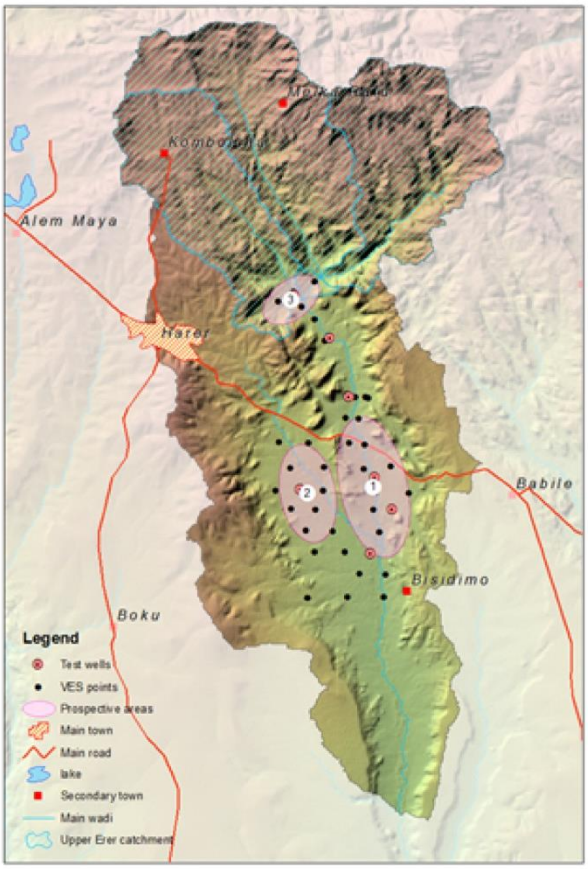
Sustainable Water Services in Harar; Ethiopia

Result 3
Regional Water Resources Assessment



Report 3.1
Regional water resources assessment and potential for long term water provision

Acacia Water

MS CONSULTANCY

Colofon

Title	.	Regional Water Resources Assessment
Client	.	SWSH
Status	.	
Date	.	28 september 2015
Project number	.	505
Project team	.	Theo Kleinendorst, Albert Tuinhof, Reinier Visser

Disclaimer

Content

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Abbreviations

ATRC	African Rainfall Climatology dataset
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
DEM	Digital Elevation Model
ECC	Ethiopian Catholic Secretariat (NGO)
FEWS-NET	Famine Early Warning Systems Network
HWSA	Harer Water Supply Authority
HPRS	Harer People Regional State
LPCD	Litres per capita per day
MCM	Million Cubic Meters
MODIS	Moderate-resolution Imaging Spectroradiometer
MSC	Mesfin Consultancy Services
NGO	Non-Governmental Organization
NMA	National Meteorological Network
NRW	Non Revenue water
RWS	Rural Water Supply
RWSSU	Rural Water Supply and Sanitation Unit
SHP	Stakeholder Platform
SRTM	Shuttle Radar Topography Mission
SWHS	Sustainable Water Services Harer State
UAP	Universal Action Plan
VEI	Vitens Evides International
WWDSE	Water Works Design and Supervision Enterprise

1 Introduction

1.1 The SWSH project

Harer People Regional State (HPRS) is suffering from water scarcity both in the towns and in the rural areas. To alleviate the urban water shortages, a new urban water system has been realized through African Development Bank financing, bringing water from Dire Dawa over a distance of 71 km to Harer city. The system has been in operation since May 2012. HWSA (Harer Town Water Supply and Sewerage Authority) has difficulties in sustainably operating the system because of technical problems - the hardness of the water is likely to disrupt the system within 2-4 years - and lack of experience. At the same time, the organisation is not able to raise more funds for investments because of its poor financial situation and the high level (45%) of the Non-Revenue Water (NRW). The Rural Water and Sanitation Support Unit (RWSSU) has insufficient capacity to enhance water conservation approaches and improve rural water supply services, while 50% of the people in rural Harer still lacks nearby access to safe water in sufficient quantities. Besides short term improvement in water supply provision, there also a need to secure the long term water availability through allocation scenarios based on an understanding and management of the water resources potential in the greater Harer area.

The Sustainable Water Service for Harer Regional State (SWHS) is a joint project of HPRS (represented by HWSA) and a Consortium of Dutch partners (managed by Vitens Evides International) to address these issues through:

- Develop a climate-proof, sustainable integrated water resources allocation approach.
- Implement innovative and sustainable water abstraction practices.
- Improve HWSA's financial capacity by reducing its NRW and increase its customer base.
- Build capacity at the RWSSU of HWSA through the decrease of rural system failure and the creation of an investment plan.
- Support HWSA in the field of design, construction, operation and maintenance.
- Implement a decalcification unit to ensure long-term system integrity of the urban water system.
- New urban water points and house connections to provide 25.000 households with safe water.
- Construct rural water supply schemes to provide access to 25.000 people.

The SWHS project has a duration of 4 years (2014-2018) and is structured around 6 main results:

Result 1. Project management and monitoring

Result 2 Decalcification installation constructed and operational

Result 3 Regional water resources assessment prepared

Result 4 Sustainable water abstractions and NRW reduction realized

Result 5 Financially and technically sustainable water services and increased access for 25,000 people

Result 6. Water buffering & rural water supply schemes constructed and operational for 25,000 people

1.2 Result 3 and 6

Within the overall SWHS program, Acacia Water has a leading role in most of the activities under result 3 and result 6, in close cooperation with the HPRS counterparts and project implementation partners, VEI, MSC and ECC

Result 3 is the Regional Water Resources Assessment and includes 4 sub results:

3.1 Regional water resources assessment completed (Acacia)

3.2 Stakeholder platform established and bi-annual meetings held (VEI)

3.3 Future water demands, source quality/protection, gap analyses completed (Acacia)

3.4 Resilient water resources allocation scenario for HPRS prepared and discussed in the stakeholder platform (Acacia and VEI)

Result 6 is covering the rural water supply (RWS) component and has the following sub results:

6.1-6.2 Water buffering pilot systems designed, built, tested and upscaling plan prepared (Acacia)

6.3. RWS baseline survey completed and RWS coverage plan endorsed (Acacia)

6.4 RWSSU, NGO's, etc. trained in sustainable abstraction practices (VEI)

1.3 Reporting structure

The reports to be compiled under the responsibility of Acacia are

Report 3.1	Regional water resources assessment and potential for long term water provision **(this report)**
Report 3.2	Future demands, gap analyses, climate change impacts and water allocation scenarios (scheduled for September 2015)

Report 6.1.1.	Quick scan for water buffering pilots (Draft Report – April 2015)
Report 6.1.2	Detailed siting, design and implementation plan for water buffering pilots (Aug 2015)
Report 6.1.3	Completion report of water buffering pilots and upscaling plan (June 2016)
Report 6.3.1	Rural water supply baseline study report (1st draft May 2014, 2nd draft May 2015)
Report 6.3.2	Water resources and rural water coverage plan (1st draft July 2015)

1.4 This report

This is report 3.1 presents the regional water resources assessment in the catchment area of Wadi Erer and Wadi Bobele. The study area includes Harer Regional state and is as such is also an input to report 6.3.1 and 6.3.2. The report is accompanied by a set of maps which will be made available to the HRPS counterparts.

The report was presented and discussed with SWHs counterparts in Harer in August 2015 and the comments are incorporated in this Final Report. The report will also serve as an input to report 3.2 which will be submitted at the end of October.

2 The project area

Figure 1 shows the major river basins in Ethiopia and the approximate location of the Harer Regional State and surroundings (red shaded area). The red shaded area is located in the upper part of the Shebele river basin, near the water divide with the Awash basin to the north (Figure 1).

