater flows in fractured volcanic rocks of plateaus, which are also the main sources of aquifer recharge. Increasing TDS to the south reflects the increasing aridity of the area and the increasing impact of evapotranspiration on the composition of the groundwater.

There are good water resources to be used for irrigation as well as for drinking water supply of people living within the area. ***The total water resources of the area have been assessed to be 2,290 Mm^3/year.***

The total volume of renewable groundwater resources of active aquifers in the area has been assessed to be 2,290 Mm^3/year.

The total number of people living within the area is 1.4 million and the need for water supply can be nearly 10.2 Mm^3/year. The assessment of drinking water demand was based on a calculation of 20 l/c.d (15 l/c.d rural and 22.5 l/c.d for towns with less than 15,000 inhabitants). The figure shows that recent demand represents less than 1 % of the renewable groundwater resources of aquifers and therefore can provide adequate drinking water even in the future considering the trends in population growth.

To select appropriate areas, data from regional as well as detailed surveys have been evaluated, and a strategy was chosen, which consists in siting hydrogeological wells for the supply of drinking water to the population based on the following:

1. Basalts, trachyte, ignimbrites, alluvial sediments and basement rocks contain groundwater, the quality of which mostly corresponds with the standards for potable water.
2. The yields of the wells, which penetrate basalts and alluvial sediments, fluctuate between 2 and 10 l/s, and they are sufficient for the supply of as many as 8,000 to 40,000 inhabitants, the consumption of per person being 20 l/day.

The main prospective regions within the area for groundwater development are considered using the following methods:

- The mountains areas occupied by the Lower Basalt in the northwest provide very good quality groundwater, which could be obtained by drilling moderately deep boreholes (150 m deep). These wells provide large quantities of groundwater, particularly when drilled to the contact zone between the basalt and the basement.
- The alluvial plains along the Gelana Valley as well as in the tectonic zones in the basement rocks provide large volumes of good quality water, which could be abstracted from a depth of 50-100 meters with very little drawdown.

- The eastern piedmont of the Amaro horst provides good quality groundwater emerging from springs that are usually used for water supply of small towns.

Despite some local and regional environmental problems the Hagere Maryam area provides good potential for feasible and environmentally sound natural and human resource management.

Introduction

Background

Among the invaluable resources nature endowed us water is the most crucial for without it life cannot be sustained. Water can be abundant or scarce depending on the geological, climatic and topographic setting of a locality. The area covered by the Hagere Maryam map sheet is considered to be a water scarce area in the southern part of the country. The topography coupled with increasing population and livestock aggravates environmental problems. It is therefore important to compile a map of water resources to be able to propose and implement appropriate protection measures during development efforts. In this context, a hydrogeological investigation was performed in the Hagere Maryam sheet area in 2015 by the Geological Survey of Ethiopia. Publication of the project results was conducted in the framework of bilateral cooperation between the Czech and Ethiopian governments, where the participation of the Czech experts was financed by the Czech Development Agency in the framework of the Czech Republic Development Assistance Program. Participation of the Ethiopian professionals was financed by the Ethiopian government.

Objective and Scope of the work

The objectives of the hydrological and hydrochemical mapping of the Hagere Maryam area (NB 37-10) at a scale of 1:250,000 with accompanying explanatory notes are to identify water bearing lithological units and their characteristics, indicate recharge and discharge areas and groundwater flow direction, and categorize potential and quality variations. The main aims of this work are to define groundwater resources and their quality variations and to indicate the suitability of groundwater for different uses.

The desktop study and field work were carried out by a group of Ethiopian hydrogeologists. Final assessment and publication of the map were carried out by a joint Czech-Ethiopian team of professionals. The names of participating experts are shown in the following list.

Name	Institution	Participation filed
Jiri Sima	AQUATEST a.s.	Editor
Muhuddin Abdela	Geological Survey of Ethiopia	Hydrogeologist – Director of groundwater resources assessment directorate supervising the work groups
Thomas Agezew	Geological Survey of Ethiopia	Hydrogeologist – group leader and the map compiler
Wibanchi Fekadu	Geological Survey of Ethiopia	Hydrogeologist – group leader and the map compiler
Robel Asamenow	Geological Survey of Ethiopia	Hydrogeologist
Yewibdar Abede	Geological Survey of Ethiopia	Hydrogeologist
Ondrej Nol	AQUATEST a.s.	Hydrogeological expert
Antonin Orgon	AQUATEST a.s.	GIS expert
Craig Hampson	AQUATEST a.s.	Language revision

1. Basic Characteristics of the Area

1.1 Location and Accessibility

The Hagere Maryam map sheet (sheet No. NB 37-10, at a scale of 1:250 000, revised version 1994) is located in the southern part of Ethiopia and covers about 18,145 km^2. The study area is located partly in the Oromia Regional State in the south and east and the Southern Nation Nationality People Regional State in the north. The town of Hagere Maryam has been renamed Bule Hore. Geographically, the Hagere Maryam map sheet area is located at a longitude of 37°30' and 39°00' east and a latitude of 5°00'and 6°00' north. In general, the area of the Hagere Maryam map sheet lies on the southern part of the Ethiopia Rift Valley and part of the Eastern Highlands. The location of the map is illustrated in Fig. 1.1. The sheet is bounded by the NC 37- 6 Dila sheet to the north, the NB 37 – 11 Negele sheet to the east, the NB 37 14 Yabelo sheet to the south and the NB 37-9 Bako sheet to the west.

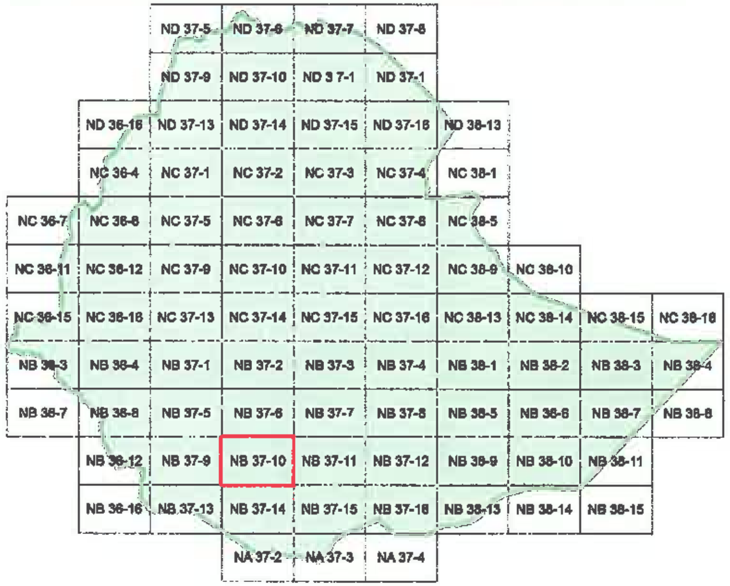


Fig. 1.1 Location map

The study area can be accessed by the roads connecting the capital city of Addis Ababa - Awassa-Moyale with an asphalt road. This asphalted road traverses the central part of the map area, passing through Agere Maryam. Dry weather roads accessible by four-wheel-drive vehicles link Hagere Maryam with Melka Soda, Gerba with Kercha and Finchaa with Galeba. There are many other important all-weather and dry-weather gravel roads leading to different parts of the mapped area. The town of Hager Maryam, the capital of the Hager Maryam zone, is located 354 km away from Addis Ababa. The towns of Kibre

Mengist and Shakiso in the northeastern part of the area can be reached by the all-weather road from Awassa via Aleta Wendo. Dry weather roads that serve the eastern part of the area include those connecting the towns of Shakiso and Dila, the Shakiso-Kenticha-Dermi Dama road and the Shakiso-Megado-Digati-Galeba road. The main accessible roads and settlements are shown in Fig. 1.2.

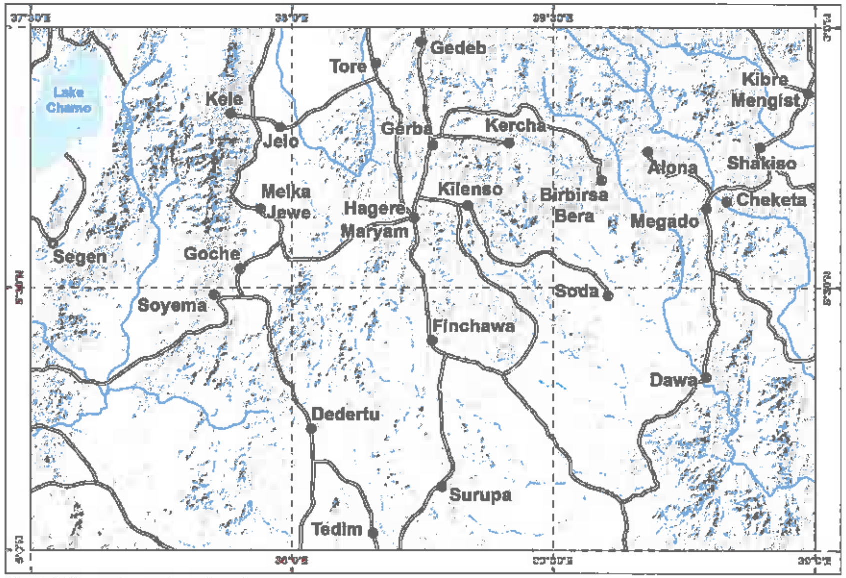


Fig. 1.2 The main roads and settlements

1.2 Population, Settlements and Health Status

The study area is administrated by two different regional states, the Oromia Regional State and the Southern Nation Nationality People Regional State. The Oromia Regional State (ORS) mostly covers the southern and eastern parts of the map sheet and the people living there speak the Oromifa language. The Southern Nation Nationality People Regional State (SNNPRS) covers the northern part of the map sheet. The extent of this regional state is also reflected in its own culture and languages.

The population density in the map area is low. The inhabitants are mainly of the Gujee, Gedeo, Burji, Konso, Gerba, Borena and Koyra ethnic groups. The Oromo language is widely spoken, being the language of the Gujee, Borena and Gerba. The Gujees are broadly distributed throughout the map area, exercising a semi-nomadic way of life. The Gedeo, Konso, Burji and Koyra basically depend on farming; the Gedeo inhabit the northern highlands, the others being confined to the western part of the map area. A nomadic way of life is practiced by the Borena and Gerba tribes, who inhabit the south-central and northwestern parts of the map area, respectively.

The ORS is represented by the Guji, Borena, and Hager Maryam zones. The Amaro, Gamu Gofa, Burji, Gedeo and Konso special woredas belong to the SNNPRS. The study area consists of 7 zones and 22 woredas. Most of the densely populated towns and villages are situated in the central part along the main asphalt road from Awassa to Zabelo. According to the Federal Democratic Republic of Ethiopia Population Census (2011) the population in the study area is 1,424,061 and detailed data are shown in Tab 1.1., and the locations of the zones are shown in Fig. 1.3.

Tab. 1.1 Population in the study area

Region	Zone	Woreda	Woreda area in the mapped area [km²]	[%]	Total population	Assessed population in the mapped area
Oromia	Guji	Adola (1)	331	27	126428	34329
Oromia	Guji	AdolaTown (2)	23	83	28287	23584
SNNP	Amaro	Amaro Sp. Woreda (3)	1338	94	172177	162030
SNNP	Gamu Gofa	Arba Minch Town (4)	1	3	101336	2694
Oromia	Borena	Arero (5)	645	9	55548	4886
SNNP	Gamu Gofa	Ariba Minich Zuriya (6)	55	6	187811	10663
Oromia	Guji	Bore (7)	28	2	242357	5234
Oromia	Borena	Bule Hora (8)	1684	100	306862	306862
SNNP	Burji	Burji Special (9)	1135	101	64888	65261
SNNP	Derashe	Derashe Special (10)	65	4	165753	7191
Oromia	Borena	Dugda Dawa (11)	3864	100	169745	169745
SNNP	Gedeo	Gedeb (12)	237	74	163975	121361
Oromia	Borena	Gelana (13)	706	52	82296	42430
Oromia	Guji	Hambela Wamena (14)	440	77	120753	93325
SNNP	Gedeo	Kochore (15)	69	32	151197	48431
SNNP	Konso	Konso Sp. Woreda (16)	649	29	270349	77215
SNNP	Gamu Gofa	Nech Sar NP (17)	223	81	0	0
Oromia	Giji	Odo Shakiso (18)	2469	59	239952	142218
Oromia	Guji	Qercha (19)	749	100	12189	12189
Oromia	Borena	Teltele (20)	965	10	81416	7744
Oromia	Guji	Uraga (21)	175	19	203140	38516
Oromia	Borena	Yabelo (22)	2246	41	118860	48155
Total						1,424,061

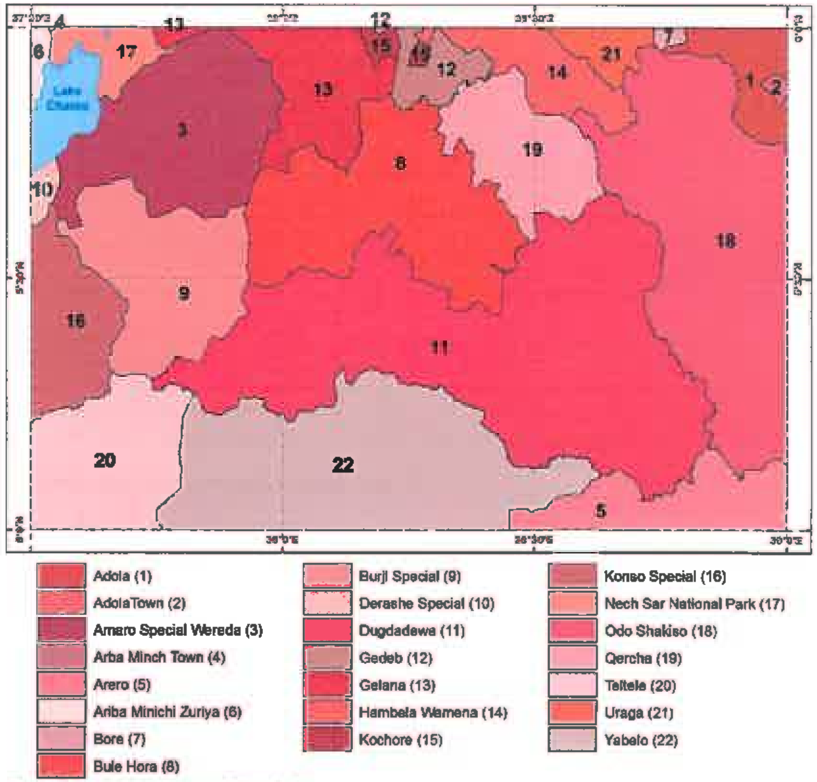


Fig. 1.3 Administrative zones (Woredas)

The rural population is mainly engaged in peasant farming with a mixed type of agricultural activity, including ploughing of cereal crops (for subsistence) and livestock breeding. They also breed horses, mules and donkeys. The urban population is mainly engaged in tertiary activity.

The major agriculture activity of the rural population of the area is the plantation of coffee and vegetable and fruits additional to various cereals. Other activities performed throughout the study area include the keeping of bees, as well as the plantation of enset, sugar cane and cotton. Cereal crops such as maize teff, sorghum, barley and wheat are also known and local people also cultivate cabbage, beans, peas and lentils.

Access to safe drinking water is limited and some statistics suggest that only 15 % of the rural inhabitants have access to safe drinking water. The WHO (2006) statistics show that 31 % of the rural population has sustainable access to improved drinking water sources (96 % of the urban population). This low number is alarming because 70 % of contagious diseases are thought to be caused by contaminated water. This is a serious problem for Ethiopia in the effort to establish a strong agricultural community that will be able to safeguard the supply of food for the whole country. One of the priorities of government policy is therefore to provide safe drinking water to rural communities. To tackle the problem with safe water supply in towns and rural area three key ministries Health, Water Resources, Energy and Irrigation, and Education have joined to launch the National One WASH program, which provides a strategic framework for achieving a national vision for universal access to hygiene sanitation. Ethiopia faces chronic problems with malaria (Fig. 1.4) which is endemic over 70 % of the country, and was once a scourge in areas below 1,500 m a.s.l. The southern part of the the Hagere Maryam sheet has a substantial malaria risk.

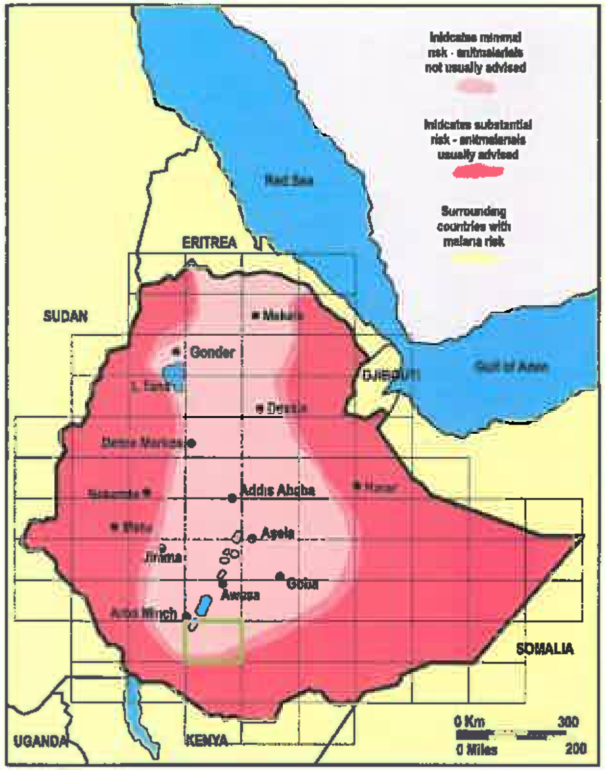


Fig. 1.4 Malaria risk in Ethiopia

1.3 Land Use and Land Cover

Poor land use practices, improper management systems and lack of appropriate soil conservation measures have played a major role in causing land degradation problems in the country. The land and water resources are in danger due to the rapid growth of the population, deforestation and overgrazing, soil erosion, sediment deposition, storage capacity reduction, drainage and water logging, flooding, and pollutant transport. In recent years, there has been an increased concern over climate change. A major effect of climate change is alterations in the hydrologic cycles and changes in water availability. Increased evaporation combined with changes in precipitation characteristics has the potential to affect runoff, frequency and intensity of floods and droughts, soil moisture, and water supplies for irrigation and generation of hydroelectric power.

Land cover includes cultivated land (large-scale farms in the Kibre Mengist area, and family farms with varying intensity of cultivation along the main asphalt road), vegetation (shrub lands, natural forests and grassland), manmade features (urban or built-up areas), small perennial swamps and water bodies. Land cover is shown in Fig. 1.5. The land use is characterized according to FAO (2000) maps and provides land use classes by the arrangements, activities and inputs of people in a certain land cover type to be used for production, change or to be maintained.

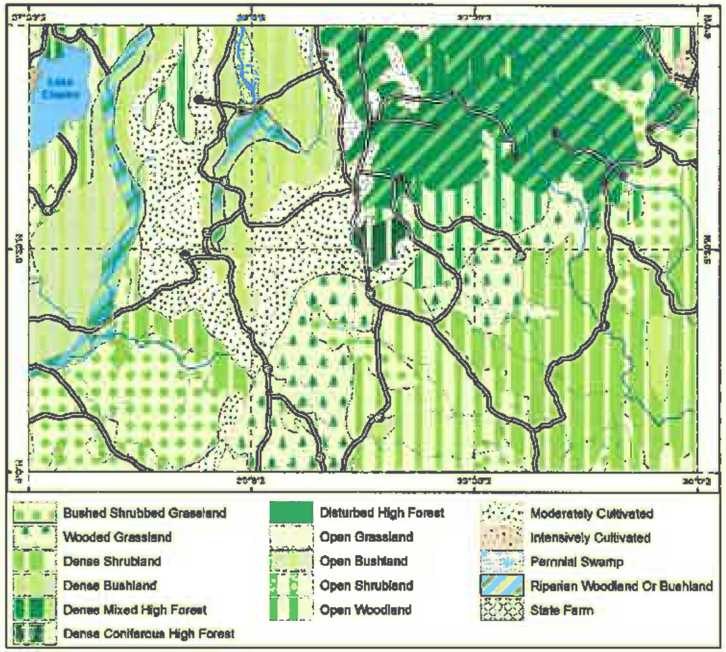


Fig. 1.5 Land cover

2. Selected Physical and Geographical Settings

The study area is located in the southern part of the Ethiopian Rift Valley and **eastern** part of the Ethiopian Plateau dissected by river valleys.

2.1 Geomorphology

The geomorphology of the area is highly variable and is generally the result of repeated volcanic and tectonic events with the associated erosion of volcanic rocks and deposition processes.

The tectonic activity and lithological variation in the area also partly or wholly control the drainage density and drainage pattern. Most of the river channels follow the Rift Valley structure and young lineaments. The most distinct geomorphological units are shown in Fig. 2.1.

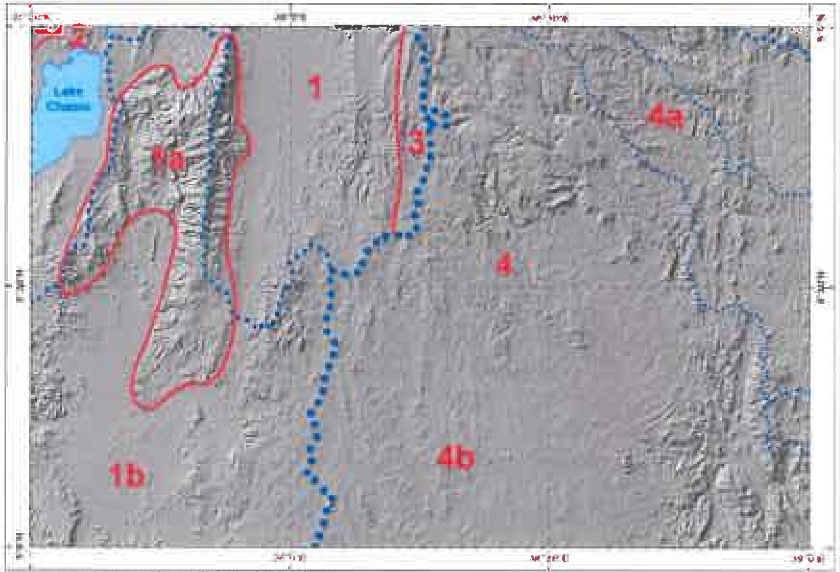


Fig. 2.1 Generalized geomorphological units

The highest peak of the study area lies to the west at an elevation of 3,232 m a.s.l. on the Sanselet mountain ridge, which is in the northern part of the Amaro horst. The lowest points on the map are areas where the Dawa and Sagen rivers leave the sheet at levels of less than 850 m a.s.l.

The north-central part of the map area is a highland plateau of mostly volcanic cover. Drainage is poorly developed, and the region mainly serves as a starting point for many southerly and southeasterly

draining rivers. In the rest of the map area, three fairly distinct physiographic regions can be identified: the western, the central and the eastern regions. In the western region, the influence of the Main Ethiopian Rift is pronounced. This area is characterized by narrow to moderately broad submeridionally trending ridges and valleys. The Amaro horst is an uplifted block that extends from the northern edge of the sheet southwards to the Segen River, gradually decreasing in elevation. To the west it is bounded by the Chamo and Segen grabens, to the east by the Gelana graben. The main perennial stream is the Gelana River that drains northward. The southwesterly draining the Segen River and many other small streams in this area are seasonal.

The central region is a broad relatively elevated block that has a longitudinal trend and exhibits a gentle southerly slope. Most of the streams in this area are intermittent and drain south. Their courses are basically controlled by the fracture system in the region.

The eastern region consists of a gently southeasterly sloping block on the west, while its eastern part is dominated by rugged topography with narrow ridges and sub-meridional trending valleys. This region is highly dissected by perennial rivers, among which the Gelana, Awata, Mormora, Dawa and Aflata are notable. The courses of these rivers are largely controlled by the Precambrian structure of the area, and they generally flow to the south or southeast.

***The rift floor* (marked 1 in Fig. 2.1)** is located in the western part of the map. Sedimentary formations form a flat plain and are only eroded along river and/or wadi banks and dominant volcanic structures are located throughout the whole rift floor. The hills are mostly cone shaped or have semi-conical crests that leave evidence of past volcanic activity. The central part of the floor is elevated and forms the Amara horst with the highest point of the map.

***Escarpment* (marked 2, 3 in Fig. 2.1)** rises on both edges of the rift, connecting its bottom with the Eastern (2) and Western Highlands (3). The escarpment is delineated by many fault bounded blocks. The margins of the rift are characterized by a few widely spaced faults with very large vertical displacements to the rift floor. This displacement becomes less and less to the south and disappears after Hagere Maryam. The tectonic escarpment itself is formed by a narrow strip of blocks, but during the hydrogeological assessment this narrow strip was extended up to the main water divide bounding the Rift Valley Lakes basin.

***The plateau* (marked 4 in Fig. 2.1)** covering about half of the sheet area is located in its western part and is generally characterized by a flat highland surface. The plateau is dissected by the deep gorges of the main rivers and in places is crowned by minor peaks. The rivers flow in valleys and are often lined by Quaternary alluvial deposits. **Deep gorges** are developed along the main rivers: Dawa and Aflata (4a), Awata, Mormora and others. They have steep slopes and cliffs along the valley sides with a depth of more than 1,000 m. The terrain in this area is rugged and access is difficult. There is a high rate of erosion flow and alluvial deposits are less common. Some rivers have cut deep exposing the Precambrian rocks but others drain the Tertiary to Pliocene volcanic rocks.

The rift floor and plateau join in the southern part of the sheet to form an undulating area with wide plains and mountain ridges 1b and 4b.

2.2 Soil and Vegetation Cover

Soil and vegetation cover reflects the basic climatic conditions of the area as well as the regional and site specific hydrological, meteorological, geological, geomorphological and erosional characteristics.

Soil is important from a hydrogeological point of view because it stores rainwater in its pores before it infiltrates to greater depths and recharges the aquifer system. The hydrology of the soils is dependent on the texture of the rocks and the degree of weathering. According to the soil map provided by the Ministry of Agriculture, the study area is covered by seven major types of soil as follows: Cambisols Luvisols, Vetrisols, Fluvisols, Nitosols, Lithosols, and Acrisols. The distribution of soil types is shown in Fig. 2.2. There are also some minor soil types in the area.

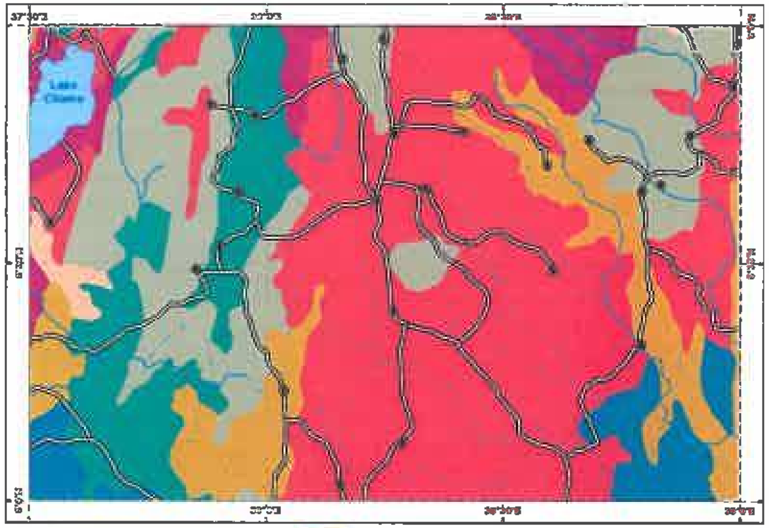


Fig. 2.2 Distribution of the main soil types

Cambisols (Chromic and Eutric):- cambisols are developed in medium- and fine-grained material derived from a wide range of rocks, mostly in alluvial colluvial and aeolian deposits. They are widely distributed and mainly cover the western and southern part of the rift floor as well as areas along rivers in the eastern plateau.

Luvisols (Chromic): - occur twice in the study area and can be found along the western and eastern parts of the sheet covering the plateau and the escarpment area. They are soils with high nutrient content.

Good drainage makes them suitable for a wide range of agricultural practices e.g. cereals and orchards. They are developed in the central part of the sheet.

Vertisols (Chromic):- vetrisols are soils with a high content of expansive clay, which is known as montomorite, and which forms deep cracks during the dry season. Vetisols typically form from highly basic rock such as basalts in a climate that is seasonally humid or subjected to erratic drought and flood or impeded drainage. Depending on the parent material and the climate they can range from grey or red to deep black. This soil type covers the shores of Lake Chamo and the area around the shallow valley of the Upper Awata and Mormora rivers in the northeastern part of the Hagere Maryam map sheet.

Fluvisols (Eutric) are developed from recent alluvial and lake deposits. The soils show clear evidence of stratification. Soil horizons are weakly developed but a distinct topsoil horizon may be present. They are mostly found at the southern part of the rift floor.

Nitosols (Eutric):- are formed from the parent material, which is mainly as base rich as the soil itself, and are commonly found in sub-humid and semi-arid climates. They represent the youngest of the forest soil orders. Eutic Nitosols are nitosols which have a high content of unstable grains. The nitosols cover small patches in the northern and eastern areas of the sheet.

Lithosols:- are genetically young soils in alluvial deposits deposited (apart from river sediment) under natural conditions where periodic flooding is common. The soils show clear evidence of stratification. Lithosols are mainly developed in the deep valleys of the Dawa River.

Acrisols (Orthic) are clay-rich and are associated with humid, tropical climates. Their low fertility poses limitations to their agricultural use, favoring silviculture, low intensity pastures and protected areas in many places. Crops that can be successfully cultivated, if the climate allows, include tea, coffee and sugar cane. They are widely distributed and mostly cover the eastern and southern parts of study area.

Vegetation

Vegetation in the map area varies with the climate. In the northern region, where the climate is relatively wet, the vegetation is dense and deciduous trees are common, making geological traversing difficult. The southern region, however, is largely characterized by scarce bushy trees, so that access and rock exposure are good.

The vegetation types of the area are varied from place to place. Eucalyptus trees, Junipers, Hagenia abyssinica, Podacarpus grcilior (zigba), and Vernonia amygdalina (bisana) are common on the highland plateaus. Common woody vegetation also includes Ficus gnaphalocarpa (oda), Syzygium guineense (dokima), Olea africana (woira), Ekerbegia capensis (ononu), Ficus vasta (warka), and Pygeum africanus (tikur inchet).

The lowland areas and especially the rift floor are dominated by acacia 'girar', thorn bushes, small shrubs and many undifferentiated ever green plants. Natural vegetation can be classified into regions of forest as in the Sidama area.

Besides the natural vegetation, plantation of different trees is common in many localities. Juniperous Procera and eucalyptus are common examples, as are coffee and false banana (enset) plantations. Bare lands are often reforested by planting various different types of vegetation. The vegetation in the Soyama area located in the western part of the sheet is shown in Fig. 2.3.

Fig. 2.3 Vegetation in the Soyama area

Wildlife in the forest area (northeastern part of the map) includes deer, and hyenas have also been observed. Apes and monkeys, including coulombs monkeys, are also common in places.

2.3 Climatic Characteristics

The northern region of the map area is characterized by a relatively wet climate; here the rainy season lasts from April to May. A little precipitation may occur, particularly in the northeast, during the months of September to October, while the region remains generally dry for the rest of the year. The southwestern part of the map area is the most arid, with precipitation occurring in April and May and September. The mean annual rainfall is less than 1,000 mm.

The weather of the Hagere Maryam map sheet is mainly controlled by the seasonal migration of the inter-tropical convergence zone (ITCZ), which is conditioned by the convergence of trade winds of the northern and southern hemispheres and the associated atmospheric circulation.

The area is climatically highly variable and is mainly characterized by the subtropical Weina Dega on the west and by arid Kolla climatic zones in the rift floor and Dawa valley temperate to humid and

temperate Dega climatic zones on the escarpment and eastern highlands. The highest point of the map in Sidama and the Amaro horst is characterized by sub-alpine Wurch.

2.3.1 Climatic Zones and Measurements

The climatic conditions of Ethiopia are mostly dominated by elevation. According to Daniel Gamatchu (1977) there are wide varieties in climatic zones. The climatic zones defined by Javier Gozálbez and Dulce Cebrián (2006) and Tesfaye Chernet (1993) are shown in Tab. 2.1.

Tab. 2.1 Ethiopian climate classification

Name / Altitude / Mean annual temperature	Precipitation below 900 mm	Precipitation between 900 and 1,400 mm	Precipitation above 1,400 mm
High Wurch (Kur) above 3,700 m below 5 °C			**Afro-alpine** meadows of grazing land and steppes, no farming *Helichrysum, Lobelia*
Wurch (Kur) 3,700–3,200 m 5–10 °C		**Sub-afroalpine** barley *Erica, Hypericum*	**Sub-afroalpine** barley *Erica, Hypericum*
Dega 3,200–2,300 m 10–15 °C		**Afro-mountain (temperate)** forest – woodland barley, wheat, pulses *Juniperus, Hagenia, Podocarpus*	**Afro-mountain (temperate)** bamboo forest barley, wheat, nug, pulses *Juniperus, Hagenia, Podocarpu, bamboo*
Weina Dega 2,300–1,500 m 15–20 °C	**Savannah** (sub-tropical) wheat, teff, some corn acacia savannah	**Shrub-savannah** (sub-tropical) corn, sorghum, teff, enset, nug, wheat, barley *Acacia, Cordia, Ficus*	**Wooded savannah** (sub-tropical) corn, teff, nug, enset, barley *Acacia, Cordia, Ficus, bamboo*
Kolla 1,500–500 m above 30 °C	**Tropical** sorghum and teff acacia bushes	**Tropical** sorghum, teff, nug, peanuts *Acacia, Cordia, Ficus*	**Wet tropical** mango, sugar cane, corn, coffee, oranges *Cyathea, Albizia*
Bereha below 500 m above 40 °C	**Semi-desert and desert** crops only with irrigation thorny acacias, *Commiphora*		

Remark: after Javier Gozálbez and Dulce Cebrián (2006), Tesfaye Chernet (1993)

The climatic zones of the study area defined based on elevation and precipitation are shown in Fig. 2.4.

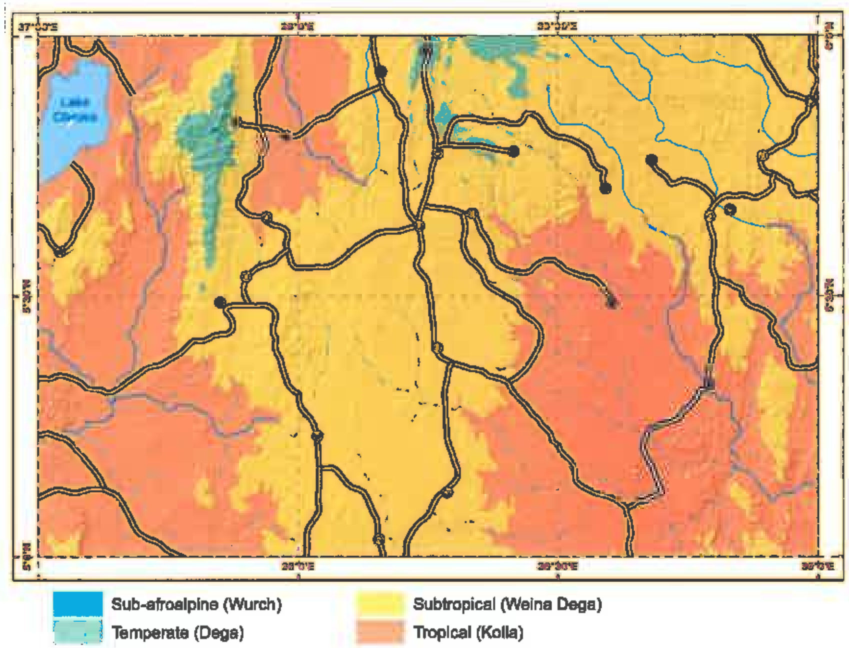


Fig. 2.4 Climatic zones

There are many meteorological stations operated by the National Meteorological Service Agency (NMSA) and WMO within the mapped area and several others are located in the near surroundings. The stations selected to evaluate the climatic data are characterized in Tab. 2.2 and shown in Fig. 2.5.

