TECH-4

Description of the Approach, Methodology, and Work Plan for Performing the Assignment

Assignment Title:

Selection of Consultant for Groundwater Potential Assessment, Detail Reconnaissance Hydrogeological Study, Groundwater Feasibility Study, Contract Administration & Supervision of Drilling of Test Wells in Metema- Chilga Area, Amhara Region

PROCUREMENT REFERENCE NO: ET-MOWE-451292-CS-QCBS

Client:

Ministry of Water and Energy

Country:

Federal Republic of Ethiopia

Name of the Program:

Horn of Africa Groundwater for Resilience Regional Program - (P174867)

Joint Venture of

SG Geotechnika, a.s. (Czech Republic) – lead company

Acacia Water (Netherlands)

Aquacon Engineering, PLC (Ethiopia)

With subconsultant

Czech Geological Survey (Czech Republic)

February 2025

Contents

INTRODUCTION AND BACKGROUND

Introduction

Groundwater is able to create drought resilience, improve the welfare of the population, utilize the land resources and for sustainable agricultural production. In this regard, the use of groundwater for water supply and/or irrigation practices is expected to result in far reaching implication in ensuring food security for urban and the rural community. The Project is part of a regional HoA initiative that aims to strengthen the resilience of targeted communities through the management and collaborative use of groundwater resources and is funded by the World Bank.

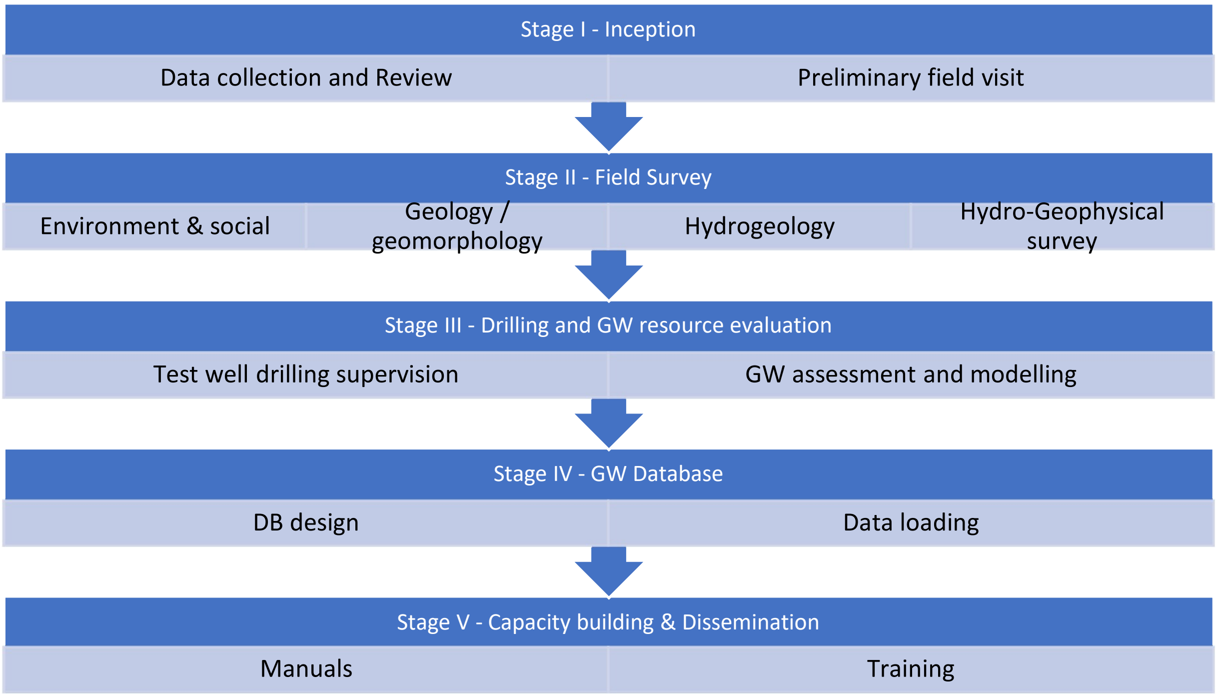
Water insecurity is a growing concern globally, especially in developing countries, where a combination of population growth, urbanization, changing consumption patterns along with improved living standards, and climate change variability put increasing pressure on water supply systems. The development of the groundwater scheme has received considerable attention in recent years. However, in many such instances, the expansion of groundwater development has not been preceded or accompanied by systematic studies to evaluate the resource potentials of the respective aquifers.