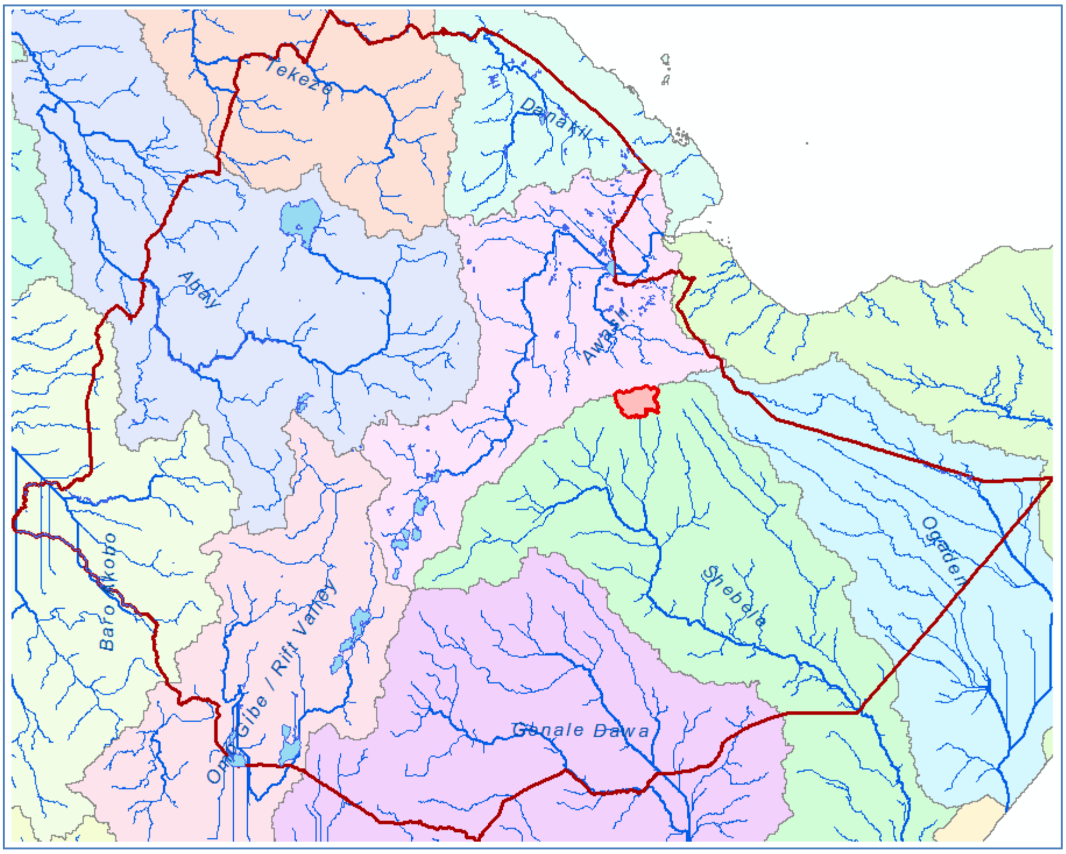

Figure 1 Major river basins with location of project area

Within the Shebele river Basin, Harer Regional State is situated on the water divide between the watersheds of Wadi Erer to the east and Wadi Gobele to the west (Figure 2). These two watersheds constitute the study area for the regional water resource assessment because hydrogeological processes are primarily watershed based. The well field in Dire Dawa which serves Harer City through a 71 km pipeline is located in the Awash River basin and hence not part of the regional water resources assessment. This source of water from outside the Shebele River Basin will be treated separately in evaluating future water allocation scenarios.

Figure 2 shows the 5 sub catchment which feed into Wadi Erer and the 15 sub catchments in Wadi Gobele

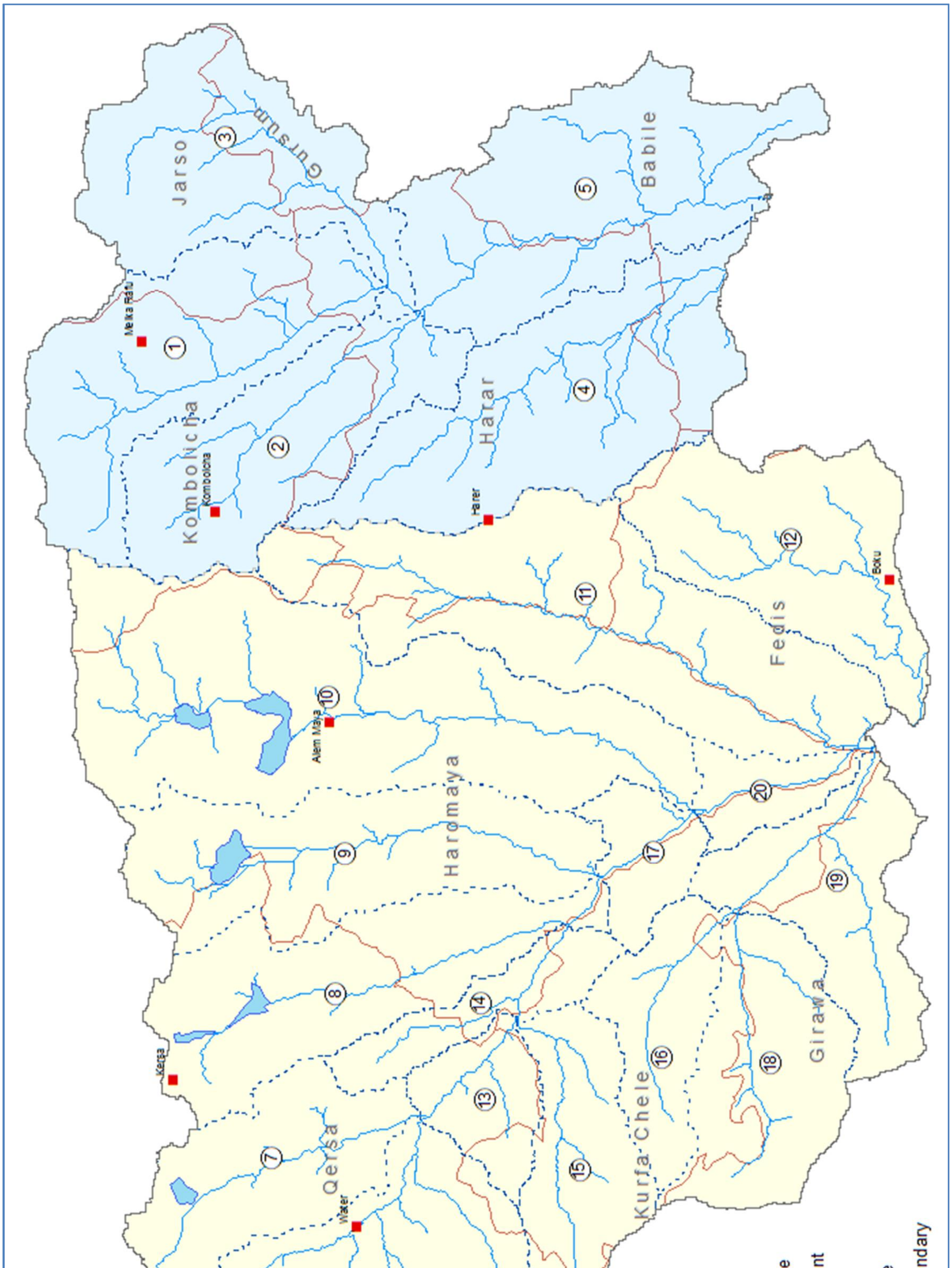

Figure 2 Boundary of the study area

3 Area description

3.1 Topography

The project area is located on the highlands near the escarpment of the rift valley. The average elevation is 1950 meter above sea level, with a minimum of 1250 and a maximum of 3300 meter.

A Digital Elevation Model (DEM) of the study area has been prepared based on a combination of Shuttle Radar Topography Mission (SRTM) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data with a horizontal resolution of 30 meter (Figure 3). This DEM is the basis for the delineation of the sub-catchments in the two main watersheds as well as the interpolation of the precipitation data over the study area. In addition, the DEM has been used to create derived products (such as flow accumulation, slope and compound topographic index) that is used as input for the identification of areas with prospects for water buffering interventions.

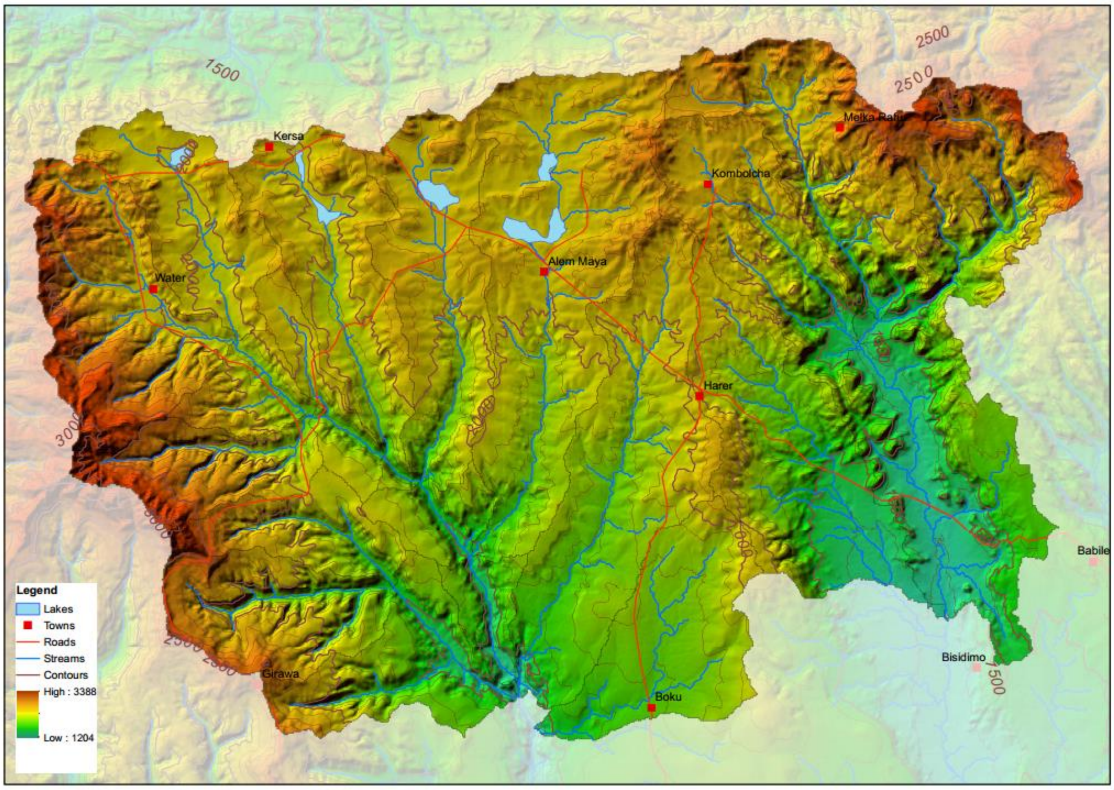

Figure 3 Topography

3.2 Hydrogeological setting

The study area is situated in the wadi Shebelle watershed near the water divide with the Awash basin to the north. The area is underlain by Precambrian basement rocks consisting of granite, migmatite and gneisses. The main water bearing formations in the area are Quaternary alluvial deposits and Mesozoic sediments (sandstone and limestone) that overlay the basement complex. Except for its weathered zone and local fractures, the basement complex itself has limited prospects as a source for water supply. Most of the Mesozoic sediments have eroded but some isolated patches remain on higher grounds near the water divide between sub-catchments. These remnant patches consist of karstified limestone of the Hamanlei formation underlain by a thin layer of sandstone (Adrigat formation). Due to the limited primary porosity of the limestone, groundwater occurs mainly in fractures here. At the fringes of the patches springs emerge at the contact with the basement rocks. Many of these springs are perennial and are used as a permanent source of water supply. Examples are the Sofi and Burka springs near Harer and the Ginella spring of the Harer Brewery.
The alluvial deposits along the wadis are widely exploited by shallow wells and form the main source of water supply in the rural areas. In the Northern part of the study area larger areas of relatively thick alluvial deposits occur. These alluvial aquifers are extensively exploited by shallow wells and boreholes with motorized pumps and water supply schemes (Alamaya, Adele, Finkile). Until recently, Harer town depended on these aquifers for its water supply.