The data shows that rainfall increases to the north and northeast and the local maxima are related to topography and altitude. Average annual rainfall is in general higher than 1,000 mm in the northern part and less than 1,000 mm in southern part of the map sheet. The maximum annual average rainfall of 1,577 mm was measured in the Amarokele meteo-station (map ID 5) in the western part of the Gelana river catchment (Amaro horst). The minimum annual rainfall of 466 mm was measured in the Surupa meteo-station (map ID 10) in the southern part of the Dawa river catchment.

An annual average rainfall of 950 mm was adopted for the Hager Maryam sheet and will be used in further calculations.

Tab. 2.2 Climatic stations of the Hager Maryam area with data about average, min. and max. rainfall

Map ID	Station	X_UTM	Y_UTM	Class	Altitude	Annual average min.-max. [mm]	Sub basin
1	Finchewa	418757	598716	4	1700	836 700 – 1,163	Dawa Kilkile
2	Lege Dembi	490772	626301	4	1720	998	Dawa Mormora
3	Shakiso	490774	637354	4	1620	1.013	Dawa Awata
4	Kibre Mengist	498008	651096	1	1680	1,051 668 - 1989	Dawa Awata
5	Amarokele	377975	645265	1/3	1649	1,577 1236 - 2,079	RVLB Gelana
6	Gumaide	339137	617631	4	1619	928 533 - 1614	RVLB Siti
7	Burji	374596	606280	3/4	1818	918 628 - 1267	RVLB Gelana
8	Chemeri Bacho	394777	615331	4	2000	892	RVLB Gelana
9	Dadim	396250	557794	4	1763	659 399 - 952	RVLB Sagen
10	Surupa	407616	552672	4	1550	466	Dawa Gora Dese
11	Gadeb	416292	653210	4	2249	1,478 914 – 2,873	RVLB Gelana
12	Hagere Maryam	415094	622671	1	1860	905 509 - 1467	RVLB Gelana

Monthly means in Hagere Maryam climatic station are shown in Tab. 2.3.

Tab 2.3 Basic climatic data for Hagere Maryam meteo-station (monthly mean)

Meteo-characteristic	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Average rainfall	14.7	26.6	76.2	152	184	48.6	44.5	23.6	56.5	135	46.7	13.9
Max temp	28.6	29.0	25.7	26.6	25.3	25.9	24.5	22.5	25.9	25.8	25.8	27.5
Min temp	10.7	11.7	11.8	13.1	13.0	12.5	11.9	12.3	12.0	12.5	11.1	10.6
Mean temp	19.6	20.3	18.7	19.8	19.1	19.2	18.2	17.4	18.9	19.1	18.4	19.0
Relative humidity	53	50	64	76	83	80	84	87	88	80	80	82
Potential Evapotranspiration	201	145	162	135	125	115	107	99	129	135	137	157
Sun shine hours	9.7	9.0	8.4	8.0	5.9	5.1	2.7	3.8	5.6	7.1	7.8	8.1
Wind speed	1.0	0.9	1.1	0.8	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.6

The mean annual ambient air temperature of Hagere Maryam is 18.9 °C (Tab. 2.3). Minimum, maximum and mean temperatures were calculated from the original data supplied by NMSA. The minimum and maximum average temperatures are 10.6 °C and 29.0 °C, respectively. The hottest and coldest months are February and December, respectively (Fig. 2.6).

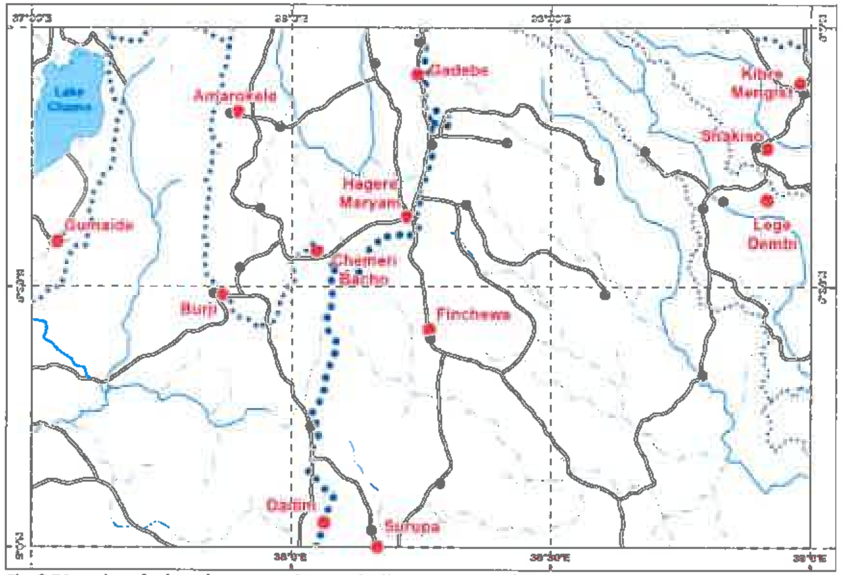


Fig. 2.5 Location of selected meteo-stations on the Hagere Maryam sheet

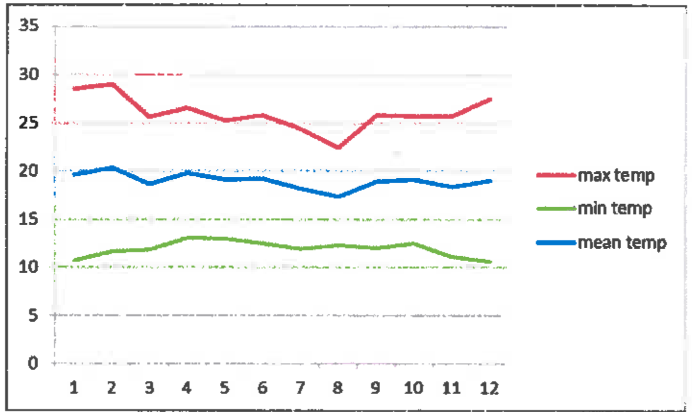


Fig. 2.6 Annual variation of temperature in °C (monthly mean)

Relative humidity (RH) determines the rate of evaporation as well as isotopic fractionation. RH was measured three times a day at a station in Hagere Maryam between 2011 and 2014. The mean monthly values of RH vary from 50 in February to 87 in August and are shown in Tab. 2.3 and Fig. 2.7 together with the potential evapotranspiration (PE), which has an average of 1,647 mm per year.

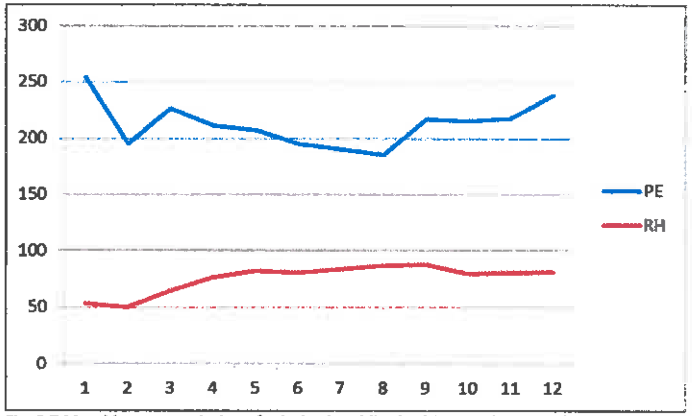


Fig. 2.7 Monthly mean variation of relative humidity (RH) in % and potential evapotranspiration (PE) in mm

The total daily evapotranspiration rate is dependent on the total daily sunshine hours. It is clear that at the Hagere Maryam station the mean maximum sunshine hours are recorded through December to February when there are approximately 9 hours of sunshine per day (2010 to 2014) as shown in Tab. 2.3

and Fig. 2.8. The mean minimum sunshine hours are registered in July when there are less than 3 hours of sunshine per day. Annual average reference crop potential evapotranspiration (mm) Gelana at Tore = 1445, Upper Gelana at Yirga Chefe = 1396 (Halcrow, 2008)

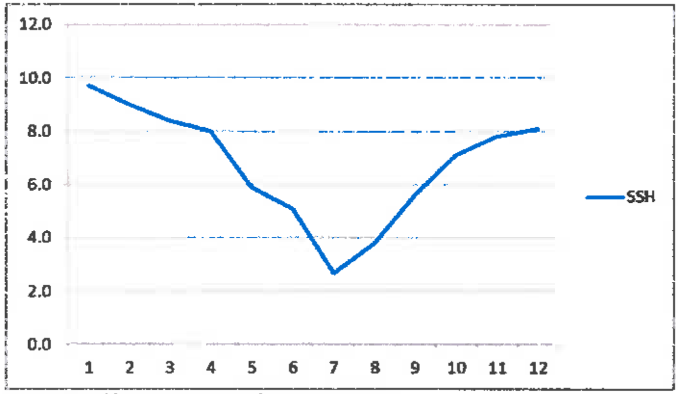


Fig. 2.8 Monthly mean variation of sunshine in hours

One factor which controls evaporation is wind speed, as saturated vapors concentrate in a limited space due to a lack of strong winds to carry them away, thereby decreasing the rate of evaporation. In the area of the Hager Maryam map sheet the wind speed is high from January to March and there is a low wind speed for the rest of the year. The mean annual wind speed is given in Tab 2.3 and is shown in Fig 2.9.

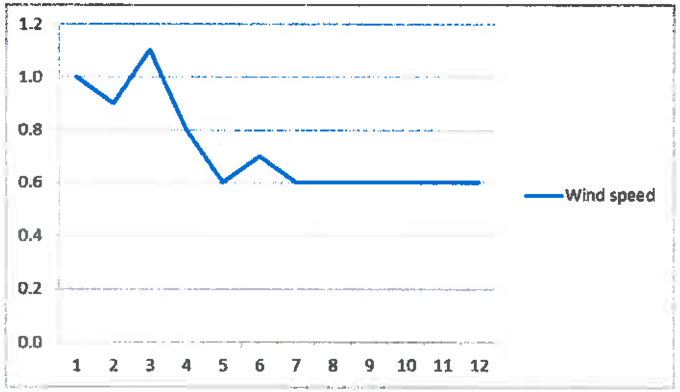


Fig. 2.9 Monthly mean variation of wind speed in m/s

2.3.1 Precipitation

The Ethiopian territory is divided into four zones marked as A, B, C, and D, each of them with different precipitation patterns. The seasonal classification and precipitation regimes of Ethiopia (after NMSA, 1996) are characterized in Tab. 2.4 and shown in Fig. 2.10.

Tab. 2.4 Characterization of the precipitation pattern in Ethiopia

Zone	Precipitation pattern
A	This region mainly covers the central and central eastern part of the country. It is characterized by three distinct seasons, and by bimodal precipitation patterns with small peaks in April and the main rainy season during mid-June to mid-September with peaks in July.
B	This region covers the western part of the country. It is characterized by a single precipitation peak. Two distinct seasons, one being wet and the other dry, are encountered in this region. The analysis of mean monthly precipitation patterns shows that this zone can be split into the southwest (b1) with the wet season during February/March to October/November, west (b2) with the wet season during April/May to October/ November, and northwest (b3) with the wet season from June to September.
C	This region mainly covers the southern and southeastern parts of the country. It has two distinct precipitation peaks with a dry season between. The first wet season is from March to May and the second is from September to November.
D	The Red Sea region in the extreme northeastern part of the country receives diffused precipitation with no distinct pattern; however, precipitation occurs mainly during the winter.

The mapped area mainly belongs to zone C which is characterized by two distinct precipitation seasons and by one dry season occurring from April to May and September to November. Precipitation patterns in Hagere Maryam and Kibre Mengist meteo stations are shown in Fig. 2.11 and 2.12 and annual variation of rainfall in Kibre Mengist station is shown in fig. 2.13.

The meteo station in Hagere Maryam has been in operation since 1975. There are several other stations with over 10 years of records, although these records are not always continuous.

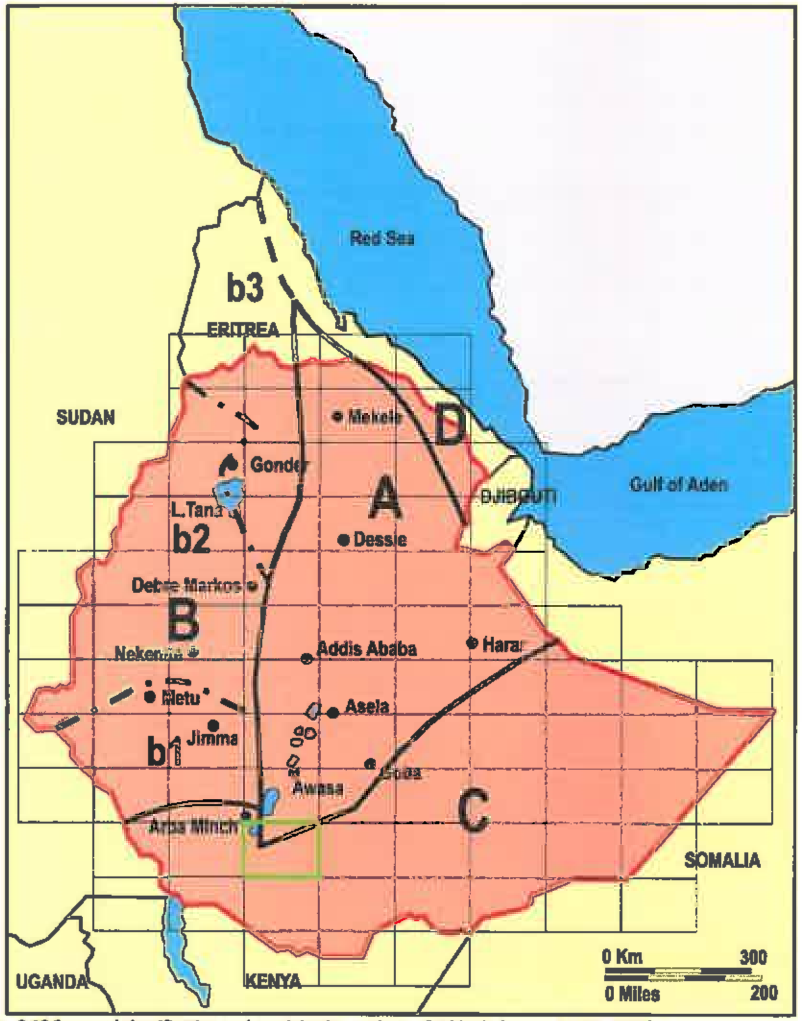


Fig. 2.10 Seasonal classification and precipitation regimes of Ethiopia (source NMSA, 1996)

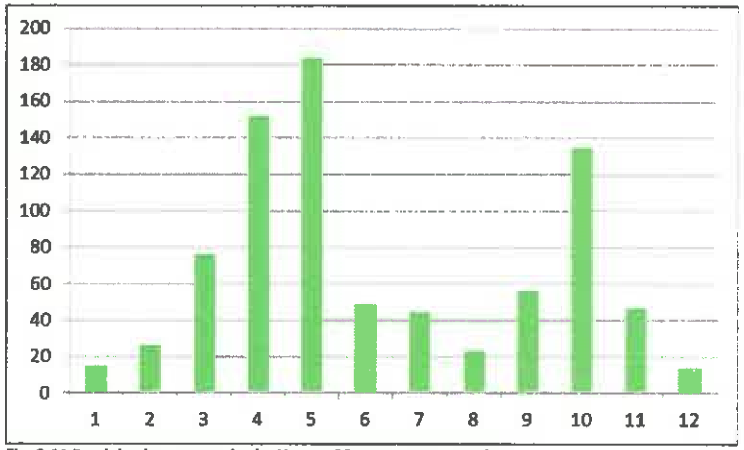


Fig. 2.11 Precipitation pattern in the Hagere Maryam meteo-station

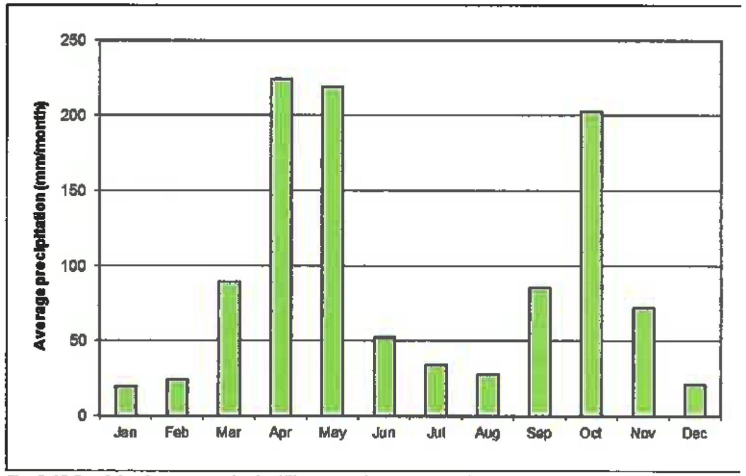


Fig. 2.12 Precipitation pattern in the Kibre Mengist meteo-station

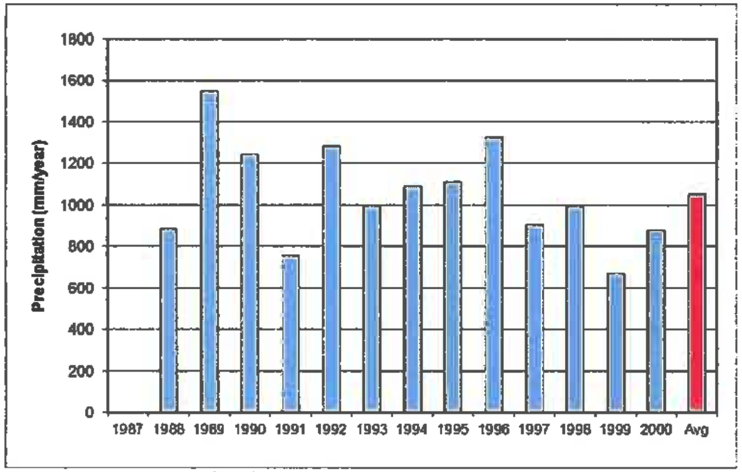


Fig. 2.13 Annual variation of rainfall in the Kibre Mengist meteo station

JICA calculated rainfall averages for various sub-basins of the Rift Valley Lakes basin and a summary of rainfall data in selected basins is shown in Tab. 2.5.

Tab. 2.5 Summary of rainfall data in selected sub-basins of the Rift Valley.

Sub - basin	Area km2	Rain average (mm)	Total rain (Mm3)
Sile - Chamo	5,011	854	4,276
Gelana	3,856	1,140	4,396
Bezo-Weyto	12,143	1,104	13,406
Konso localized	1,685	851	1,434
Segen	5,230	815	4,263

2.4 Hydrography and Hydrology of the Area

The area of the Hager Maryam map sheet is found within the Rift Valley Lakes basin in the western and Genale - Dawa basin in the eastern part of the sheet. The principal river basins and sub-basins of the area of the Hagere Maryam map sheet are shown in Fig. 2.14.

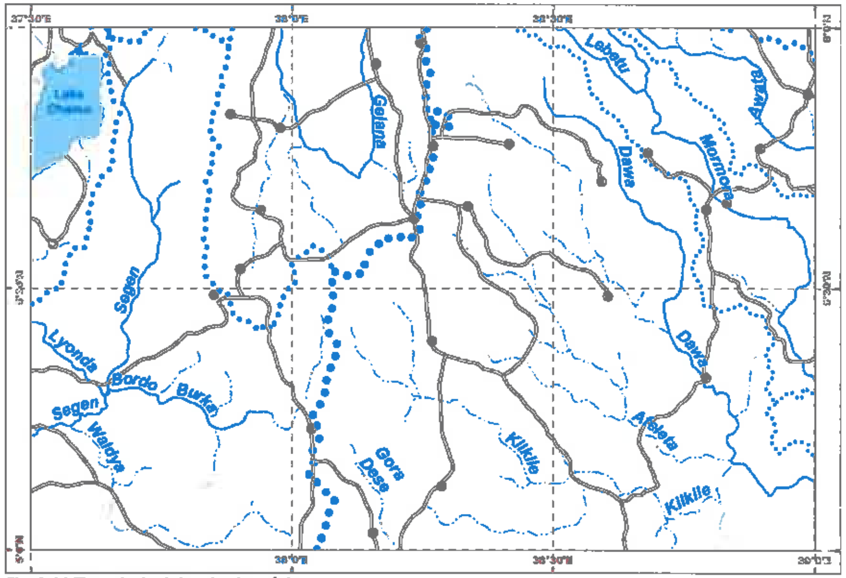


Fig. 2.14 The principal river basins of the area

2.4.1 Surface Water Network Development

The Hager Maryam topographic map sheet is divided by the main surface water divide and the largest part belongs to the Genal – Dawa basin in the east and smaller part to the Rift Valley Lakes basin in the west.

Genale – Dawa basin occupies about 60 % of the study area in the eastern part of the Hagere Maryam map sheet. The major perennial rivers flowing in the drainage basin are the Wawa, Mormora and Awata rivers and some of their tributaries. The drainage is parallel and follows structures in volcanic as well as in basement rocks and all main rivers flow in a southeasterly direction.

Rift Valley Lakes basin occupies about 40 % of the study area. It is divided from the Genale Dawa basin by the escarpment with a N-S trending tectonic structure. The Gelana and Sagern and their tributaries are the main perennial rivers in the western part of the sheet. The drainage forms a sub-parallel pattern mainly flowing towards the south and later towards the north based on the internal structures of the rift floor represented mainly by the Amaro horst.

Lake Chamo is located in the northwestern corner of the sheet, at an elevation of 1,108 m.a.s.l. The lake is the last big lake of the system in the Main Ethiopian Rift. Lakes Abaya and Chamo form a single basin because the two lakes are hydrologically interconnected to the Kulfo River, transferring water from Lake Abaya into Lake Chamo with a difference in levels between the lakes of 61 m. Outflow from Lake Abaya by the Kulfo River and other rivers such as the Sile and Sego and an ephemeral stream to the south contribute to Lake Chamo. Halcrow (2008) mentioned that there is some flow from Lake Chamo to the Segen River, towards Lake Chew Bahir, when lake levels are extremely high.

Currently, three large-scale irrigation schemes are planned by the MoWR for rivers contributing to Lake Abaya. On the Gelana River there are plans for a net irrigation command area of 5,356 ha. The command area currently being considered for the River Gidabo has a net area of 9,215 ha, and there are plans for a rehabilitation scheme for existing state farms on the Lower Bilate River providing a net area of 7,715 ha.

2.4.2 River Flow Regime

There are a large number of river gauging stations within the Genal – Dawa and the Rift Valley Lakes basins. Some of them are operational but many of the stations have no reliable data and/or data at all. In the area of the Hagere Maryam sheet there are 4 registered gauging stations (see Fig. 2.13).There is also a water level fluctuation station located on Lake Chamo. Other river gauging stations are within the neighboring sheets and data from these stations were also used for the assessment of surface as well as baseflow values and for comparing and correcting data from the Hager Maryam area. The basic data of the river stations from the sheet are summarized in Tab. 2.6.

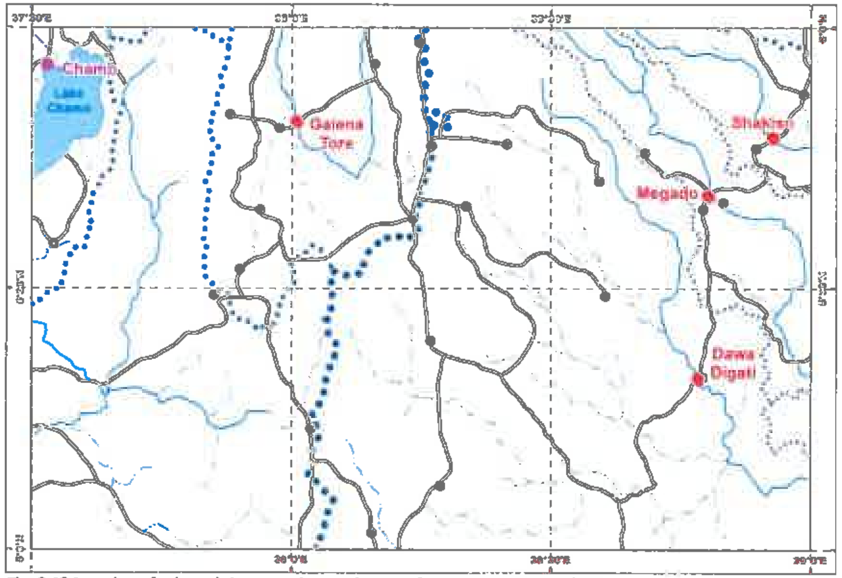


Fig. 2.13 Location of selected river gauging stations on the Hagere Maryam sheet

Tab. 2.6 Data on the river gauging stations

Map ID	Station No	River / Lake	Station	UTM_X	UTM_Y	Elevation	Area km²	Basin Sub
1	RG6	Dawa	Digati	476732	588650	1150	2,376	Dawa
2	RG5	Mormo ra	Megado	478296	627225	1660	1,321	Dawa
3	RG4	Awata	Shakiso	492914	639269	1640	1,624	Dawa
4	82035	Gelana	Tore	391079	642945	1297	1,523	Gelana
L4	L4	Chamo Lake	Arba Minch	337274	655622	1116	NA	

Records from all of the stations reflect the fact that the river discharge is directly proportional to the intensity of rainfall within the basin. There is a high discharge fluctuation between the wet and dry seasons of the year. The rivers usually show two high flow periods in May and September to October (see Fig. 2.21 and 2.29 for the Mormora and Gelana rivers). The period from December to April is characterized by low flow when most of the smaller rivers are completely without water. Runoff data are summarized in Tab. 2.7.

The data shows that specific runoff is higher (approximately 10 l/s/km²) in the eastern part of the area, which receives more rainfall in the Highlands along surface water divide between the Wabe Shebelle and Genale-Dawa catchments. The rivers on the floor of the rift valley receive less precipitation, particularly in the south. The lowest precipitation is in the southern part of the sheet and is reflected by the low specific runoff of the Dawa River. Based on the data discussed above the ***adopted value of the specific runoff for the Hagere Maryam sheet is 10. l/s/km² for the north eastern highland and 2.5 l/s/km² for the rift floor (including escarpment areas which are relatively small on the sheet) and practically the whole eastern part of the sheet and a value of 1 l/s/km² was adopted for the southeastern part of the sheet resulting in a value of 4 l/s/km2 for the whole Hagere Maryam sheet.***

Tab. 2.7 Runoff data

Map ID	River	Station	Mean flow [m³/s]	Annual flow [mm]	Annual precip. [mm]	Area [km²]	Specific runoff [l/s.km²]	Dominant Aquifer
1	Dawa	Digati	2.54	83.7	830	2375.7	1.07	Volcanic
2	Mormora	Megado	13.1	300.7	1,050	1375	9.5	Basement
3	Awata	Shakiso	16.56	324.4	1200	1611	10.3	Basement
4	Gelena	Tore	4.44	92.0	1181	1523	2.9	Alluvium/floor
	Upper Gelana	Yirga Chefe	0.25	83.0	1637	285	0.9	Volcanic/floor

The measured discharge of the Dawa at the Digati river gauge in the period from 1999 to 2005 is shown in Fig. 2.14. The figure shows that the flow is relatively regular (1.45 to 3.56 m³/s); however, the total value of annual flow and particularly maximal monthly flow can vary substantially from year to year. The river was not flowing in May 2001 and 2004 and the highest daily discharge of 60.13 m³/s (6th of May, 2005) was recorded at the river gauge. The calculated mean annual flow of 2.5 m³/s for the Digati station represents flow generated mainly in the Eastern Highlands where the Dawa River rises (originates) and which receives the highest precipitation within the basin. Annual variability of the mean annual flow of the Dawa River at the Digati river gauge is shown in Fig. 2.15. Annual variability of average, average of minimal monthly and minimum of minimal monthly discharge are shown in Fig. 2.16 and Fig. 2.17.

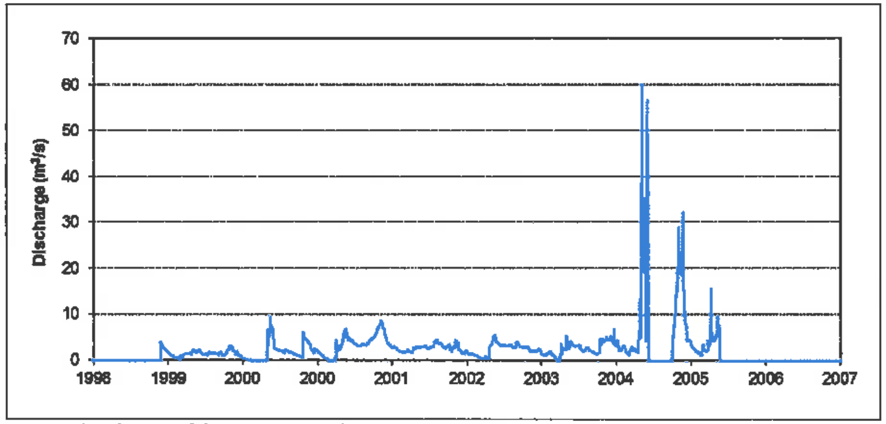


Fig. 2.14 Flow diagram of the Dawa River at the Digati river gauge

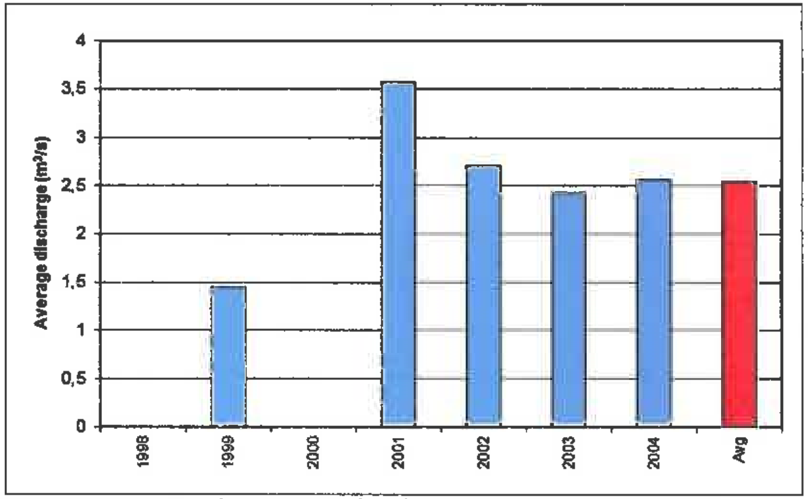


Fig. 2.15 Annual variability of the mean annual flow of the Dawa River at the Digati river gauge

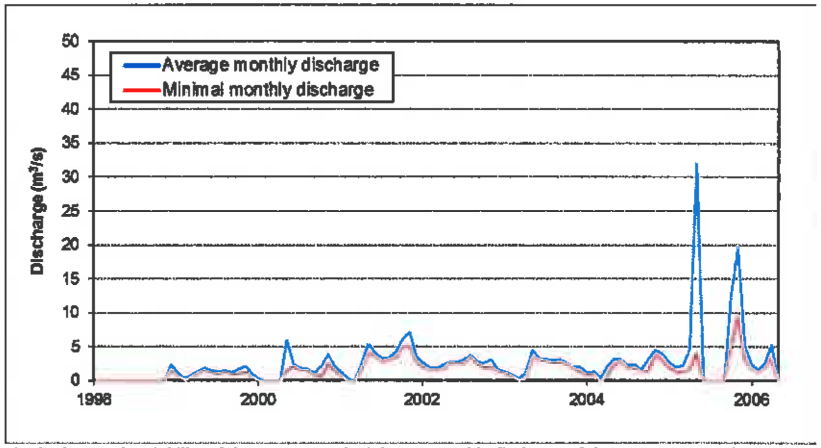


Fig. 2.16 Annual variability of the average and minimum monthly discharge of the Dawa River at the Digati river gauge

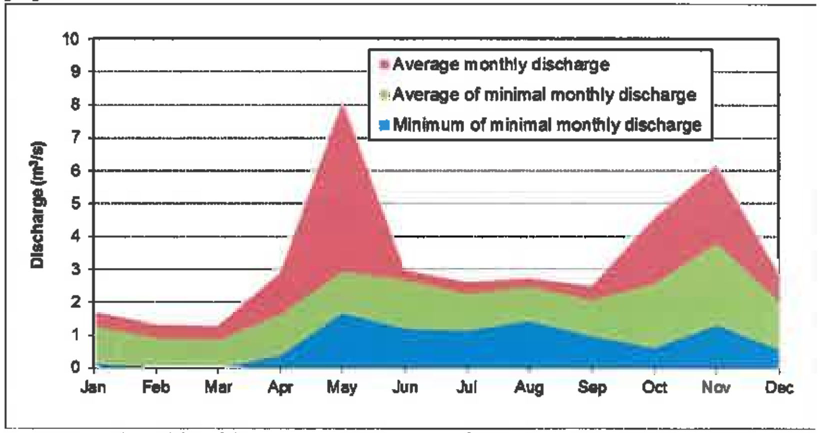


Fig. 2.17 Annual variability of the average monthly, average of minimal monthly and minimum of the minimum monthly discharge values of the Dawa River at the Digati river gauge

The measured discharge of the Mormora River at the Megado river gauge in the period from 1982 to 2005 is shown in Fig. 2.18. The figure shows that the flow is relatively regular; however, the total value of annual flow and particularly maximal monthly flow can vary substantially from year to year (from 6.65 to 26.74 m^3/s). The river was not flowing in April 1998 and the highest daily discharge of 176 m^3/s (21st of October, 1989) was recorded at the river gauge. The calculated mean annual flow of 13.1 m^3/s for the Megado station represents flow generated mainly in the Eastern Highlands where the Mormora River rises (originates) and which receives the highest precipitation within the basin. Annual variability of the mean flow of the Mormora River at the Megado river gauge is shown in Fig. 2.19. Annual variability of the average, average of minimal monthly and minimum of minimal monthly discharge is shown in Fig.2.20 and Fig. 2.21

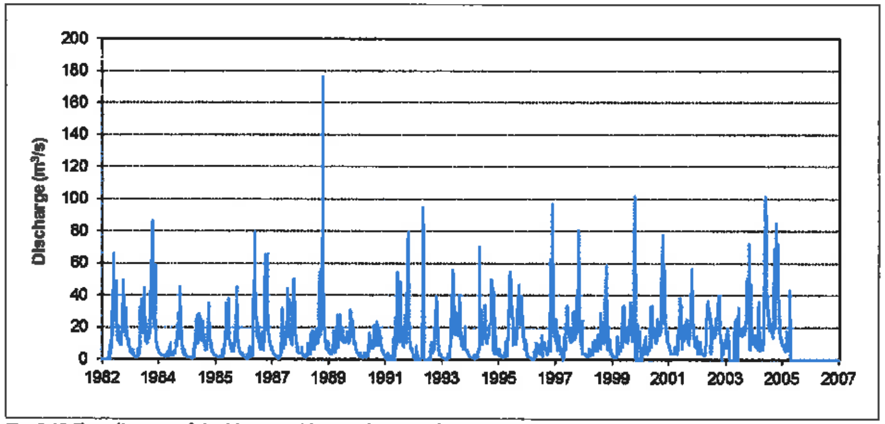


Fig. 2.18 Flow diagram of the Mormora River at the Megado river gauge

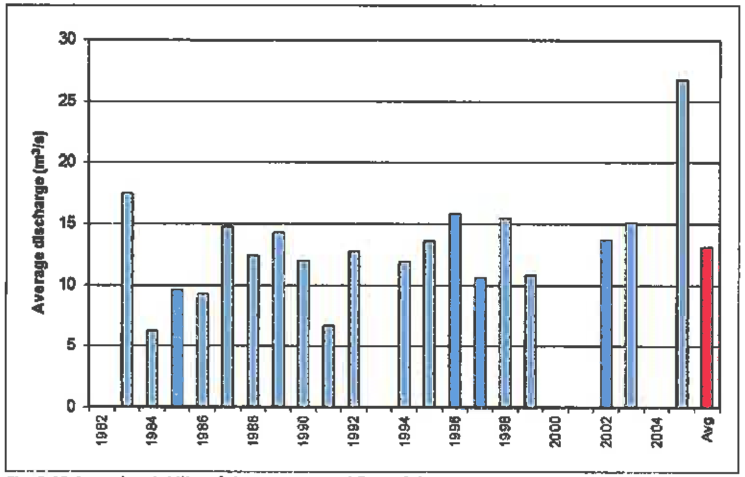


Fig. 2.19 Annual variability of the mean annual flow of the Mormora River at the Megado river gauge