Exploration of groundwater potential has been undertaking with a very good results in different parts of Ethiopia. So far, many groundwater resource assessment and evaluation projects covering broad areas were completed mainly by the Ministry of Water and Energy, UNICEF and Agricultural Transformation Agency/Institute. These include Raya-Kobo-Girana (Northern), Teru-Chifra (North Eastern), Allaidege (Main Ethiopian Rift), Meskan-Mareko-Silte, Lower Bilate (Rift Valley), Adaa-Becho-Addis Ababa (Central), Fafem-Jerer (Eastern) and Ambo-Welkite (Western) areas groundwater resource assessment and evaluation projects are the major ones completed in the past. Of these, the water supply source of Addis Ababa City and its surrounding towns is mainly groundwater (about 60 to 70%).

Therefore, in order to derive the optimum benefit from a groundwater scheme, a proper resource study has to be carried out. However, unlike surface water processes, most of the groundwater activity is invisible in the strata that lie below the ground surface. Measurement and monitoring of groundwater flow are therefore extremely difficult. Therefore, in order to minimize most of the simplifying assumptions in groundwater assessment programs, several integrated exploration approaches should be applied. As part of the integrated approach to groundwater exploration, combination of geological, hydrological, hydrogeological and geophysical exploration tools needs to be implemented. Groundwater recharge is an essential component of such investigation and therefore must be estimated before attempting to develop the groundwater model of an area. Hence, the core and ultimate goal regarding this project shall be to estimate the quantity and investigate the quality of the groundwater available in an area for water supply and/or irrigation development.

The proposed studies shall be carried out in five stages. The First Stage (Stage-I) of the investigation is the Inception Stage composed of review of previous works, overlay analysis to determine groundwater prospective areas, develop conceptual hydrogeological model, preliminary field visit and submission of Inception report and maps. The Second Stage (Stage-II) comprises field hydro-geophysical surveys in specified target areas to select sites for test and/or pilot production wells, drilling and testing, including maps and bidding documents. During the Third Stage (Stage-III), detail hydrogeological investigation shall be conducted at a specific target area with the aid of test and/or pilot production wells that shall be drilled and tested to assess the groundwater resource; evaluation and management activities that includes determination of aquifer parameters and estimation of total exploitable groundwater resource together with analytical and/or numerical groundwater modelling used for groundwater management shall be carried out. The final activities are preparation of Groundwater Database in Stage-IV, and information dissemination and capacity building in Stage-V.

The diagram below is meant to provide a clear picture of the main tasks required to be implemented.



Project workflow as per ToR

Objectives of the Assignment

The general objective of the investigation is to determine the potential (prospective) groundwater sites for groundwater development for intervention of the current and future water demand under consideration of the climate change impacts.

The specific objectives of the study are summarized as follows:

The general objective of the investigation is to determine the potential (prospective) groundwater sites for groundwater development for intervention of the current and future water demand under consideration of the climate change impacts.