Using the available geological maps 1:250000 and Landsat imagery a detailed lithological map has been prepared that serves as a base for the water resources assessment (Figure 4).

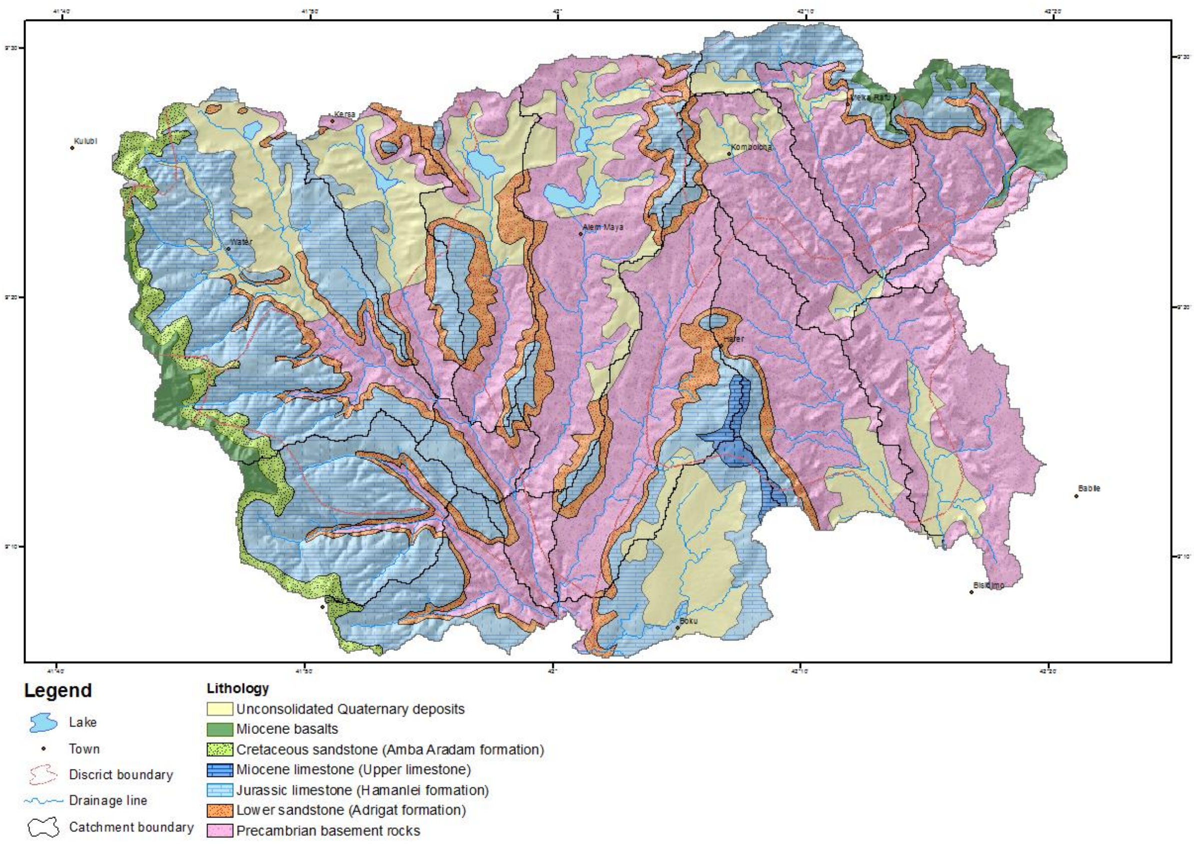

Figure 4 Lithology

3.3 Precipitation

Precipitation data has been acquired from the NOAA Global Historical Climate Network (GHCN) for the following stations in and near the study area:

Table 1 GHCN rainfall stations

Station	First year	Last year	Altitude (m)	Annual precipitation (mm/yr)
Babile	1968	1984	1710	688
Deder	1968	1984	2350	1189
Dire Dawa	1952	2013	1146	636
Gelemso	1969	1984	1820	1001
Gursum	1969	1984	1900	723
Harer	1902	1984	1980	746
Jijiga	1952	1999	1644	713

Because the available GHCN climate data is not sufficient, detailed precipitation data was collected from the National Meteorological Agency and existing reports (Table 2).

Table 2 Supplementary precipitation data

Station	Altitude (m)	Average precipitation (mm/yr)
Dengego	2350	789
Aselso	1230	612
Kulubi	2440	974
Hurso	1138	505
Alem Maya	2011	746
Harer	1980	866

To complete the precipitation data further, all available daily precipitation records of the Africa Rainfall Climatology dataset (ARC-2) from the Famine Early Warning System Network (FEWS-NET) have been downloaded. This resulted in a dataset of daily precipitation from 1983 to 2014 on a 0.1 arc-degree grid (10 by 10 km cells). The dataset has been recalibrated with available historical data, supplementary data from available studies and reports and NMA data. The result has been combined with the digital elevation model using a cokriging technique to prepare a high resolution dataset with 30 year time series of daily precipitation. The long-term annual precipitation average is presented in Figure 5 below.

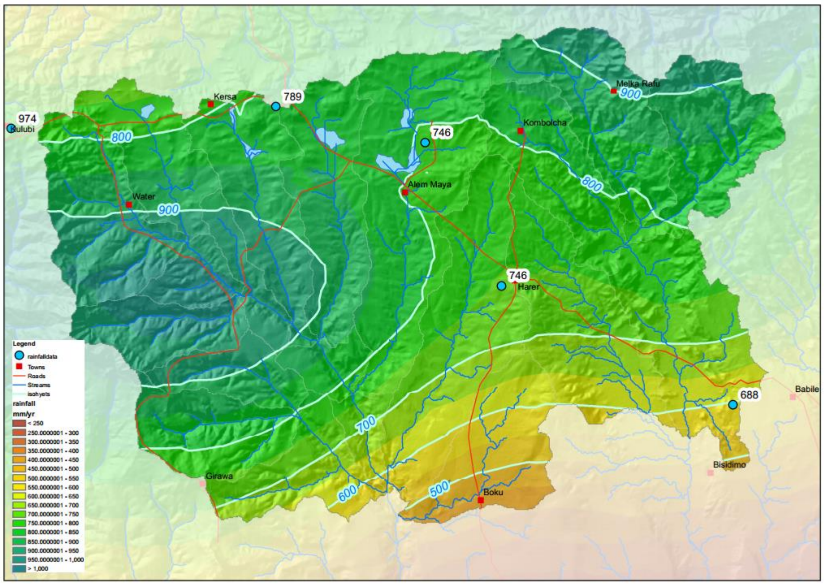

Figure 5 Annual precipitation distribution

3.4 Evapotranspiration

No evapotranspiration data is available for the study area, except for some sparse data from the National Meteorological Authority (Alemaya station). Instead, monthly MODIS satellite evapotranspiration data is used (MOD16 dataset, 2000-2014). The MODIS long term annual average evapotranspiration varies in the study area between 300 and 600 mm and reaches an average of 65% of the annual precipitation. The net precipitation (precipitation minus evapotranspiration) shows a surplus in most of the project area (Figure 6). In the very south, with less rainfall, extensive agriculture and higher temperatures, a precipitation deficit occurs (e.g. Boku). It should be noted that the MOD16 dataset is calculated using an algorithm that is based on the Penman-Monteith equation and incorporates surface stomatal resistance and vegetation information derived from MODIS land products. Open water evaporation is not included.