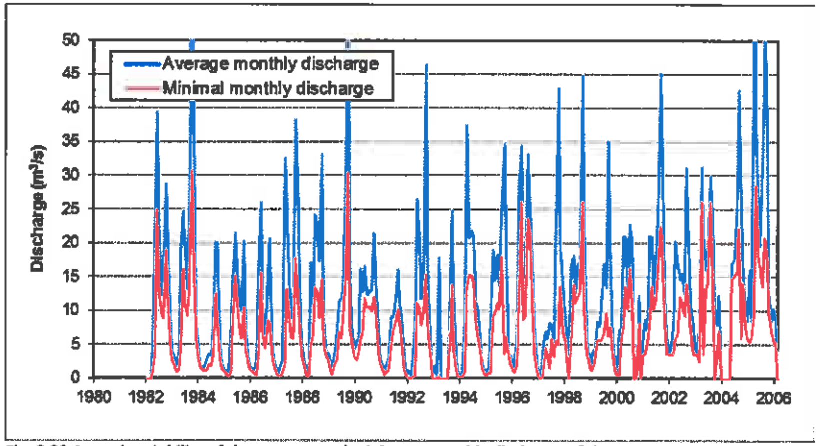


Fig. 2.20 Annual variability of the average and minimum monthly discharge of the Mormora River at the Megado river gauge

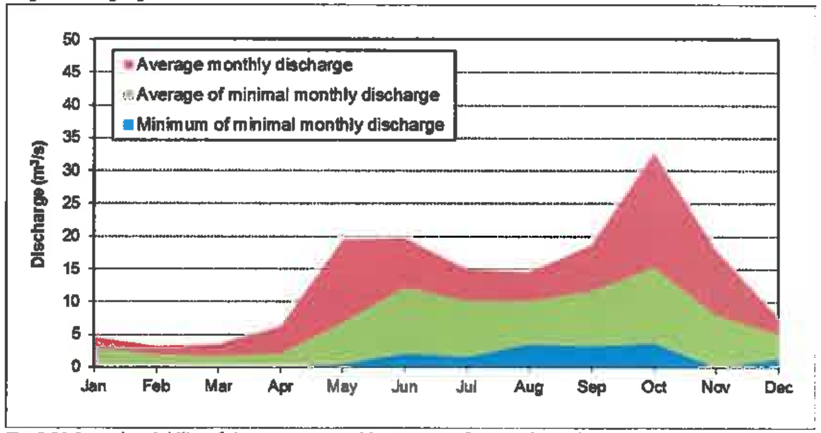


Fig. 2.21 Annual variability of the average monthly, average of minimal monthly and minimum of minimum monthly discharge values of the Mormora River at the Megado river gauge

The measured discharge of the Awata River at the Shakiso river gauge in the period from 1983 to 2005 is shown in Fig. 2.22. The figure shows that the flow is relatively regular; however, the total value of annual flow and particularly maximal monthly flow can vary substantially from year to year (from 10.8 to 23.2 m^3/s). The river was not flowing in April of 1992 and the highest daily discharge of 169.6 m^3/s (22nd of October, 1989) was recorded at the river gauge. The calculated mean annual flow of 16.56 m^3/s for the Shakiso station represents flow generated mainly in the Eastern Highlands where the Awata River rises (originates) and which receives the highest precipitation within the basin. Annual variability of the mean flow of the Awata River at the Shakiso river gauge is shown in Fig. 2.23. Annual variability of the average, average of minimal monthly and minimum of minimal monthly discharge is shown in Fig. 2.24 and Fig. 2.25

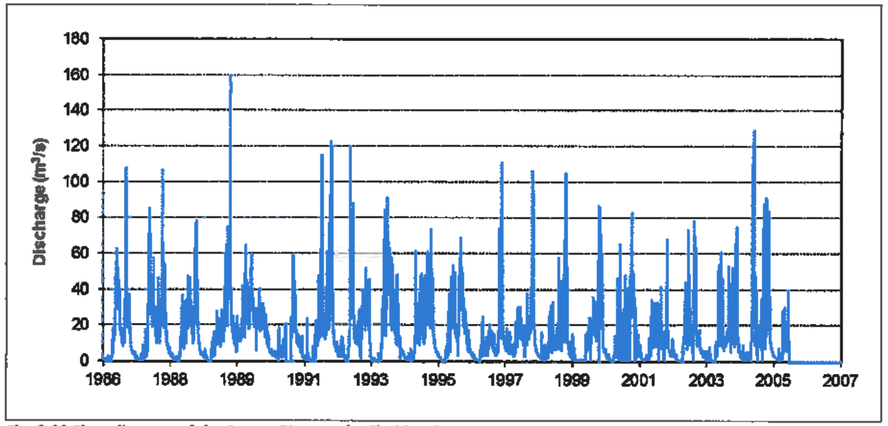


Fig. 2.22 Flow diagram of the Awata River at the Shakiso river gauge

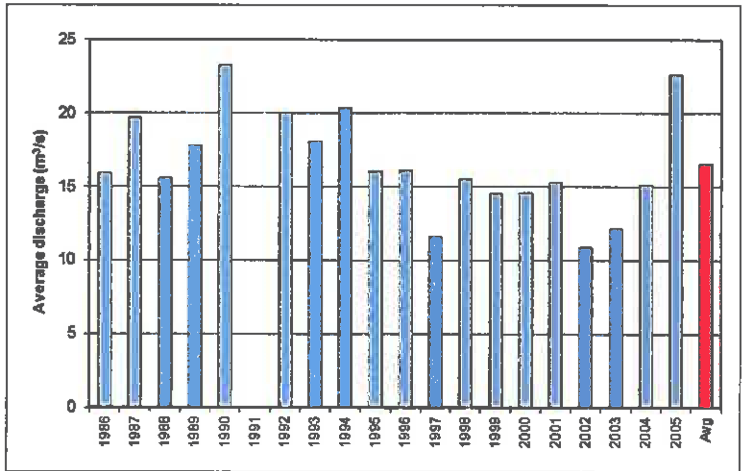


Fig. 2.23 Annual variability of the mean annual flow of the Awata River at the Shakiso river gauge

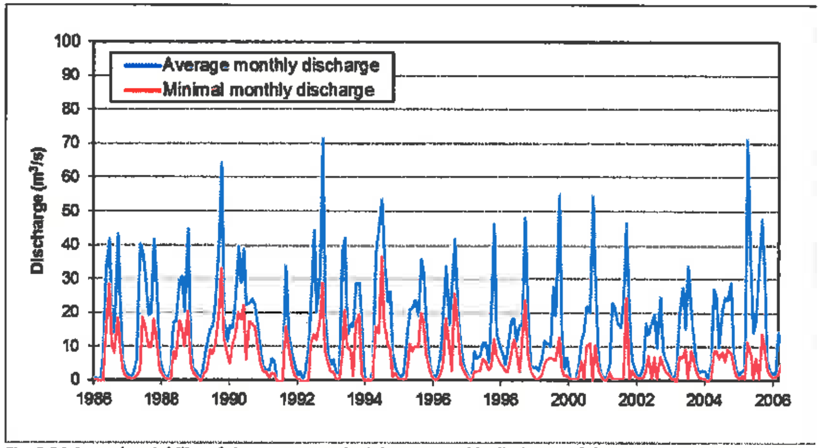


Fig. 2.24 Annual variability of the average and minimum monthly discharge of the Awata River at the Shakiso river gauge

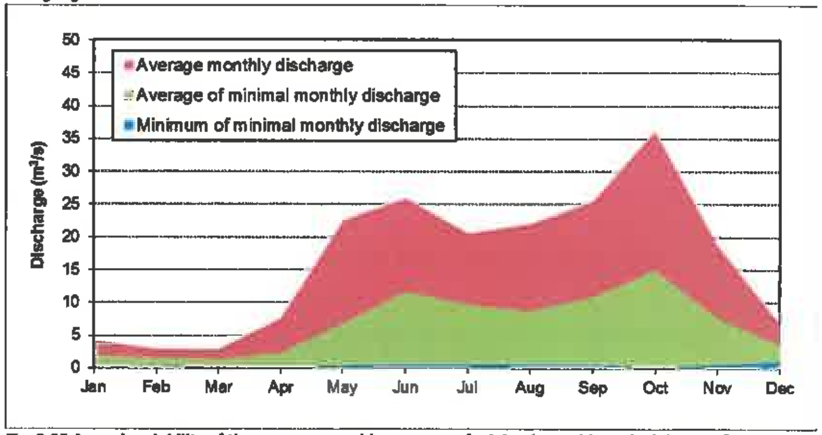


Fig. 2.25 Annual variability of the average monthly, average of minimal monthly and minimum of minimum monthly discharge values of the Awata River at the Shakiso river gauge

The measured discharge of the Galena River at the Tore river gauge in the period from 1990 to 2005 is shown in Fig. 2.26. The figure shows that the flow is relatively regular; however, the total value of annual flow and particularly maximal monthly flow can vary substantially from year to year (from 2.36 to 7.4 m^3/s). The lowest daily discharge of 0.133 m^3/s (21st of March, 1994) and the highest daily discharge of 18.04 m^3/s (15th of May, 1993) were recorded at the river gauge. The calculated mean annual flow of 4.44 m^3/s for the Tore station represents flow generated mainly in the southern part of the rift floor and adjacent eastern escarpment where the Galena River rises (originates) and which receives relatively good precipitation within the basin. Annual variability of the mean annual flow of the Galena River at the Tore river gauge is shown in Fig. 2.27. Annual variability of the average, average of minimal monthly and minimum of minimal monthly discharge is shown in Fig. 2.28 and Fig. 2.29.

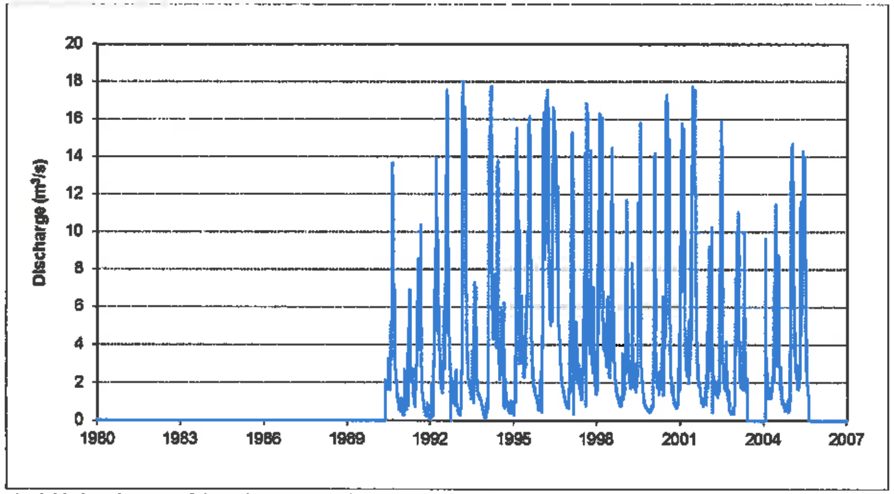


Fig. 2.26 Flow diagram of the Gelana River at the Tore river gauge

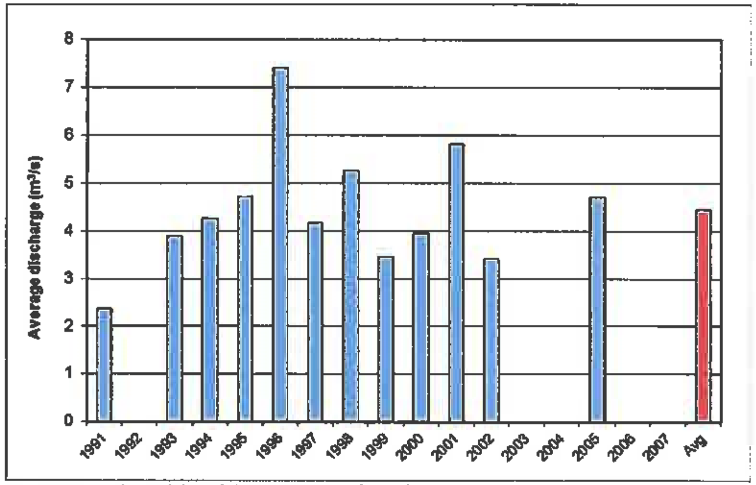


Fig. 2.27 Annual variability of the mean annual flow of the Gelana River at the Tore river gauge

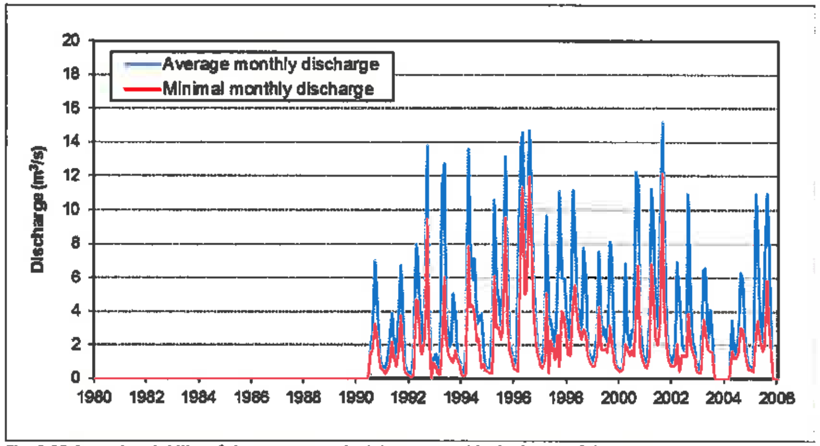


Fig. 2.28 Annual variability of the average and minimum monthly discharge of the Gelana River at the Tore river gauge

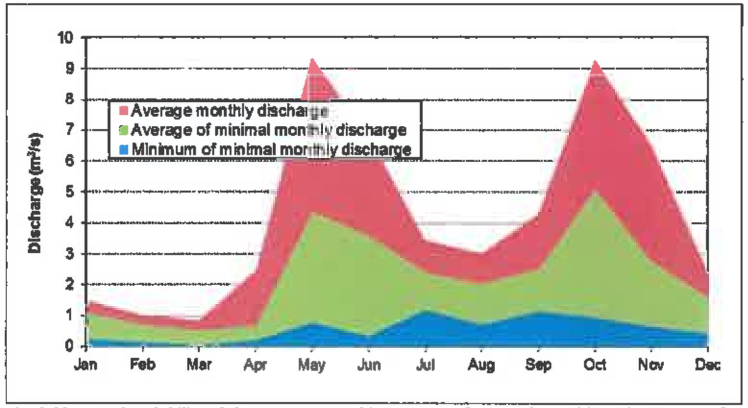


Fig. 2.29 Annual variability of the average monthly, average of minimal monthly and minimum of minimum monthly discharge values of the Gelana River at the Tore river gauge

2.4.3 Baseflow

Baseflow represents one of the most important types of information on groundwater resources in the Hager Maryam map sheet area. The methods were analyzed by Bogena et al. (2005) and it was found by means of a correlation analysis that the appropriate baseflow values can be determined on the basis of daily river discharge data. Hydrograph separation and the Kille method were used for the baseflow separation. Results of baseflow assessed by the Kille method are shown in Fig. 2.30 and data in Tab. 2.8 together with baseflow data assessed by the hydrograph separation method. Separation of hydrograph and results of separation are shown in Fig. 2.31. A comparison of the assessment of baseflow using the Kille method and hydrograph separation is shown in Tab. 2.8 show very small differences between the assessment of baseflow using the Kille method and hydrograph separation.

The assessment of specific runoff based on data from flow measurements and calculated specific runoff in the gauging stations and the appropriate area of the pertinent river basin within the Hager Maryam map sheet area considering the elevation and rock composition of the area are shown in Tab. 2.8.

Tab. 2.8 A comparison of the assessment of baseflow using the Kille method and hydrograph separation

Map ID	River	Station	Area [km²]	Specific runoff [l/s.km²]	Kille method [m³/s]	Hydrograph separation [m³/s]	Specific baseflow [l/s.km²]	Dominant Aquifer
1	Dawa	Digati	2375.7	1.07	1.86	2.21	0.78/0.93	volc/basement/ highland
2	Mormora	Megado	1375	9.5	5.5	8.75	4.0/6.3	Basement
3	Awata	Shakiso	1611	10.3	3.5	2.84	2.17/1.76	Basement
4	Gelena	Tore	1523	2.9	1.63	2.34	1.9/1.54	Allu/rift
	Upper Gelana	Yirga Chefe	285	0.9	0.22	0.23	0.77/0.81	volc/rift

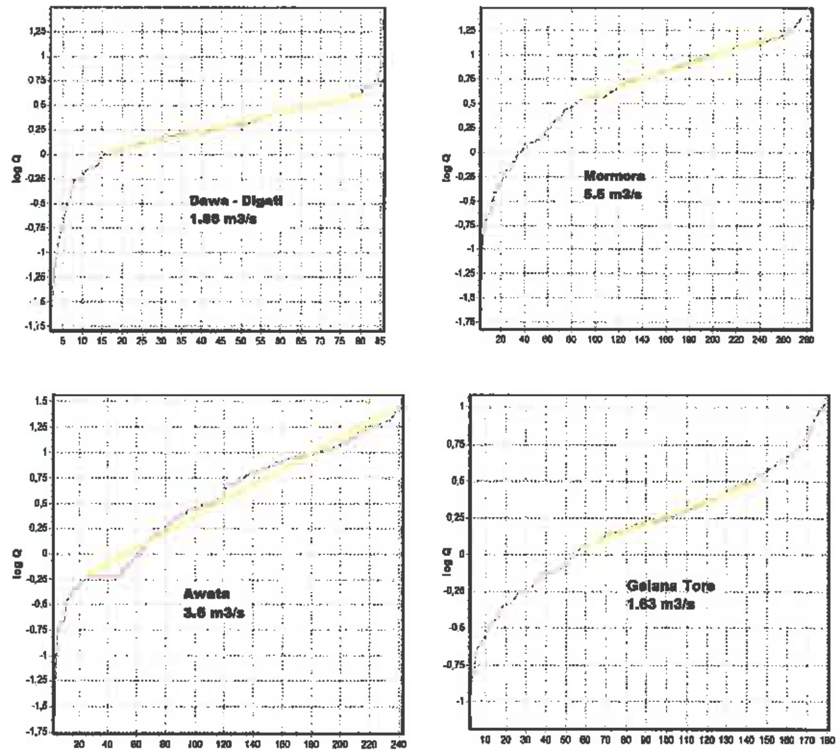
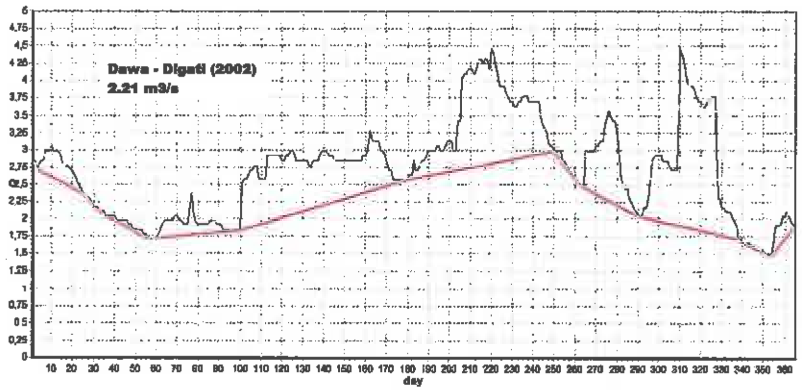
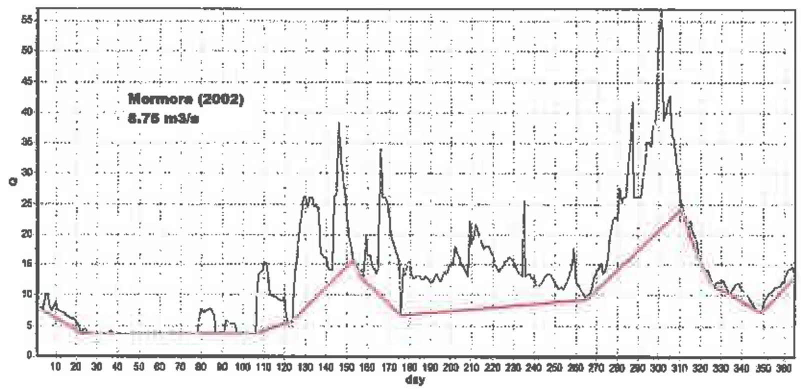
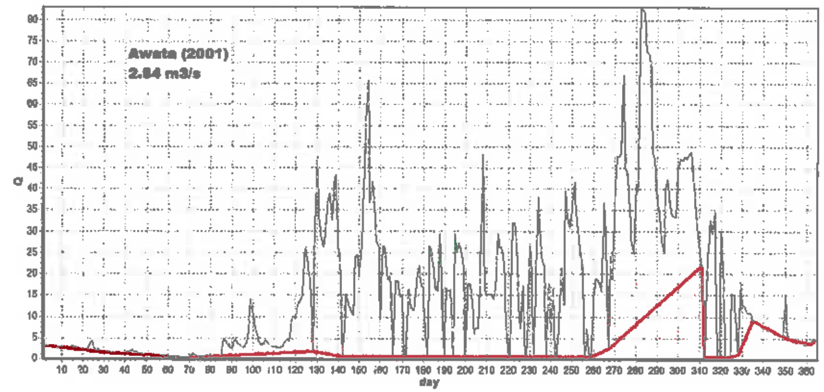


Fig. 2.34 Kille baseflow separation







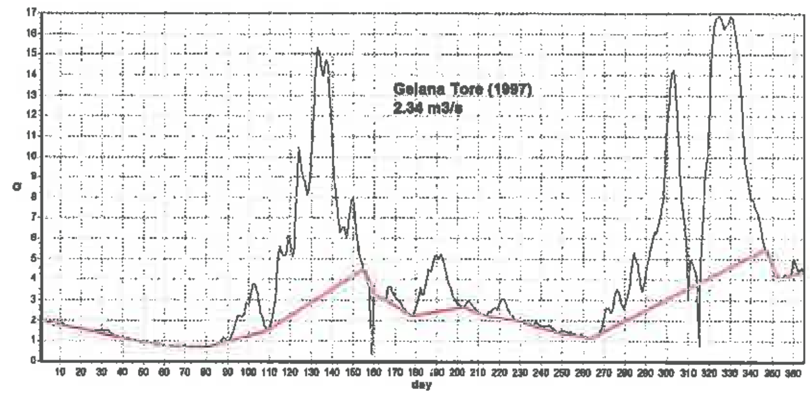


Fig. 2.35 Hydrograph of baseflow separation (Part 1 and 2)

The assessment of specific baseflow is based on data from hydrograph separation and using the Kille method. ***The specific baseflow is assessed for the Hager Maryam sheet based on data from the river gauges shown in Tab. 2.8, and is 3.5 l/s.km² for the Northeastern Highlands and 1.6 for the Rift Floor, 0.9 l/s.km² for the Southeastern Lowlands. The adopted value of the specific baseflow is 1.9l/s.km² for the whole Hagere Maryam sheet.***

2.4.4 Sediment load

Sediment yields from river catchments usually show a negative correlation between river flow and sediment concentrations. Such a negative correlation, where sediment concentrations diminish with increasing flow, is definitely discernible for the Gelana at the Tore station 82035 (see Tab. 2.9) according to Halcrow (2008). This negative correlation is in place of the expected positive correlation between river flow and sediment concentrations. Apparently, the early rains that signal the end of a long dry season are effective in causing sediment discharge, but after vegetation is reestablished in the catchments the sediment discharge is very much reduced. Measurements of sediment load for the Gelana River at Tore the gauging station show that the average sediment concentration over the sampling period was 582 mg/l. The mean annual discharge is 156 m^3/sec. An estimate of annual sediment discharge was made by combining these values to give an annual amount of 0.07 million tons. This is equivalent to an average of 46 t/km^2/year over a catchment of 1,523 km^2. A study by WWDSE (2007) estimated similar values of sediment yields from the Gelana River 40 t/km^2/year and JICA estimated 19 t/km^2/year and 70 t/km^2/year for the Gidabo River.

Tab. 2.9. Sediment load in the Gelana River at the Tore gauging station

Sampling date	Q m3/s	Sediment in mg/l
2-Sep-89	2.80	81.78
2-Sep-89	2.77	127.54
7-Jun-90	5.48	166.70
7-Jun-90	6.48	132.73
8-Jun-90	4.59	61.69
23-Aug-90	2.72	108.85
23-Aug-90	2.86	145.63
31-Jul-90	2.47	47.10
31-Jul-90	2.60	42.13
27-Jun-95	3.40	61.60
17-Mar-96	1.59	33.16
29-Dec-96	2.07	25.83
1-Nov-03	1.99	22.72
26-Aug-04	1.26	28.14
27-Aug-04	1.39	25.31

Rivers flowing from the western escarpment contribute less water but they bring a large amount of sediment, particularly to Lake Abaya. The catchments of the Abaya lakes require soil and water conservation measures such as reforestation, construction of check dams across gullies, and terracing etc. This is an affective and lasting solution to mitigate the problem of the rise in lake levels both in Lake Abaya as well as Lake Awassa.

2.5 Water Balance

The total surface water resource of the RVLB is estimated by Halcrow (2008) to be just over 5,300 m^3/year, calculated from the total annual average river flow into the lake systems under 'natural' conditions i.e. without human abstractions. Tab 2.10 shows the volume of water flowing to Lake Camo and nearby lakes. The total volume of the water in the system amounts to a per capita water availability of 597 m^3, which is well below the threshold of 'water scarcity' of 1,000 m^3/capita/annum. This will decline to 232 m^3/capita/annum by the end of 2034 because of population growth – a situation of extreme water scarcity.

2.10 Surface inflow into the selected lakes

Lake	Total surface water resources [Mm^3]	Part in the Rift Valle Lake basin
Abaya	2,512	47
Chamo	506	10
Chew Bahir	598	11

Gelana, Gidabo and Bilate river basins were studied from the point of view of irrigation in2007. The water resource analysis by Halcrow (2008) shows about 18,350 ha of new irrigation development may be 'allowable' from a water resources perspective in the Awasa-Abaya-Chamo basin. For Lake Awasa, the sustainable limit is estimated to be about 500 ha. When 'allowable' irrigation is phased in with other water demands the surface water resources are further depleted to a maximum of 5,057 Mm3/year, a decrease of 2.4 %. Also, as the RVLB lakes are already either in a state of decline or in a very precarious balance, caution must be used when undertaking any future development. The amount of evaporation from Lake Chamo and nearby lakes according to JICA (2012) is shown in Tab. 2.11.

Tab. 2. 11 Evaporation from selected lakes

Lake	Area km^2	Pan [mm]	Evaporation [Mm^3]
Abaya	1,084.8	1850	2,013.1
Chamo	315.3	1847	582.4
Chew Bahir	762.8	1395	1,064.1

The following formula was used by JICA to find the amount of groundwater resource recharge.
GWR = Σ(Ei_net x BFIi)
where: GWR = amont of groundwater recharge
Ei_net = net evaporation from each major lake
BFIi = base flow index for each major lake basin

It was assumed that 2.5% of the groundwater is used for consumption and the amount is added to the result of groundwater recharge amounts calculated in the previous section. The final results are compiled in Tab. 2. 12.

Tab. 2.12 Groundwater recharge into selected lakes

Lake	E_{net}	BFI	GWR	Others	Total
Abaya	585.1	0.62	362	14.6	377.4
Chamo	282.2	0.68	191.9	7.1	199.0
Chew Bahir	412.7	0.74	305.4	10.3	315.7

2.6 Drought and Climate Changes

Drought

The whole Ethiopian territory is often affected by reoccurring droughts causing famine. The impact of drought is severe both in the arid lowlands as well as the highlands of Ethiopia. The existence of drought and desertification is well known from geological and archeological evidence as well as from historical documents and on-going measurements. It is a matter of fact that the center of the Ethiopian civilization was shifted about 1,000 km from Axum in the dry north to Addis Ababa located in the more humid center of the current (modern) Ethiopia over the last 2,000 years. The northern and eastern parts of the country appeared to be highly vulnerable to reoccurring drought and famine.

Despite to the fact that Southwestern Ethiopia is not considered as a drought prone region (see Fig. 2.36) the area can be classified as an areas of high variability of rainfall and considered these areas as being drought prone.

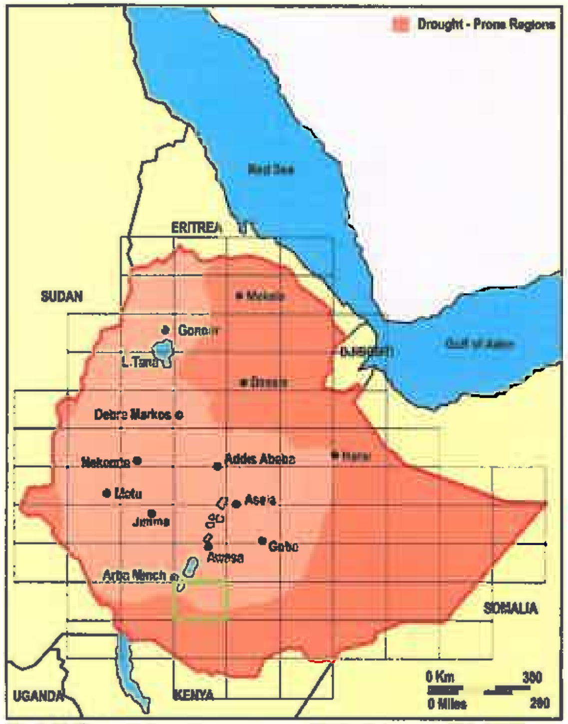


Fig. 2.36 The most drought prone areas of Ethiopia (source: RRC, 1985)

Climate Change

Current climate change poses a significant challenge to Ethiopia by affecting food security, water and energy supply, poverty reduction and sustainable development efforts, as well as by causing natural resource degradation and natural disasters. For example the impacts of past droughts such as those of 1972/73, 1984 and 2002/03 are still fresh in the memories of many Ethiopians. Floods in 2006 caused substantial loss to human life and property in many parts of the country. In this context, planning and implementing climate change adaptation polices, measures and strategies in Ethiopia will be necessary.

The agricultural sector is the most vulnerable to climate variability and change. In terms of livelihoods, small scale rain-fed subsistence farmers and pastoralists are the most vulnerable.

The major adverse impacts of climate variability in Ethiopia include:

- Food insecurity arising from the occurrence of droughts and floods.
- Outbreaks of diseases such as malaria, dengue fever, water borne diseases (such as cholera, dysentery) associated with floods and respiratory diseases associated with droughts.
- Heavy rainfalls which tend to accelerate land degradation.
- Damage to communication, road and other infrastructure by floods.

Major floods occurred in different parts of the country in 1988, 1993, 1994, 1995, 1996 and 2006. All of them caused loss of life and property. The DPPA estimate is about 199,000 critically affected people due to the flood in the country. It is known that 2006 flooding caused the following disasters (NMA, 2006) and more than 364 fatalities in Southern Omo and more than 6,000 (updated to 8,350 after August 15) people were displaced, where around 14 villages were flooded. More than 900 livestock drowned over the South Omo area. In addition, 2,700 heads of cattle and 760 traditional silos were washed away (WFP).

3. Geological Settings

The study area of the Hagere Maryam sheet covers a large part of the eastern and southern part of the Main Ethiopian Rift Valley. The map sheet is covered mainly by Tertiary volcanic flows, some tuffs and by basement rocks, and to a lesser extent by Quaternary alluvial and other superficial deposits.

3.1 Previous Work

Concise and General Geology of Ethiopia was written by Mohr (1975) and was later modified by Kazmin (1972). Merla et al. (1979) mapped Ethiopia as a whole, but the map is rather generalized. The whole descriptive geology of Ethiopia was compiled by Mengesha et.al. (1996).

Jelenc (1966) described the geology of the eastern part of the map area and the exposures along the Hagere Maryam-Yabello road. With the exception of the northwestern part, the Hagere Maryam map sheet was mapped by Hunting Geology and Geophysics Limited (1969) during a photogeological survey. Mohr (1962) briefly discussed the geology of parts of the Hagere Maryam area in his book "Geology of Ethiopia". Kazmin (1972) distinguished three complexes in the Precambrian rocks of the country: the Lower, the Middle and the Upper Complexes.

Systematic regional mapping and mineral exploration work was conducted by the Adola Gold Exploration Project of the Ethiopian Mineral Resources Development Corporation in the eastern part of the map area from 1979 to 1981. Further work was carried out in the eastern part of the Hagere Maryam map sheet by the Training for Mineral Exploration Project of the Institute of Geological Surveys.

The following description of the stratigraphy, lithology and geological development is based on Memoir No. 8 by Woldegbriel Genzebu, Nasir Hassen and Tesfaye Yemane (1994).

3.2 Stratigraphy and Lithology of the Main Geological Units

The Hagere Maryam map sheet is underlain by Precambrian basement rocks, Cenozoic volcanic rocks and Quaternary cover. Extensively exposed high grade Precambrian gneisses exhibit early granitization and migmatization of varying intensities. They are generally metamorphosed to middle to upper amphibolite facies, with pockets of granulitic rocks in the west. Structures developed in high grade gneisses are believed to correspond to the Mozambique orogeny.

The narrow N-S trending Adola low grade belt, mainly consisting of strongly deformed but weakly metamorphosed volcanic and sedimentary rocks, occurs in the eastern part of the map sheet. These rocks are thought to be younger than the surrounding high grade gneisses and may be correlated with the Upper Proterozoic rocks of the Arabian-Nubian shield. Various igneous plutons of Precambrian age are also exposed in the area of the map sheet.

Cenozoic volcanic rocks are widespread in the northern and western parts of the map sheet. They are mainly basaltic flows with lesser felsic rocks. The volcanic rocks are subdivided into pre-rift, rift and post-rift volcanic rocks.

A general stratigraphy scheme of the area with the age and generalized lithological description of the formations is shown in Tab. 3.1. The thickness of individual formations is not known.

Quaternary eluvial and alluvial sediments and lacustrine deposits are well developed in the western part of the area, where Cenozoic faulting and rifting were significant and developed the Camo, Segen and Gelana valleys.

Stratigraphy		Symbol	Lithology
Quaternary	Holocene	Q, Qa, Qe	Alluvium, eluvium and lacustrine sediments
	Pleistocene	Qc, Qd	Basaltic cinder cones and basalt
		Qb	Basalt flows with minor trachytic tuff
		Qs, Qn	Basaltic lava cones and vesicular basalt
Tertiary	Miocene	Ngs, Ngu, Ngb, Ngm	Rhyolite plugs and flows, Upper basalt, tuff and lapilli, Middle basalt
	Eocene / Oligocene	Pgs, Pgl	Rhyolitic ignimbrite with minor tuff, Lower basalt
Precambrian	Proterozoic?	Low grade Adola Group Pmsc, Ppss, Pcas	Metasediments, phylite, amphibolite, chlorite schists
		High grade Pmbg, Pmqg, Pqfg, Pbfg, Pmcg, Pfbg, Pfmz, Pbag, Pmqg, Phqg, Pmfg, Phbg, Pdfg	Various types of gneiss, metaquartzite, and granulite
		Intrusive rocks Phhg, Pbgt, Pmgb, Psva, Pspt, Phbt, Pumf, Ptts, Pmdt, Pqsy, Phmg, Pmbg, Pbqg, Pgbg, Pghg	Granite, metagabro, amphibolite, serpentine, hornblendite, ultramafic rocks, talc, diorite, syenite, metagranite, plagioclase gneiss

Intrusive rocks

Gneissose hornblende-biotite metagranite (Pghg) occupy a large area west of Hagere Maryam town. The general trend of the rock body is north-south, although exposures of the granite are discontinuous and patchy. Foliated biotite metagranite (Pgbg) this unit is exposed in the southeast corner of the map area, forming ridges arranged en echelon that rise majestically above the surrounding area. Hornblende-biotite-quartz-plagioclase gneiss (Pbqg) occurs in the east-central part of the map sheet, occupying a large area. Biotite metagranite (Pmbg) includes a pluton consisting of three oval north-south elongated ridges south of Finchaa village in the south-central part of the map sheet. Hornblende-biotite metagranite (Phmg) outcrops as a crescent shaped body making up of small granitic ridges. Quartz syenite (Pqsy) forms two oval quartz syenite plutons, intrusive into the adjacent gneisses, and are present in the southwestern part of the map sheet. Metaquartz diorite (Pmdt) consists of two large plutons and associated smaller bodies up to 1.5 km across, all found in the eastern part of the map sheet. Talc-tremolite schist (Ptts) is mainly exposed in the eastern part of the map sheet, forming prominent ridges along two meridional belts each 750 m wide on average. Undifferentiated metaultramafics (Pumf) consist of various minor ultramafic bodies which are grouped in this unit. They include highly weathered and altered undifferentiated rocks as well as metapyroxenites and birbirites. Hornblendite (Phbt) occurs as small bodies of hornblendite northeast of Galeba village. Serpentinite

(Pspt) is exposed as small patches, often hill forming, in the eastern part of the map area. Subvolcanic amphibolite (Psva) occurs as a chain of elongate bodies mainly restricted to the western edge of the Adola low grade belt, and extending N-S for about 50 km. Metagabbro (Pmgb) forms weakly foliated gabbroic plutons found southwest of Shakiso town, mainly lying in the Adola low grade belt. They occur as a cluster of bodies, which are concordant to the country rock. Biotite granite (Pbgt) occurs mostly in the eastern part of the map sheet, the largest body; however, occurring in the southwest. Hypersthene-hornblende granite (Phhg) is comprised of intrusive bodies well exposed on the Berguda ridges, in the Chebi Arboro area and in the western part of the map sheet north of the Segen River.