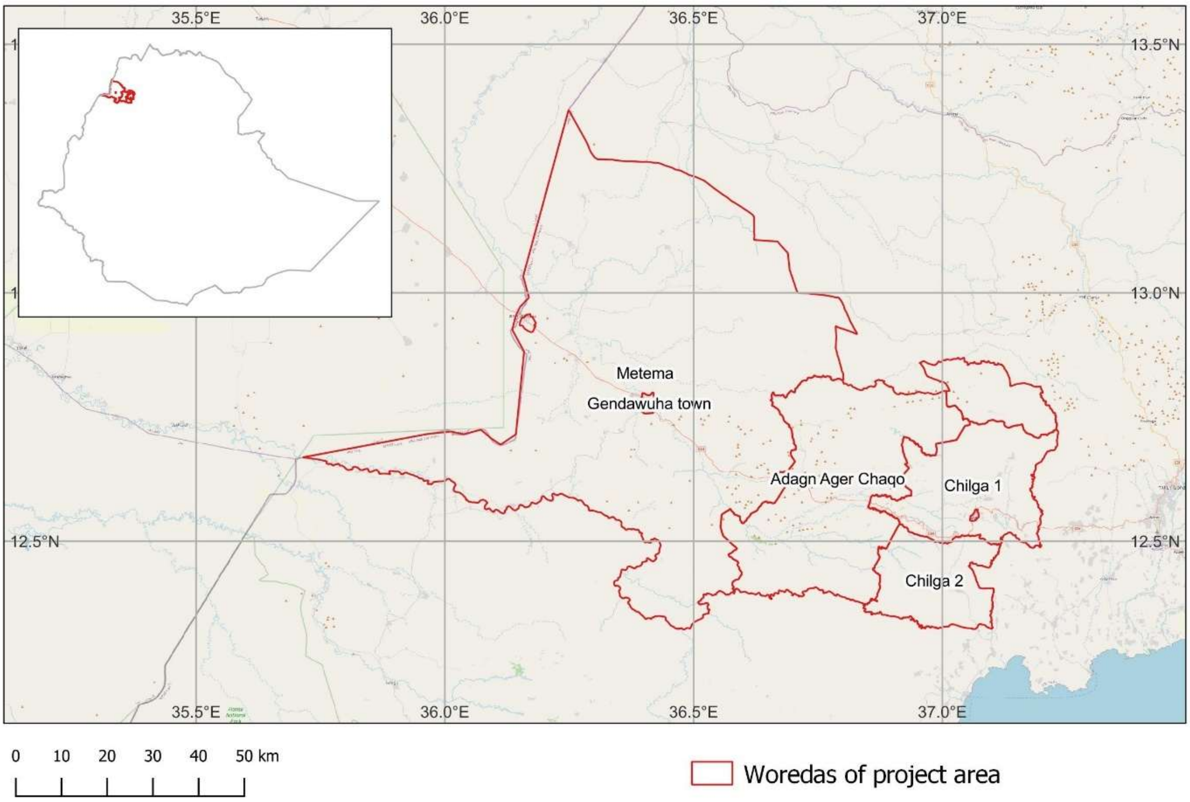
The specific objectives of the study are summarized as follows:

- Undertake water demand assessment for multipurpose utilization.
- Determine the hydrogeological condition of the area: identify sites, evaluate recharge, and discharge conditions, delineate spatial distribution of different aquifers, determine hydraulic parameters, analyze water quality of the aquifers, and assess impacts of future exploitation of the potential aquifers.
- Qualitative and quantitative evaluation of the groundwater resources on selected potential sites or prospective areas.
- Bidding document preparation for drilling and testing of test/pilot production wells.