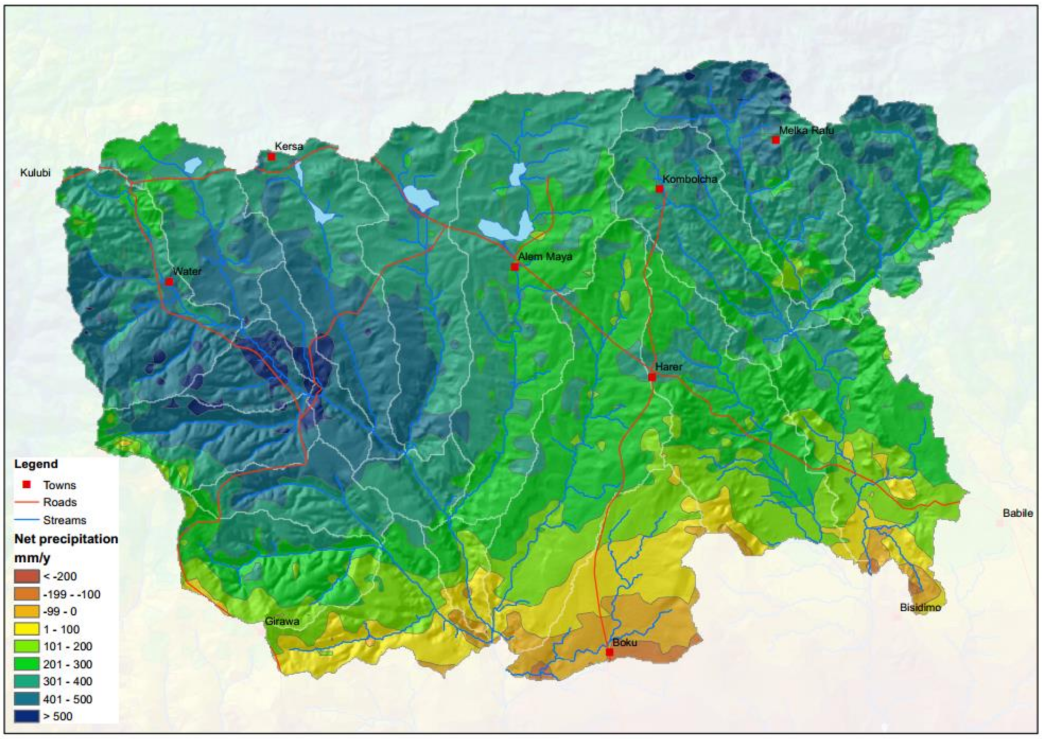

Figure 6 Net precipitation (2000-2014)

The annual variation in precipitation and evapotranspiration shows a seasonal pattern (Figure 7). There is a clear dry season from November to February when evapotranspiration generally exceeds the precipitation. The wet season runs from March to September, with an intermission in June.

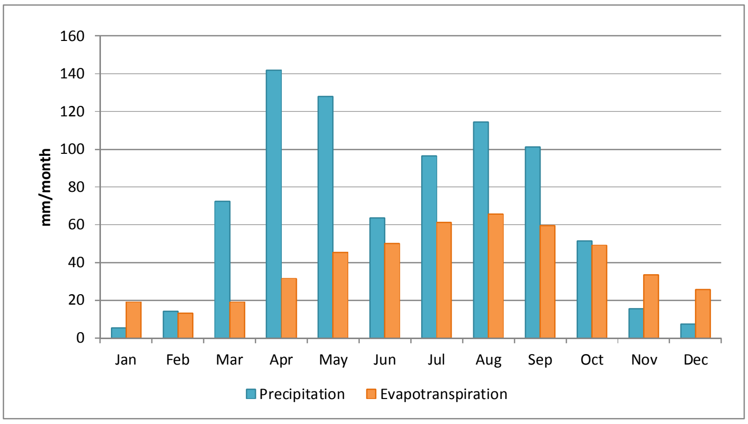

Figure 7 Monthly variation in precipitation and evapotranspiration (2000-2014)

3.5 Vegetation and land use

Maps with vegetation cover and land use were created from remote sensing data. Sources are Landsat 7 and Landsat 8 with a resolution of 30 meter. Although this resolution is sufficient for land use and vegetation mapping, ground truth was collected for calibration of the classification.

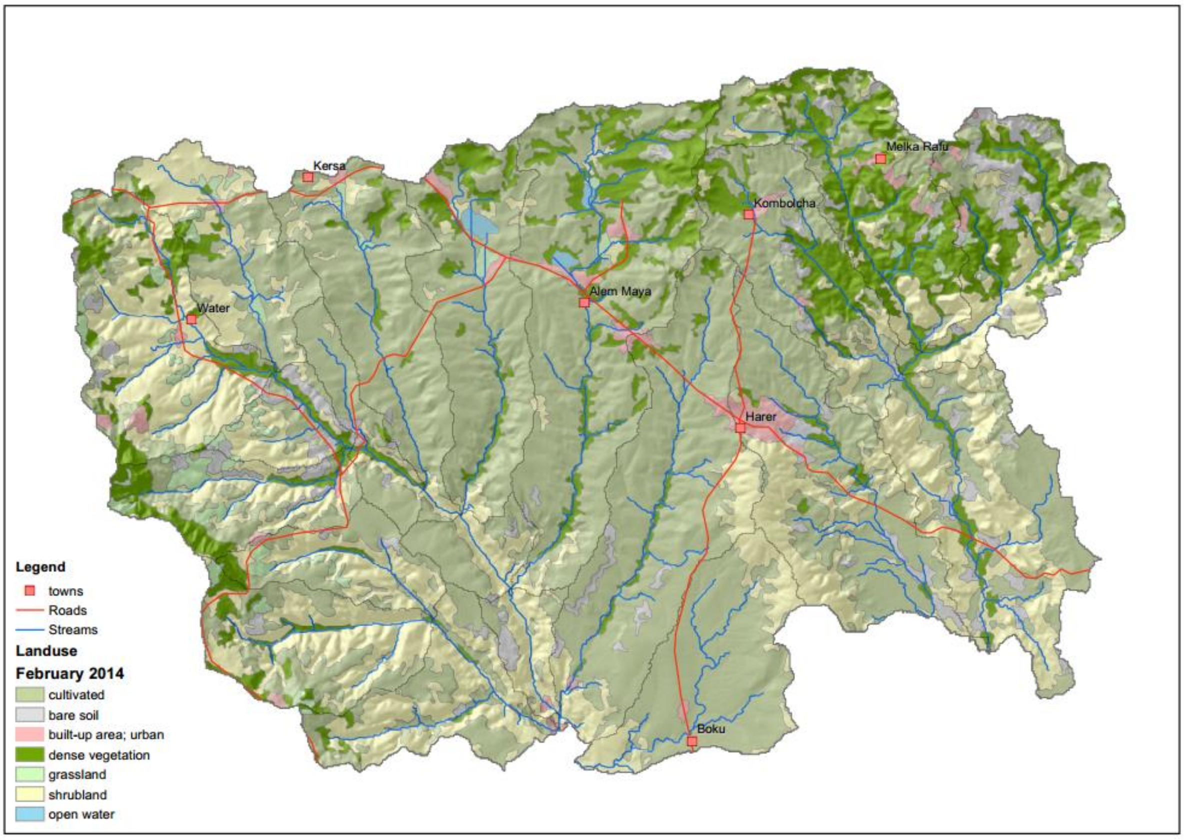

Figure 8 Landuse

Figure 8 shows that the major part of the study area is covered by bare soil and cultivated lands. The cultivated lands consist mainly of rain fed agriculture including quat production which is rapidly expanding in the eastern part of the study area.

No detailed data are available yet on the distribution of the different drop types, the area under irrigation and the demand for expansion of irrigated cropping. Available information will be invalided in the final version of this report

4 Water balance and water quality

4.1 Water use

The rural population uses mostly shallow wells for water supply. Community water supply schemes with boreholes and hand pumps are scattered throughout the area (Figure 9), but no reliable data about the abstractions exists. The current abstraction for drinking water is estimated as 15 lpcd for the rural areas and 20 lpcd for the urban areas (UAP, 2006). The estimated population in the two watersheds is currently 1.2 million. This corresponds to a total water use of nearly 7 MCM/y.

There are two larger groundwater abstractions in the area: HWSSA and Harer Brewery, both in the alluvial deposits north of Alemaya. The total yearly abstracted volume is estimated at 2.8 MCM/y.

A third large groundwater abstraction (in the lower Erer wadi) is under preparation by HWSSA. This new well field will augment the water supply to Harer Town.

HWSSA imports water from the Aselso and Hulul wellfields near Dire Dawa (Awash River Basin) for the water supply of Harer. The current wellfield production is estimated at 60 lps, or 1.9 MCM/y. HWSSA supplies the larger towns along the pipeline (Adele, Alemaya and Aweday). More details on the groundwater abstraction and water conveyance can be found in the VEI/HWSA reports on Result 4.

4.2 Runoff

There are four gauging stations in the project area:

- Alameya
- Adele
- Dawe Garamuleta
- Erer Guda

Unfortunately, none of the stations could be used to determine the surface water outflow of the sub-catchments because of missing or incomplete records or unsuitable locations. Instead, the runoff was estimated from the water balance equation

The outflow from every sub-catchment should be equal to the surface water runoff and groundwater discharge. Overland flow and surface water runoff are not included here because of lack of data on rainfall intensities and surface water flow.

4.3 Water balance

In order to estimate the water availability per sub-catchment we have used a simple water balance approach. The annual precipitation and evapotranspiration has been computed for every sub-catchment (Table 4). The net precipitation ranges from 16 mm/y (sub-catchment 12) to almost 500 mm/y (sub-catchment 13), with an average of 303 mm/y (38% of the precipitation).
Several authors have studied the recharge mechanisms in the area. Yeshayahu (1969) estimated a recharge of 7% on the sedimentary rocks and 5% on the alluvial plains. Gibb/Seureca (1996) suggested 5% of the annual precipitation. WWDSE (1997) studied the recharge per geological formation as part of the Abbay Basin Master Plan Study (Table 3).