Stratified high grade metamorphic rocks
High grade metamorphic rocks are exposed in the majority of the map area, often forming the submeridionally trending outcrops (ridges) accompanied by domes (Bari Dome).

Hornblende-hypersthene-auartz-diopside-labradoritegranulite (Pdfg) is medium to coarse grained, mesocratic to melanocratic, weakly to well foliated. The hornblende-biotite-quartz-feldspar gneiss intercalated with biotite-quartz-feldspar gneiss (Phbg) unit underlies the western part of the map sheet, extending north-south along the Amaro horst. The magnetite-quartz-feldspar gnneiss (Pmfg) unit occurs in two large areas covering over 1,500 km^2. In the Soyoma area this unit is generally ridge forming. Hornblende-quartz-feldspar gneiss (Phqg) is one of the main components of the elliptical Bari Dome. Biotite-hornblende-quartz-feldspar gneiss (Pmqg) occurs in limited areas at the Berka and Bari areas. The interlayered quartz-feldspar gneiss and hornblende gneiss (Pbag) unit also occur in the Bari dome. The metaquartzite (Pmqz) unit occurs as narrow, elongate ridges trending NNW. Oliaoclase-hornblende-biotite-quartz gneiss, calc-silicate, biotite and biotite-hornblende gneisses (Pfbg) are found exposed over a limited area east of Finchaa village. Augen biotite-quartz-feldspar gneiss, strongly granitized, (Pmcg) forms a large north-south running belt that widens southwards to the east of Finchaa. The biotite-quartz-feldspar gneiss, strongly migmatized, (Pbfg) unit is exposed in the northeastern part of the map sheet, covering an area of about 50 km^2. Oligoclase-quartz-microcline gneiss (Pqfg) is widely distributed in the eastern part of the map area. Biotite-quartz-oligoclase gneiss medium-grained amphibolite and minor oligoclase-quartz-microcline gneiss (Pfqg) are widely distributed in the eastern part of the map area, this unit was termed the Aflata Formation prior to this study. Biotite-microcline-quartz gneiss medium grained amphibolite, garnet-staurolite gneiss, graphitic schist and marble (Pbmg) are exposed in the eastern part of the map sheet and the unit was termed the Kenticha Formation. The dominant rock type, biotite-microcline-quartz gneiss, is a medium-grained, leucocratic rock with a mostly schistose but in places banded fabric. It is generally hard and ridge forming.

Stratified low grade metamorphic rocks
Low grade metavolcanic and metasedimentary rocks are exposed in the eastern part of the map area, forming the submeridionally trending Adola low grade belt, 5-10 km wide and over 100 km long.

Fine to medium–grained amphibolite and plagioclase-chlorite-actinolite schist (Pcas) are exposed on the outer limbs of the Megado syncline. Phyllite metasiltstone and metasandstone (Ppss) make up the core of the Adola low grade belt. Primary sedimentary structures such as current ripple marks, graded bedding and slump structures are well preserved. Metasandstone and metaconglomerate (Pmsc) are closely associated, mostly being intercalated and at places showing a gradational relationship. These rocks are of restricted occurrence, being found mainly in the central part of the Adola low grade belt and often forming ridges. Cross-bedding and graded bedding are also well exhibited. Based on the displayed primary sedimentary structures, the deltaic deposition of this rock type is suggested.

Volcanic rocks
The Tertiary and Quaternary volcanic rocks are related to the development of the Ethiopian rift system. These volcanic rocks occupy about one third of the map sheet and occur in both topographically high and low areas. The elevated and rugged terrain of the Amaro horst, and Mounts Shole and Getra are localities where the volcanic rocks are found at high altitudes.

The Tertiary volcanic rocks in the region are underlain at places by thin residual red sandstone varying thickness from 4 to 40 m, but outcrops are so scattered that they are not possible to be shown in maps of this scale. Volcanic rocks are subdivided into three groups on the basis of their relationship to the Cenozoic rifting.

Pre-rift volcanic succession consisting of six units

Arba Minch felsic tuff (Pga) is the oldest Tertiary volcanic unit found in the surveyed area. It is too small to be shown on a map of this scale. The rock is reddish brown, fine grained, highly altered and shows cataclastic textures.

Lower Basalt (Pgl) is the most widespread volcanic unit in the map sheet, occurring mainly in its northern and western parts. It directly overlies the Precambrian basement. The Lower Basalt is characterized by thick, extensive lava flows that locally show columnar jointing and weathering. It is thickest in the northern part of the Amaro horst and on Mount Getra, where sections 600 to 700 m thick are present. On the western flanks of Mount Shole almost 100 m of this unit is observed. The flows are generally separated by baked surfaces and can be distinguished by their degree of weathering.

Shole Ignimbrite (Pgs) is exposed on the Amaro horst, east of Tore, on Mounts Shole (131 m thick) and Rudo, and around Gedeb and Gerba and it separates the Lower Basalt (Pgl) from the Middle Basalt (Ngm). The ignimbrite is well to poorly welded and locally shows columnar jointing. Occasionally pumice fragments show flattening. Cavities filled by secondary minerals are locally common. Exposures on Mounts Shole, Rudo and Dilo and at Burji village consist mainly of ignimbrite with thin (2 to 4 m) beds of tuff.

Middle Basalt (Ngm) is well exposed on the Amaro horst, south of Lake Chamo and in the southwestern corner of the map sheet. On Mount Dilo it consists of black aphanitic basalt 110 m thick. Up to 90 m of subhorizontal basalt of this unit occurs on Mount Melega in the Gumayde Highlands. This unit is about 60 m thick on Mounts Shole and Rudo, and in the southwestern corner of the map sheet. Columnar jointing is common.

Beyana laminated and lapilli Tuff (Ngb) overlie the Middle Basalt. At places a paleosoil layer up to 0.5 m thick is developed beneath it on the Ngm unit, this typically being reddish brown silty clay. From Beyana village to Mount Kimbiro the Ngb unit decreases in thickness from 17 to 5 m.

Upper Basalt (Ngu) is exposed along the western border of the map sheet. It is totally absent on the Amaro horst, and on Mounts Ir Getra and Shole. The unit always lies on the Beyana Tuff and sometimes is capped by flows of Sharenga Rhyolite, as in the western Segen basin. The thickness of the Ngu unit is in excess of 30 m on Mount Melega, decreasing to 20 m a few kilometers north and south of this mountain. In the southwest of the map sheet, the Ngu unit is not more than 15 m thick. The Upper Basalt is composed of a single flow of fresh columnar jointed basalt.

Sharenqa Rhyolite (Ngs) occurs in the form of plugs (200 up to 2,000 m in diameter), flows and dykes. Outcrops are found along the western border of the map sheet.

Post rift volcanic succession consist of five units

Nechsar Basalt (Qn) is found just east of Lake Chamo, and lies on the Precambrian basement with a thickness of 10 m.

Segen basalt cones (Qs) are very recent, well preserved lava cones outcropping in the Segen basin and standing up to 100 m above their surroundings. The cones found east of Mount Kelo have been affected by normal faulting.

Bridge of God Basalt (Qb) consists of basalt flows intercalated with thin beds of trachytic tuff and scoriaceous basalt.

Degabulae Basalt (Qd) small, fault bounded tongues of basalt, each covering 200 to 500 m^2, lie on top of the Nechsar basalt along the western margin of the Nechsar plain.

Chamo cinder cones (Qc) are found only in the Chamo basin and consist of reddish brown scoria or scoriaceous basalt.

Quaternary sediments

Aerial photographs were used to delineate the contacts of the Quaternary sediments in the map area which are loosely subdivided into three groups.

Eluvium (Qe) is loose residual material ranging from accumulations of cobble sized fragments to soils. The ultramafic rocks near Surupa village are covered by a brownish black montmorillonitic soil that grades to a light brown soil where the underlying rocks are felsic. In the Gelana, Segen and Chamo basins the eluvium consists of subrounded to subangular pebbles and cobbles set in a poorly sorted matrix of coarse sand. The thickness of the eluvium in these basins ranges from 2 to 14 m.

Alluvium (Qa) consists of sandy gravel, silt and clay, mainly occurring along river courses of very low gradient. In contrast to the eluvium, alluvial sediments are predominantly fine grained. Alluvium in the Segen basin consists of silty clays with minor detrital feldspar, quartz and rounded rock fragments. In the Gelana basin, the alluvium is buff to grey silts and clays with subordinate sands. The thickness of the Qa unit varies from place to place, the maximum being 15 m in the Gelana basin.

Undifferentiated superficial sediments (Q) are exposed in the Chamo basin. They generally consist of buff to brown, well laminated clays intercalated with sands and silts.

3.3 Structures

Precambrian structures in basement rocks exhibit many structures varying in size from large scale to microscopic, which indicates that these rocks have been subjected to polyphaser deformation. Some of them are poorly represented due to the superimposition of later deformation and metamorphism.

The earliest recognizable planar feature is defined by a well-developed layering in the high grade gneisses, formed by segregation of minerals. Intense migmatization and granitization has developed along the layering. No major structure belonging to this deformational phase has been distinguished. Folds and lineation belonging to this phase of deformation are very scarce.

The second deformational phase is resulting in well-developed structures in the map area. Large north-south running antiforms and synforms form major structural features in the Gariboro-Burjiji area, in the southeastern part of the map sheet. In the central part of the map area, southeast of Hagere Maryam town, large open folds with subhorizontal to gently plunging north-south axes which extend for over 15 km have been recorded. Here the folds are parallel to the general lithologic trend.

The third deformational phase generated mainly widespread large to small shear zones and associated asymmetric folds. These shear zones generally trend NNW, NNE and N-S, with steep dips to east or west. Large-scale shear zones are observed in the Amaro, Galeba, Burjiji, Katawicha, Sirupa and other areas of the map sheet, being restricted to the high grade metamorphic rocks.

The fourth deformational phase generated structures similar to the second phase and these structures are seen mostly in the Adola low grade belt. The structural trend is north-south, with steep dips to the east or west. This is the first tectonic event to affect the rocks of the Adola low grade belt. Folds associated with this deformation are tight to close, with generally upright, north-south trending axial planes.

The fifth deformational phase generated north-south trending shear zones and associated asymmetric folds.

The sixth deformational phase is the last deformational phase and deformations are seen at many spots in the surveyed area. The deformation is weak and is represented mainly by mesoscopic, open, symmetrical folds with small amplitudes (a few centimeters to meters).

All lineaments derived from satellite images are mostly fractures (both joints and faults), but include stream segments, topographic depressions, and ridges. N-S trending lineaments (0°-010°) are dominant in the area. Such lineaments up to 20 km long are common, and are particularly abundant in the eastern and western parts of the map sheet. NW trending lineaments (300°-330°) are the second most common group, being especially widespread in the central and western parts of the area. NNE trending lineaments (010°-030°) are also widespread and generally display lengths varying from 5 to 10 km. A few prominent NE trending lineaments are present in the eastern part of the map area.

N-S faults occurring in the western part of the map sheet are associated with the Main Ethiopian Rift. They are mostly normal faults connected with the formation of graben and horsts that developed during the Cenozoic.

Cenozoic structures are relating to the rifting processes. The Main Ethiopian Rift terminates south of Lake Abaya where the rift valley splits into the Chamo and Gelana basins separated by the 20 km wide Amaro horst. The Segen basin lies just south of the Chamo basin.

Normal faulting has caused units to be tilted to the west. Rift faulting has given rise to high relief, with elevations ranging from 3,232 m a.s.l. on top of the Amaro horst to 800 m a.s.l. in Brinder village. It is suggested that Lakes Chamo and Gelana are rift basins bounded by steeply dipping, N-S trending normal faults.

The Gelana basin is more than 60 km long and 3 to 15 km wide. It is of gentle morphology and underlying units dip 10° to 30° west. The major N-S faults bounding the Gelana basin die out at the latitude of Burji village, causing the disappearance of this basin.

Along the western edge of the Amaro horst normal faults dip steeply west. A major N-S trending Precambrian sinistral strike-slip shear zone is present along the Amaro horst. It appears that the presence of this structure facilitated the formation of the horst, rift related faults in this area commonly being subparallel to the Precambrian shearing.

The Segen basin is situated in the southwestern corner of the map sheet, running north for about 60 km before being interrupted by NW-SE trending faults. Its floor lies at an elevation of 900 m a.s.l. The northwestern margin of the basin is not bounded by a fault. Further south, the basin fault escarpment bounds it to the west with the vertical component of faulting of about 500 m.

N-S to NNE trending faults are common in the western part of the map sheet. They are normal faults up to several kilometers long and form the major boundaries of the Amaro horst and the rift basins. NW trending faults are the second most prominent set of faults in the western part of the map sheet. They are well developed on the Amaro horst and the Gumayde highlands, dislocating the pre-rift volcanics and most of the N-S faults that bound the Amaro horst. They range in length from two to over fifty kilometers.

3.4 Geological History

The high grade stratified gneisses, mainly of sedimentary (and volcanic) origin, represent the oldest rocks in the map area. The regional gneissic layering and the highly appressed folds of the first phase of latitudinal trend are the earliest recognizable structural elements in these rocks, having developed during this phase. The accompanying metamorphic event was obviously of high grade. The rocks were subject of several other deformation phases. Emplacement of the post-tectonic plutons Pbgt and Phhg, at about 554 Ma and 529 Ma respectively, appear to be the last events in the history of the basement rocks of the Hagere Maryam area.

The Cenozoic geologic history of the region is outlined below:
1/ Deposition of the basal red sandstone (Pgr).
2/ The earliest volcanic unit recognized in the area is the Arba Minch felsic tuff (Pga).
3/ Extrusion of the Lower basalts in the region began in the Middle Eocene.
4/ The Shole Ignimbrite (Pgs) was formed.

5/ There is no evidence of volcanism during the Early Oligocene.
6/ The Middle Basalt (Ngm), Beyana Tuff (Ngb) and Upper Basalt originated successively, probably in the Middle Miocene.
7/ In the Middle to Late Miocene rifting commenced on N-S and NNE trending faults, leading to the formation of the Amaro horst bounded to the west by the Chamo and Segen basins and to the east by the Gelana basin.
8/ Rhyolitic plugs and flows (Ngs) formed concomitantly with the rifting.
9/ Rifting continued, the rift attaining its present form by early Pliocene time.
10/ After the formation of the Amaro horst, volcanic and tectonic activity was confined mainly to the Chamo basin. The tilting of Quaternary units in the Chamo basin demonstrates active faulting of this age.
11/ Finally, continuing erosion led to the deposition of Quaternary sediments and formation of the present topography.

Spreading of rift floor can be observed until now and it gives origin of surface cracks in many parts of the Rift Valley.

4. Hydrogeology

Hydrogeology of the Hagere Maryam map sheet is based on the assessment of data collected from existing reports and maps and during field work. Some previous hydrogeological work at different scales; however, data for the area of the map sheet are scarce.

The sheets of Dila (Thomas Agezew, Jiri Sima, 2014) to the north, Negele (Getachew Zewdie, 2011) to the east, Yabelo (Yohannes Belete, 1993) to the south of the Hagere Maryam map sheet have been compiled by GSE.

1. Extensive and moderately productive or locally developed and highly productive porous aquifers ($T = 1.1–10\ m^2/d$, q = 0.011–0.1 l/s.m, with spring and well yield Q = 0.51–5 l/s). The aquifers consist of Quaternary alluvial and eluvial sediments, polygenetic infill of depressions and volcano-sedimentary rocks.
2. Extensive and moderately productive fissured aquifers ($T = 1.1–10\ m^2/d$, q = 0.011–0.1 l/s.m, with Q = 0.51–5 l/s). The aquifers consist of basalts of rift floor, ignimbrite, rhyolite and trachyte of the highlands and escarpment.
3. Extensive and moderately or locally developed and highly productive mixed porous and fissured aquifers ($T = 1.1–10\ m^2/d$, q = 0.011–0.1 l/s.m, with spring and well yield Q = 0.51–5 l/s). The aquifers consist of volcanic, sedimentary and pyroclastic rocks of the Central volcanic complexes, and pumiceous pyroclastics of the Nazret group.
4. Extensive low productive fissured aquifers ($T = 0.11–1\ m^2/d$, q = 0.0011–0.01 l/s.m, with spring and well yield Q = 0.051–0.5 l/s). The aquifers consist of high and low grade metamorphic rocks and granite.

The hydrogeological map of Ethiopia at a scale of 1:2,000,000 was published by Tesfaye Chernet (1993). He classified the geological units of Ethiopia into four major groups depending on the type of permeability and the extent of the aquifer. This hydrogeological map was the basic document for preparation of the field work. Tesfaye (1993) identified for the highlands the following units:

- Other sedimentary and volcanic rocks along rivers and plain areas with fissured porosity classified as moderately or low productive aquifers; the specific yield of wells was estimated to be in the interval 0.05–1.1 l/s.m and total yield of wells with 20 m of drawdown varies in the interval 0.45–9.9 l/s in moderately productive aquifers.
- Recharge and discharge characteristics were derived as 150–250 mm for the highlands.
- The highlands were classified as an area with major water resources. These were assessed to be widespread and moderate to large in quantity. Groundwater and surface water are of good chemical quality (TDS less than 500 mg/l). Most of the streams are perennial; there are many cold springs, and the groundwater level is between 0 and 100 m and can be exploited in low relief areas (valleys).
- Groundwater chemistry is characterized as being bicarbonate (HCO3) in the highlands.

The Rift Valley is characterized by the following units:

- Lacustrine and swamp deposits, volcano-lacustrine deposits of the rift floor (around Awasa and Abaya lakes), moderately productive porous aquifer.
- Ignimbrite and pumice of the rift floor with subordinate lacustrine deposits (between Awasa and Abaya lakes), moderately productive fissured aquifer.

The fluoride content is generally above 1.5 mg/l and groundwater is bicarbonate in type in the Rift Valley bottom. Major water resources are characterized as "Lowland 1" with widespread and moderate to large quantities of surface and/or groundwater with variable chemistry and TDS from 500 to 3,000 mg/l. Most streams are perennial and groundwater is 0–150 m b.g.l. Annual recharge in the region is between 50 and 150 mm. Discharge of water points can be large, moderate as well as low.

The latest assessment of groundwater resources in the Lakes Region was done by Halcrow (2008) and by JICA (2012). The Master Plan Study by Halcrow (2008) compiled studies of both the geology and the hydrogeological conditions of the RVLB. Yield of wells and springs from different lithological units was described as follows:

Wells yield in l/s was assessed to be as follows:

- Lacustrine sediment 4.03
- Ignimbrite 2.81
- Basalt 2.67
- Volcanic sand 2.06
- Pyroclastic and sedimentary rocks 1.5

Spring yield in l/s was assessed to be as follows:

- Aglomerate 6.7
- Basalt 4.46
- Ignimbrite 17.17
- Lake sediment 36.7
- Rhyolite 22.5
- River gravel 2.0
- Scoria 13.25
- Soil 4.5
- Trachyrhyolite 1.5

Springs with records of both yield and temperature were evaluated. The evaluation shows that most of the springs with high yields are from thermal spring sources. It can also be noted that thermal spring yields are highly variable (from 1.5 l/s up to 75 l/s). Representative aquifer parameters assessed by Halcrow (2008) are shown in Tab. 4.1.

Tab. 4.1 Representative aquifer parameters

Formation	Transmissivity [m2/day]	Yield [l/s]
Ignimbrite	1–1,300	0.1–8.0
Basalt	39–130	2.7–3.0
Lacustrine deposits	10–2,800	1.0–6.6
Alluvium	40–345	1.0–6.0

In general, highly productive water sources can be found in the area between the escarpment and the flat lowlands. A high groundwater gradient can be expected on the escarpment. High discharge cannot be expected on the escarpment on the eastern and western ridges of the valley based on the conclusions of the JICA (2012) study.

An assessment of the potential of various aquifers based on the discharge of wells and springs and the major lithology performed by JICA (2012) is shown in the following Tab. 4.2.

Tab. 4.2 Aquifer parameters by JICA (2012)

Aquifer	Symbol	Lithology	Q [l/s]			Sp. cap [l/min/m]			T [m2/day]		
			Ave	Max	Min	Ave	Max	Min	Ave	Max	Min
Pleistocene tuff, welded tuff and basalt	AL/Q	Alluvium	2.8	6.5	0.2	0.5	1.2	0.1	75.3	92.6	43.0
	Lac 1	Gravel, sand mud	4.6	7.3	1.5	0.3	0.7	0.01	69.0	137.0	1.0
	W	Tuffs and pumice	5.5	47.0	0.2	0.7	1.8	0.02	42.5	84.8	0.2
	G	Rhyolite welded tuff	4.6	18.5	0.2	0.5	1.5	0.01	65.3	173.9	0.0
	tb	Basaltic tuff	6.3	22.0	0.1	2.2	6.9	0.04	242.0	914.4	12.5
	ba	Basalt	2.9	7.7	0.2	0.3	0.9	0.05	77.7	211.7	2.7
Tertiary tuff and basalt	Rh, N2b	Rhyolite lava and tuff	4.9	19.6	0.6	0.2	0.4	0.1	9.3	24.8	0.1
	N1n N1ar	Rhyolitic tuff and basalt	3.9	6.0	2.0	0.2	0.2	0.2	12.6	12.6	12.6

A complex assessment of hydrogeological data, including water point inventory, hydrological and climatic characterization was performed by Lahmeyer (2005) in "Genale-Dawa River Basin Integrated Master Water Plan Study Project" providing statistic assessment of borehole yield (Tab. 4.3).

Tab. 4.3 Aquifer classification based on well yield for Genale-Dawa basin

Formation	Yield [l/s]			Spec. capacity [l/s m]			Number of wells
	Range	Mean	Median	Range	Mean	Median	
Alluvium	0.50–3.75	2.01	1.47	0.02–8.92	1.657	0.23	7
Basalt Q	1.70	2.39	2.00	0.05–0.38	0.160	0.12	7
Basalt T	1.50–4.40	3.15	3.15	0.01–1.22	0.339	0.12	10
Ju +Jh	0.83–7.00	2.58	1.50	0.01–35.00		0.04	7
Gt + Qa	0.13–6.50	2.18	1.76	0.02–0.87	0.268	0.10	6
Hm +Qa	0.20–4.67	1.56	0.93	0.02–1.33	0.232	0.08 9	9
Lm + Qa	1.40–5.00	2.80	2.00	0.11–36.00	0.253	0.29	3

Remark: Gt–granite, Hm–gneiss, migmatite, Ju–Urandab f., Jh–Hamanlei f., Qa–Quaternary alluvium, Lm–limestone

Superficial sediments and weathered zone of basement rock was always considered to form one shallow aquifer in areas covered by the basement rocks.

4.1 Water Point Inventory, Methodology and Procedures

The overall hydrogeological study has three different phases, namely pre-field work, field work and post field work, and used different types of equipment in order to achieve its objective with the available resource and within the allotted time. The list of equipment and different tasks in each phase are discuses below:

Phase 1 pre field work:- prior to the field work the relevant material is collected from the Basic Geosciences Mapping and Geo-information Center of the Geological Survey of Ethiopia (previous studies including inventories). Topographic map are purchased from the Ethiopian Mapping Agency. A semi hydrogeological map is also produced and an identification of gap made.

Phase 2 field work:-The field work is performed as soon as the necessary desk study (pre-field work) has completed spring, dug well and borehole inventories based on the ENGDA format, which includes several parameter characterizing each water point i.e. yield, lithology, static water level etc. The respective water samples are taken wherever possible. Field temperature, pH and EC measurements, geological and hydrogeological observations, environmental condition assessments and the relevant data from water bureaus at federal, regional, zone and woreda levels as well as private sources are collected.

Phase 3 post field work: - The main task of this phase is based on detailed field observation, yield measurements of water points, chemical results of the water samples to produce a hydrogeological report and hydrogeological map. Data are processed with the help of software such as Global Mapper-8, DEM, ArcGIS-10.0, Surfer-8, Aquachem-4 and Excel, as well as homemade software and applications. Based on the detailed field observation, yield measurements of water points, chemical analysis of the water samples aquifer classification and identification of productivity geological unit and recharge condition are made. In general, the main task is to use the data collected during the above two phase to produce the hydrogeological report and hydrogeological map. A list of materials used during the study is shown in Tab. 4.4.

Tab 4.4 List of materials used during the study

No	List of material	Purpose
1	Topographic and Geological map of scale 1:250,000	base map for hydro geological map
2	GPS	Acquiring position
3	pH and EC meter	For field measurement of pH and EC
4	Solution such as pH (4.7 and 9) and dissolved salt (kcl)	For calibration of pH and EC meter
5	Distilled water	Washing pH and EC
6	Plastic sample bottles	To store representative sample
7	Camera	To take photos
8	Stationary material	For field and office work
9	Computer and various software applications	For report writing
10	Field car	Transport

The field water point inventory was based on a desktop study, during which the relevant materials like geological and drilling reports and maps and aerial photographs were collected from the regional geology department of GSE. Important climatic and gauging station data and topographic maps were obtained from various offices. The desktop study also included preliminary data interpretation and preparation of field maps using satellite images, aerial photographs and a digital elevation model (DEM) of the terrain with the geology as a background.

Satellite images and aerial photographs at a scale of 1:60,000 were used during the field work. Existing reports about borehole data were collected from regional water bureaus. A GPS was used for navigation and locating the water points. The water points were characterized by location, lithology, topography, and field measurements of pH, temperature and EC were taken. Pictures and video sequences were captured for documentation and interpretation. The static water levels of open hand dug wells were measured using an electrical sounding deeper. A summary of the field inventory is shown in Tab. 4.4 and an extract from the water point inventory database is shown in Annex 1. Groundwater from water points representing important parts of the area's hydrogeological system was sampled for chemical analysis (see Chapter 6 and Annex 2). During the field investigation, 63 water points were thoroughly inventoried and 60 water samples were collected (see Tab. 4.5). The static water level of open wells was measured using electrical sounding instruments wherever possible. Additional data about water points were collected during desk study and derived from drilling reports provided by the Zone and Woredas Water Bureaus (number in brackets). The hydrogeological and hydochemical maps were compiled based on 255 water points and 65 analyses, respectively

Tab. 4.5 Summary of field inventory

Water point type	Number of inventory	Sampled
Borehole (BH)	43 (125)	41 (5)
Dug well (DW)	4 (34)	4
Spring (CS)	12 (33)	11
Surface water (RW)	4	4
Total	63 (192)	60 (65)

4.2 Hydrogeological Classification/Characterization

The qualitative division of lithological units is based on the hydrogeological characteristics of various rock types using water point inventory data and by analogy with surrounding map sheets and previous works. The lithological units were divided into groups with dominant porous and fissured permeability and mixed permeability. The last group is represented by basement rock where groundwater is accumulated mainly in regolith and fissured zones. This division served for a definition of the basin's aquifer/aquiclude system. Since quantitative data such as permeability, aquifer thickness and yield are not adequate or evenly distributed enough to make a detailed quantitative potential classification; analogy was used for characterization of rocks without the adequate number of water points. Hence, the hydrogeological characterization of the study area reveals the following aquifer/aquiclude systems:

Units with porous permeability, where groundwater is accumulated in and flows through pores of an unconsolidated or semi-consolidated material. Porous materials of Quaternary age are represented either by lacustrine sediments with subordinate fluvial, colluvial and eluvial sediments developed in grabens and depressions of lakes and/or along valleys of former and existing rivers or by pyroclystic and unwelded tuff materials. The porous aquifers are widely developed over the study area. The aquifer with porous permeability forming aquifers is expressed on the hydrogeological map in blue.

Units with fissured permeability, where groundwater is accumulating in and flows through the weathered, jointed and fractured part of volcanic rocks. The porosity of lava flows may be high but the permeability is largely a function of a combination of the primary and secondary structures (joints and fissures) within the rock. In addition, the permeability of lava flows tends to decrease with geological

time. The pyroclastic rocks between lava flows are generally porous but usually less permeable due to poor sorting. They can be represented by impermeable unwelded tuff in some part of the volcanic sequence. Hence, extensive volcanic ash beds may form semi-horizontal barriers to water movement (infiltration) resulting in lower productivity of basaltic units located at greater depth. Layers of paleosoil of various thicknesses in between lava flows are also less permeable and usually consist of clay material on the one hand, whereas layers of fluvial and lake sediments and pumiceous pyroclastic materials between various lava flows can enhance well yield on the other hand.

Tertiary and Quaternary volcanic formations represented by basalts, rhyolite, trachyte and ignimbrite form aquifers with good fissured porosity. The units with fissured permeability forming aquifers are expressed on the hydrogeological map in green.

Basement rocks represent fissured aquifers of low potential. The groundwater in the hard rock is practically all stored in the fractured zones and the weathered mantle called overburden or regolith. The groundwater body should not be continuous, particularly during rainy season when shallow groundwater in regolith disappears and groundwater is accumulating only in deep pockets along fissured zones. The depth of fractured aquifer zones is generally no more than 50–70 m below the surface. The fractures will tend to close at depth. The faults and joints in igneous rocks are nearly vertical, except for narrow fractures, which are more or less parallel to the rock surface, sheeting and exfoliation. The greatest permeability is found in the sub-soil zone within the partly decomposed rock. Wells tapping this zone have yields roughly an order of magnitude greater than in the fresh rock. The aquifers are expressed in the model of the hydrogeological map in brown/red.

4.3 Elements of the Hydrogeological System of the Area (Aquifers and Aquitards)

The hydrogeological map shows aquifers and aquitards (formations with local and limited groundwater resources) defined based on the character of the groundwater flow (pores, fissures), the yield of springs and the hydraulic characteristics of boreholes. The following aquifers and aquitards were defined:

4. ***Extensive (2,670 km²) and moderately productive or locally developed and highly productive*** porous aquifers (T = 1.1–10 m2/d, q = 0.011–0.1 l/s.m, with spring and well yield Q = 0.51–5 l/s). The aquifers consist of Quaternary alluvial deluvial and mixed deposits (Q, Qa, Qe). The aquifers are shown in light blue.
5. ***Extensive (4,461 km²) and moderately or locally developed and highly productive fissured aquifer*** (T = 1.1–10 m^2/d, q = 0.011–0.1 l/s.m, with Q = 0.51–5 l/s). The aquifers consist of volcanic rocks (dominantly the Lower Basalts – Pgl). The aquifers are shown in light green.
6. ***Extensive (11,014 km²) and low productive* fissured aquifers** (T = 0.11–1 m^2/d, q = 0.0011–0.01 l/s.m, with spring and well yield Q = 0.051–0.5 l/s) developed in low and high grade metamorphic and intrusive rocks. The aquifers are shown in red/brown.

The following detailed hydrogeological characteristics of the aquifers and hydrogeological characteristics of the individual lithological units are described based on archive data and data collected during desk work and field observation during field season of 2015 (Annex 1). Hydraulic characteristics of wells taken from drilling reports are in the tables in Annex 1a.

4.3.1 Extensive and Moderately Productive Porous Aquifers

The porous aquifers altogether make up 2,670, km^2, accounting for about 15 % of the area and consist of alluvial sediments (Qa), eluvia (Qe) and undifferentiated superficial sediments. Porous aquifers occur mainly in the eastern part of the sheet along the banks of the Chamo Lake, in the Sagen and Gelana rivers valleys (Geleto, Jirme plains and Gelana Shamole and Jelo marshes). Other superficial sediments occur along the road from Hagere Maryam to Yabelo and form several plains there (Kuya, Ifeta Ferda and Debeka Milmili plains). They also occur in the areas of Birindar and Deteru. The only occurrence of superficial sediment in the western part of the sheet is on the Agemsa Plain. Porous aquifers developed in porous media are shown in light blue in Fig. 4.1.

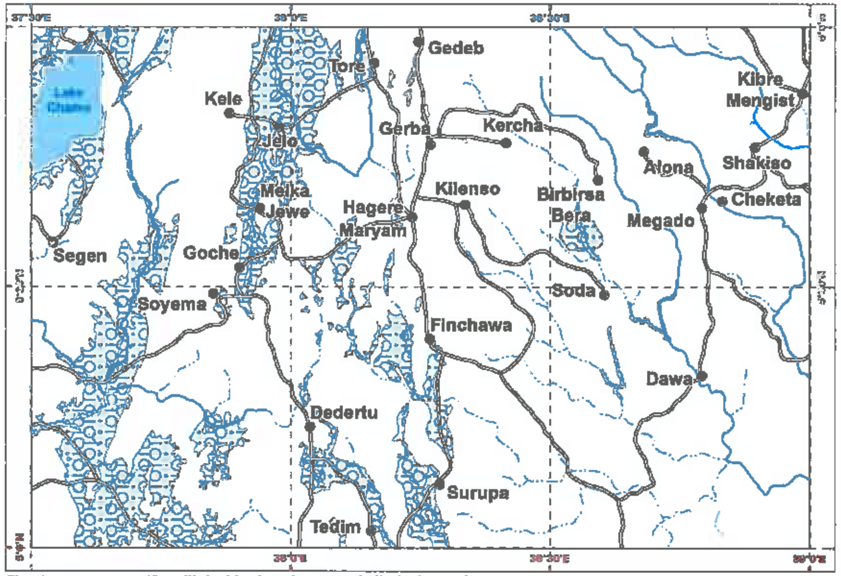


Fig. 4.1 Porous aquifers (light blue) and aquitards (light brown)

The largest number of wells drilled in the porous aquifer is in the Gelana woreda where 23 shallow wells were drilled along the Gelana River. Wells are 15 to 91 m deep and are usually drilled in sand, clay and gravel; however, some of them have been drilled to the underlying basalt and tuff. The static groundwater level varies from 4 to 40 m, unfortunately the yield of wells is not recorded. The greatest thickness of porous material of 73 m was encountered by wells LGBH2 in the Bulto area at an altitude of 1319 m a.s.l. With increasing altitude thickness of porous material is decreasing and basalts are encountered in lower parts of these wells (e.g. LGBH6 in the Dima area in altitude of 1687 m a.s.l.).

Fluctuation in groundwater levels in superficial sediments has been reported from Cheleletu town where it was about 4 m (documented in WDW 1) and from the Hagere Mariam area where it was about

5 m. The fluctuation of watertable in the Hagere Maryam area represents the difference between surface water and groundwater in water holes which are dug into the river bottom during the dry season when the river is not flowing.

Tab. 4.6 Basic statistics of yield of water points from porous aquifers in l/s

Number of data / sheet	Max	Min	Median	Average
20 / Dila sheet	47	0.05	0.3	8.2
7 / Hagere Maryam	8	0.04	2.0	2.6

Data about the yield of water points from aquifers developed in porous aquifers from the Hagere Maryam sheet were combined with data from the neighboring Dila sheet to which the porous aquifers continue and the frequency of their yield is shown in Tab. 4.6 and is plotted in Fig. 4.2.