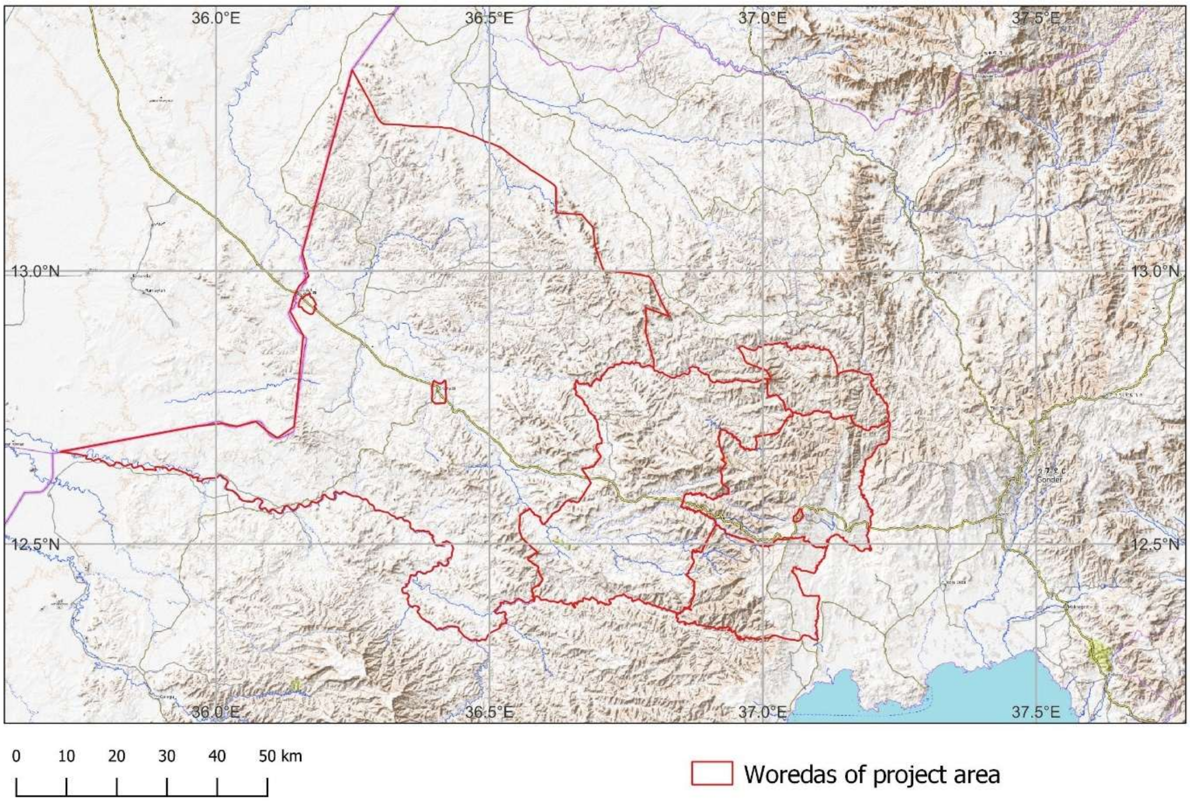
- Supervision of test and/or pilot production wells drilling and testing.
- Carry out analytical and/or numerical model of the main aquifer of the area to recommend appropriate groundwater exploitation and management.
- Evaluate groundwater resources and develop strategy of groundwater resources development and protection with their cost estimates.
- Create detailed groundwater resource potential maps.
- Identify promising areas for groundwater development.
- Conduct enhancement of the national groundwater database and carry out massive processing and uploading of existing data collected from all over the country.
- Build the capacity of MoWE and Regional Water Bureaus by providing on-the-job

Project Area and its geological and hydrogeological settings

The proposed study area is situated in Amhara Region and surrounding the Metema-Chilga area comprising of 2 woredas namely Metema and Chilga. Its extent is about 12,595 km^2 that lies between 12.32^o to 13.45^o Latitude and 35.86^o to 37.23^o Longitude geographic coordinate. Its elevation is approximately in the range of 527 m a.s.l in the valleys and over 2300 m a.s.l in the mountains. The study area is situated within the Abay Basin and Tekeze Basin.



Overview of the project area



Topographic map of the project area

Extensive knowledge of the consultant and experience with the project area allows us to preliminary describe the expected geological and hydrogeological settings.

Regional Geology of the project area is relatively monotonous and consist of Tertiary volcanic, Paleozoic sediments covered by Quaternary sedimentary rocks along border of Ethiopian and Sudan and sediments of Chilga formation west of the Goner town.

Volcanic rocks units in the project area correspond to the (i) Paleogene basalts with intercalations of rhyolites and pyroclastic rocks and (ii) Rhyolitic to trachytic volcanoclastic deposits with subordinate felsic lava. The units are of pre-rift phase of volcanic activity resulting in Trap basalt sequence. The Ethiopian Plateau volcanic succession forms a typical, flat topped plateau topography, often extensively eroded, and dissected by deep gorges. The volcanic succession of the NWP consists of the Ashangi and Aiba Basalts. The basaltic pile is made up of the lower Ashangi Basalts characterized by thin lava flows (< 10 m) and volcaniclastic layers forming a relatively smooth or less steep topography. The upper basaltic succession (commonly referred to as the Aiba Basalts) comprises thicker lava flows (10–50 m) that characteristically form cliffs at exposures

The Chilga sedimentary basin is Norh-South running tectonic graben which is 15 km in length and up to 3 km in width. Lignite-containing sediments (clay, silt, ash, shale) deposited in the graben and the age of the sediments is estimated to be Pliocene.

Palaeozoic sediments have been mapped at the border area; however, it forms a small outcrop and is covered by thin (10 to 20 m) Quaternary sediments.