Table 3 Recharge as percentage of annual precipitation (WWDSE, 1997)

Formation	Recharge
Quaternary deposits	3%
Basalt	2%
Upper Limestone	10%
Hamanlei Limestone	10%
Adigrat Sandstone	2%
Basement rocks	2%

Based on the recharge coefficients from WWDSE (1997), the existing lithological map and available precipitation data the recharge per sub-catchment has been estimated (Table 4). The recharge ranges from 15 to 74 mm with an average of 35 mm/year. This figure corresponds to previous studies (ref).

Table 4 Water balance components per sub-catchment in mm/y

Nr	Area	P	ET	R	Q	Qout
1	150	867	495	34	3.1	371
2	124	801	474	19	3.5	326
3	131	853	514	29	2.9	335
4	175	698	486	20	4.4	209
5	175	691	510	15	1.1	182
6	150	895	498	67	2.4	391
7	101	827	459	50	2.7	366
8	131	867	454	39	2.5	411
9	145	851	478	30	3.3	345
10	274	807	493	24	14.3	272
11	205	706	493	26	3.0	211
12	126	537	522	16	1.5	14
13	40.2	955	464	53	1.8	492
14	42.6	926	463	54	1.7	462
15	79.3	946	541	64	2.1	399
16	60.2	889	518	74	1.5	375
17	34.3	831	488	39	1.2	344
18	101	816	580	67	1.9	233
19	92.2	686	573	45	1.0	114
20	29.4	690	539	18	0.8	153
Total	2367					
Average		**807**	**502**	**35**	**3.9**	**371**

Legend for the column headings:

Nr	Sub-catchment number (see Figure 2 for locations)
Area	Area of sub-catchment (km²)
P	Annual precipitation (mm/y)
ET	MODIS evapotranspiration and open water evaporation (mm/y)
R	Groundwater recharge (mm/y)
Q	Groundwater abstractions for domestic and industrial use (mm/y)
Qout	water balance rest term: precipitation minus evapotranspiration minus abstractions (mm/y).

The data in table 4 show that more than 40% of the rainfall leaves the study area through the two main wadis: Gobele and Erer. The Qout is the calculated term in the water balances but could be checked if gauging stations are installed in the two main wadis. This is strongly recommended in order to provide reliable information on the overall water balance and strengthen the knowledge base to define and implement future water allocation scenarios.

4.4 Water quality

Although the groundwater and surface water is generally of good quality, the limestone aquifers may show elevated salinity due to dissolution of gypsum and evaporates. Due to poor sanitation practises the shallow groundwater in urban areas is subject to bacteriological contamination.

The map on Figure 9 shows the locations of water sources in the project area. The pink dots represent 61 sources with water quality data. The data is attached as Annex 1. Within the boundary of Harer Region the well inventory originates from the baseline survey carried out for the current project. Information about the water sources in Oromia State originates from the Oromia Water Bureau in Harer.

Due to limited time and budget, water quality analysis was restricted to the areas that show prospects for water resources development in terms of water availability. Samples have been collected from the Quaternary deposits near Kersa, Haromaya, Adele, Kombolcha, Wadi Erer, the spring zone south of Harer and along the road from Harer to Boku. The chemical analysis was carried out by the laboratory of Harer Brewery.

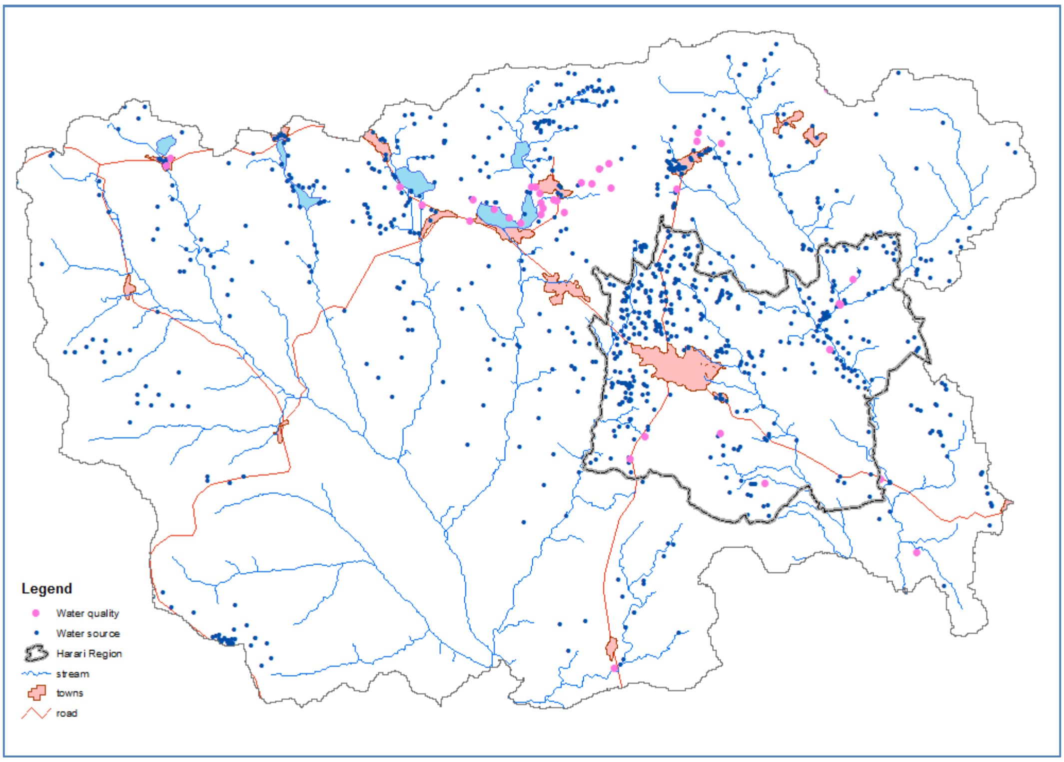

Figure 9 Water sources

5 Water resources potential

5.1 The Pre-Cambrian basement

The Precambrian basement rocks which cover most of the study area, have limited scope for water resources development because of their negligible storage capacity. In relatively flat areas where a considerable weathered zone has developed, dug wells may yield sufficient water for domestic use or small scale irrigation. Other prospective areas are the wider wadi beds which are filled with alluvial sediment which are recharged during periods of wadi flows.

The most promising areas for water resources development shown 1n Figure 10 below and are described in the next paragraphs.

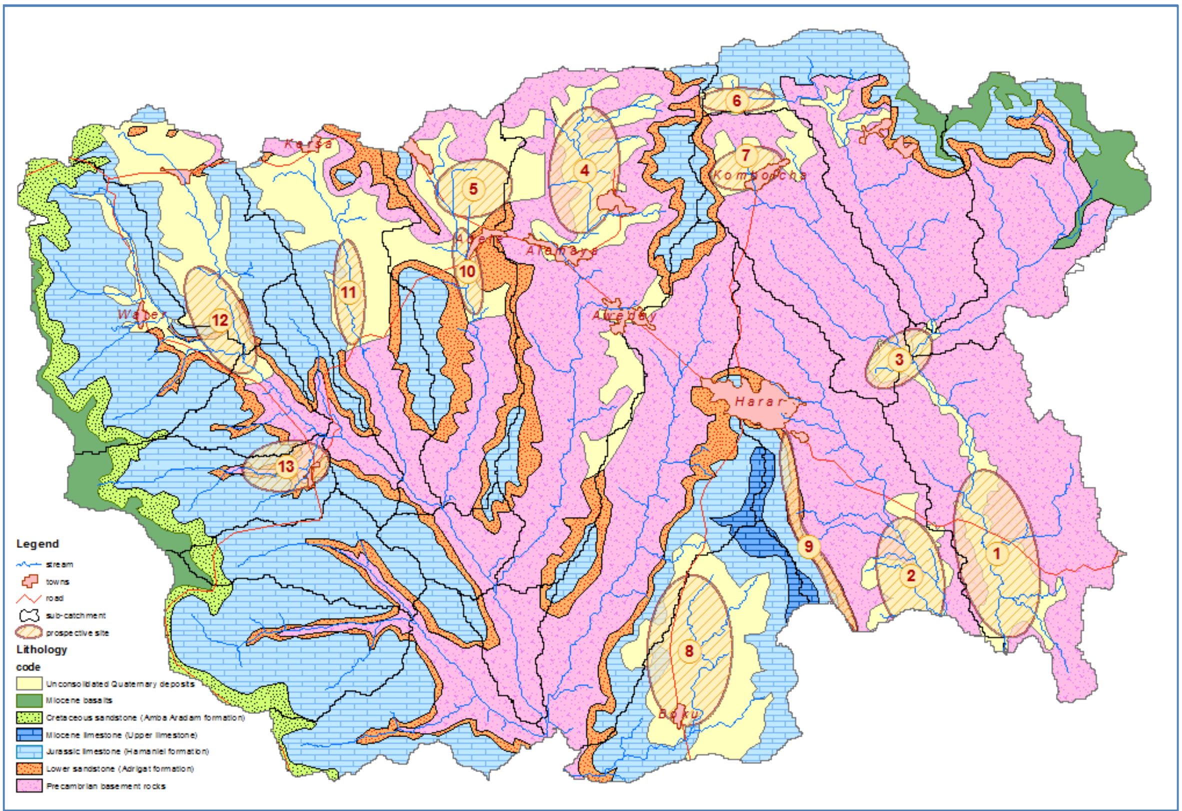

Figure 10 Prospective water resources development areas

5.2 The alluvial deposits in the Northern part of the study area

In the Northern part of the project area relatively thick alluvial deposits have accumulated in depressions in the basement rock (prospective areas 4,5,6,7,10,11,12). The depressions are structurally controlled and are filled with alluvial deposits and colluvium. Groundwater is near the surface (less than 10 meter deep) and is exploited by dug wells for irrigation. Tube wells are drilled up to 60 meter deep and capture the unconsolidated sediments and weathered basement rock. Yields are generally less than 10 lps.