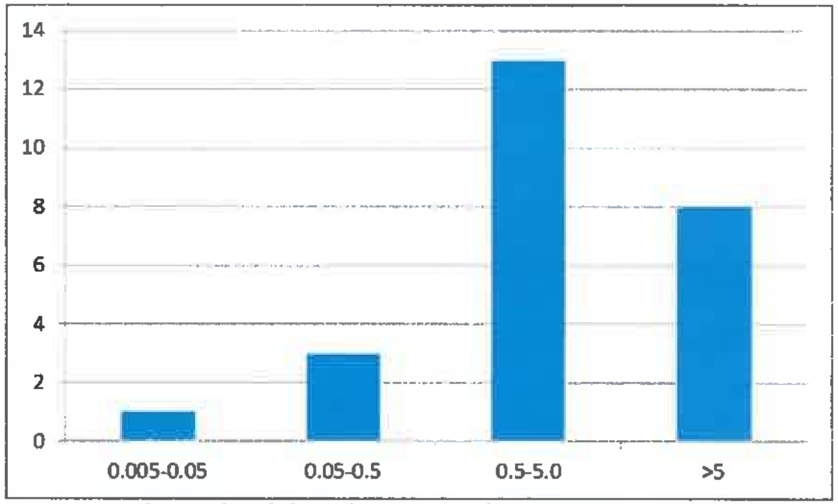


Fig. 4.2 Frequency (number of cases) of yield of water points (in l/s) from porous aquifers

Porous aquifers of the Hagere Maryam sheet represent a large potential for the development of shallow groundwater by dug and drilled wells. Groundwater is good in quality and can be used for domestic as well as for household irrigation purposes.

4.3.2 Extensive and Moderately or Locally Developed and Highly Productive Fissured Aquifers

The fissured aquifers of moderate productivity make up 4,461 km^2, accounting for 25 % of the area and consist dominantly of basalts with some ignimbrite and rhyolites and minor tuffs. These aquifers are characteristic for the western and north-central part of the sheet. Their age and geomorphological setting dictate their hydrogeological characteristics, with fissure flow being dominant. Open faults and fault systems may also provide significant groundwater flow paths. Where these are extensive, they may allow regional transfer of groundwater. Fissured aquifers developed in volcanic rocks shown in Fig. 4.2.

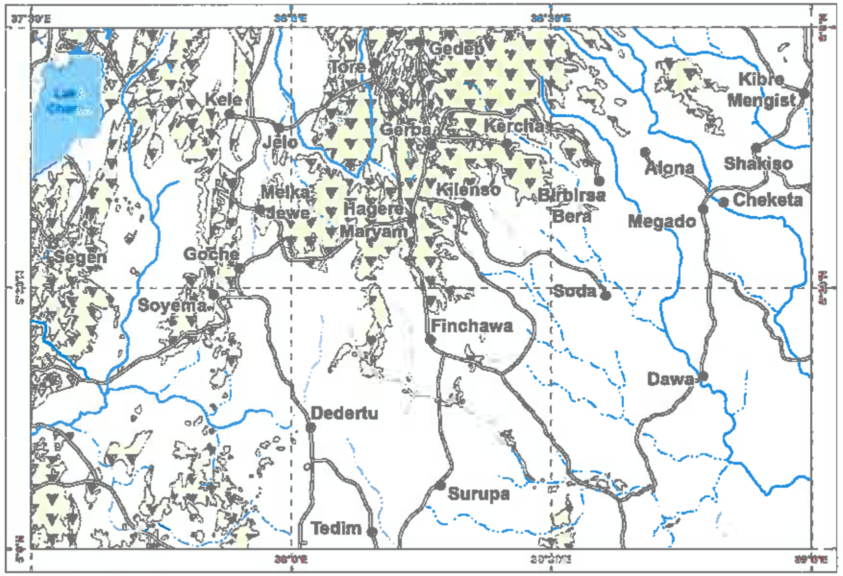


Fig. 4.3 Fissured aquifers

Basalts usually form less viscous thin lava flows and may be significantly affected by weathering, brecciation and may be interbedded with lacustrine or fluviatile deposits (some wells drilled for water supply of Hagere Maryam). Groundwater flows through joints, fractures, scoria intercalations and coriaceous horizons and interbedded sediments. The continuity of fractures in both horizontal and vertical planes provides the aquifers their hydraulic continuity with adjacent units and aquifers. The frequency of yield of water points from fissured aquifers hosted by various volcanic rocks basic statistics are given in Tab. 4.7 and are shown in Fig. 4.4.

Tab. 4.7 Basic statistics of yield of water points from fissured aquifers in l/s

Number of data / sheet	Max	Min	Median	Average
27	10.35	0,02	2.5	3.4

Wells drilled for the water supply of Hagere Maryam have a relative high yield 5 to 17 l/s caused by the existence of several layers of highly weathered basalt, gravel intercalations and by a relatively thick (about 20 m) layer of fragmented basalt at the base of this flow and a highly decomposed basement, which is usually described as sand in geological logs. This contact is very important from a hydrogeological point of view leads to high yields. The spring WSC2 yielding about 2.5 l/s of groundwater, which is used for water supply of Soyama town, is in a similar position near the contact

between basalt and the underlying basement. It is supposed that springs located on the eastern slope of the Amaro horst gain their water from capping basalt and emerge at the contact of basalt with the underlying basement.

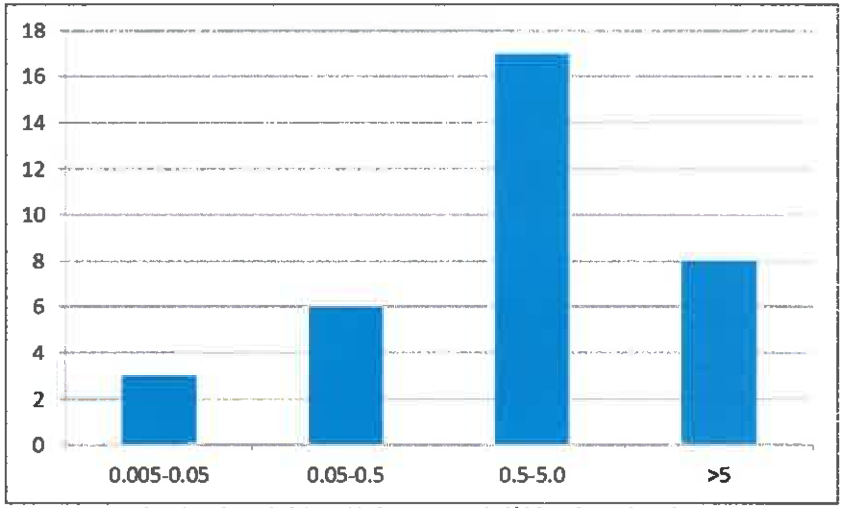


Fig. 4.4 Frequency (number of cases) of the yield of water points (in l/s) from fissured aquifers

Ignimbrite and rhyolitic lava flows are more viscous and are often thicker than basalts and less widespread, being located closer to the source volcano or extrusion. Jointing, fissures and regional faulting represent the major sources of secondary porosity. Where these flows are extensive, springs may occur and aquifers have potentially high yields.

4.3.4 Extensive and Low Productive Fissured Aquifers

The basement rocks are classified as a low productive fissured aquifer, which makes up 11,014 km^2, accounting for 60 % of the area and consists of various crystalline (highly and low metamorphic and igneous) rocks of Precambrian age. The basement rocks occupy large areas in the southeastern part of the sheet in the eastern highlands along the Genale and Dawa rivers and the Borana lowlands located in the south. Aquifers with low productive fissured permeability are shown on the hydrogeological map in brown/red color. The extent and location of the low productive fissured aquifers developed in basement rocks are shown in Fig. 4.5 The biotite gneiss sometimes appears massive while quartzo feldsphatic gneiss are highly sheared, fractured and weathered, but the weathering resistance of quartz and feldspars leads to the development of coarse residual material.

The discharge of springs varies from 0.018 l/s to 0.06 l/s during the dry period when they were measured in the field. Data about the yield of water points from aquifers developed in basement rocks from the Hagera Maryam sheet were combined with data from the neighboring Negele, Dodola and Dila sheets and the frequency of their yield was plotted in Fig. 4.5 and Tab. 4.8. The basement rocks of the sheet are classified as a low productive fissured aquifer considering their position at the bottom of valleys along stream channels, and in flat lands. These locally developed aquifers are convenient for groundwater storage and their groundwater resources can be developed by wells. The well sites can be located using simple geophysical measurements, e.g. VES. The measurements are important in fissured aquifers developed in crystalline rocks for location of zones with a higher frequency and openness of fissures additional to the estimation of the depth of the groundwater level.

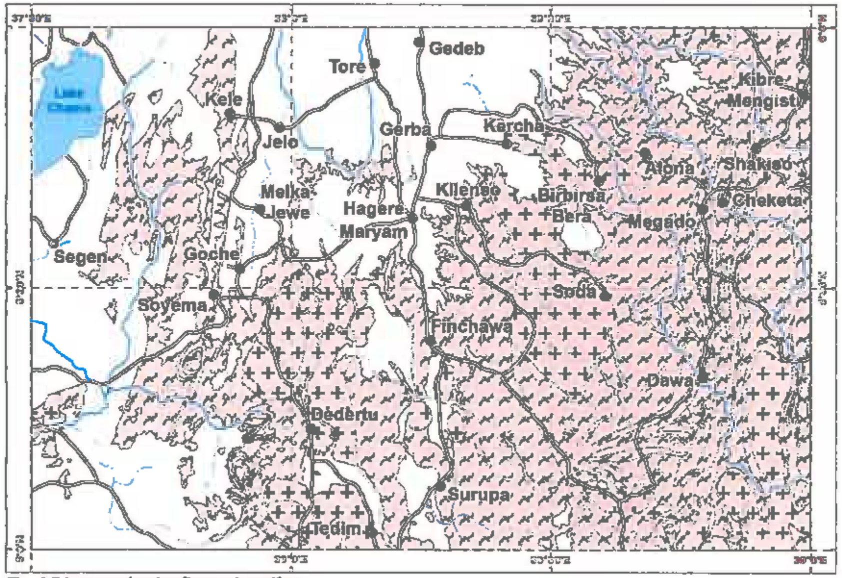


Fig. 4.5 Low productive fissured aquifers

Tab. 4.8 Basic statistics of the yield of water points from low productive fissured aquifers in l/s

Number of data / sheet	Max	Min	Median	Average
9 / Hagere Maryam	6.0	0,02	0.45	1.7
25 / Negele, Dila, Dodola	4.0	0.018	2.0	4.84

Productivity data when the yield of springs and wells is considered together shows classification of the basement aquifer into the category of moderately productive fissured aquifers. The real characteristic of the productivity of basement rocks is shown by the yield of springs only. Springs represent local hydrogeological characteristic of the basement rocks and that is reason for classification of basement to category of low yield fissured aquifer. Yield of wells is representing anomaly because wells are located in river/wadi valleys where their yield represent mainly character of superficial sediment (usually sandy)

and a deeply weathered and decomposed basement because it was subject to deep fissuring due to regional faulting and the existence of regional lineaments.

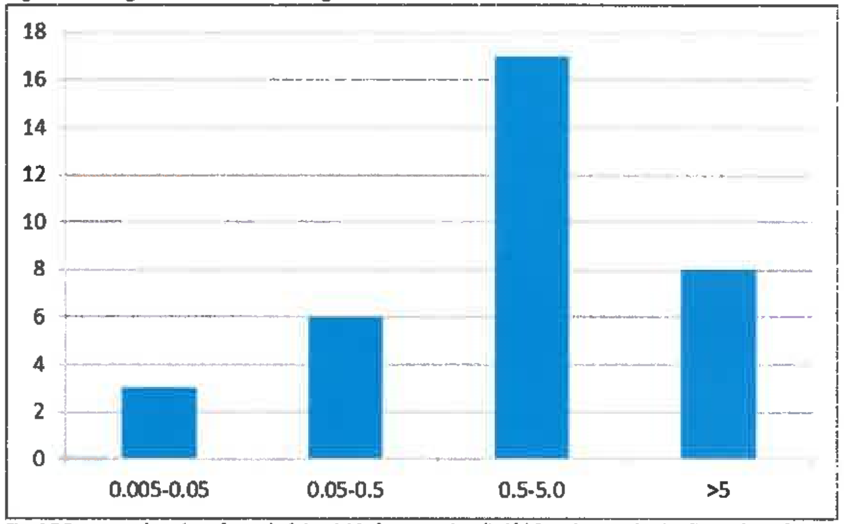


Fig. 4.5 Frequency (number of cases) of the yield of water points (in l/s) from low productive fissured aquifers

The water points were mostly observed along streams where this unit is subjected to regional faults and local fractures. This fact is well documented in wells (OBH40, LBH5, OBH21, OBH22, OBH23, EBHI2, EDW2, EBH16, ODW2, ODW3, OBH58, OBH61) located on the bank of rivers running parallel to the regional faults (lineaments) as shown in Fig. 4.6.

The aquifer developed in basement rocks of the Hagere Maryam sheet represents an important source of groundwater for the area. There are mainly water points with relatively high discharge providing groundwater of a good quality. The area benefits from the fact that the eastern part of the sheet receives an adequate volume of precipitation, the rock is affected by tectonic events and high grade crystalline rocks with quartz veins tend to weather into permeable soils (regolith). Groundwater can be developed by relatively cheap shallow wells with yields of about 1 l/s that are a good source of water for supplying rural communities.

The location of shallow and deeper wells should be done based on structural analysis using satellite imagery and should be confirmed by local geophysical measurements.

The annual variation of groundwater levels can be up to 4 m. It was confirmed by digging of water wells in a dry wadi bed after the flowing surface water disappears from the river course. A water hole has been dug near well EBHI2, Idy Negele, near Melka Soda village.

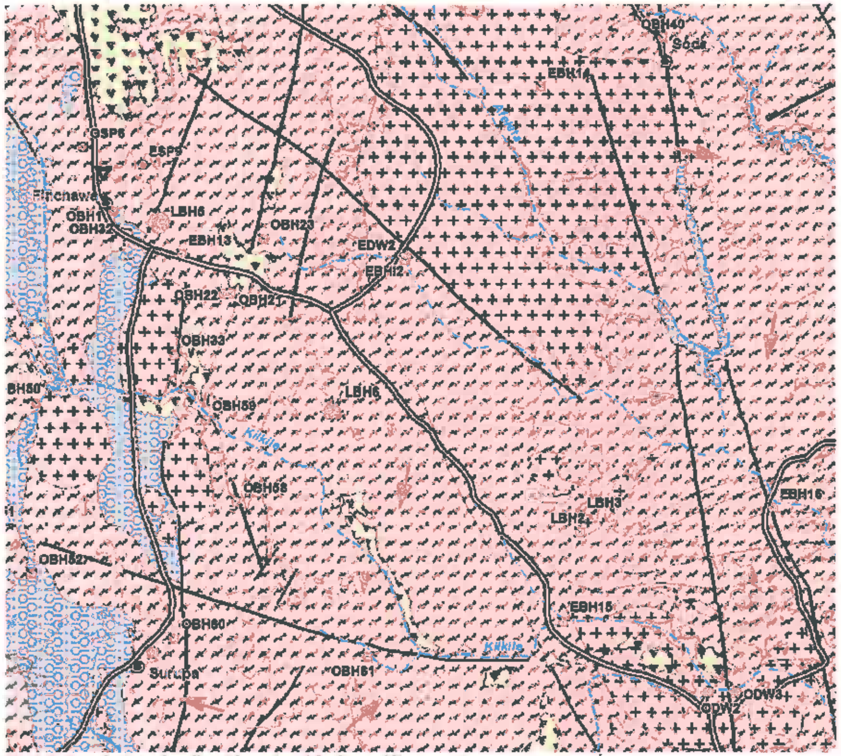


Fig 4.6. Correlation of wells with regional faults and lineaments

The basement represents a relative good aquifer when groundwater is developed nearby local and regional faults along wadis where deep fissured and weathered zones form large groundwater resources.

4.4 Hydrogeological Conceptual Model

The general concept of infiltration and groundwater circulation in the Hagere Maryam map sheet is divided into areas built by the basement in the eastern part of the sheet and by basaltic rocks accompanied by deep graben (Gelana and Sagen valleys) connected with the rifting processes in the western part of the sheet.

The general hydrogeological concept of the area is based on the assumption that infiltration is negligible in areas with slopes of more than 25° and runoff is dominant. Shallow local groundwater circulation can

be developed but springs are small (more or less in the form of seepages and/or intermittent springs). Slopes between 3° to 25° have a certain amount of infiltration and infiltrated groundwater is manifested in the form of perennial springs. The area of the valley bottom with slopes less than 3° represents the main accumulation of groundwater infiltrating directly into outcrops of superficial sediment developed in the valley and is also recharged by a rapid interflow from the surrounding mountains.

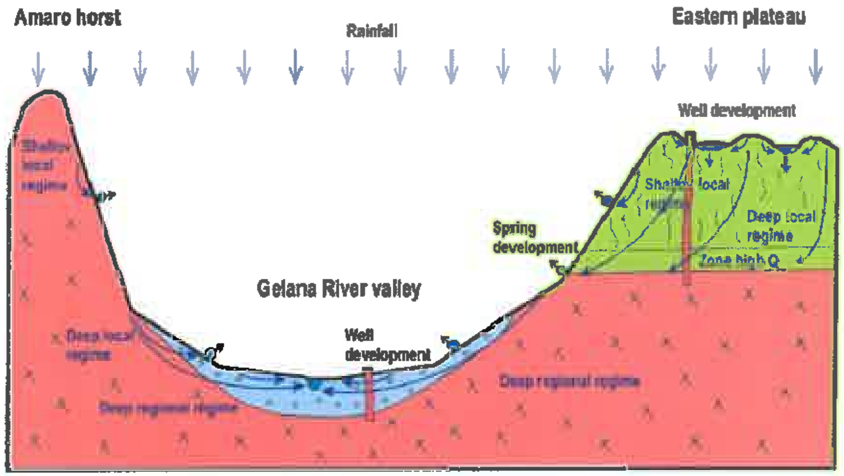


Fig. 4.7 Conceptual model of the western part of the Hagare Maryam sheet

The western part of the sheet (Fig. 4.7) can be represented by the Gelana River valley. This condition is also valid for the Sagen (in the west) and Gidabo (in the north) river valleys. An undulating eastern plateau is built by basalt in the northern part of the sheet. There are small intermountain depressions filled by superficial sediments (red soil) with a thickness of about 20 m. There is direct infiltration into superficial sediments; however, the depressions receive some water from the surrounding hills as well. Part of the infiltration water forms a shallow local regime which feeds groundwater in these depressions. Groundwater of these small intermountain depressions is consumed by evapotranspiration because of the shallow groundwater table, but part of the groundwater infiltrates to greater depths and feeds a deeper (the main aquifer of the eastern plateau on the sheet) aquifer developed in volcanic rocks (see Fig. 4.8). The main aquifer developed in volcanic rocks (mostly in lower basalts) is also recharged by direct infiltration from rainfall. A deep local regime is formed in the aquifer developed in volcanic rocks. The volcanic rocks (lower basalts) directly overlay the basement in the study area. When the first lava flows of the lower basalts poured out from fissures originating through rifting processes the basal part of the lava flow was in contact with the cold basement rock and the fast cooling lava become scoriaceous or formed blocks and boulders. Alternatively, they covered the basement that was exposed for a long time to weathering and was deeply decomposed, leading to the development of a "sand" layer at the top of the basement. This combination of deeply weathered basement and easy slacking base of basaltic flows gives origin to the zone of high yield encountered by wells. This is confirmed by wells drilled to the contact of the basalt with basement having a discharge of 5 to 25 l/s.

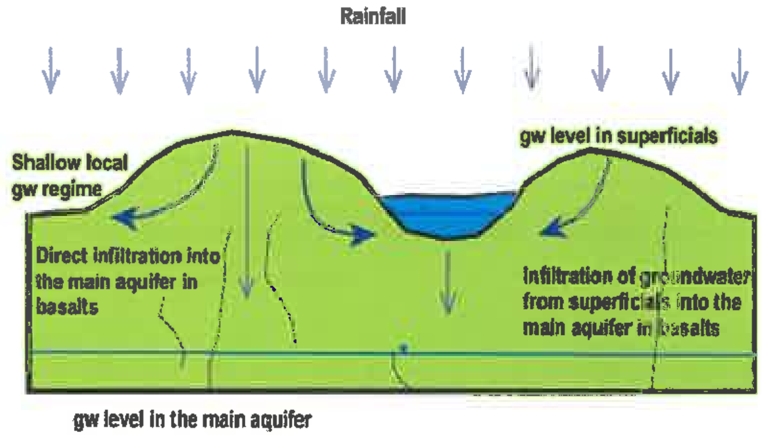


Fig. 4.8 Conceptual model of the hydrogeological regime in intermountain depressions

The high yielding zone has the potential for relative large springs like WSC2 yielding about 2.5 l/s of groundwater, which is used for water supply of Soyama town and is located on the eastern flank of the Amaro horst. The Amaro horst is built mainly of crystalline rocks but there are some basalts on the top of the horst. Basalts give origin to the formation of a shallow and possibly deeper local groundwater regime which is manifested by springs emerging on the eastern flank of the horst and is used for water supply of towns located at the foot of the horst (Kele, Dano BultoJilola, and others). These springs usually emerge at places where perpendicular faults cross the Amaro horst. A similar situation is also found on the western flank of the horst and adjacent to the Sagen River valley.

The Amaro horst and the Gelana River valley were subjects of a study using satellite data from the ALOS PALSAR-2 by (JAXA: Japan Aerospace Exploration Agency) which operates from May 2014 http://www.eorc.jaxa.jp/ALOS/en and provides information about differences of relative moisture of the surface. The PALSAR data has a resolution of 10 meters and the PALSAR L-band reaches the soil profile approximately 23 cm below the surface. This penetration rate eliminates the effect of vegetation on the overall moisture. On the contrary to the C-band in SAR data, which can be plagued by the loss of a coherent signal due to vegetation, the fully-polarized ALOS PALSAR allows better characterization of wetland and vegetation structures as well as ground features. The processed scenes were dated in January, which represents the dry period in the study area. The processing is based on the idea that relatively high moisture in some areas indicates the presence of relatively shallow groundwater (a few meters below ground level) at the end of the dry season. The areas with high moisture are shown in the composition in a blue color. The best resolution was found when the number of classes was reduced from 4 to 3. The interpretation of the PALSAR L band shows the first area of relative high moisture on the eastern slope of the Aamaro horst (marked No.1), which corresponds to the development of the shallow local regime shown in fig. 4.7. The second area of relative high moisture is just at the foot of the slope to the east of the road (marked No. 2). This shows the existence of the shallow groundwater there, which can be explained by the fact that the alluvial and coluvial fans developed just at the foot of the

Amaro horst become thinner and thinner with distance from the horst and the material is finer than at the higher parts of the fans, so groundwater emerges from the fans near the surface and/or on the surface in the form of springs. The third area of relative high moisture occurs in the Gelana River valley, where shallow groundwater accumulates in superficial sediments (marked No.3).

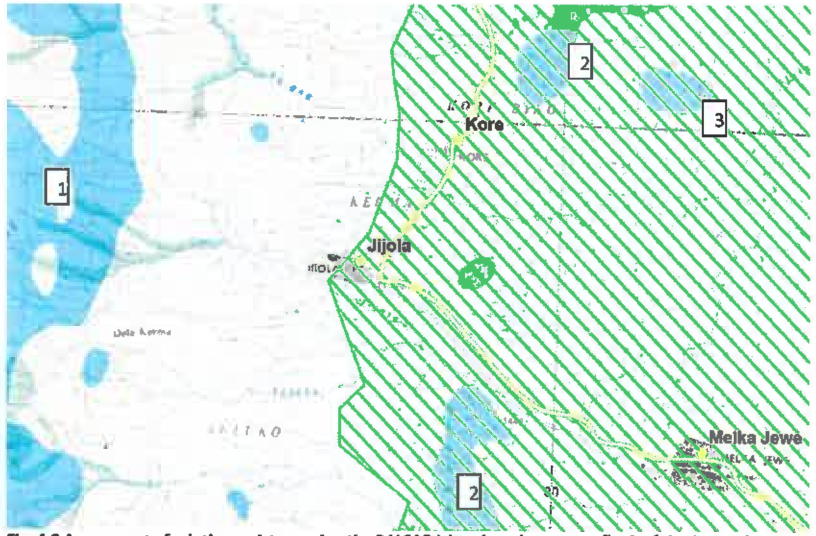


Fig. 4.9 Assessment of relative moisture using the PALSAR L band on the eastern flank of the Amaro horst

The conceptual hydrogeological model of the eastern part of the map sheet is completely different. It is related to groundwater occurrence in areas built by the crystalline rock of the African shield. The groundwater in this type of hard formation can be economically used only in the event that overburden of weathered and decomposed material over the basement is sufficiently thick and saturated by water to provide enough groundwater for water supply. Usually, this is not a common situation and discharge of springs or wells is very small, because the shallow local groundwater regime is not able to maintain groundwater flow and accumulation during dry periods.

Large groundwater accumulations can be found only in areas where basement rocks are broken by faulting along the regional faults and lineaments. In these areas and zones the thickness of decomposed (loose) material is much higher 20-50 m, providing a good opportunity for the accumulation of groundwater. The direction of wadis and permanent river courses usually follows the regional faults and lineaments. Wide fractured zones are usually related to wide wadis. The loose material in wadis and fractured zones is saturated directly by rainfall infiltration but also indirectly by bank infiltration from flowing rivers after rain episodes. This hydrogeological setting leads to the development of a deeper (deep) local groundwater regime, which can maintain groundwater flow and accumulation throughout the whole year. The conceptual model for the occurrence of groundwater is shown in Fig. 4.10. Wells (drilled and dug) are usually concentrated along wide wadis on the Hager Mariam sheet and other areas built by the basement in the southern as well as in the northern parts of Ethiopia. The depth of wells usually varies from 50 to 100 m. Simple VES measurements are usually used to obtain information on the local groundwater depth and thickness of loose material.

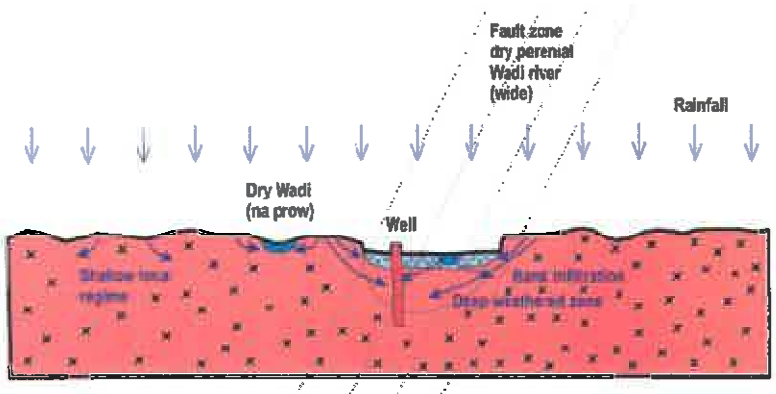


Fig. 4 10 A conceptual model of the occurrence of groundwater in areas built by the basement rock

The existence of deep regional groundwater flow is expected; however, direct evidence in the form of hot springs is missing in the sheet area, although it is known from the Wora Kore hot spring located on the Negele sheet.

The principles of the general conceptual model of the Hagere Maryam sheet are based on seven mechanisms of recharge as well as discharge as follows:

- direct recharge to outcropping aquifers
- vertical recharge from overlying aquifers (mainly developed in superficial sediments) into underlying aquifers build by basalts
- horizontal recharge between aquifers and from rivers during high waters and flowing water in wadis (after rain episodes)
- direct discharge by springs from outcropping aquifers in hill slopes, deep valley and along prominent faults
- direct discharge to rivers
- indirect discharge into aquifers of valleys
- indirect discharge from one aquifer to another (vertical as well as horizontal)

Groundwater is under water table conditions; however, artesian conditions are also known, particularly when highly yielding zone at the base of basaltic aquifers and weathered basement is encountered by drilled wells in deeper valleys e.g. a well drilled for water supply of Hagere Maryam.

Groundwater flow is in general parallel with the surface water flow system and is from the north, west and south to the valleys of the main rivers. The western part of the sheet where aquafers are developed in volcanic rocks is characterized mainly by deeper local and regional circulation and the groundwater

flows for relatively long distances to be drained by rivers and Lake Chamo. The eastern part of the sheet where aquafers are developed in basement rocks is characterized mainly by shallow local circulation and the groundwater flows for short distances (see the hydrogeological map on the CD).

Groundwater (boreholes and springs) remains the main source of water supply for towns and villages within the Hagere Maryam map sheet.

4.5 Annual Recharge in the Area

There is large volume of data from different reports about the assessment of recharge; however, these data vary significantly. The regional mechanism of recharge of aquifers in the area has been described above. As is the case in other areas the groundwater is recharged from precipitation depending on its intensity and annual distribution, topographical gradient of the area, as well as the lithological composition (particularly in the vertical profile) of outcropping rocks and their tectonic disturbance. A substantial part of the groundwater is recharged from direct precipitation. There is also a seasonal but very significant amount of recharge to localized aquifers from most of the permanent as well as intermittent streams after rains when the level of water in rivers is above the groundwater level in the surrounding aquifers developed in superficial sediments covering the basement. Aquifers along the rivers are recharged by the surface water of streams as the flow of many streams is controlled by structures.

Recharge assessment was performed by WWDST (2003) based on rainfall infiltration (recharge from rainfall) according to the rainfall infiltration factor (RIF) to be about 6% for both alluvial sediments and volcanic rocks of the Gelana and Gidabo River basins. The recharge area of outcrops of lithological units was considered only if the slope of the terrain is less than 20 %. WABCO (1990) in the Water Resources Development Master Plan for Ethiopia states a figure of 5 % recharge to the aquifers in the RVLB, representing about 57 mm of the annual recharge.

Tesfaye (1993) characterized recharge in the highlands to be between 150 to 250 mm on the eastern plateau and about 50 to 150 mm in the rift basin on the Hagere Maryam sheet.

The adopted recharge is 50 mm/year for the eastern part of the Negele sheet and 100 mm/year for the western part of Negele sheet (Getachew Zewdie, Jiri Sima, 2011).

Recharge calculated from mean values of baseflow shows a possible variability form 19 mm to 160 mm as shown in Tab. 4.9

Tab. 4.9 Infiltration data

Ma p ID	River	Station	Area [km^2]	Annual flow [mm]	Annual precip. [mm]	Annual infilt. [mm]	Annual infilt. [%]	Dominant Aquifer
1	Dawa	Digati	2375.7	33.7	830	19	2	Basement
2	Mormora	Megado	1375	300.7	1,050	160	15	Basement
3	Awata	Shakiso	1611	324.4	1200	69	6	Basement
4	Gelena	Tore	1523	92.0	1181	41	3	Alluvium/floor
	Upper Gelana	Yirga Chefe	285	83.0	1637	66	4	Volcanic/floor

Low annual infiltration shown by the Dawa in Digati corresponds to high evapotranspiration of rainfall in the southern part of the area where the aridity of the climate increases and the accumulation of groundwater is limited only to alluvial and tectonic zones of aquifers along rivers and wadis. The relatively high infiltration shown by the Mormora and Awasa rivers corresponds to the high elevation of these catchments with relatively high rainfall and less evapotranspiration. Infiltration of nearly 50 mm for the Gelana River corresponds to the calculation of recharge of other catchments in the southern part of the Rift Valley.

Compared to the adopted average depth of precipitation of 950 mm, the calculated infiltration (recharge) can be assessed as being about 50 mm i.e. 5.5 % of the precipitation depth.

7. Hydrogeochemistry

One of the important tasks of the water point inventory and data collection was to study the groundwater chemistry and to assess the groundwater quality for its use within the mapped area. Therefore, a study of the groundwater quality was carried out on the different aquifers (geological formations) of the area as well as various parts of the water circulation system (rain and surface water, as well as groundwater). The results of the hydrochemical study can help to understand the groundwater circulation within the aquifers in addition to comparing the water quality with various standards.

Tesfaye Chernet (1993) identified the hydrochemical characteristics of the natural waters, which were collected from different sources and the recharge/discharge conditions of the groundwater. According to Tesfaye Chernet:

- the water resources of the Rift valley consist of cold groundwater with TDS below 1,000 mg/l, groundwater of the highland has TDS below 500 mg/l in eastern part of the sheet
- the groundwater chemistry is characterized as being dominantly calcium-bicarbonate or calcium-magnesium-bicarbonate sodium-bicarbonate types of water.

Hydrochemical characterization assessed by Halcrow (2008), JICA (2012), Zenaw (2003), and Tesfay (1982) and other authors provide similar results to the previous characterization.

5.1 Sampling and Analysis

A total of 65 water samples were collected from boreholes (41), dug wells (4), springs (11), and surface water (4) in the study area and data on an additional 5 water analyses were collected from different basin study and drilling reports. All of the water samples collected for laboratory analysis were submitted to the central laboratory of GSE and analyzed for chemical composition. The chemistry of the water obtained from the samples is shown in Annex 2. Chemical analysis of the major constituents (Mg, Ca, Na, HCO_3, SO_4, Cl) and secondary constituents (K, NO_3, F, HBO_2, CO_2, SiO_2), and measurements of electrical conductivity (EC) and pH at room temperature were performed in the laboratory. Field measurements of pH, temperature and electrical conductivity were made at the time of sampling. The analytical results were presented graphically on a hydrochemical map to facilitate visualization of the water type and their relationships. Suitability of groundwater for drinking, industrial and agricultural purposes is assessed based on the pertinent quality standards. Reliability of the analyses was assessed using the cation-anion balance. The assessment showed that none of the samples exceeded the reliability level of 10 %. The frequency of the level of balance is shown in Tab. 5.1 and Fig. 5.1.

Tab. 5.1 Level of balance

Level of balance [%]	Frequency	Cumulative frequency [%]
Less than 5	48	64.9
5–10	22	94.6
10–15	4	100.0
More than 15	0	100.0

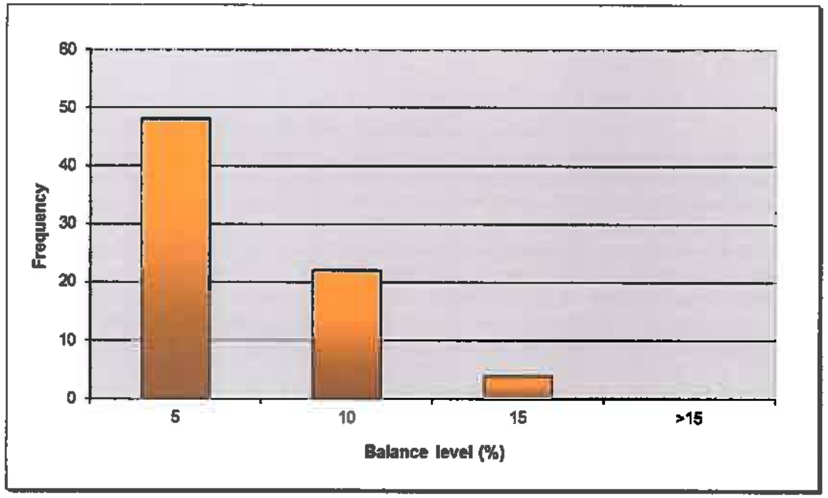


Fig. 5.1 Level of cation-anion balance

5.2 Classification of Natural Waters

Classification of natural water was used to express the groundwater chemistry on the hydrochemical map. Hydrochemical types are classified based on the Meq% representation of the main cations and anions by implementing the following scheme:

- Basic hydrochemical type, where the content of the main cation and anion is higher than 50 Meq%. This chemical type is expressed on the hydrochemical map by a solid color.
- Transitional hydrochemical type, where the content of the main cation and anion ranges between 35 and 50 Meq%, or exceeds 50 % for one ion only. A dominant ion combination is expressed on the hydrogeological map by the relevant colored horizontal hatching. The secondary ion within the type is expressed by an index (e.g. Mg^{2+}).
- Mixed hydrochemical type, where the content of cations and anions is not above 50 Meq% and only one ion has a concentration over 35 Meq%. This type is expressed on the hydrogeological map by the relevant colored vertical hatching.