Quaternary sediments cover is mainly found close to major rivers and extensive deposits are found on the low-lying areas of the Metema plain. It covers a vast area of the western lowlands which is the continuation of the Sudanese plain. Alluvial soils and eluvial sediments are also found in some places along other river channels and their tributaries in the study area. Alluvium consists of more or less stratified deposits of gravel, sand and clay which are moved by the stream flow from higher to lower ground. Channel and terrace deposits are also known within alluvial deposits. The river channel deposits contain coarse material such as sand, gravel, cobbles and blocks. As observed in the study area, the alluvial sediments grade from clay and silt at the top to coarser sand and gravel at the bottom (following an upwardly thinning sequence).

Regional hydrogeological system is based on the classification of qualitative and quantitative parameters of the hydrogeological characteristics of various rocks:

Units with intergranular permeability, where groundwater is accumulated in and is flowing through pores of unconsolidated or semi-consolidated material. Porous materials of Quaternary and Tertiary age are represented by fluvial, lacustrine and colluvial sediments developed in depressions (sediments of lakes) and/or along valleys of former and existing rivers. The intergranular aquifers are only locally developed and scattered over the study area. These intergranular aquifers have moderate and locally high productivity (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).

Units with fissured permeability, where groundwater is accumulating in and flowing through the weathered and fractured and jointed parts of sedimentary and volcanic rocks. Fine to medium grained sandstone has a good fissured porosity. 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. Layers of paleosoil of various thicknesses in between lava flows are also less permeable and consist usually of clay material. On the other hand, layers of fluvial and lake sediments between various lava flows can enhance yield. Hence, extensive volcanic ash beds may form semi-horizontal barriers to water movement (recharge) resulting in lower productivity of basaltic units located at greater depth. These fissured aquifers have moderate and locally high productivity (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).

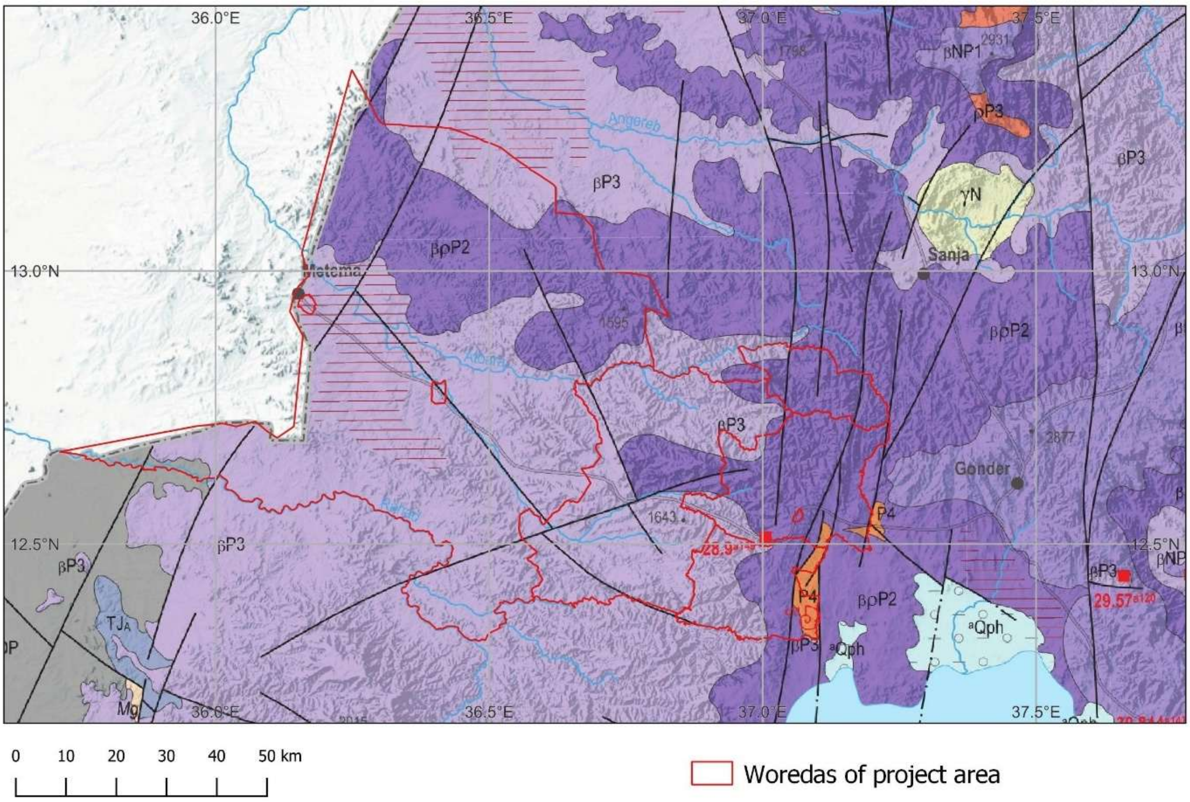
Eluvium (regolith) and alluvial materials with low thickness cover large areas of the Metema plain representing limited aquifers in unconsolidated material with shallow groundwater for local use providing a variable amount of groundwater based on thickness variation and proximity to recharging areas. The regolith is derived from volcanic rocks and can be mixed with alluvial, glacial and soil material. The aquifers are about 30 m thick and can be used primarily for household irrigation. The yield of the unit varies from 0.001 to 0.1 l/s. Shallow groundwater development is usually by hand dug and/or hand drilled wells. These aquifers are mainly recharged directly by rainfall.