5.2.1 The Alemeya sub basin

An area of specific interest is the area around Alemeya (areas 4 and 5) which is an isolated sub basin (Figure 11) where three perennial lakes exist (lake Adele, lake Finkile and lake Alemaya). The basin is surrounded by 200 meter high granite hills. The eastern border consists of limestone sediments deposited over the basement rocks. This makes the lake area basically a closed basin. The southern border however, has 2 possible outlets: one south of Adele Town and south of Alemaya town.

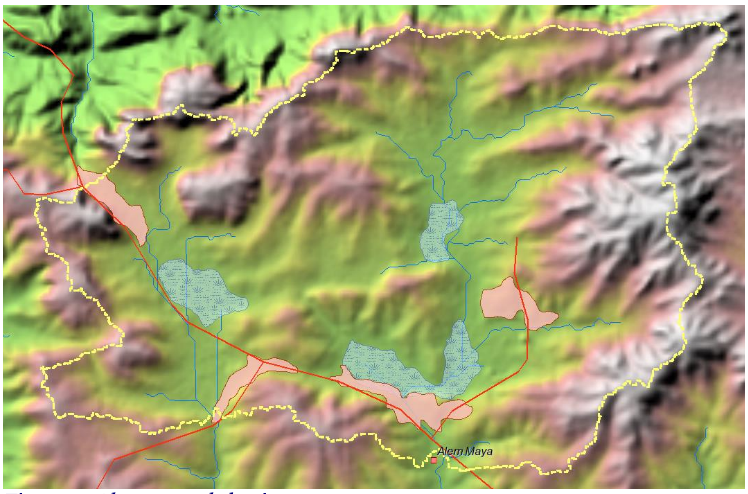

Figure 11 Alemaya sub-basin

The groundwater potential of the area has been estimated below.
The annual precipitation on the entire sub-basin amounts to 815 mm or 170 MCM/y. The actual evapotranspiration and open water evaporation from the three lakes is 111 MCM/y, or 66% of the annual precipitation. The total groundwater abstraction is estimated as 4.2 MCM/y (boreholes for the brewery, HWSSA and the edible oil factory as well as abstractions from shallow wells and boreholes for domestic use). If we use the recharge figures from WWDSE (1997), the annual groundwater recharge is 24 mm/y (5 MCM/y). This means that the current abstractions are would reach up to 84% of the groundwater recharge. The water demand in 2030 is estimated as 5 MCM/y (based on an average growth rate of 2.5% and a water consumption of 50 lpcd). These figures suggest that in the future the area cannot be self-sufficient in terms of water supply.

Component	mm/y	MCM/y
Precipitation	815	170
Evapotranspiration	535	111
Abstraction	20	4.2
Recharge	24	5.0
Outflow	260	54

The groundwater monitoring program at Finkile (Harer Brewery) shows an average groundwater recovery of 4 meter during the wet season. 50% of the recovery is attributed to direct recharge, 50% is ascribed to increased groundwater flow during the wet season. When using a porosity of 20%, the direct recharge would be 40 mm (8.3 MCM/y).
Whichever recharge rate is adopted, there is a considerable volume of water that leaves the catchment, either through surface runoff or through groundwater flow (total 54 MCM/y). The only surface outlets are near Alemaya town and just south of Adele town.

5.3 Alluvial deposits along wadi Erer and wadi Decheo

The unconsolidated sediments along the main wadis in the South-eastern part of the project area (areas 1,2 and 3) show good prospects for groundwater development. According to a recent study (ref) the combined thickness of the alluvial deposits and the weathered basement rocks ranges from 20 to 50 meter. HWSSA is currently constructing a 100 lps well field in the unconsolidated sediments along lower Erer and wadi Decheo (prospective areas 1 and 2 in Figure 12).

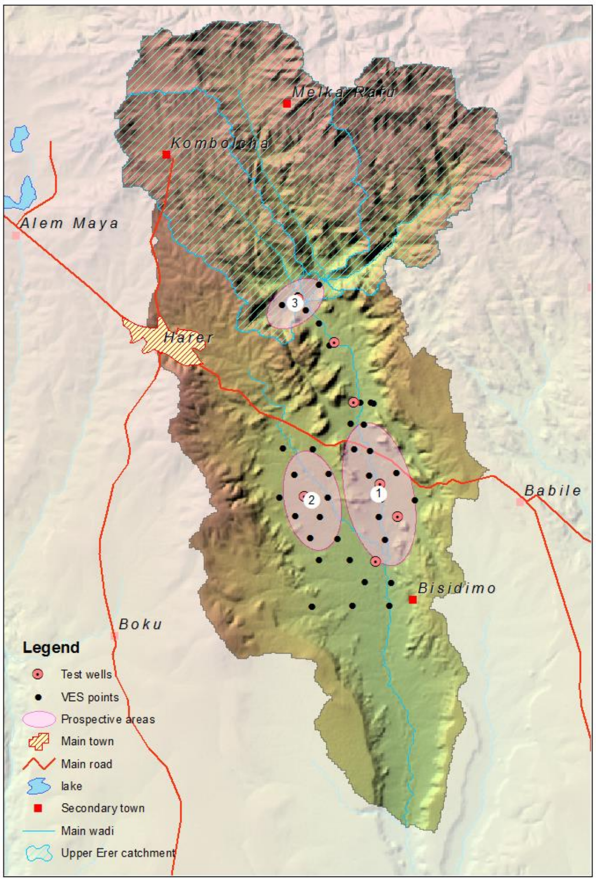

Figure 12. Wadi Erer and Wadi Decheo

Prospective area 3 represents a confluence area of three watersheds with an overall area of 406 km². The long term net precipitation on the contributing watersheds is calculated as 347 mm or 141 million m³/y. Recharge is limited due to the impermeable nature of the basement rocks. It is estimated as 8% of the net precipitation, or 11 million m³/y.

The 3 wadis have deposited a 10 meter thick layer of alluvial material (mostly sand and gravel) on top of the weathered bedrock material. The total thickness of unconsolidated material reaches up to 40 meter. This phreatic aquifer forms a perfect storage reservoir for groundwater that can be exploited through large diameter wells in combination with infiltration gallery and/or a subsurface dam. The expected yield is several tens of litres per second.

5.4 Western limestone plateau between Weter and Kurfa Chele

The western part of the study area receives more than 900 mm/y of precipitation and consists of a dissected limestone plateau (Hamanlei formation). The limestone has a good secondary porosity due to karstification but the groundwater table is deep. Springs emerge at the contact between the limestone and lower sandstone (Adrigat formation). In areas where no springs exist, groundwater may be found through boreholes penetrating the limestone and lower sandstone. Boreholes should be sited carefully into regional fractures or karst structures to ensure sufficient recharge. (Prospective area 13)

5.5 Limestone plateau north of Boku

Prospective area 8 (north of Boku) consists of a gently dipping limestone plateau (Hamanlei formation) on the western slopes of the limestone hills that extend up to Harar. On the eastern side of the hills a number of perennial springs emerge (e.g. Sofi, Burka). On the western side the limestone is covered by a layer of weathered material (clay, silt) and no springs exist. Here, accurately sited deep boreholes may capture the deep groundwater in the lower limestone or underlying lower sandstone (Adrigat Formation). The depth to the basement is expected to be more than 200 meter and the groundwater table may be too deep for a hand pump. To the north, along the road to Harar, a number of boreholes with motor pumps are used to supply the villages west of the road by gravity.

5.6 Spring areas of Hakim Gara and Barcalle Gara

Prospective area 9 is the situated directly south of Harar, on the eastern fringe of the limestone plateau. The area is known as Hakim Gara or Barcalle Gara. The limestone is highly fractured and exhibits extensive karst features (doline /sinkhole karst). It is an excellent recharge area. Precipitation infiltrates on top of the plateau through the soil or directly through fractures and potholes in the limestone and emerges through springs (see Figure 13). Six perennial springs have been identified with an estimated total base flow of 20 lps. One spring (Ginella) is used by Harar Brewery. The other springs are only partly used for local drinking water supply and small scale irrigation. The springs may be captured and connected to a gravity system to supply the lower lying villages.