The chemistry of groundwater in the Hagere Maryam area reflects the hydrological (aquifer) system and system of groundwater circulation and its variability in the geology and hydrogeology of the area consisting of different volcanic rocks partly intercalated with sedimentary and volcano-sedimentary rocks, aquifers developed in superficial sediments and basement rocks. The dominant hydrochemical types of groundwater in the study area are calcium-bicarbonate (see Tab. 5.2). The second most common chemical type is sodium-bicarbonate. These two types are represented mainly by basic and some transitional types. Sodium-bicarbonate type is mainly developed in the southwest and calcium-bicarbonate type is mainly developed in the north and northeast

The low TDS and dominant calcium-bicarbonate type of groundwater indicate the fast hydrogeological regime of the area receiving a relatively high volume of precipitation where groundwater flows in fractured volcanic rocks of plateaus, which are also the main sources of aquifer recharge. Increasing TDS to the south reflects increasing aridity of the area and increasing impact of evapotranspiration on composition of groundwater.

Tab. 5.2 Summary of hydrochemical types

Hydrochemistry	Type	Number of cases	Percentage
$CaHCO_3$	Basic	29	39.2
$CaMgHCO_3$	Basic	1	1.4
$NaHCO_3$	Basic	5	6.8
$CaHCO_2$	Trans	13	17.6
$CaMgHCO_3$	Trans	4	5.4
$CaNaHCO_3$	Trans	1	1.4
$NaHCO_3$	Trans	3	4.1
$NaCaHCO_3$	Trans	5	6.8
CaCl	Trans	2	2.7
$NaMgHCO_3$	Trans	1	1.4
$NaSO_4$	Basic	1	1.4
$CaHCO_3Cl$	Basic	2	2.7
$CaHCO_3SO_4$	Trans	1	1.4
$CaMgHCO_3SO_4$	Trans	1	1.4
$MgHCO_3SO_4$	Trans	1	1.4
$CaNaHCO_3SO_4$	Trans	1	1.4
$CaMgSO_4HCO_3$	Trans	1	1.4
CaCl	Basic	2	2.7

The hydrochemistry of groundwater of the area is expressed on the hydrochemical map by the relevant colored hatching (for transitional and mixed types). To facilitate the visualization of the classification of water types the percentage of the major cations and anions of the analyzed samples is plotted on the Piper diagram as shown in Fig. 5.2.

The basic statistical data for values of electric conductivity (EC), total dissolved solids (TDS) and concentration of chloride (Cl) are shown in Tab. 5.3.

Tab. 5.3 Groundwater descriptive statistics of TDS, EC and Cl values

	TDS [mg/l]	EC [µS/cm]	Cl [mg/l]
Average	465.2	501.6	20.5
Median	350.5	342	1.6
Minimum	97.4	97	161.9
Maximum	2,284	3,070	8.2
Count	74	74	74

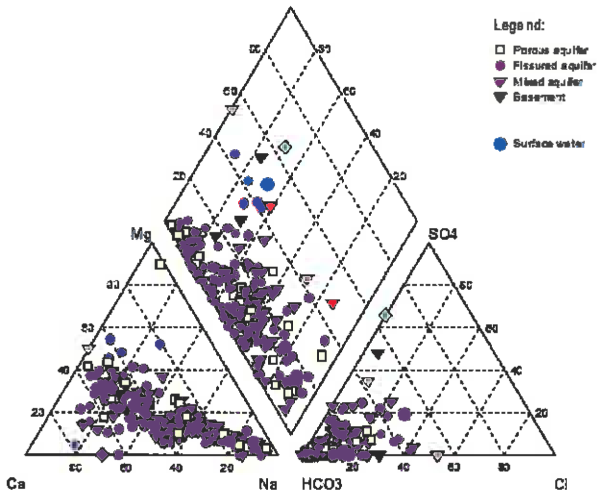


Fig. 5.2 Piper diagram for the classification of natural waters of various aquifers

Groundwater residence time along flow paths, length of water-rock interaction, lithology, ionic exchange, and evaporation play a significant role in the increment TDS and formation of groundwater composition. Major changes in the chemical composition of groundwater occur firstly in the soil zone during the concentration of salts by evaporation and evapotranspiration. A high rate of evaporation and low rainfall concentrates the salts in the soil and when high rainfall occurs it leaches the salts in the soil and moves dissolved solids downwards towards the aquifers saturated by groundwater. The second most important reaction is a result of the contact of water with carbon dioxide. This mechanism is believed to form the sodium bicarbonate groundwater chemistry of the majority of the groundwater.

The development in TDS, which shows no trend, and the relatively uniform hydrochemistry and dominant calcium-magnesium-bicarbonate type of the groundwater indicate the dynamic hydrogeological regime in the western highlands and their structures, including grabens. Groundwater mainly infiltrates into aquifers in the highlands with a cold climate receiving a high volume of precipitation and flows in all directions to the drainage areas formed by the rivers and grabens of the highlands. It flows into lithologicaly homogeneous fissured aquifers developed in various Tertiary volcanic rocks, as well as lithologicaly inhomogeneous fissured and mixed aquifers developed in various volcanic and volcano-clastic-sedimentary rocks, and unconsolidated Quaternary lacustrine sediments in grabens. The gradual development in TDS follows the surface water drainage system. This variability in TDS is shown by idealized isosalinity lines on the hydrochemical map.

5.2.1 Surface Water

Samples taken from four rivers are used to characterize the hydrochemistry of surface water. The composition of river water is relatively uniform and TDS varies insignificantly from 97 to 225 mg/l, based on the character of the river and the main source of water in the river. The surface water chemistry of these rivers is of transitional calcium – sodium - bicarbonate type and represents mainly groundwater drained by the Gelana Rivet at Kombolcha and Tore, Afeleta at Melka Soda, and Awata at Shakiso. The hydrochemistry of surface water is shown on the hydrochemical map by a pie chart.

5.2.2 Groundwater

Groundwater from aquifers hosted in basalt and alluvial sediments is of calcium-bicarbonate type in the northeastern and sodium-bicarbonate type in the southwestern part of the sheet. The types of groundwater are not dependent on the morphological position of the aquifer on the plateau, the type of aquifers (fissured, basement, or porous) or rock type (basalt, basement, alluvial sediments).

Alluvial sediments have groundwater with TDS varying from 151 to 2,284 mg/l. The higher values of TDS are also typical for groundwater accumulated in basement rocks (190 to 1,166 mg/l). Plateau groundwater is characterized by low TDS, which varies from 100 to 500 mg/l; however, higher or lower TDS can be found randomly.

The hydrochemistry of groundwater is expressed on the hydrochemical map by a solid color for the basic type and by the relevant colored horizontal hatching for transitional types.

5.3 Water Quality

The water quality in the mapped area was assessed from the point of view of drinking, agriculture and industrial use.

5.3.1 Domestic Use

To assess the suitability of water for drinking purposes, the results of the chemical analyses were compared with the Ethiopian standards for drinking water (see Tab. 5.5.) published in the Negarit Gazeta No. 12/1990 and The Guidelines of Ministry of Water Resources (MoWR, 2002).

Tab. 5.5 shows that groundwater in the mapped area is convenient for drinking. This situation reflects the fact that the groundwater dissolves solids from volcanic and mixed volcano-sedimentary aquifers and is in contact with the geothermal systems of the rift valley floor. The groundwater of the highlands only requires fixing of pH by simple water treatment and removal of fluorides in several cases.

Tab. 5.5 Groundwater chemistry compared to drinking water standards and guidelines

Property	Range (min–max) [mg/l]	Ethiopian standards (1) and MoWR Guidelines (2) [mg/l]		Number of exceeding values	
		Highest desirable level	Maximum permissible level	Highest desirable level	Maximum permissible level
Na (2)	4.05-648.5		358		1
Ca (1)	2.05-142.45	75	200	13	0
Cl (1)	1.63-160.9	200	600	0	0
Cl (2)	1.63-160.9		533		0
HBO_2	0-0		0.3		0
(free) ammonia		0.05	0.1		
Fe (1)		0.1	1		
Fe (2)		0.4			
Mg (1)	0.1-94	50	150	1	0
Mn (1)		0.05	0.5		
Mn (2)			0.5		
SO_4 (1)	0.05-1003	200	400	2	2
SO_4 (2)	0.05-1003		483		1
TDS (1)	97.39-2284	500	1500	23	2
pH (1)	5.71-9.88	7.0 - 8.5	6.5 - 9.2	30	9
pH (2)	5.71-9.88		6.5 - 8.5		9
NO_3 (1)	0.13-166.25	10	45	12	2
NO_3 (2)	0.13-166.25		50		2
F (1)	0.03-7.4	1	1.5	5	4
F (2)	0.03-7.4		3		2

Particular interest was paid to the content of nitrates in groundwater. The content of nitrates is not related to the rock composition (type) but it reflects pollution of groundwater by human and/or animal waste. The background content of nitrates in groundwater is about 5 to 10 mg/l depending on the relevant land cover. In forest areas it can be even higher because of the decomposition of various plants and other organic material. The nitrate content in the Hagere Maryam area varies from 0.13 mg/l to 166 mg/l (Fig. 5.4).

Water samples (12 out of 74 or 16 %) with a nitrate content of above 10 mg/l show that the first (shallow) aquifers are polluted by human activity. The value of 10 mg/l is considered as the natural content of nitrates in the groundwater. The content of nitrates in 2 water points exceeds 50 mg/l (64.24 and 166.25 mg/l in samples WBH1 and EBH18) showing higher local pollution by nitrates. This pollution is an important factor particularly in vulnerable groundwater resources. This fact also has to be considered when planning for the future development and protection of groundwater resources in the area. Proper location of water points and suitable protective measures should be applied to boreholes, springs and dug wells used for human water supply.

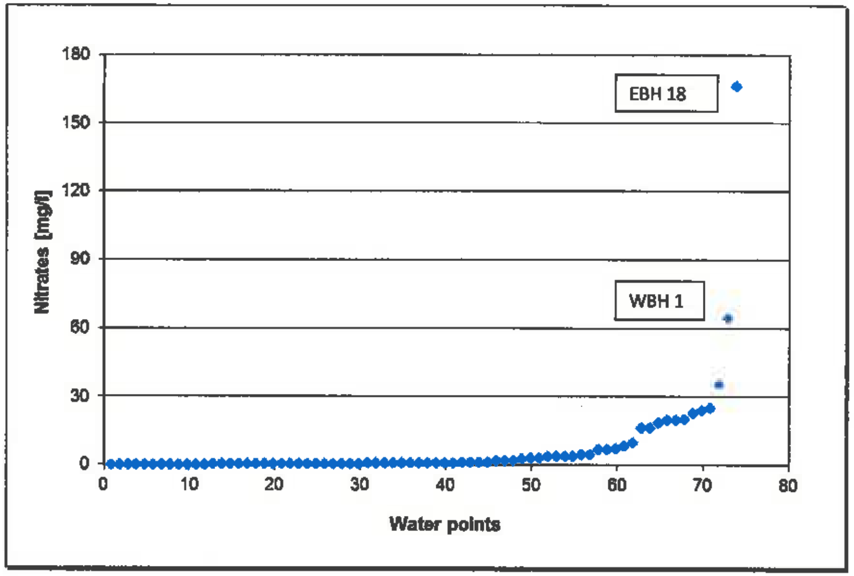


Fig. 5.4 Content of nitrates in the analysis of water in the study area

5.3.2 Irrigation and Livestock Watering Use

Agricultural standards for the quality of groundwater used for irrigation purposes are determined based on the Sodium Adsorption Ratio (SAR), total dissolved solids and United States Salinity Criteria (USSC). The Sodium Adsorption Ratio (SAR) is used to study the suitability of groundwater for irrigation purposes. It is defined by SAR = Na/[(Ca+Mg)/2] where all concentrations are expressed in mg/l.

Tab. 5.6 Suitability of water for irrigation

Value of SAR	Water class	Number of samples in the range
< 10	Excellent	60
10–18	Good	8
18–26	Fair	3
> 26	Poor	3

The majority (96%) of the water samples (see Tab. 5.6) from the study area were found to be suitable for irrigation since they show the SAR value within the water quality class of excellent and/or good for agricultural purposes. Most of water types having sodium (Na) as the dominant cation also have good water quality for irrigation because of a relatively low content of sodium. Application of the United States Salinity Criteria (USSC) revealed that only 2 samples have medium high salinity but are still satisfactory for some irrigation (see Tab. 5.7).

Tab. 5.7 Salinity criteria for irrigation

EC values [µS/cm]	Class	Remarks	Number of cases
< 250	Low salinity	Good	21
250–750	Moderate	Good for soils of medium permeability for most plants	39
750–2,250	Medium high	Satisfactory for plants having moderate salt tolerance, on soils of moderate permeability with leaching	13
2,250–4,000	High	Satisfactory for salt tolerant crops on soils of good permeability with special leaching	1
> 4,000	Excessive	Not fit for irrigation	Nil

The criteria for livestock watering mainly based on the value of total dissolved solids (TDS) are shown in Tab. 5.8 using the Criteria of the Department of Agriculture, Western Australia (1950) and Raghunath (1987). All of the tested water resources can be used for livestock watering.

Tab. 5.8 Suitability of water for livestock watering

Animals	Upper limit of TDS [mg/l]	Number of samples exceeding the limit
Poultry	2,860	1
Pigs	4,290	Nil
Horses	6,435	Nil
Cattle (dairy)	7,150	Nil
Cattle (beef)	10,000	Nil
Adult sheep	12,900	Nil

6.3.3 Industrial Use

Industrial water criteria establish the requirements for the quality of water to be used for industrial processes that vary widely. Thus, the composition of water for high pressure boilers must meet extremely strict criteria, whereas water of low quality can be used for cooling of condensers. The suitability of water for use in industry is shown in Tab. 5.9.

Tab. 5.9 Suitability of water for use in industry

Industry or use	Solids (TDS) [mg/l]	pH	Chlorides as Cl [mg/l]	Sulfates as SO_4 [mg/l]	Number of samples in the range
Brewing	500–1,500	6.5–7.0	60–100		1
Carbonated beverages	< 850		< 250	< 250	65
Confectionary	50–100	> 7.0			1
Dairy	< 500		< 30	< 60	42
Food canning and freezing	< 850	> 7.0			36
Food equipment washing	< 850		< 250		65
Food processing general	< 850				65
Ice manufacture	170–1,300				66
Laundering		6.0–6.5			6
Paper and pulp fine	< 200				13
Paper groundwood	< 500		< 75		50
Paper bleached cardboard	< 300		< 200		30
Paper unbleached cardboard	< 500		< 200		51
Paper soda and sulfate pulps	< 250		< 75		21
Rayon and acetate fiber pulp production	<100				1
Rayon manufacture		7.8–8.3			7
Sugar	< 100		< 20	< 20	1
Tanning		6.0–8.0			65
Textile			< 100	< 100	66

Remark: Sugar requirements for TDS are in general low

Of almost equal importance for industry as the quality of the water used is the relative time constancy in the concentration of various components. As a result, adequate groundwater quality often becomes a primary consideration in selecting a new industrial plant location. Groundwater from the mapped area can be used for industry in general, but some specific technologies require water treatment before it can be used in the technology.

Incrustation hazard is important for the design of various pipes as well as technological processes. Incrustation occurs if concentrations exceed the limits shown in Tab. 5.10. Corrosion hazard occurs if concentrations exceed the limits shown in Tab. 5.11.

Tab. 5.10 Concentration limits for incrustation

Component	Concentration [mg/l]	Number of sample in the range
Bicarbonates (HCO_3^-)	> 400	62
Sulfates (SO_4^{2-})	> 100	68
Silicon (Si)	> 40	30
Iron (total)	> 2	Not analyzed
Manganese (total)	> 1	Not analyzed
Hydrogen sulfide (H_2S)	> 1	Not analyzed
Total hardness (TH as $CaCO_3$)	> 200	Not analyzed

Tab. 5.11 Concentration limits for corrosion

Component	Concentration and/or value	Number of sample in the range
pH	< 7	45
EC	> 1,500 µS/cm	72
Chloride (Cl^-)	> 500 mg/l	74
Hydrogen sulfide (H_2S)	> 1 mg/l	Not analyzed
CO_2	> 50 mg/l	Not analyzed
Dissolved oxygen (O_2)	> 2 mg/l	Not analyzed
Total hardness (TH as $CaCO_3$)	< 100 mg/l	Not analyzed

There is a low threat of incrustation or corrosion when such groundwater is used in pipes for public water supply or for delivery of water for industry or agriculture. The value of pH should be balanced in any case for both industrial as well as drinking water.

8. Natural Resources of the Area

Natural resources of the Hagere Maryam area vary in origin relating to the geological composition, soil conditions, water, wind and solar radiation, as well as human resources.

6.1 Energy Potential

The energy potential of the Genale and Dawa (including Mormora and Awata) rivers is moderate and arises from the combination of large river flow volumes and a topography offering both deep and confined areas for potential dam storage and high water head providing a good potential for turbines.

Geothermal resources are not a large as in the Main Rift Valley; however, further study may highlight the possibilities of economic geothermal power generation.

The area has a good potential for the development of solar and wind energy. It should be feasible to use the produced energy for local supply e.g. running pumps for groundwater development or for distribution of irrigation water. It could also be feasible to use this electricity for running local small businesses such as grain mills, coffee washers, food (milk and coffee) processing and conservation industry etc.

6.2 Industrial Minerals

Kaolinitic clays that are suitable for the production of bricks, tiles, pipes, etc. are available in the study area, mostly as products of weathering of volcanic rocks. A study conducted by the GSE in other parts of the Rift Valley revealed that the kaolin is of good quality for filter, ceramic and fiberglass industries.

Quaternary deposits and laterite soil are used for agriculture and brick work as well as pottery work.

The occurrence of ignimbrite plays an important role in the construction sector serving as a good material for cobble stone work in towns, masonry work for roads, bridges, buildings, crushed aggregate for concrete and road foundations, and dimension stones for buildings. Scoria, which is found on the majority of the rift floor, serves as good quality construction material. Basalt and other volcanic rocks are also good construction materials for all types of construction.

The basement rocks cover a large area in the western part of the sheet and are frequently used as road construction material where volcanic rocks do not exist. Talc, graphite, mica and asbestos are known to occur in the map area. Metallic mineral resources, particularly the Kenticha low grade belt has a good potential for primary gold but it is also well known for mining of gold placers, particularly along the Awata and Mormora rivers and their tributaries where a lot of gold panning sites exist. The belt is also known for containing tantalum minerals and for pegmatite with quartz crystals of optical quality.

Placer gold has been produced in the Adola region, in the eastern part of the map area, since the mid 1930's, with about 31 tons of gold being produced between 1942 and 1981. Prior to 1965 only a couple of primary gold sites were known in the Adola region. The work of the Adola Gold Exploration Project resulted in the discovery of the Lega Dembi deposit and a number of other promising targets. Among those considered significant, and currently undergoing detailed exploration, is the Sakaro occurrence. The Kumudu, Serdoshet, Korkoro, Wollena and Chamola occurrences, earlier thought to be promising, are presently abandoned sites. All the above sites are confined to the Adola low grade belt. The northern section of the Lega Dembi deposit is estimated to contain reserves of 15-20 tons of gold to a depth of 120 m, with an average of 10 g of gold per ton.

A number of nickel occurrences e.g. Tula, Ula Ulo and Kilta are associated with serpentinite bodies. The occurrence of residual chromite in Dermi Dama, like the others in the region, is associated with a serpentinite body about 50 m wide by 100 m long. Rutile is found as either eluvial or alluvial occurrences. Manganese was reported 6.5 km east of the Sirupa-Finchaa road in the south-central part of the map area and radioactive mineralization was reported in the central part of the map area.

6.3 Agricultural Potential

Most of the northern area of the sheet is suitable for agricultural activity like the planting of wheat, barley, bean and pea crops as well as for wood production. The main crops cultivated in the rift floor are maize, vegetables and fruits. Traditional farming methods prevail; however, green houses are becoming more common and irrigation agriculture is being partly developed. Irrigation agriculture is being widely developed along the Bilate River using water from the river and its tributaries for irrigation. Irrigation projects using water from the Gidabo and Gelana rivers are also under preparation.

Bee keeping is common in the area due to dense forest cover and existence of perennial rivers. Both old and modern methods of bee keeping are common particularly northeast of Shakso in the Bore area.

Coffee is commercially planted around Shakiso and in areas northwest, along the road to Hagere Salam.

6.4 Water Resources

Water resources of the studied area depend mainly on rainfall and other climatic characteristics, as well as the hydrological, geological and topographical settings of the study area. The ultimate source of all natural potable water is rain, but in places where it is rarely present other means have to be devised to meet public demand. There are many meteorological stations operated by the Meteorological Institute in the mapped area. Selected meteorological stations with long-term measurements were used to assess precipitation depth. ***The long-term mean annual rainfall of the area has been assessed to be about 950 mm/year.***

The area of the map was calculated from a 1:250,000 hydrogeological map and an area of ***18,145 km² is used for further calculation.***

The areas of active aquifers that have the ability to store and transmit water were calculated based on the hydrogeological map. The active aquifers (Tab. 6.1) of porous and fissured permeability cover an area of 18,145 km^2.

Tab. 6.1 Aquifers of the study area

Aquifers	Area [km^2]
Porous aquifers	2,670
Fissured aquifers in volcanic and basement rocks	4,461 + 11,014
Total of the area	18,145

The runoff characteristics vary widely because of the variability in climatic conditions and hydrogeological characteristics between different observation points.

Surface river flow measurements are performed in many gauging stations in the Hagere Maryam area and river flow measurements were considered in the assessment of surface and baseflow values. The surface flow-baseflow assessment is highly affected by the quality of flow measurements, the effect of bank groundwater storage, difficulties in flow measurements of the wide and unstable river channel and unknown groundwater flow beneath the gauging stations. ***For further calculations, the value of specific surface runoff of 4.0 l/s.km² and specific baseflow of 1.9 l/s.km² for aquifers in the Hagere Maryam sheet.*** The assessed water resources of the Hagere Maryam area are shown in Tab. 6.2.

Tab. 6.2 Assessment of water resources of the Hagere Maryam area

	Input	Area [km^2]	Resources total	Remark
Precipitation	950 mm	18,145	17,237Mm^3/year	
Total water resources – map	4 l/s.km^2	18,145	2,290 Mm^3/year	30 % rainfall
Renewable groundwater resources active aquifers	1.9 l/s.km^2	18,145	1.019 Mm^3/year	5.9 % rainfall
Static groundwater resources of fissured aquifers in basalt*	5 % porosity 100 m thickness	4,331	21,655 Mm^3	Not proved
Static groundwater resources porous aquifers	15% porosity 100 m thickness	2,670	40,050 Mm^3	Not proved

*) static groundwater resources are not considered in all area of the low productive fissured aquifers developed in basement rocks, because accumulation of groundwater which can be developed for effective water supply in relative very small.

Water resources of the area are huge; however, their future utilization within the area depends on changes in the climate, human demands for water, and water resource management practices. Groundwater resources of the highlands which represent an open hydrogeological system are flexible in use with appropriate water management. Groundwater resources accumulated in low productive fissured aquifers developed in basement rocks should be developed very carefully so as not to over pump their local and limited resources.

6.4.1 Surface Water Resources Development

Despite the fact that river gauge measurements show relatively moderate, but logical, evapotranspiration, when nearly 30 % of precipitation is drained as total runoff from the area, there are good water resources to be used for irrigation, as well as for drinking water supply of people living within the area. The total water resources of the area have been assessed to be 2,290 Mm^3/year.

The surface water of the area should be primarily used for irrigation as well as for large and small scale electricity generation in the highlands. The irrigation plans and an assessment of potential and environmental impacts are discussed in detail by Halcrow (2008) and by JICA (2012) for the Lakes Region and by various other specific studies like WWDSE (2004).

6.4.2 Groundwater Resources Development

The river gauge measurements show that nearly 30 % of precipitation is drained as total runoff from the area and about 6 % of precipitation infiltrates and appears as baseflow. There are good groundwater resources to be used for the supply of drinking water to people living within the area. There is also the potential to use groundwater of the area to support irrigation, particularly household irrigation using shallow groundwater in the Gelana River valley and basement area as well as drinking water for people living outside of the mapped area. The total volume of renewable groundwater resources of active aquifers in the area has been assessed to be 2,290 Mm^3/year.

Considering the fact that the total number of people living within the area is 1.4 millons (Tab. 1.1) the need for water supply can be nearly 10.2 Mm^3/year. Assessment of drinking water demand was based on a calculation of 20 l/c.d (15 l/c.d rural and 22.5 l/c.d for towns with less than 15,000 inhabitants). The figure shows that recent demand represents less than 1 % of the renewable groundwater resources of aquifers can provide adequate drinking water even in the future considering the trends in population growth.

Tesfay (2001) describes water supply issues and predicts that a large number of areas fall into the category of "water scarcity" areas because of an increase in population and in demands for more water for agriculture, industry and the community. This situation will be even worse in 2025 based on the trends in population growth. He defined "water scarcity" and "water stress" as cases where less than 1,000 m^3/year and less than 500 m^3/year are available annually per capita, respectively. These limits represent about 511 and 256 Mm^3/year; however, they are not supposed to be covered only from groundwater. Comparing these limits to the overall water resources of the area of 2,290 Mm^3/year, the scarcity limit represents is exceeded and the stress limit is about 17 % of the overall water resources of the sheet. It is necessary to state that the limits are based on the idea of massive human, agriculture and industrial development in the area over the next 15 years.

Most of the people within the area live in large or small towns and villages, which are supplied particularly from drilled wells. In addition to the further development of protected springs and dug wells, the water supply based on drilled wells represents the most sanitary secure water and should be applied for small towns as well as for rural inhabitants.

To select appropriate areas, data from regional as well as detailed surveys have been evaluated, and a strategy chosen which consists in siting of the hydrogeological wells for the supply to population on the following basis:

3. Basalts, trachyte, ignimbrites, alluvial sediments and basement rocks contain groundwater, the quality of which mostly corresponds with the standards for potable water.

4. The yields of the wells, which penetrate basalts and alluvial sediments fluctuate between 2 and 10 l/s, and they are sufficient for the supply for as many as 8,000 to 40,000 inhabitants, the consumption of per person being 20 l/day.

Within the area, the main prospective regions are considered for groundwater development by various methods:

- The mountains areas occupied by the Lower Basalt in the north-west provide very good quality groundwater that could be obtained by drilling moderately deep boreholes (150 m deep). These wells provide large quantities of groundwater, particularly when drilled to the contact zone between the basalt and the basement.
- The alluvial plains along in the Gelana Valley as well as in the tectonic zones in the basement rocks provide large volumes of good quality water that could be abstracted from a depth of 50-100 meters with very little drawdown.
- The eastern piedmont of the Amaro horst provides good groundwater emerging from springs that are usually used for water supply of small towns.

The proposed depth of boreholes sited in the study area should be designed based on the optimum cost and yield of individual wells. During the final siting of each well it is necessary to consider that the final depth of the proposed wells is governed by the level of groundwater which is given by the drainage level (spring altitude, surface water level in river or lake) and surface level of the site selected for well drilling. The drainage level (groundwater level) for each specific site should be derived from the nearby spring and/or surface water level in the river (particularly in case that deep river canyon is nearby) and should be confronted with the site specific surface level of the drilling site and wells drilled before in the vicinity of the proposed well.

The most difficult question will be supply to rural areas with a widely spread population. This should be done from local centers where water wells will be drilled and connected to places of water use with relatively long distribution pipes. Effectiveness and cost of water supply systems for the rural population should be studied as a site specific problem in the future. Springs that emerge from the volcanic formations, especially from the Eastern Highlands, and Amaro horst have a good discharge. The development of springs discharging an adequate volume of water is the best method for securing water supply in these two areas.

Potential groundwater resources existing in the highland areas at the northern part of the sheet surpass the current needs of people living in these areas. They even surpass the potential demand of water when agriculture, living standards and industry will be developed in the future in the area. Groundwater is generally of good quality and a minimum number of samples are not convenient for drinking. The groundwater from sampled points can be used for drinking purposes after the supply system is secured by chlorination. There is a chance to use the groundwater of the highlands for water supplies of the adjacent Rift Valley as well as the Borana lowlands where there is a problem with water scarcity and quality, particularly high TDS.

Some of the existing water points do not represent safe water supplies as they show an increasing content of nitrates in shallow water supply systems. Deeper wells currently represent a safe type of water supply; however, they have to be protected against pollution from local sources like human and animal waste (sources of pathogens, chlorides and nitrates) as well as from potential industry (tanneries, textile industry, flower plantations, etc.). The minimum required distance of water supply wells and potential pollution sources should be maintained during water resource development in towns and villages. The same level of interest should also be applied to the development and protection of groundwater resources for rural communities. It should be necessary to start with relatively concentrated communities where the feasibility and impact of developed schemes will be most significant.

In addition to priority in development of groundwater for safe drinking water supply, it should be possible to select the most fertile soil nearby human settlements and adequate water resources to be developed for irrigation based on groundwater to increase the stability of food supply in prolonged periods of drought. The problem was discussed by Tsur and Issar (1998) who stated that if, as it commonly found in reality, the supply of surface water is uncertain then groundwater plays a role in addition to that of increased water supply: the role of a buffer that mitigates the undesired effects of uncertainty in supply of surface water.

Development and protection of the water resources of the area and the environment as a whole have a principal importance for the development of the infrastructure with subsequent impacts upon the eradication of poverty (development of irrigated agriculture, maintaining livestock during drought). Access to safe drinking water improves the health level of the population (statistics show that 40 % of child death rates are related to water borne diseases). About 35 % of the rural population has access to safe drinking water in the area and about 70 % of infections are related to contaminated water resources. This is a serious problem for the creation of strong farm and pastoral as well as industrial communities capable of full time engagement in working activity. It is therefore important to provide safe drinking water to communities. It is necessary to state that recent years and WaSH program brought significant improvement in safe water supply to towns and communities of the mapped area. Protection of the environment, particularly prevention of soil erosion and degradation leading to food and water scarcity, is an important development aspect within the area. This aspect is based on the importance of water retention which is of primary importance with regard to the increase in population numbers, bringing with it an increase in demands on soil use. The water potential of the area requires feasible and environmentally sound water management.

Other important tasks for the future development are to obtain knowledge about the groundwater resources of the area and to monitor fluctuations in groundwater levels and quality. No monitoring well has been drilled within the aquifers for this purpose. It is recommended to drill several monitoring wells e.g. next to climatic stations and river gauging stations and conduct groundwater monitoring together with measurements of climate characteristics. Selection of monitoring points for observation of groundwater level (quantity) and quality fluctuations in lacustrine and volcanic aquifers should be discussed with the Woreda Water Offices and possibly Hagere Maryam University.

6.5 Human and Land Use Resources and Development

There is a large human resource potential within the area. The total assessed population is 1.4 million and the average population growth in the region is 3 %. Taking this into account the population of the area will double in the next 20–25 years. This represents a large potential of manpower for agricultural production as well as for developing industry using the natural resources of the area as well as services. Agricultural irrigation should be practiced and livestock husbandry should use more effective methods

of livestock breeding, but a key element for the development of the region is the fundamental development of industrial production and services.

Improvement of the health status of inhabitants using safe water supply systems, utilization of the remaining water resources for agricultural irrigation (particularly household irrigation) and for industry and services using other natural resources of the area will improve the standard of life and help to eradicate poverty within this part of Ethiopia.

6.6 Environmental Problems and their Control / Management

Attention is paid to the eradication of poverty, protection of the environment and natural resources as well as the increase in education in this field. The explanatory notes provide information for planning in sustainable economic development, other sectorial planning, management in the use of natural and human resources and protection against natural hazards. The text concentrates on the identification and protection of water resources, soil (particularly protection of soil against erosion), protection against natural hazards and the support of correct wastewater and solid waste management.

Protection of water resources should be concentrated on better practices in sanitation within small towns, villages and rural settlements following principles of WASH program. About 95 % of the surface and groundwater is fair in quality and can be used directly and/or after some treatment (chlorination) for drinking; agricultural and industrial purposes (see Chapter 5). The use of ponds for rain water harvesting is also common in some parts of the study area; however, this type of water resource can be very dangerous when used for human consumption. Indication of improper sanitation practices is reflected in the increase of nitrates from human and animal waste in the shallow groundwater that is used by drilled wells. Water development practices should be based on basic principles of protection as follows:

1. The source of groundwater should not be drilled directly in the center of the village/town.
2. The final design of the well and distribution system should prevent direct percolation of water from the surroundings of the well along its casing to the groundwater.
3. A well should be designed upstream from the groundwater flow direction in respect to existing and potential pollution sources (village, industrial and other similar areas).
4. The required minimal protection zones should be respected by land use development in the vicinity of wells.
5. Regular monitoring of water levels and quality should be performed.
6. There should be improvements in the general application of sanitation and waste management practices, particularly by applying the principles of the WASH program.

Soil erosion and protection is one of the limiting factors of sustainable development of agriculture within the area. The prominent factors for soil degradation in Ethiopia are population pressure, deforestation, poor agricultural techniques, overgrazing and drought. Data about soil erosion in the area are scare. The human causes of soil erosion relate mainly to ploughing and seeding when the heaviest rainfall occur and when crop cover is limited. Another human factor which contributes to soil erosion is the short fallow period (one to four years). Soil burning which destroys the organic matter content of the soil is another adverse factor.

Anti-erosion measures consist of several techniques. Some of the most frequent techniques can be defined as follows:

1. The area of steep slopes along the deep gorges where reforestation is not possible can be terraced (similar to the Konso area and/or on the slopes in the northern part of the country).
2. Retention of water in the countryside–construction of small dams for irrigation can help not only for the accumulation of water for irrigation, but also to slow down runoff after heavy rains and the accumulation of suspended material (eroded soil) in small dams. The accumulated material can be subsequently excavated and used as a fertilizer for arable land.
3. Accumulation of groundwater in arid area of the Borana Zone using subsurface dams in wadis.
4. Wicker fascine is a cheap and very simple anti-erosion measure that can be practiced in all parts of the area either separating agricultural fields of individual owners or implemented inside the field when the fields are big enough and highly prone to erosion.
5. Creation of shrubs/tree rows preventing wind erosion and slowing down surface runoff.
6. Covering artificial cuts (along roads and other constructions) by nets or geo-textile.
7. Other technical measures and agricultural practices.

A focus on soil conservation, particularly on sandy soil, is one of the most important factors for environmentally sound land use. Soil conservation contributes significantly to the food security in the area.

Natural hazard and protection against the consequences of earthquakes, landslides, rock falls and other hazards is important for the preservation of human lives, property and arable land.

Susceptibility to exogenous risks differs both in quantity and quality between the valley and plain engineering geological provinces. The following natural hazard potentials have been identified:

- Slopes of the deep erosion valleys in the highlands with repeated rockslides of all sizes and small to medium sized rock falls.
- Repeated rock falls along the upper rims of the deeply cut valley sides.
- River floodplains have been included into risk susceptible units because of the possibility of floods which can be very severe after torrential rains. The observed lithological-structural changes in cuts of alluvial soils indicate the occurrence of catastrophic floods carrying substantially increased volumes of coarse materials in sub-historical times.
- Soil erosion and protection has been addressed above so we can say that areas especially susceptible to erosion are on medium and low energy relief in residual and sandy soil units derived from ignimbrite. Intensive deforestation and agricultural production in these areas will result in a further increase in the erosion susceptibility.

Wastewater and solid waste management is important for environmentally sound development of the area. Appropriate management in this field protects not only the environment and soil and water resources but also human health against exposure to harmful pathogens and chemicals.

Recent practice is to release wastewater from households as well as from small scale industrial and agro-industrial production directly to the environment. Wastewater is discharged directly to rivers and/or lakes without appropriate treatment. Wastewater is mixed with surface water and is used for irrigation as well as for drinking by people living downstream from wastewater discharge points. People use this polluted water from the river without any knowledge about the potential harm to their health.

There is little chance to educate a large number of people about the possible adverse health impact of using polluted water and that is why the wastewater producers have the responsibility to treat the water to remove substances harmful for human health and environment in general. Infiltration of polluted water to the groundwater threatens the groundwater resources in the area, which is very well documented by the increasing content of nitrates in groundwater.