Outcrops of Chilga formation and Paleozoic sediments have no hydrogeological importance.

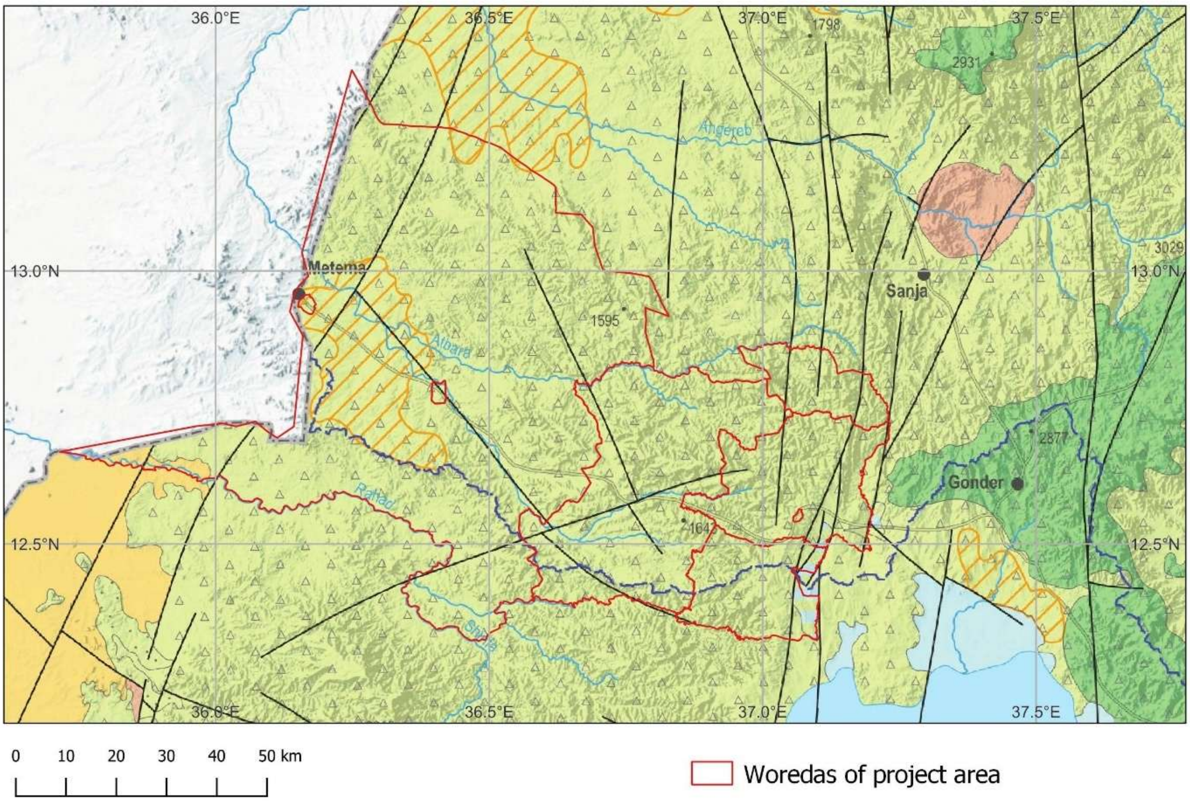
Based on the data of the total runoff and baseflow from the area, there are good surface as well as groundwater resources to be used for irrigation as well as for drinking water supply of people living within the area.