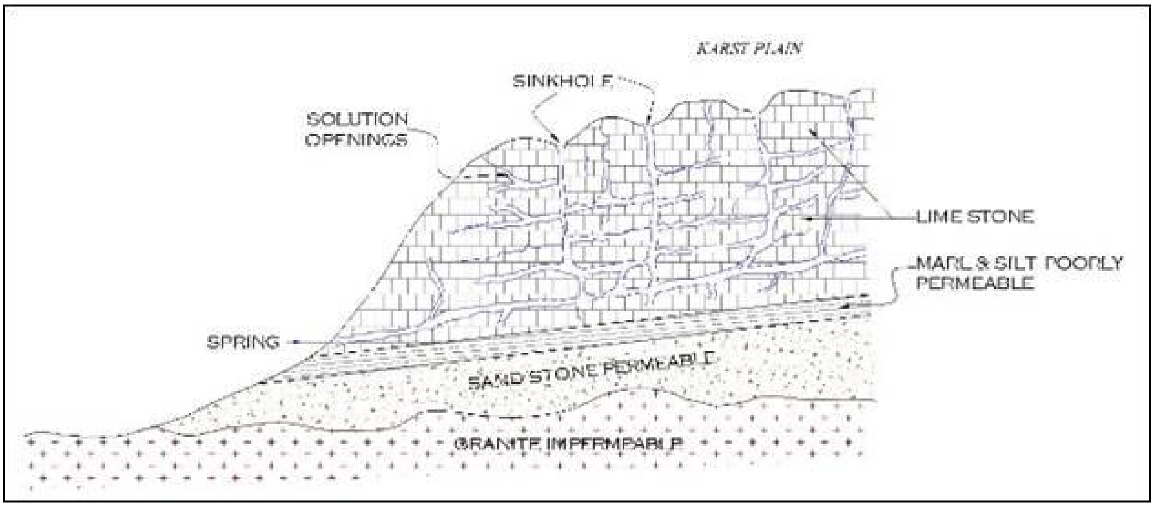

Figure 13. Schematic section of the spring recharge at the Hakim Gara area

6 Conclusions

Water allocation is a management decision to match available resources with the water demands and is based on economic, social and political priorities. Scenarios for water allocation are important in order to take timely decision on investments which are needed implement the scenarios and secure the that future water supply demands are timely covered in a cost effective and socially acceptable way

This report presents the assessment of the regional water resources and forms an important input to the development of water allocation scenarios which the Stakeholder Platform will discuss for decision making to secure the long term water supply for the different sectors. Additional building stones for the water allocation scenarios are

- The current gap between available resources and water demands from the different sectors
- Changes (increase) in water demands during the planning period (15-25 years)
- Impacts of climate change on available water resources and on the water demands

These components will be studied in the coming months and reported in the water allocation scenario report (Report 6.2). The information from this report already gives some direction to the formulation of scenarios which are summarized below:

Conclusions on the water resources assessment are:

- A substantial part of the rainfall in the sub basins is discharged as runoff and eventually leaves the study area through Wadi Erer and Wadi Gobele. Data on runoff are absent and installing gauging stations in these main wadis and in selected sub catchments (Alemeya sub basin) is urgently needed to create a reliable knowledge base for decision making
- The runoff is seasonal and capturing runoff for productive use will require water buffering solutions to create the storage capacity. Large dams are a logical option and some dams are already in the planning stage. Dams are "grey" infrastructure solutions and it is recommended to compare this with 'green" infrastructure investments[1] . The water buffering pilots under Result 6 will provide the scope for alternative ("green-grey") solutions.
- In terms of water availability, the main water resources prospective areas are the Alemeya Basin (and other alluvial deposits in the north east) and the groundwater reserves in Wadi Erer and Decheo. These areas may be developed to provide water to a wider area in combination with the long term water provision form the Dire Daws wellfield
- Most of the other prospective areas are important for the local drinking water supply but do not have the capacity to serve larger areas or to provide water for large scale irrigation.
- Few detailed studies are available of the prospective areas except for the lower Wadi Erer (HWSA) and the Alemeya Basin (Alemeya University, IWMI). For Alemeya it is important to do additional studies to improve the understanding of the water balance including a detailed study of runoff flow through the 2 outlets (section 5.1.2).

[1] Green infrastructure refers to natural or semi natural systems that provide services for water resources management with equivalent or similar benefits to conventional (built) "grey" water infrastructure (IUCN, UNEP, a.o. , 2014, *Green Infrastructure : Guide for Water Development)*

Preliminary remarks on the allocation scenarios

- The demand for drinking water supply and industrial water supply are fairly well known from the 2007 census and estimates of the future demands can be made on the basis of population growth rate scenarios and per capita water consumption. A first estimate of the increase in drinking water demands (based on projected population density and unit water consumption figures) is presented in figure 14. It shows that the largest increase is expected in the urban areas (Harer, Aweday, Alemaya, Adele) as well as the north-eastern part of the project area (Kombolcha, Melka Radu).

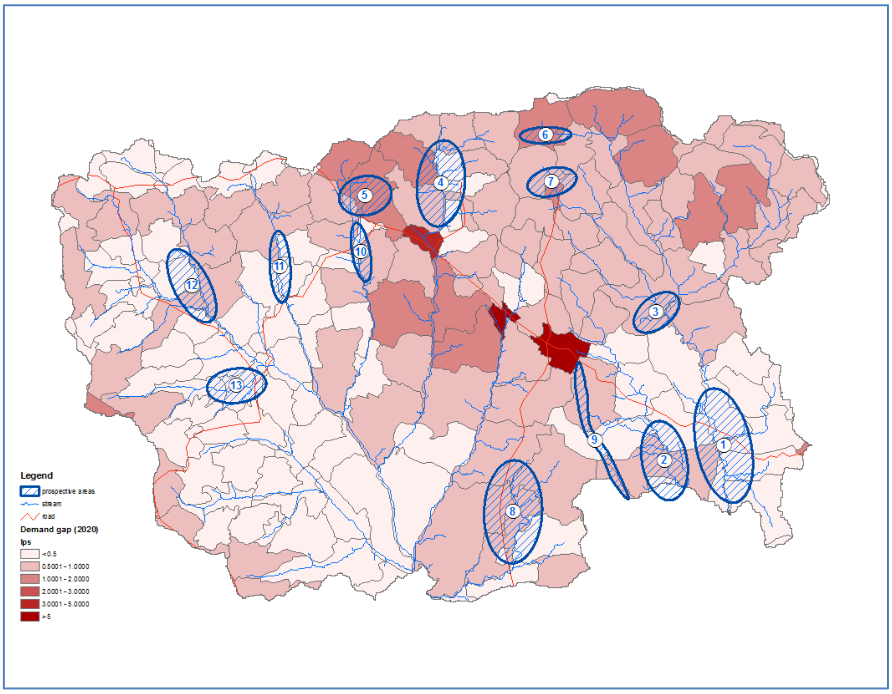

Figure 14 Increase in drinking water demand (2020) and prospective areas for water development

- Figure 14 also shows the prospective areas for water development (Figure 10). The main (drinking) water demands along the Dire Dire Dawa –Jijiga road are currently covered from the Dire Dawa pipe line and from the Alemeya sub basin (area 4 and 5). Additional water will be made available from the lower Wadi Erer (area 1 and 2). The allocation plan should confirm that these sources provide a long term source of water for this main demand area
- Additional water could be developed from the upper part of Erer Wadi (area 3) and serve both local water supply and provide additional water to urban Harer. Harer Brewery and HWSA are exploring the option to join forces for a water supply from area 3.
- For the remaining areas the focus should be on development of the water resources (and water buffering) to serve the nearby demands for drinking water and industrial water.
- Water demands for agriculture is a difficult component. There is a growth in irrigation of quat but it is not clear yet how this development is controlled by the Oromia and Harer Government. The water resources assessment indicates that water for large scale irrigation is not available unless large scale water buffering investments are made. This will be further assessed in Report 6.2
- The report 6.2 will summarize the development options of the water development areas which can serve as a basis for detailed studies and the development of investment programs and funding proposals by the HPRS and Oromia Government