Solid waste management is poorly practiced within the study area. Alarming is the location of a landfill near towns where the existing waste is deposited without any sorting usually in permeable volcanic rocks.

A focus on environmental care and protection of natural resources will contribute to better living standards of the people living within the area and also to an increase in their working output leading to an increase in food security.

6.7 Touristic Potential of the Area

There is relatively good touristic potential. Hagere Maryam town itself with about 70,000 inhabitants is about 2,000 m above sea level; it has a pleasant climate and it is also in a beautiful location nearby coffee plantations. Hagere Maryam town is a good starting point for longer trips to other tourist areas.

8. Conclusions

Over the past 40 years natural disasters on the Ethiopian territory have increased both in frequency and intensity and have led to severe social impacts, particularly in the southern part of the country. Evidence has long suggested that disaster risk reduction has a high cost-benefit ratio. Disasters also divert a substantial amount of national resources from development to relief, recovery and reconstruction, depriving the poor of the resources needed to escape poverty. Disasters cannot be avoided but there are ways to reduce risks and to limit their impacts.

These explanatory notes to the hydrogeological and hydrochemical map of the Hagere Maryam area provide the results of the joint Czech-Ethiopian projects. The mapping activity was carried out by field groups of hydrogeologists of the GSE in framework of the project joint project in 2015. The mapped area covers 18,145 km^2 and is inhabited by 1.4 million people.

There is a moderate potential for development of surface water for small-scale irrigation and electricity generation in the area because of large rivers in the highlands (Mormora, Awata and Dawa); however, construction of dams and other water management structures should carefully considered in plans for development and environmental protection.

Groundwater accumulates in relatively porous aquifers developed mainly in alluvial sediments and in fissures aquifers developed in volcanic and basement rocks.

Using this detailed information, coupled with geographical, climatic, geological and hydrogeological information, three prospective regions for the development of ground water have been identified.

- The high volcanic mountains composed of basaltic volcanic rocks which form double permeability aquifer systems; good quality water could be obtained from moderately deep boreholes.
- The alluvial plains where intergranular, sedimentary aquifers occur; both shallow and deep ground water resource could be developed with relatively small drawdowns.
- The eastern and southern areas composed of basement rocks where groundwater can be developed along wadis which are controlled by local and regional faults and lineaments using dug and drilled wells having depth 20 to 100m.

Groundwater is of good quality and practically all of the groundwater resources can be directly used for drinking, industrial as well as agricultural purposes. Groundwater should be primarily used for drinking water supply; it should be also used for irrigation but there should be clear evidence that pumping for irrigation does not lead to over pumping of the groundwater resources and cause degradation of the aquifer. Should the aquifer be used for irrigation, monitoring wells are recommended to be drilled together with the production wells for systematic observation of changes in groundwater levels, quality of pumped water and optimization of the pumping system.

The water types in the study area are dominantly Ca–HCO_3 and Na–HCO_3 types with low TDS of groundwater. Local pollution of groundwater by nitrates occurs in rural as well as urban areas due to a lack of protection of water sources. In the case of developed springs their surroundings should be protected against pollution because most of the springs have shallow groundwater circulation and

human as well as animal waste (problem of watering animals directly from the spring) can easily and quickly penetrate the groundwater resources. Springs should be developed by a solid concrete box and it is preferable that the water will flow from the spring by a tube and distributed to people 10–20 m from the spring (lower position of water distribution point). The area of the protection box should be protected against the entry of people and animals; in particular animals should be completely prevented entry. The water distribution systems (bono) should preferably be equipped with a system minimizing discharge of water when it is filled into containers. In the case that water is used for animal watering it should be transported by a tube and distributed to the animals about 20–30 m from the well (lower position of water distribution point – cattle bin). The area of the well head should be protected against accumulation of surface water by drainage ditches and the entrance of animals to the well's surroundings should be completely eliminated.

It is advisable to use geophysical investigation to select locations for siting of wells where the regolith is thick and volcanic rocks are deeply weathered and soft. Groundwater can be totally missing when the regional groundwater table in the aquifer is not reached and/or in cases where the drilled part of the basalt is massive without joints and fissures. The geophysical exploration in basement areas can confirm or deny existence of deep (100 m) fissured zone and position of ground water level in wadis selected for well siting.

Due to the hydrogeological properties of the study area, water supply programs should consider the exploitation of water supply resources through springs, drilled and hand-dug wells depending on position of development site.

Reasons for springs and dug wells are: easy to implement, cost effective, easy to maintain by local communities, the aquifer is shallow and is recharged by infiltrated rainwater as well as river water which is relatively fresh after rainfall episodes (in the case wells dug in aquifers which are connected to rivers).

Drilling of boreholes should be concentrated to aquifers developed in volcanic rocks and thick alluvial and other superficial sediments developed in valleys. Groundwater quality mostly corresponds with the standards for potable water.

The proposed groundwater development should take into consideration the protection and conservation of the natural resources of the area. Particular interest should be paid to soil conservation and groundwater protection using the appropriate agricultural methods to decrease soil erosion and to the implementation of water resource protection to protect groundwater against pollution and over pumping, particularly in rural and urban settlements where pollution by nitrates is increasing. Monitoring of environmental components, particularly surface water flow and sediment load, in gauging stations in the lower reaches of the river should be enhanced. Recent inappropriate wastewater and solid waste management has to be considerably improved.

Despite some local and regional environmental problems the Hagere Maryam area provides good potential for feasible and environmentally sound natural and human resource management.

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Annex 1 Water point inventory, Boreholes from field inventory

Map ID	Site/Kebele	Woreda	Zone	UTM E	UTM N	Elevation	Depth	SWL	Q l/s	topo	T	EC	pH	Aquifer
EBH1	Ebella	Bule Hora	Borena	421400	627430	1961			2.22	Flat plan	22	338	7.4	Basalt
EBH2	Sareji Abude Madana	Bule Hora	Borena	424163	626013	2014	42			Gentle slope	19.9	249	6.5	Basalt
EBH3	Kelinso Mekonis	Bule Hora	Borena	426678	628702	1958				Gentle slope	22.9	288	7.1	Basalt
EBH4	Gedeb	Gedio	Gedeb	416685	654697	2236	107		8.0	Flat plain	20	156	7.5	Basalt
EBH5	Halobare	Gedio	Gedeb	421597	654546	2076	42			Flat plain	21.2	373	7.8	Basalt
EBH6	Warka Galbesa	Gedio	Gedeb	424022	659374	2022	36			Basin Depression	19.8	188.9	6.7	Basalt
EBH7	Banko Chalchale	Gedio	Gedeb	426213	655541	1967				Depression	24.3	111.5	6.86	Basalt
EBH8	Kercha	Kercha	Guji	433803	638469	2000	86		2	Undulating	19.2	269	7.1	Basalt
EBH9	Gurachy Gildu	Kercha	Guji	438792	635748	1990				Flat	19.2	304	8.01	Basalt
EBH10	Darsasake	Kercha	Guji	449832	640719	2034	75		7.0	Depression Swampy	18.8	149.8	6.0	Basalt
EBH11	Bilida Kojoba	Kercha	Guji	439412	646948	2041	100		10	Flat	22	325	7.6	Basalt
EBH12	Banko Michicha	Kercha	Guji	434842	644483									basaltic volcanic rocks
EBH13	Beji Kasa Namesa	Dawa Dugde	Borena	424009	593424	1547	35			Valley	24.3	681	6.6	Regolith metamorphic rocks
EBH14	Die Dawa	Dawa Dugde	Borena	447906	604492	1375	50	5		Plain	26.6	239	6.38	Soil intrusive rocks
EBH15	Deru Denfle	Dugde Dawa	Borena	449356	569074	1277	50?			Plain Wadi Kirkile	28.4	1798	7.3	Alluvium, basement
EBH16	Afelata	Melka Soda	Borena	463302	576608	1091	90			River plain Afelata River	30.2	524	8	Alluvium basement
EBH17	Manti Gerbi	Shakiso	Guji	488371	639505	1667					21.1	236		metamorphic rocks
EBH18	Bedekessa	Shakiso	Guji	487213	642856	1660				Valley, Bedakessa River	21.9	965		Alluvium, basement
EBH19	Welabo	Shakiso	Guji	484563	645296	1718	54				16.8	561		Alluvium, basement
EBH20	Anforen	Adola	Guji	491706	654869	1709	30			Depression	20.8	593		Basement
EBHI1	Birbirsa Bera	Kercha	Guji	437876	627885	1612				Valley				Basalt
EBHI2	Idy Negele	Melka Soda	Guji	438827	592951	1351	97			Plain				Regolith basement
WBH1	Hagere Maryam hotel	Bule Hora	Borena	415108	623111	1865	102		8.0	Gentle slope	18.3	590	7.47	Basalt Lower
WBH2	Jeldo	Bule Hora	Borena	394186	611035	1779	70		0,04	Plain	25.3	380	7.37	alluvium Basalt
WBH3	Suro	Bule Hora	Borena	397216	615755	1743	135		10.35	Valley	25.6	320	7.61	Basalt

Map ID	Site/Kebele	Woreda	Zone	UTM E	UTM N	Elevation	Depth	SWL	Q l/s	topo	T	EC	pH	Aquifer
WBH4	Habas	Bule Hora	Borena	399498	616040	1716				Valley	24.4	310	7.75	alluvium Basalt
WBH5	Moto Koma Hora	Bule Hora	Borena	405636	618659	1910				Undulating	22.1	230	8.0	Basalt
LWBH6	Bule Kegna Town suppl.	Bule Hora	Borena	411306	621461	1768			8.0	Plain				alluvium Basalt
WBH7	Medeba Berguda	Bule Hora	Borena	388250	609689	2080	62		0.5	undulating	21.2	810	7.13	Granite
WBH8	Goche	Burji	Segen	379601	611858	1593	30			Valley flat	27	1220	7.18	eluvium gneiss
WBH9	Jello	Amaro	Segen	386634	643148	1313				Flat plain	27.4	530	7.4	Alluvium
WBH10	Mancity	Tore	Borena	389631	639909	1313	28			Flat plain	27.2	1180	7.38	Alluvium
LWBH1 1	Chemori Town supply	Bule Hora	Borena	412103	626293	1750				Flat				alluvium Basalt
LWBH1 2	Chemori Town supply	Bule Hora	Borena	412076	625877	1743				Flat				alluvium Basalt
LWBH1 3	Chemori Town supply	Bule Hora	Borena	411999	625531	1748	93			Flat				alluvium Basalt
LWBH1 4	Chemori Town supply	Bule Hora	Borena	415017	631015	1738	135			Undulating				Basalt
WBH15	Gara	Tore	Yabelo	392617	644355	1290	76			Flat	28.6	1120	7.25	Alluvium
WBH16	Ano	Tore	Yabelo	399913	649394	1504	38		3.0	Undulating	23.6	970	7.2	Basalt ignimbrite
WBH17	Taye Bodisa	Tore	Yabelo	407433	653821	1715	49	23	1.0	Flat	22.6	430	7.08	Basalt
WBH18	Kare	Kochore	Dila	406457	665953	1719			6.9	Undulating	23	370	7.71	Basalt and rhyolites
WBH19	Anchebe	Kochore	Dila	407943	661103	1851				Undulating	23.4	380	7.14	Basalt
WBH20	Tore town	Gelana	Borena	406447	656268	1709	65			Undulating	28.9	360	7.47	eluvium Basalt
WBH21	Killincho	Burji	Segen	366867	599430	1732				Undulating	24	560	7.27	Basalt
WBH22	Yundefaro	Konso	Segen	343534	590130	927	60			Flat	28.5	850	7.43	Alluvium
WBH23	Segen	Konso	Segen	336469	578613	851	20		5	Stream channel	27.2	970	8.1	Alluvium
WBH24	Binde	Teltele	Yabelo	346346	567067	929				Flat	36.5	320	7.67	Alluvium basaltic volcanic rocks
WBH25	Tedim	Yabelo	Yabelo	407816	557680	1568				Flat	25.7	950	7.4	alluvium Meta-granite

Boreholes from archive of Woredas and Zone with geological logs

Map ID	Site name Kebele	UTM N	UTM E	Elevation [m a.s.l]	Depth (m)	Aquifer (filter)	SWL (m)	Yield (l/s)	DD (m)	Spec q (l/s/m)	T pump. (m^2/d)	T rec. (m^2/d)	Yield recom. (l/s)	Geology at site	Remarks
LBH1	Hado Negele / Finchewa /Teltele	559904	338240	1368	133, 27	21-124	8.3	5.8	39.1	0.15	7.2	NA	6.5	Sediments, basal, scoria	Demis Zewdie 2015
LBH2	Baya Gundi no. 1	575000	450500		150			abandoned						Soil, basement	AQUA Bore holes, 2010
LBH3	Baya Gundi no. 2	57600	4505000		100			abandoned						Soil, basalt, basement	AQUA Bore holes, 2010
LBH4	Surupa	567000	422000		40	11-39	7.75	0.45	25,12 (2.62)					Bedrock	Oromia, 2005
LBH5	Finchwuha	595500	422500		60	21-57	3.43	6.0						Sand, boulder, granite	KLR-Ethio, 2009
LBH6	Cheme 1	583000	434000		72	9-66	2.32	4.5	3.92		60.7	89.7		Alluvial, granite	KLR-Ethio, 2009
LBH7	Gelasa Negeso	622038	436991	1582	51	11-45	4.6	2.5		0.12				Sand, basement	Ethio Water

Galana Woreda borehole summary with geological logs

MapID	Site / Kebele	Zone	Woreda			Z	Depth	SWL	Aquifer
LGBH1	Odolla/ Shamole Oda	Yabelo	Galana	385543	656164	1273	40	22	Sand, clay, gravel
LGBH2	Bulto/ Mexxarri	Yabelo	Galana	388708	638224	1319	73	38	Gravel, clay
LGBH3	Mansiti/ Mexxarri	Yabelo	Galana	389674	639908	1308	42	22	Sand, clay, gravel
LGBH4	Ano/ Qarsa	Yabelo	Galana	399911	649391	1499	45.75	3.6	Gravel, basalt
LGBH5	Gora/ Shamole Shida	Yabelo	Galana	392611	644351	1294	67	28	Sand, clay, gravel
LGBH6	Dima/ Quarsa	Yabelo	Galana	405699	649747	1687	45	22	Gravel, basalt
LGBH7	Malka Hida/ Tore Badiya	Yabelo	Galana	407428	653821	1720	49	23	Gravel, basalt
LGBH8	Dibira/ Barriti	Yabelo	Galana	402661	659710	1754	50	28	Clay, basalt
LGBH9	Koba Konte/ Barriti	Yabelo	Galana	402662	659711	1746	91	31	Clay, tuff, gravel, basalt
LGBH10	Gobta/ Barriti	Yabelo	Galana	404522	673230	1702	91	40	Clay, gravel, basalt
LGBH11	Danse/ Tore Magala	Yabelo	Galana	407409	657406	1747	59		Clay, gravel, (basalt)
LGBH12	Samallo/ Samallo	Yabelo	Galana	410175	650958	1994	48	4	Clay, grave
LGBH13	Shoro/ Chalbesa	Yabelo	Galana	395562	670812	1342	15	2	Gravel, basalt
LGBH14	Suke/ Giwe	Yabelo	Galana	401883	667249	1454	51		Clay, basalt
LGBH15	Marare/ Chalbesa	Yabelo	Galana	401531	670745	1424	49		Ash, gravel, basalt
LGBH16	Golbo/ Erganasa	Yabelo	Galana	364268	657083	1186	20	3.6	Sand, gravel
LGBH17	Shaqarsa/ Erganasa	Yabelo	Galana	364444	660683	1232	27	10.4	Sand, gravel
LGBH18	Shaqarsa/ Ododarba	Yabelo	Galana	364512	660968	1257	18	9	Sand, gravel
LGBH19	Dhosa Goda/ Erganasa	Yabelo	Galana	356199	654232	1181	49		Gravel, sand
LGBH20	Sulula/ Erganasa	Yabelo	Galana	358536	655301	1164	65		Clay, gravel
LGBH21	Oda/ Wodo Darba	Yabelo	Galana	367480	677228	1201	58		Clay, gravel
LGBH22	Qarcame/ Magala	Yabelo	Galana	405469	656295	1684	60		Clay, sand, gravel
LGBH23	Malka Haya/ Tore Badiya	Yabelo	Galana	405543	656342	1640	30		Clay, sand

Borehole from JICA (2012) database

Map ID	Zone, woreda, kebele, Site name	UTM - E	UTM - N	Elevation	Depth	Yield l/s	F	Aquifer
OBH1	Borena, Bule Hora, Finch Wuha town	419412	596305	1621	0	0.00	0.95	metamorphic rocks
OBH2	Borena, Bule Hora, Hag.Mar.Keb 3	415499	622669	1904	0	0.00	0.52	basaltic volcanic rocks
OBH3	Borena, Bule Hora, Hagere Maryam	413837	621972	1818	0	0.00	0.96	basaltic volcanic rocks
OBH4	Borena, Bule Hora, Gerba town	418915	638495	2242	0	0.00	0.76	ignimbrite
OBH5	Borena, Bule Hora, Ebela town	421407	627430	2006	0	0.00	1.52	basaltic volcanic rocks
OBH6	Borena, Gelana, Boriti wachu	403458	655683	1684	0	0.00	0.70	alluvium
OBH7	Borena, Gelana, Baritu Wachu, BWL	404199	661754	1697	0	0.00	0.93	eluvium
OBH8	Borena, Gelana, Baritu Wachu, Kobakante	403632	657382	1687	0	0.00	0.62	alluvium
OBH9	Borena, Gelana, Baritu Wachu, Wachu	403643	660671	1696	0	0.00	0.65	eluvium
OBH10	Borena, Gelana, Jirme, Mume	406324	659016	1736	0	0.00	0.72	basaltic volcanic rocks
OBH11	Borena, Gelana, Jirme, Tore Jirma	405823	657217	1701	0	0.00	0.42	eluvium
OBH12	Borena, Gelana, Metari, Kombolcha	390366	642746	1303	0	0.00	1.22	alluvium
OBH13	Borena, Gelana, Qarssa, Dima	404940	650106	1685	0	0.00	1.24	basaltic volcanic rocks
OBH14	Borena, Gelana, Qarssa, Dogo	392975	641720	1344	0	0.00	0.90	eluvium
OBH15	Borena, Gelana, Qarssa, Qarssa	404157	651237	1679	0	0.00	1.90	alluvium
OBH16	Borena, Gelana, Sam Alo, Ada	410121	647539	1970	0	0.00		basaltic volcanic rocks
OBH17	Borena, Gelana, Shamole, Gora	393942	648219	1282	0	0.00	0.32	eluvium
OBH18	Borena, Gelana, Tore, Chabit	406682	652902	1712	0	0.00	0.34	basaltic volcanic rocks
OBH19	Borena, Gelana, Tore, Tore Town	406444	656268	1715	0	0.00	1.83	eluvium
OBH20	Borena, Gelana, Tore town	406448	656272	1718	0	0.00	0.68	eluvium
OBH21	Borena, Hagere Maryam, Bokko, Addadi Fardo1	427282	590785	1572	0	0.00	0.50	metamorphic rocks
OBH22	Borena, Hagere Maryam, Bokko, Addadi Fardo2	426783	590805	1562	0	0.00	0.27	metamorphic rocks
OBH23	Borena, Hagere Maryam, Bokko, Jirme	429454	594439	1550	0	0.00	0.13	metamorphic rocks
OBH24	Borena, Hagere Maryam, Bule Hora, Bule Hora#1	415500	622667	1908	0	0.00	0.65	basaltic volcanic rocks
OBH25	Borena, Hagere Maryam, Bule Hora, Bule Hora#2	414759	622319	1849	0	0.00	0.24	basaltic volcanic rocks
OBH26	Borena, Hagere Maryam, Bule Hora, Bule Hora#3	413840	621974	1819	0	0.00	0.41	basaltic volcanic rocks
OBH27	Borena, Hagere Maryam, Burqa Arbicho, Burqa	410370	614339	1735	0	0.00	0.27	alluvium
OBH28	Borena, Hagere Maryam, Burqa Ebola, Burqa Ebala	421397	627434	1990	0	0.00	0.27	basaltic volcanic rocks
OBH29	Borena, Hagere Maryam, Chamari Bacha, Chamari Bacha	410901	625535	1793	0	0.00	0.62	alluvium
OBH30	Borena, Hagere Maryam, Didole Hara, Didole Hara	398548	624664	1760	0	0.00	0.00	basaltic volcanic rocks
OBH31	Borena, Hagere Maryam, Didole Hara, Didole Wachu	406721	620879	1946	0	0.00	0.21	basaltic volcanic rocks
OBH32	Borena, Hagere Maryam, Fircha, Fircha	419424	596312	1680	0	0.00	0.92	metamorphic rocks
OBH33	Borena, Hagere Maryam, Fircha, Jigessa	423507	586746	1505	0	0.00	0.54	intrusive rocks
OBH34	Borena, Hagere Maryam, Garba, Garba1	419108	638297	2250	0	0.00	1.60	ignimbrite
OBH35	Borena, Hagere Maryam, Garba, Garba2	418914	638499	2242	0	0.00	1.43	ignimbrite
OBH36	Borena, Hagere Maryam, Hera Lapitu, Hera Lapitu1	418693	643067	2343	0	0.00	0.05	ignimbrite
OBH37	Borena, Hagere Maryam, Hera Lapitu, Hera Lapitu2	422784	643145	2420	0	0.00	0.78	basaltic volcanic rocks
OBH38	Borena, Hagere Maryam, Kuya, Kuya2	415101	614710	1871	0	0.00	0.70	basaltic volcanic rocks
OBH39	Borena, Hagere Maryam, Kuya, Kuya3	417129	616173	1847	0	0.00	0.10	basaltic volcanic rocks
OBH40	Borena, Hagere Maryam, Malka Soda, Malka Soda	455994	607707	1295	0	0.00	0.19	metamorphic rocks
OBH41	Borena, Hagere Maryam, Melekoma Hara, Melkoma Hara	406053	619049	1924	0	0.00	0.06	basaltic volcanic rocks
OBH42	Borena, Hagere Maryam, Muri Meda, Muri Meda1	418148	629911	1902	0	0.00	0.15	basaltic volcanic rocks

Map ID	Zone, woreda, kebele, Site name	UTM - E	UTM - N	Elevation	Depth	Yield l/s	F	Aquifer
OBH43	Borena, Hagere Maryam, Muri Meda, Muri Meda2	418324	630429	1911	0	0.00	0.00	basaltic volcanic rocks
OBH44	Borena, Hagere Maryam, Qilenso Mokonisa, Qilenso Rasa	427171	629023	2012	0	0.00	0.00	metamorphic rocks
OBH45	Borena, Hagere Maryam, Qilenso Mokonisa, Qilenso1	426540	625714	1995	0	0.00	0.00	basaltic volcanic rocks
OBH46	Borena, Hagere Maryam, Qilenso Mokonisa, Qilenso2	426581	625506	1982	0	0.00	0.00	basaltic volcanic rocks
OBH47	Borena, Teltele, Saba, Brindar	346342	567053	930	0	0.00	0.13	basaltic volcanic rocks
OBH48	Borena, Teltele, Saba, Birdar	346350	567056	936	0	0.00	0.50	basaltic volcanic rocks
OBH49	Borena, Yabello, Bildim Raso, Dhaka Baru	410628	587112	1572	0	0.00	0.00	metamorphic rocks
OBH50	Borena, Yabello, Bildim Raso, Didiga(adama tako)	414328	583605	1560	0	0.00	0.00	metamorphic rocks
OBH51	Borena, Yabello, Bildimma, Bora	409464	575519	1616	0	0.00	0.00	metamorphic rocks
OBH52	Borena, Yabello, Bildimma, Dhanicha	413988	572257	1619	0	0.00	0.00	alluvium
OBH53	Borena, Yabello, Bule Biishan, Arbicho	361669	556786	1045	0	0.00	0.24	eluvium
OBH54	Borena, Yabello, Dhadim, Dhadim1	407818	557682	1570	0	0.00	0.00	alluvium
OBH55	Borena, Yabello, Dhadim, Dhadim2	408203	556478	1572	0	0.00	1.35	alluvium
OBH56	Borena, Yabello, Dhedertu, Agamsa	393088	574610	1675	0	0.00	0.08	intrusive rocks
OBH57	Borena, Yabello, Dhedertu, Chabi Harbu	391663	556159	1562	0	0.00	0.49	intrusive rocks
OBH58	Borena, Yabello, Surupa, Buneyata	427594	577006	1508	0	0.00	0.00	metamorphic rocks
OBH59	Borena, Yabello, Surupa, Oda Kilkile	425555	582450	1460	0	0.00	0.09	metamorphic rocks
OBH60	Borena, Yabello, Surupa, Surpha	423475	567960	1610	0	0.00	0.00	metamorphic rocks
OBH61	Borena, Yabello, Tula Wayu, Qurqura	436313	566701	1386	0	0.00	0.12	metamorphic rocks
OBH62	Borena, Yabello, Tula Wayu, Sagada	439560	556245	1414	0	0.00	0.43	metamorphic rocks
OBH63	BURJI	374737	590400	1801	0	1.50		basaltic volcanic rocks
OBH64	BURJI	374494	605132	1810	0	0.00		eluvium
OBH65	GEDEO	415473	659170	2445	0	0.00		basaltic volcanic rocks
OBH66	KONSO	340044	618188	1590	0	2.50		basaltic volcanic rocks
OBH67	WOLAYITA	373910	649340	1912	150	0.00		metamorphic rocks
OBH68	Konso, Konso	339393.7	618023.9	1625	0	0.00	0.00	basaltic volcanic rocks
OBH69	Konso, Konso	336053.5	611398.2	1429	0	0.00	0.00	basaltic volcanic rocks
OBH70	Konso, Konso	352643.4	598091.7	876	0	0.00	2.50	eluvium
OBH71	Konso, Konso	351528	594777.4	878	0	0.00	3.50	eluvium
OBH72	Konso, Konso	342654.5	591480.5	940	0	0.00	0.00	alluvium
OBH73	Konso, Konso	341546.2	591483.1	946	80	0.00	0.27	basaltic volcanic rocks
OBH74	Konso, Konso	343760.3	590372.3	910	0	0.00	0.00	alluvium
OBH75	Konso, Konso	336053.5	611398.2	1436	0	0.00	0.00	basaltic volcanic rocks
OBH76	Konso, Konso	334939.9	609189.6	1314	0	0.00	0.89	basaltic volcanic rocks
OBH77	Konso, Konso	337177.9	618029.4	1595	0	0.00	0.00	basaltic volcanic rocks
OBH78	KONSO, Gumayide (kebele)	340044	618188	1390	0	2.50		basaltic volcanic rocks
OBH79	KONSO, Loltu (kebele)	335106	610012	1809	98	1.10		basaltic volcanic rocks
OBH80	BURJI, Soyama (kebele)	374494	605132	1780	0	0.00		eluvium
OBH81	BURJI, Soyama (kebele)	374494	605132	1810	0	0.00		eluvium
OBH82	KONSO, Gumayide (kebele)	340044	618188	1590	0	2.50		basaltic volcanic rocks
OBH83	KONSO, Loltu (kebele)	335106	610012	1346	98	1.10		basaltic volcanic rocks
OBH84	WOLAYITA, Shola Kodo	373910	649340	1912	150	0.00		metamorphic rocks
OBH85	BURJI, Burji, Werdeya dimbeyo (kebele)	379416	609396	1247	60	0.50		eluvium
OBH86	BURJI, Burji, Werdeya gude (kebele)	379360	607956	1719	51	2.00		alluvium

Map ID	Zone, woreda, kebele, Site name	UTM - E	UTM - N	Elevation	Depth	Yield l/s	F	Aquifer
OBH87	BURJI, Burji, Werdeya dimbeyo (kebele)	379416	609396	1809	60	0.50		eluvium
OBH88	BURJI, Burji, Werdeya gude (kebele)	379360	607956	1709	51	2.00		alluvium
OBH89	KONSO, Konso, Tarso (kebele)	333911	589989	1330	95	0.00		basaltic volcanic rocks
OBH90	KONSO, Konso, Tarso (kebele)	333911	589989	1223	95	0.00		basaltic volcanic rocks
OBH91	Gedeo, Gedeb	410018	616778		47	0.00		basaltic volcanic rocks

Springs from field inventory

Map ID	Site name	Woreda	Zone	UTM - E	UTM - N	Elevation	Q l/s	Topo	Aquifer	T	EC	pH	Remark
ECS1	Sorile	Bure Hora	Borena	486400	622029	1895	1.1	Valley side	Basalt	19	108	7.0	Developed
ECS2	Halobare	Gedeb	Gedio	421861	654644	2047	0.02	Hill side	Basalt	18.7	272	6.9	Contact
ECS3	Warka	Gedeb	Gedio	423215	655884	2208	0.54	Depression	Basalt	18.9	274	6.6	
ECS4	Banko Chalchala	Gedeb	Gedio	427832	654786	1997	10.0	Depression	Basalt	19.6	253		
ECS5	Soke	Guji	Kercha	440866	622956	1494	0.06	Depression	Gneiss	20.4	584	6	
ECS6	Hofe	Guji	Kercha	435172	637894	2018	0.5	Depression	Colluvium	19.1	323	6.5	Perched
ECS7	Dersa Edera	Guji	Kercha	447793	641076	2030	0.2	Depression	Basalt	19.1	159	6.1	
ECS8	Bukisa Bilida	Guji	Kercha	442875	643139	1969	2.5	Fracture	Basalt	19.5	251	6.5	Swamp
ECS9	Welgai Medanu	Borena	Dugda Dawa	421409	599358	1698	0.02	Fracture	Pegmatite calcite	23.6	193	6.8	Finchewa Town supply
WCS1	Hichini			390039	609332	2093	none	Valley	Granite				Stagnant
WCS2	Harteshe	Burji	Segan	368552	607086	2148	2.5	Slope break	Basalt	21	200	7.19	Contact with basement
WCS3	Danse	Borena	Gelana	407999	656617	1779		Topo break	Basalt	24.6	150	7.45	

Dug Wells from field inventory

Site ID	Site name	Zone	Woreda	X UTM	Y UTM	Elevation [m a.s.l]	Depth [m]	SWL	Topo	Aquifer	Field T	Field EC [µS/cm]	Field pH
EDW1	Gatessa Dibisa*	Guji	Kercha	437876	627885	2050	8		Rugged	Basalt	20.4	486	7.26
EDW2	Idy Negele**	Borena	Mekla Soda	438859	593142	1342	4	3.5	Plain	Soil	23.4	815	7.26
WDW1	Cheleletu***market place	Dila	Cheleletu	405920	663240	1696	2.5	2.0	Plain	Soil/basalt	22.2	540	
WDW2	Jirme	Borena	Gelana	405819	657219	1695	9			Basalt	28.5	340	7.34

*Variation in water level is 4 m

**Variation in water level is 4 m

***Variation in water level is 2 m

Springs from JICA (2012) database

Map ID	Zone, Woreda, Kebele, Site name	UTM - E	UTM - N	Altitude	Yield l/s	F mg/l	Aquifer
OSP1	KONSO, Konso, Segengent (Kebele)	338005	618248	1590	0.10		basaltic volcanic rocks
OSP2	WOLAYITA, Sodo Zuriya, Soro wumura (Kebele)	373944	652445	1936			metamorphic rocks
OSP3	Borena, Bule Hora, Sorile Wachu	428646	622044	1871		0.34	basaltic volcanic rocks
OSP4	Borena, Gelana, Tore, Danse	408186	656677	1731		0.66	ignimbrite
OSP5	Borena, Gelana, Danse	408188	656677	1731		0.56	ignimbrite
OSP6	Borena, Hagere Maryam, Burqitu, Burqitu	417439	600551	1652		0.49	metamorphic rocks
OSP7	Borena, Hagere Maryam, Qilenso Mokonisa, Mekanisa1	426946	626452	1931		0.00	metamorphic rocks
OSP8	Borena, Hagere Maryam, Qilenso Mokonisa, Mekanisa2	427139	626059	1944		0.00	metamorphic rocks
OSP9	Borena, Hagere Maryam, Qilenso Mokonisa, Suke1	424573	626758	1984		0.24	basaltic volcanic rocks
OSP10	Borena, Hagere Maryam, Qilenso Mokonisa, Suke2	424022	625964	1965		0.34	basaltic volcanic rocks
OSP11	Borena, Hagere Maryam, Sorile Wachu, Haro	430212	620527	1881		0.29	basaltic volcanic rocks
OSP12	Borena, Hagere Maryam, Sorile Wachu, Sorile Wachu	428665	622048	1883		0.79	basaltic volcanic rocks
OSP13	BURJI, Burji	378773	581400	1641	0.20		metamorphic rocks
OSP14	BURJI, Burji	367275	598190	1970			basaltic volcanic rocks
OSP15	BURJI, Burji	371148	598900				basaltic volcanic rocks
OSP16	BURJI, Burji	368594	610372	2313	0.04		basaltic volcanic rocks
OSP17	DAWURO, Loma	371747	659100	2055			metamorphic rocks
OSP18	DAWURO, Loma	371359	655020	2435			metamorphic rocks
OSP19	DAWURO, Loma	371403	655120	2457			metamorphic rocks
OSP20	DAWURO, Loma	372029	657070	1328			metamorphic rocks
OSP21	DAWURO, Mareka	371141	659030	1851			basaltic volcanic rocks
OSP22	DAWURO, Mareka	371147	659420	2053	0.10		basaltic volcanic rocks
OSP23	GEDEO, Kochere	409892	658220	1930			ignimbrite
OSP24	GEDEO, Kochere	408449	633710	2020			metamorphic rocks
OSP25	GEDEO, Kochere	410902	633320	2040			metamorphic rocks
OSP26	GEDEO, Kochere	411059	642120	2003			basaltic volcanic rocks
OSP27	HADIYA, Misha	366914	649685	2498			basaltic volcanic rocks
OSP28	KONSO, Konso	338005	618248	1564	0.10		basaltic volcanic rocks
OSP29	WOLAYITA, Sodo Zuriya	373944	652445	1936			metamorphic rocks
OSP30		340514	663331	1897			basaltic volcanic rocks
OSP31		390174	616377	1778	1.00		basaltic volcanic rocks
OSP32		413840	621971				basaltic volcanic rocks
OSP33	HADIYA, Misha, Buama (Kebele)	366914	649685	1638			basaltic volcanic rocks

Dug wells from JICA (2012) database

Map ID	Zone, Woreda, Kebele, Site name	UTM - E	UTM - N	Altitude	Depth	Yield l/s	F mg/l	Aquifer
ODW1	Borena, Gelana, Metari, Idi Bira	388630	643888	1304			0.36	alluvium
ODW2	Borena, Arero, Galaba, Galaba	458945	564357	1220			0.16	intrusive rocks
ODW3	Borena, Arero, Galaba, Galaba	460814	564376	1218			0.19	metamorphic rocks
ODW4	Borena, Gelana, Jirme, Ela Bofa	405779	658197	1691			0.46	basaltic volcanic rocks
ODW5	Borena, Gelana, Jirme, Mogasso	406062	662349	1705				basaltic volcanic rocks
ODW6	Borena, Hagere Mariam, Kuya, Kuya1	415547	614569	1873			0.03	basaltic volcanic rocks
ODW7	BURJI, Burji,	380256	643600	1554				eluvium
ODW8	BURJI, Burji	375082	558500	1785				basaltic volcanic rocks
ODW9	BURJI, Burji	375137	571600	1797				eluvium
ODW10	BURJI, Burji	375356	641000	1709				metamorphic rocks
ODW11	BURJI, Burji	379416	609396	1809	6.0	0.5		eluvium
ODW12	BURJI, Burji	379360	607956	1709	5.1	2		alluvium
ODW13	GAMO GOFA, Arba Minch Zuria,	344759	658830	1199	9.3			basaltic volcanic rocks
ODW14	GEDEO, Kochere	415344	657290	2439				basaltic volcanic rocks
ODW15	GEDEO, Kochere	415545	660640	2452				basaltic volcanic rocks
ODW16	GEDEO, Kochere	415721	662790	2450				basaltic volcanic rocks
ODW17	GEDEO, Kochere	415736	662450	2441				basaltic volcanic rocks
ODW18	GEDEO, Kochere	404950	642420	1690				basaltic volcanic rocks
ODW19	GEDEO, Kochere	405370	650760	1700				eluvium
ODW20	GEDEO, Kochere	417785	650680	2464				ignimbrite
ODW21	GEDEO, Kochere	418371	652890	2455				ignimbrite
ODW22	GEDEO, Kochere	417752	637820	2507				ignimbrite
ODW23	GEDEO, Kochere	406520	663110	1715				basaltic volcanic rocks
ODW24	GEDEO, Kochere	406712	648390	1749				basaltic volcanic rocks
ODW25	GEDEO, Kochere	406837	636140	1756				basaltic volcanic rocks
ODW26	GEDEO, Kochere	407845	638330	1825				basaltic volcanic rocks
ODW27	GEDEO, Kochere	409815	646140	1974	20.1			ignimbrite
ODW28	KONSO, Konso	335106	610012	1346	9.8	1.1		basaltic volcanic rocks
ODW29	KONSO, Konso	333911	589989	1223	9.5			basaltic volcanic rocks
ODW30		415526	622663	0				basaltic volcanic rocks
ODW31	Borena, Bule Hora,Fesheka	415103	614718	1861			1.24	basaltic volcanic rocks
ODW32	Borena, Bule Hora, Burka	410367	614341	1752			0.47	alluvium
ODW33	Borena, Bule Hora, Lipitu	418697	643063	2343			1.13	ignimbrite
ODW34	Borena, Gelana, Qersa	404157	651237	1686			1.60	alluvium
ODW35	Borena, Gelana, Chabitti	406680	652905	1708			0.99	basaltic volcanic rocks
ODW36	Borena, Gelana, Jirme	405821	657215	1706			0.66	eluvium
ODW37	Borena, Gelana, Burqa	403644	660672	1695			0.27	eluvium

River samples from field inventory

Site ID	River name	Zone	Woreda	X UTM	Y UTM	Elevation [m a.s.l]	Depth [m]	With	Speed	Flow m^3/s	Aquifer	Field T	Field EC [µS/cm]	Field pH
ERV1	Afeleta	Borena	Melka Soda	444174	604505	1282	0.3	5	0.5	0.75	Basement	22.8	187.6	7.8
WRV1	Gelana at Kombolcha	Tore	Yabello	390688	643012	1291	1	6		3.0	Alluvium	22.9	240	7.88
WRV2	Gelana at Tore	Tore	Yabello	405706	650375	1667					Basalt	21.2	190	7.7
ERV2	Awata in Shakiso	Shakiso	Guji	492086	639200	1624	1	28		9.3	Basement	20.7	96.3	

Annex 2 Chemical analyses (data in mg/l)

ID	Na^+	K^+	Ca^{2+}	Mg^{2+}	CO^{2-}_3	HCO_3^-	Cl^-	F^-	SO^{2-}_4	NO^-_3	SiO_2	pH	EC,µS/Cm	TDS
EBH 1	11.95	3.11	39.75	14.40	ND	213.50	7.94	0.14	<0.10	4.42	55.21	7.27	342.00	350
EBH 2	6.16	2.58	22.30	6.45	ND	90.03	30.20	0.17	<0.10	0.89	56.92	6.34	244.00	216
EBH 3	15.40	1.94	28.90	6.05	ND	143.96	8.36	0.20	<0.10	24.81	45.37	7.33	285.00	275
EBH 4	7.02	2.78	14.42	5.60	ND	100.04	1.63	0.29	<0.10	<0.44	41.09	7.54	157.00	173
EBH 5	34.95	2.88	31.00	15.55	ND	259.86	2.20	0.25	<0.10	<0.44	48.79	8.18	371.00	395
EBH 6	4.65	1.62	22.20	7.90	ND	102.48	3.90	0.24	<0.10	6.65	30.39	6.88	187.00	180
EBH 7	5.40	1.36	11.74	3.52	ND	70.76	1.63	0.25	<0.10	0.89	47.08	7.06	110.00	143
EBH 8	34.35	1.24	22.20	5.55	ND	167.14	7.66	0.18	<0.10	1.33	35.01	7.28	265.00	275
EBH 9	34.50	1.88	23.75	7.90	2.40	189.10	3.47	0.25	<0.10	<0.44	32.10	8.34	301.00	295
EBH 10	5.85	0.88	26.20	9.75	ND	163.48	5.81	0.24	<0.10	<0.44	32.10	7.14	242.00	244
EBH 11	13.95	1.38	28.55	15.75	ND	207.40	4.40	0.28	<0.10	<0.44	47.94	8.08	318.00	320
EBH 12	17.60	3.40	27.80	9.75	ND	197.64	5.18	0.55	<0.10	<0.44	42.80	7.55	286.00	305
EBH 13	8.40	0.95	26.20	11.40	ND	148.84	4.04	0.98	<0.10	0.44	39.38	6.45	237.00	241
EBH 14	67.20	1.01	51.30	9.30	ND	303.78	8.08	0.13	5.00	1.33	57.78	6.77	675.00	505
EHDW 1	15.80	7.96	63.30	8.10	ND	241.56	22.69	0.22	22.80	9.75	40.23	7.23	472.00	432
EHDW 2	54.20	3.51	76.60	30.80	ND	488.00	9.22	0.15	38.28	18.61	37.66	7.33	786.00	757
EHDW 3	5.70	2.25	11.90	7.20	ND	57.00	5.96	0.13	34.22	1.33	25.68	6.63	138.00	151
EHDW 4	15.20	2.15	91.30	16.20	ND	258.64	33.68	0.22	16.08	22.59	36.38	6.67	772.00	492
ECSP 1	5.64	0.70	10.83	2.98	ND	37.00	6.89	0.15	0.99	3.10	32.10	6.15	113.00	100
ECSP 2	4.60	1.24	30.35	12.55	ND	164.70	5.32	0.13	<0.10	3.10	40.66	6.94	268.00	263
ECSP 3	5.15	1.50	29.75	9.10	ND	161.04	6.59	0.14	<0.10	8.42	47.94	6.66	275.00	270
ECSP 4	8.80	1.72	30.10	9.00	ND	146.40	7.23	0.18	<0.10	0.89	49.65	6.55	254.00	254
ECSP 5	22.50	2.55	59.70	28.00	ND	253.76	35.88	0.24	14.25	35.44	42.80	6.91	577.00	495
ECSP 6	11.75	1.10	26.30	13.55	ND	185.44	9.22	0.26	<0.10	2.66	42.37	6.65	323.00	293
ECSP 7	7.58	0.62	14.48	6.10	ND	73.22	11.91	0.12	<0.10	<0.44	32.53	6.11	160.00	147
ECSP 8	4.05	0.88	36.00	13.05	ND	131.76	9.57	0.14	<0.10	4.43	33.81	6.57	250.00	234
ECSP 9	11.15	3.89	25.30	7.10	ND	108.58	6.31	0.39	8.50	<0.44	60.78	6.83	194.00	232
ERV 1	6.65	1.60	18.65	7.15	ND	107.36	6.45	0.14	10.91	0.89	29.53	7.71	188.00	189
ERV 2	5.06	1.12	11.60	3.36	ND	36.60	13.47	0.08	9.28	0.44	16.38	7.09	97.20	97
EBH 15	125.00	7.46	142.45	94.00	ND	699.10	129.00	0.67	465.70	1.33	50.92	7.56	1767.00	1716
EBH 16	49.30	3.27	47.10	12.40	ND	180.00	35.45	0.26	137.20	0.44	25.24	8.15	517.00	491
EBH 17	16.83	1.60	20.35	6.10	ND	31.72	42.89	0.06	27.03	3.99	39.45	5.71	233.00	190
EBH 18	83.50	3.16	65.75	38.25	ND	240.34	79.40	0.21	67.35	166.25	49.59	6.97	949.00	794
EBH 19	22.40	1.20	66.50	24.50	ND	195.20	39.70	0.10	122.00	3.99	57.12	6.64	552.00	533
EBH 20	32.30	3.51	56.60	28.40	ND	151.30	34.70	0.09	165.70	7.09	32.77	6.65	586.00	512
WBH 1	37.80	2.94	72.30	22.50	ND	214.72	39.70	0.09	6.14	64.24	48.26	7.23	568.00	509
WBH 2	31.15	3.09	37.30	11.35	ND	203.74	12.55	0.14	6.35	0.44	49.59	7.71	359.00	356
WBH 3	32.65	3.69	26.15	7.65	ND	175.70	7.59	0.12	5.85	0.44	50.92	7.55	300.00	311
WBH 4	50.25	0.46	14.75	3.90	ND	172.02	12.90	0.11	10.90	0.44	23.44	7.78	297.00	289
WBH 5	45.05	0.66	2.05	0.10	28.80	20.74	11.41	0.08	1.82	0.44	17.71	9.88	217.00	129

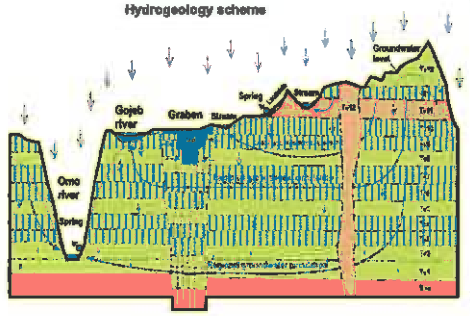
WBH 7	41.20	2.46	86.40	23.20	ND	131.76	160.90	0.03	28.95	23.92	71.73	6.49	780.00	571
WBH 8	102.25	2.32	128.25	49.75	ND	711.30	60.79	0.60	19.95	16.39	73.95	7.15	1188.00	1166
WBH 9	27.30	2.73	79.30	22.00	ND	330.60	6.20	0.25	6.50	0.89	63.32	7.56	515.00	539
WBH 10	145.50	1.96	80.00	36.75	ND	619.78	29.90	0.32	122.60	0.44	61.15	7.61	1115.00	1098
WBH 15	173.75	4.90	67.50	26.50	ND	697.80	18.78	0.39	30.74	0.44	37.64	7.30	1089.00	1058
WBH 16	40.75	3.36	133.50	43.00	ND	618.50	16.66	0.29	6.03	3.99	74.72	7.05	938.00	941
WBH 17	18.30	3.36	56.00	15.80	ND	270.80	5.53	0.14	<0.10	0.44	55.35	6.58	417.00	426
WBH 18	24.70	4.17	41.50	11.35	ND	257.40	2.84	0.10	<0.10	0.44	47.38	8.02	355.00	390
WBH 19	9.45	1.62	53.83	17.15	ND	239.12	5.67	0.10	<0.10	0.89	44.59	6.77	367.00	372
WBH 20	27.85	5.92	30.90	11.35	ND	220.80	1.92	0.10	1.64	0.44	61.99	7.68	373.00	363
WBH 21	21.00	1.40	53.30	20.30	ND	280.60	13.26	0.11	39.89	0.44	53.14	7.25	451.00	483
WBH 22	81.10	2.02	55.90	42.30	ND	497.76	22.33	0.10	16.79	19.49	48.26	7.88	815.00	786
WBH 23	178.00	13.40	24.75	16.50	ND	602.70	23.68	0.24	39.89	0.44	49.15	8.30	969.00	949
WBH 24	648.50	18.52	24.00	18.00	ND	470.90	25.45	1.65	1003.00	0.44	73.50	7.88	3070.00	2284
WBH 25	70.75	6.70	118.75	31.75	ND	573.40	9.39	7.40	66.42	0.89	77.93	7.57	915.00	963
WCSP 1	29.90	7.15	65.00	17.70	ND	97.60	113.23	1.60	40.32	19.94	49.59	6.55	620.00	442
WCSP 2	6.40	1.18	29.50	8.25	ND	125.70	2.62	0.12	<0.10	0.44	29.67	6.88	202.00	204
WCSP 3	11.42	1.56	13.52	3.68	ND	85.40	2.34	0.14	7.73	<0.44	60.66	7.22	141.60	186
WRW 1	9.40	3.43	27.05	8.10	ND	126.90	5.67	0.18	19.06	0.89	24.79	7.45	226.00	225
WRW 2	6.50	3.40	23.05	6.90	ND	104.92	5.46	0.15	8.52	6.65	25.23	7.39	182.60	191
WDW 2	23.10	3.62	36.85	11.00	ND	207.40	3.40	0.12	3.27	0.44	25.23	7.25	323.00	314
LWBH 11	42	3.3	33.44	8.21		256.2	5.46	0.56	0.1	0.13		7.48	384	349
LWBH 12	32	3	59.28	15.5		322.1	11.14	0.65	1.14	0.7		6.65	495	446
LWBH 13	41.5	3.5	44.8	11		219.6	4.6	0.54	81.6	0.25		6.65	495	407
LWBH 6	21	2.8	77.5	28.3		366.4	36.4	1.06	2.51	2.1		7.13	697	538
LWBH 14	96	4.4	26.6	6.84		269	14.56	5.12	77.68	0.22		7.49	591	500

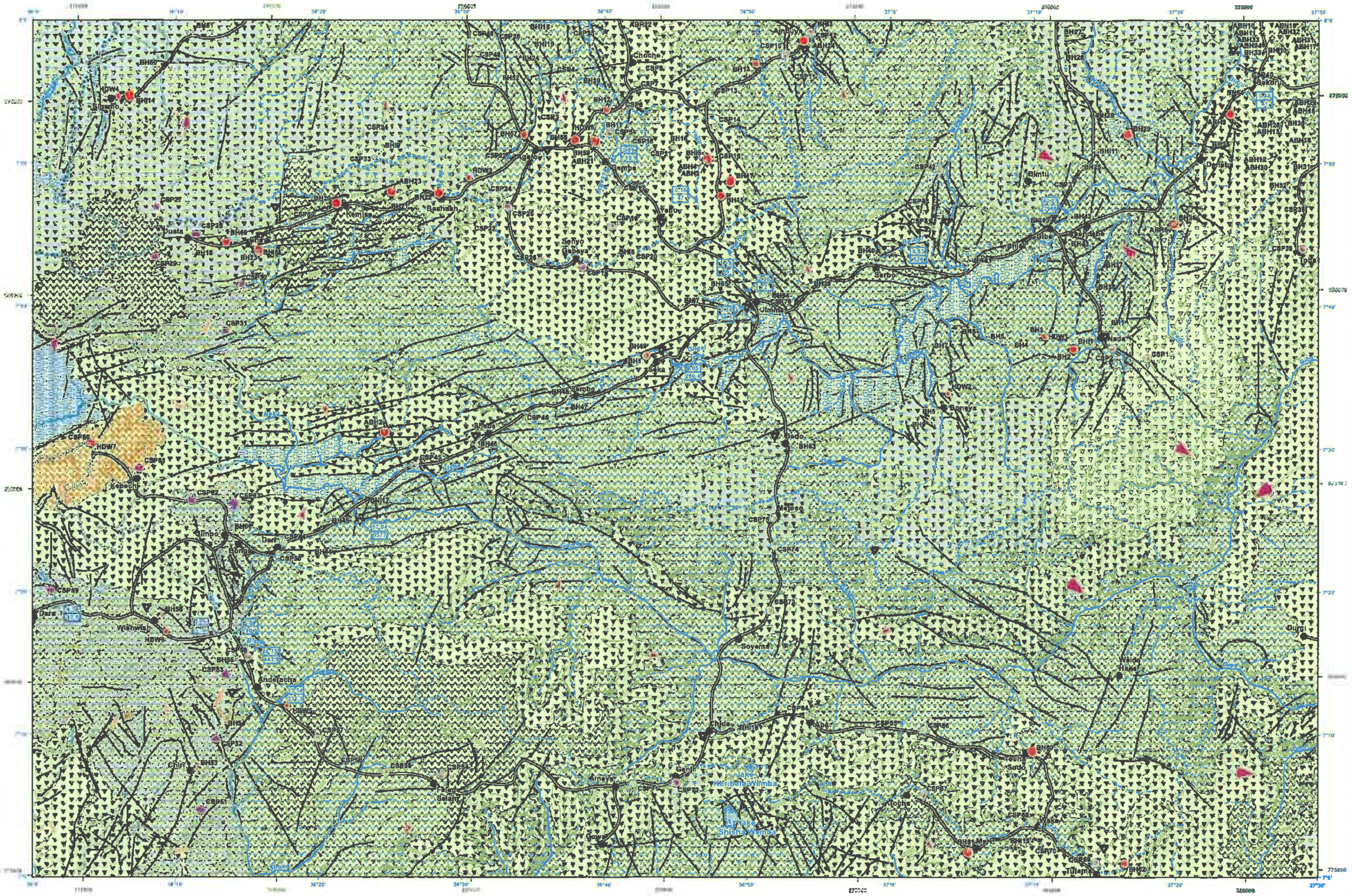
HYDROGEOLOGICAL MAP OF JIMA NB 37-1

Map sheet scheme

Scheme of main basins

Hydrogeology scheme





Hydrogeological mapping (2015) by:
Thomas Agezew, Marta Wegu, Kindye Alemnew

Chief Compilers: Thomas Agezew
Editor: Jiri Sima
Digital cartography: Antonin Orgon

Scale 1:250 000

Geology compiled by:
Workineh Haro, Asamnew Besufikad,
Daba Bulto, Fekadu Beletes (2012)

Printed by the Geological Survey of Ethiopia in collaboration with the Czech Republic Development Cooperation - 2015

LEGEND:

Groundwater and rocks

- Extensive and moderately productive or locally developed and highly productive porous aquifers ($T = 1.1–10\ m^2/d$, $q = 0.011–0.1$ l/s.m, with spring and well yield $Q = 0.51–5$ l/s). The aquifers consist of Quaternary alluvial deposits.
- Extensive and moderately productive fissured aquifers ($T = 1.1–10\ m^2/d$, $q = 0.011–0.1$ l/s.m, with $Q = 0.51–5$ l/s). The aquifers consist of basalts and trachyte.
- Extensive and moderately or locally developed and highly productive mixed porous and fissured aquifers ($T = 1.1–10\ m^2/d$, $q = 0.011–0.1$ l/s.m, with spring and well yield $Q = 0.51–5$ l/s). The aquifers consist of volcanic, sedimentary and pyroclastic rocks.
- Formation consisting of a minor fissured aquifer with local and limited groundwater resources – Aquiclude. The formation consists of the trachyte plugs and phonolite.

Shallow groundwater flow direction
Deep groundwater flow direction

Representation of detailed data

Springs - yield l/s
- 0.005 - 0.05
- 0.05 - 0.5
- 0.5 - 5
- >5
- Yield not known

Surface water and hydrography

- Climatic station
- Main basin surface water divide
- Sub-basin surface water divide 1ST order
- Perennial river
- Intermittent river
- Flow gauging station (mean runoff in m^3/s / basin area in km^2)

Manmade hydrogeological features

- Borehole with yield 0,5 - 5 l/s
- Borehole with yield greater than 5 l/s
- Borehole not tested / yield not known
- Dug well

Lithology

- Alluvial sediments
- Basaltic volcanic rocks
- Phonolite
- Rhyolite
- Trachyte, trachy-basalt
- Pumice, pyroclastic and unwelded tuff

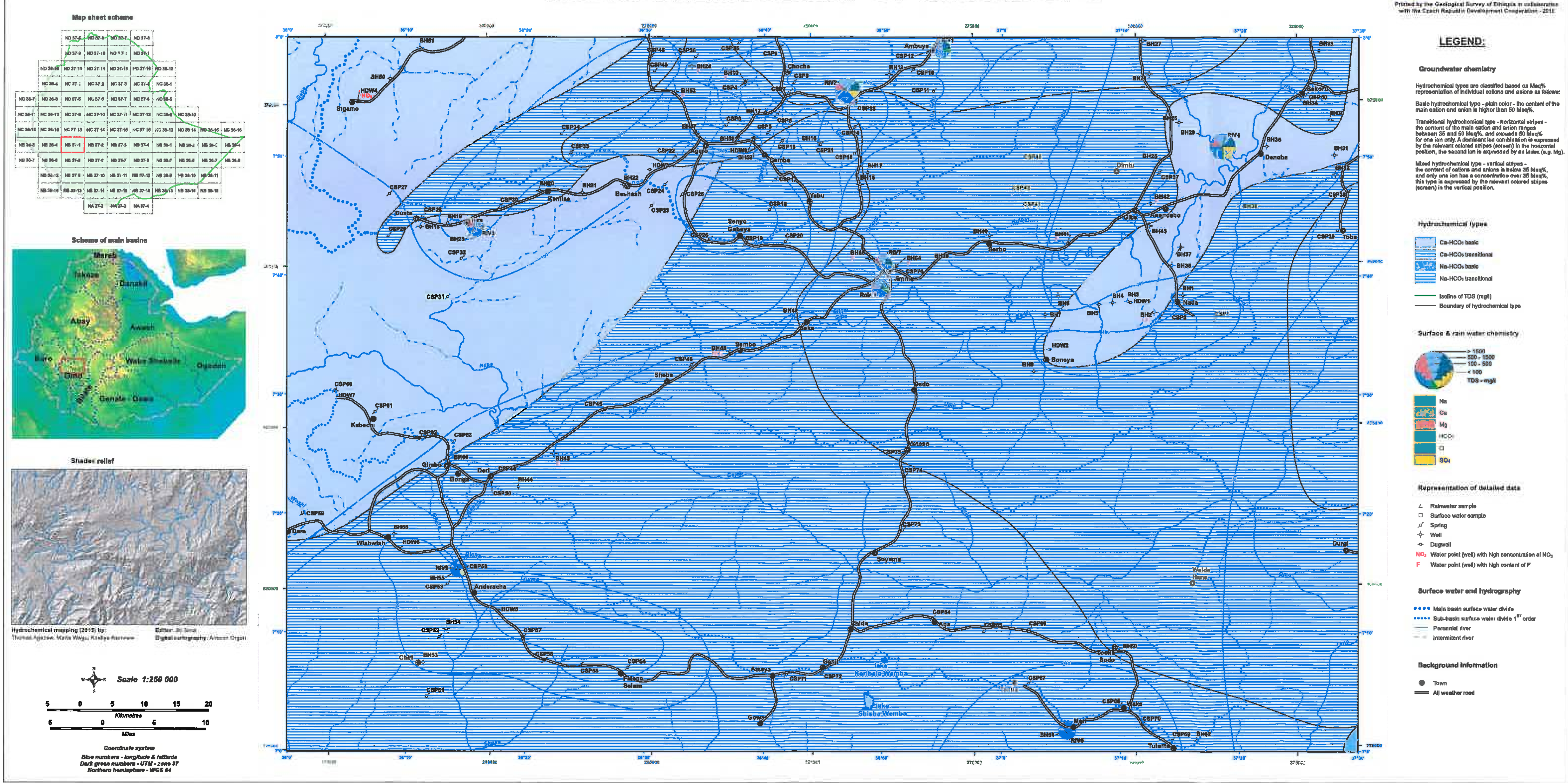
Geological information

- Fault

Background information

- Town
- All weather road
- Contour line

HYDROCHEMICAL MAP OF JIMA NB 37-1



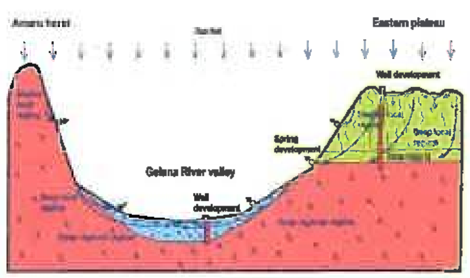
HYDROGEOLOGICAL MAP OF NB 37-10 HAGERE MARYAM

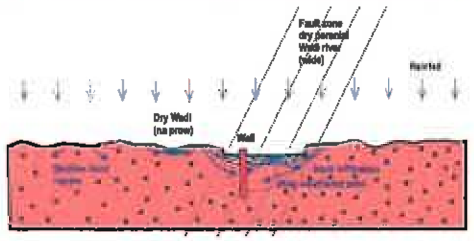
Printed by the Geological Survey of Ethiopia in collaboration with the Czech Republic Development Cooperation - 2016

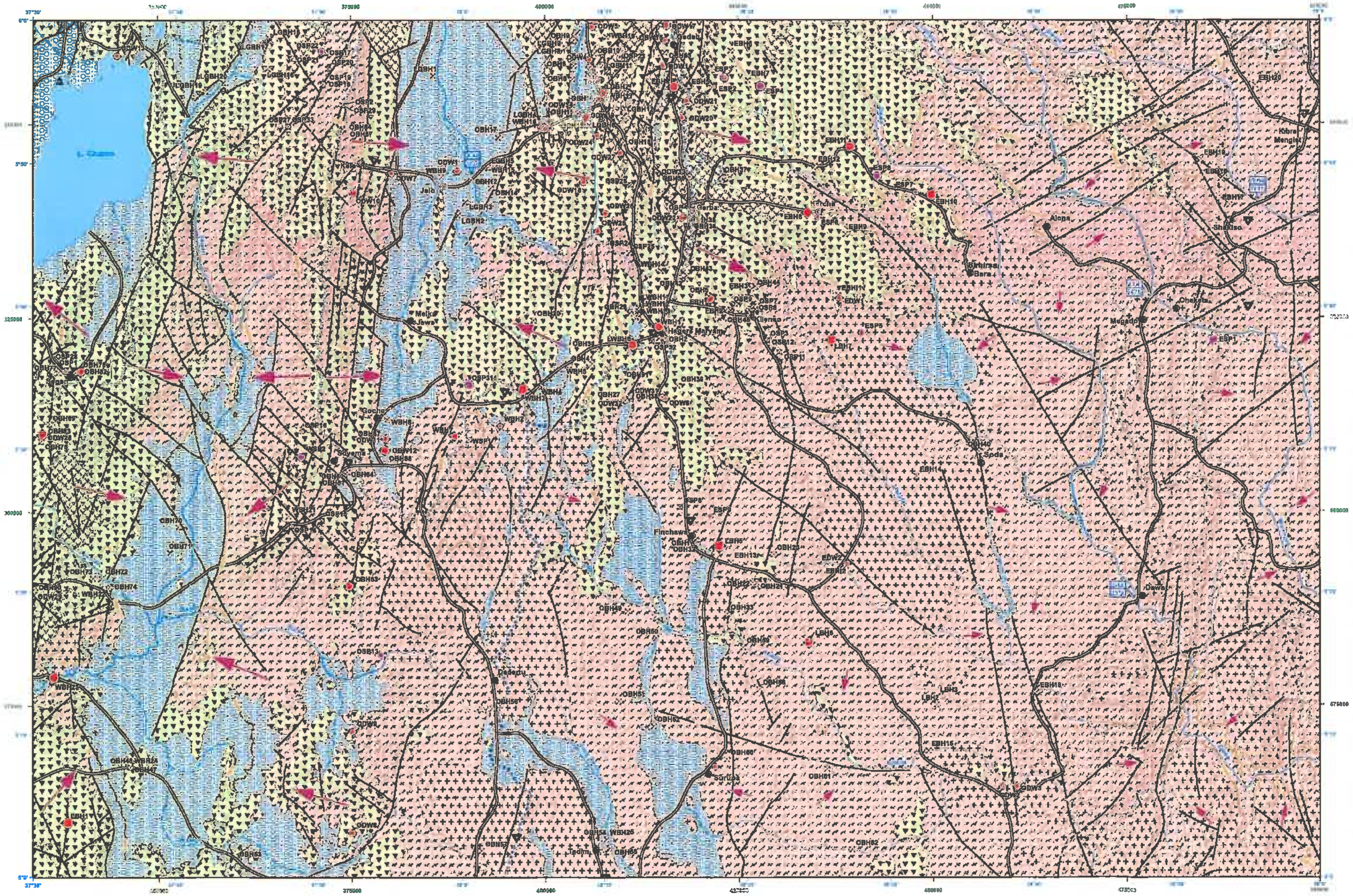
Map sheet scheme

Scheme of main basins

Hydrogeology scheme







LEGEND:

Groundwater and rocks

Extensive and moderately productive or locally developed and highly productive porous aquifers ($T = 1.1–10\ m^2/d$, $q = 0.011–0.1$ l/s.m, with spring and well yield $Q = 0.51–5$ l/s). The aquifers consist of quaternary alluvial, deluvial and mixed deposits (Q, Qa, Qe).

Extensive and moderately or locally developed and highly productive fissured aquifer ($T = 1.1–10\ m^2/d$, $q = 0.011–0.1$ l/s.m, with $Q = 0.51–5$ l/s). The aquifers consist of volcanic rocks (dominantly the Lower Basalts – Pgl).

Extensive (11,014 km2) and low productive fissured aquifers ($T = 0.11–1\ m^2/d$, $q = 0.0011–0.01$ l/s.m, with spring and well yield $Q = 0.051–0.5$ l/s) developed in low and high grade metamorphic and intrusive rocks.

Shallow groundwater flow direction

Deep groundwater flow direction

Representation of detailed data

Springs

- Spring with yield 0,0051 - 0,05 l/s
- Spring with yield 0,051 - 0,5 l/s
- Spring with yield 0.51 - 5 l/s
- Spring with yield greater than 5,1 l/s
- Spring with not known yield

Surface water and hydrography

- Climatic station
- Lake staff gauge
- Main basin surface water divide
- Sub-basin surface water divide 1ST order
- Sub-basin surface water divide 2ND order
- Perennial river
- Intermitent river

Flow gauging station $\left(\frac{\text{mean runoff in } m^3/s}{\text{basin area in } km^2}\right)$

Manmade hydrogeological features

- Borehole with yield 0.005 - 0.05 l/s
- Borehole with yield 0.05 - 0.5 l/s
- Borehole with yield 0,5 - 5 l/s
- Borehole with yield greater than 5 l/s
- Borehole not tested / yield not known
- Dug well

Lithology

- Clay, sand, gravel, polygenetic infill of depression
- Basaltic volcanic rocks
- Ignimbrite
- Pumice, pyroclastic and unwelded tuff
- Intrusive rocks
- Metamorphic and igneous rocks

Geological information

- Fault

Background information

- Town
- All weather road
- Contour line

Hydrogeological mapping (2015) by:
Thomas Agezew, Wibanchi Fekadu, Robel Assmenow, Yewibdar Abeda

Supervision: Muhuddin Abdela
Chief Compilers: Thomas Agezew and Wibanchi Fekadu
Editor: Jiri Sima
Digital cartography: Antonin Orgon

Scale 1:250 000

Kilometres: 5 0 5 10 15 20
Miles: 5 0 5 10

Coordinate system
Blue numbers - longitude & latitude
Dark green numbers - UTM - zone 37
Northern hemisphere - WGS 84

Geology mapping:
Woldegabriel Genzebu, Nasir Hassen, Tesfaye Yemane, GSE, (2014)

HYDROCHEMICAL MAP OF HAGERE MARYAM NB 37-10

Map sheet scheme

Scheme of main basins

Shaded relief

Hydrochemical mapping (2018) by:
Thomas Agezew, Yitbarek Fekadu

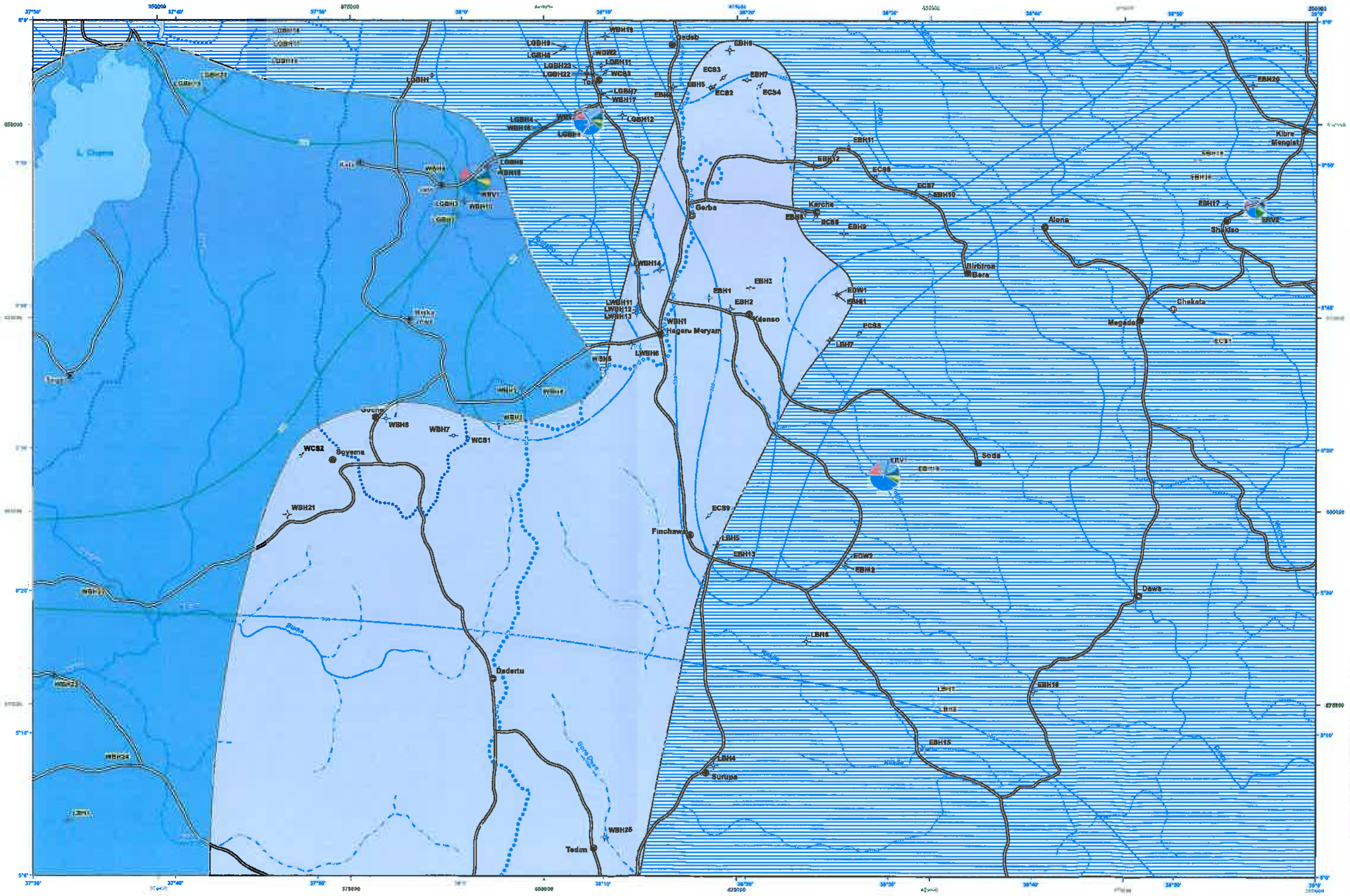
Editor: Jiri Sima
Digital cartography: Antonin Orgon

Scale 1:250 000

Kilometres

Miles

Coordinate system
Blue numbers - longitude & latitude
Dark green numbers - UTM - zone 37
Northern hemisphere - WGS 84



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LEGEND:

Groundwater chemistry

Hydrochemical types are classified based on Meq% representation of individual cations and anions as follows:

Basic hydrochemical type - plain color - the content of the main cation and anion is higher than 50 Meq%.

Transitional hydrochemical type - horizontal stripes - the content of the main cation and anion ranges between 35 and 50 Meq%, and exceeds 50 Meq% for one ion only. A dominant ion combination is expressed by the relevant colored stripes (screen) in the horizontal position, the second ion is expressed by an index (e.g. Mg).

Mixed hydrochemical type - vertical stripes - the content of cations and anions is below 35 Meq%, and only one ion has a concentration over 35 Meq%, this type is expressed by the relevant colored stripes (screen) in the vertical position.

Hydrochemical types

- $Ca-HCO_3$ basic
- $Ca-HCO_3$ transitional
- $Na-HCO_3$ basic
- Isoline of TDS (mg/l)
- Boundary of hydrochemical type

Surface & rain water chemistry

> 1500
500 - 1500
100 - 500
< 100
TDS - mg/l

- Na
- Ca
- Mg
- HCO_3
- Cl
- SO_4

Representation of detailed data

- Surface water sample
- Spring
- Well
- Dugwell

Surface water and hydrography

- Main basin surface water divide
- Sub-basin surface water divide 1ST order
- Sub-basin surface water divide 2ND order
- Perennial river
- Intermittent river

Background information

- Town
- All weather road