Annex 1

Water Quality Data

Date	X _COR	Y_COR	sample id	TDS	T-Hardness	CaCO3	Ca	Mgco3	Mg	Fe	F	Mn	Al	NH3	NO3	PH	Turbidity	EC	Na	K	Cl	Cl2	SO4	PO4	NH4	Remarks
24/03/2014	198705	1020014	TW-4-1		300	155	62	145	42.0	0.06	0.88	0.008	0.00	1.00	0.03	7.40	2.20									
25/03/2014	198705	1020014	TW-4-2		330	185	74	145	42.1	0.03	0.57	0.002	0.00	0.64	0.04	7.60	7.66									
26/03/2014	198705	1020014	TW-4-3		285	200	80	85	24.5	1.04	0.74	0.006	0.00	0.31	0.01	7.40	8.16									
27/03/2014	198705	1020014	TW-4-4		300	188	75	113	32.5	0.30	1.50	0.002	0.01	0.30	0.05	7.60	8.10									
15/04/2014	199997	1017639	TW-6	416	210	168	66	42	11.0	0.40	0.80	0.003	0.05	0.10	0.15	7.35	0.28	832								
04/08/2014	0	0	TW-7	1170	410	216	87	134	47.2	0.64	1.47	0.010		1.16	0.19	7.15	2.80	2340								
05/08/2014	0	0	TW-9	775	290	148	59	142	41.2	0.11	1.52	0.004	0.02	0.31	0.05	7.50	1.04	1550								
21/11/2013	0	0	GW-OSIS							0.21	0.53	0.008		0.63		7.05	1.01									
27/03/2014	198705	1020014	TW-4		360	189	76	154	44.0	0.05	0.35	0.002	0.01	0.30	0.05	7.60	81.00									
27/03/2014	198705	1020014	TW-4		350	244	98	106	25.8	0.07	0.35	0.010	0.01	0.30	0.05	7.25	6.42									repeated result
11-26-2013	193644	1033772	Erer Health Centre							8.09	1.00	0.003				7.55	1.91									10 meter borehole
12/05/2013	182726	1039793	Jibraeilo							0.21	1.05	0.050				7.40	0.55									
21/11/2013	0	0	A/yhu kebt/ta							0.21	1.21	0.020		0.30		7.55	0.75									
13/02/2012	0	0	IFFEBATE reservior	383	320	226	91	94	27.3	0.03	0.25	0.018			2.30	6.94		793								
13/02/2012	0	0	Aseliso reservior	424	337	295	118	74	22.0	0.21	0.42	0.043		0.03	0.10	6.83		880								
22/11/2007	800276	1058325	16	418	368	260	104	108	31.5	0.78	0.51	0.077		0.58	0.20	7.96	0.00	859								
11-22-2007	800722	1058418	11	449	430	282	113	148	43.0	0.14	0.54	0.160		0.90	0.60	7.73	3.00	928								
11-25-2007	800484	1058356	14	433	370	240	96	130	38.0	0.11	0.44	0.050		0.68	0.30	8.18	0.00	893								
10/08/2007	801738	1058408	17	467	450	284	114	166	48.1	0.09	0.41	0.070		0.86	0.02	7.98	0.00	965								
10-17-2007	801325	1058420	4	469	440	340	136	100	29.0	0.75	0.67	0.000		0.72	0.00	7.60	2.00	967								
06-27-2007	801425	1058252	15	472	496	360	144	136	39.4	0.12	0.50	0.000		0.47	0.00	7.60	3.00	978								
09/05/2007	801606	1058257	10	461	436	284	113	152	43.4	0.10	0.39	0.000		0.96	0.00	7.96	1.00	955								
23/04/2014	0	0	Bergadstream		436	252	101	144	44.0	0.01	0.40	0.005	0.00	0.82	0.44	7.45	0.25									
01/01/2010	176750	1043171	HW-1	408	384	324	91		35.3	0.03	0.15	Trace			12.50	7.62		664	11.7	1.40	14.3		11	0.08	0.28	
01/01/2010	175571	1041113	HW-3	414	371	343	122		15.2	Trace	0.50	Trace			7.00	7.27		693	19.0	1.00	20.0		17	0.10	0.15	
01/01/2010	828104	1040460	HW-4	474	326	229	106		13.7	Trace	0.45	Trace			14.25	7.34		708	32.0	4.60	46.6		50	0.12	0.15	
01/01/2010	828272	1041936	HW-5	336	239	194	78		9.8	Trace	Trace	Trace			21.50	7.68		528	28.0	1.80	28.5		19	0.06	0.25	
01/01/2010	170767	1041348	HW-7	500	345	255	109		16.7	Trace	0.50	0.050			5.00	7.54		793	51.0	2.00	63.7		66	0.04	0.22	
01/01/2010	172611	1040355	HW-8	648	428	355	97		42.1	Trace	0.80	0.020			5.00	7.65		966	70.0	1.30	42.8		151	0.08	0.26	
01/01/2010	171799	1040751	HW-9	1890	868	292	183		93.1	Trace	0.50	0.050			17.50	7.38		2920	290.0	2.30	461.7		468	0.04	0.65	
01/01/2010	173319	1042855	HW-10	318	152	149	36		14.2	0.02	1.10	Trace			8.50	7.68		484	52.0	2.60	35.2		72	0.06	0.39	
01/01/2010	178675	1044507	SP-1	404	332	310	93		22.5	Trace	Trace	Trace			19.50	7.09		628	6.3	0.60	9.5		12	0.04	0.13	
01/01/2010	178049	1044093	SP-2	418	349	326	91		27.4	Trace	0.50	Trace			19.50	7.15		669	7.3	0.80	8.6		11	0.06	0.19	
01/01/2010	177517	1043059	SP-4	494	386	347	102		29.9	Trace	0.15	Trace			14.30	7.06		780	10.7	8.00	19.0		27	0.06	0.19	
01/01/2010	178840	1042810	SP-6	448	438	355	123		29.9	Trace	Trace	Trace			14.25	7.00		736	6.5	1.30	12.4		17	0.04	0.40	
01/01/2010	174135	1041428	BH-0	494	412	353	126		22.1	Trace	Trace	Trace			8.00	7.66		804	31.0	1.40	31.4		25	0.25	0.15	
01/01/2010	173975	1041732	BH-1	444	256	269	77		14.7	Trace	0.96	0.020			10.00	7.36		702	61.0	2.40	37.1		72	0.08	0.13	
01/01/2010	173925	1042432	BH-7	632	510	447	152		29.4	Trace	0.45	Trace			8.00	7.35		1033	51.0	1.70	57.0		25	0.06	0.65	
01/01/2010	173961	1040960	S2	523	456	395				0.02	0.70	0.008			13.20	7.34	0.76	1046								72 m well depth where water level is at 18 m
01/01/2010	175044	1041919	A3	338	455	290				0.01	0.65	0.006			19.80	6.86	7.76	676								48 m well depth where water level is at 12 m
01/01/2010	173644	1042885	A8	468	465	405				Trace	0.65	Trace			26.40	7.55	0.16	936								
01/01/2010	174861	1041958	M1	473	376	380				0.01	1.00	0.008			24.20	7.39	14.37	946								58 m well depth where water level is at 14 m
05/06/2014	823239	1042742	RC1	627	320	295	115	25	7.1	0.08	0.77	0.004	0.00	0.9	0.85	7.50	0.00	1256		3.50	5.0	0.44	41	0.22		
05/06/2014	807010	1043943	RC3	1,16 ppt	380	202	81	178	50.9	0.25	1.55	0.006	0.03	0.99	0.66	7.04	0.58	2330		5.70	1.0	0.31	47	0.05		58 meters deep hand dug well
05/06/2014	807341	1044479	RC4	512	300	165	66	135	38.6	2.30	0.50	0.002	0.01	0.78	1.20	7.06	2.52	1023		3.80	1.9	0.51	23	0.77		
05/06/2014	165740	1041642	RC2	918	410	277	111	133	38.0	0.04	1.36	0.014	0.02	0.65		7.36	1.01	1836		3.20	1.1	0.10	272	2.90		9 meter hand dug well, private
06/06/2014	183410	1042748	RC5	265	265	170	68	95	27.1	9.80	0.34	0.001	0.04	0.70	0.92	6.80	0.13	434		0.00	0.8	0.30	26	0.59		15 meter deep borehole
06/06/2014	184868	1046609	RC6	161	140	40	16	100	28.6	0.17	0.24	0.004	0.00	0.50	0.23	6.86	0.30	322		4.30	1.3	0.73	39	0.86		9.5 meter hand dug well
06/06/2014	184774	1046020	RC7	203	170	105	42	65	18.6	0.08	0.00	0.000	0.00	0.00	0.88	7.00	0.29	406		1.50	0.0	0.01	4.0	0.05		6.5 meter hand dug well
06/06/2014	186460	1045888	RC8	159	160	100	40	60	17.1	1.02	0.00	0.003	0.00	0.00	0.31	6.90	0.01	320		0.70	0.0	0.00	4.0	0.26		45 meter borehole, Chloride added on 5-6-2-14
06/06/2014	193845	1049624	RC9	167	170	75	30	95	27.1	3.45	0.45	0.004	0.01	0.00	0.54	7.60	0.28	334		4.00	0.6	0.19	1.0	0.71		spring in basalt area
09/09/2014	197501	1022675	RC10	358	360	194	78	166	47.4	0.02	0.76	0.011	0.00	0.83	0.16	7.00	2.40	715		3.10	0.0	0.00	0.0	0.62		35 meter deep borehole
09/09/2014	193969	1031657	RC11	462	340	178	71	162	46.3	7.80	0.99	0.012	0.00	0.55	0.06	7.00	0.06	924		3.20	0.4	0.01	70	0.34		hand dug well
09/09/2014	195605	1036450	RC12	761	390	203	81	187	53.4	0.05	8.32	0.020	0.06	1.00	0.20	6.82	0.32	1548		1.90	0.6		165	1.50		10 meter hand dug well in sand
09/09/2014	194634	1034801	RC13	720	320	269	108	51	14.6	0.11	0.46	0.011	0.02	0.93	0.08	7.00	0.00	1443		2.00	0.1		165	0.91		5 meter hand dug well
09/09/2014	194674	1034692	RC14	688	330	269	108	61	17.4	0.81	1.40	0.016	0.00	0.55	0.18	6.95	0.39	1377		5.80	0.0		160	0.24		5 meter hand dug well
11/09/2014	181203	1025597	RC15	362	330	134	54	196	56.0	0.04	0.61	0.006	0.02	0.95	0.32	7.16	0.08	718		6.20	0.3		16	0.54		90 meter deep borehole
11/09/2014	179081	1009612	RC16	479	310	189	76	121	34.6	0.09	1.20	0.019	0.04	0.94	0.08	6.96	129.00	957		4.00	0.1		92	0.69		9 meter hand dug well
11/09/2014	180122	1024097	RC17	572	480	298	119	182	52.0	0.04	1.19	0.008	0.02	0.78	0.15	6.95	0.45	1144		3.40	0.1		180	1.10		Deep borehole
13/06/2014	186412	1025861	RC18	352	320	212	85	108	30.9	1.04	1.33	0.006	0.02	0.64	0.19	6.74	0.15	705		1.70	0.1		26	0.43		Spring
13/06/2014	189503	1022382	RC19	356	260	188	75	72	20.6	0.04	1.52	0.005	0.01	0.15	0.16	7.27	0.12	711		3.2	0.0		44	0.48		Spring

c

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