The main lithological units are as follows:

- Palaeozoic sediments along the border with Sudan and in Chilga graben (OP and P4)
- Pre-rift volcanic rocks of Ashangi and Aiba units (BP3 and BP2)
- Quaternary sedimentary cover and regolith (horizontal hatching)



Geological map of the project area (derived from Verner et al., 2024)



Hydrogeological map of the project area (derived from Sima et al., 2024)

General approach and key advantages of our proposal

Central to our proposal and a key advantage of our Consortium, is the experience we have acquired in Ethiopia and the western Ethiopia (Amhara Regional State) and areas surrounding of Chilga (Aykel town) and Metema areas utilizing and testing a range of datasets, analytical tools, and approaches tailor-made for aquifer assessment in such a unique context. More specifically our approach is based on the following key assets:

- We are introducing Integrated approach synthetizing multidisciplinary expertise into comprehensive but understandable outputs tailored for client needs.
- The Consultants team combines experience of international and national companies with professional experts and staff.
- Extensive experience in GW investigations in Ethiopia (including the project area) and worldwide allows us to understand local specifics and to see the subject complexity bringing in up to date methods and innovations along with robust time proved methods at the same time.
- We can engage and communicate with local stakeholders in their language.
- Our previous knowledge of the area and relevant data sources allows us to incorporate many specific local details, including climate change challenges as shown in our methodology below.
- In respect of cyber security, JV consultants are using only legal software with permanent awareness of released system updates and deploying security patches. Individual companies of the JV are backed with professional IT departments following the security standards required in EU. Any concerns or requirements in respect of cyber security raised by the client could be effectively addressed in this regard.

Risk and mitigation measures

In the proposed study, various risks can arise, impacting the successful execution and completion of the study. The Consultant shall therefore identify, assess, and manage these risks effectively during the course of the assignment implementation. Some of the potential risks anticipated to be associated with the proposed Aquifer assessment include but not limited to the following:

Risk management in the Proposed Aquifer Study

RISK ITEM	RISK	MITIGATION
Data Quality and Availability	Incomplete or inaccurate data regarding the aquifer.	▪ Conduct a thorough data quality assessment. ▪ Collaborate with local agencies, research institutions (Gonder University), and communities to ensure access to reliable and comprehensive data. ▪ Implement data validation and verification procedures.
Technical Challenge	Unforeseen technical challenges in data collection, analysis, or interpretation.	▪ The Consultant has proposed qualified team of expertise, with experience in aquifer studies.

RISK ITEM	RISK	MITIGATION
		■ Conduct reconnaissance fields visits to identify and address potential technical issues.
Regulatory and Permitting Issues	Delays or complications due to regulatory hurdles or challenges in obtaining necessary permits especially the drilling permits.	■ Work closely with regional environmental and water regulatory bodies. ■ Stay informed about relevant regulations and permit requirements. ■ Initiate the permitting process early and maintain open communication with regulatory authorities.
Community Engagement and Opposition	Opposition or resistance from local communities	■ Develop a comprehensive community engagement plan. ■ Communicate transparently about the study's objectives, benefits, and potential impacts. ■ Involve local communities in the decision-making process and address concerns proactively.
Environmental Impact	Unintended negative environmental impacts from the study	■ Conduct a thorough environmental impact assessment. ■ Implement best practices and safeguards to minimize any adverse effects. ■ Comply with local and international environmental regulations.
Political and Social Stability	Political instability or social unrest in the project area.	■ Monitor political and social conditions in the region. ■ Establish contingency plans for potential disruptions. ■ Maintain open communication with regional and local authorities.
Knowledge Transfer and Capacity Building	Insufficient knowledge transfer to local stakeholders.	■ Develop a capacity-building plan. Include training sessions for local stakeholders and ensure knowledge transfer throughout the project. Foster collaboration with regional and local institutions.

RISK ITEM	RISK	MITIGATION
Health and Safety	Workplace accidents or health risks to project personnel.	■ Implement stringent health and safety protocols. Provide appropriate training to project personnel. Regularly assess and address potential health and safety risks.

SECTION A – TECHNICAL APPROACH AND METHODOLOGY

1. Stage 1 - Inception

Main activities: **Data collection & Overlay analysis, Preliminary field visit**

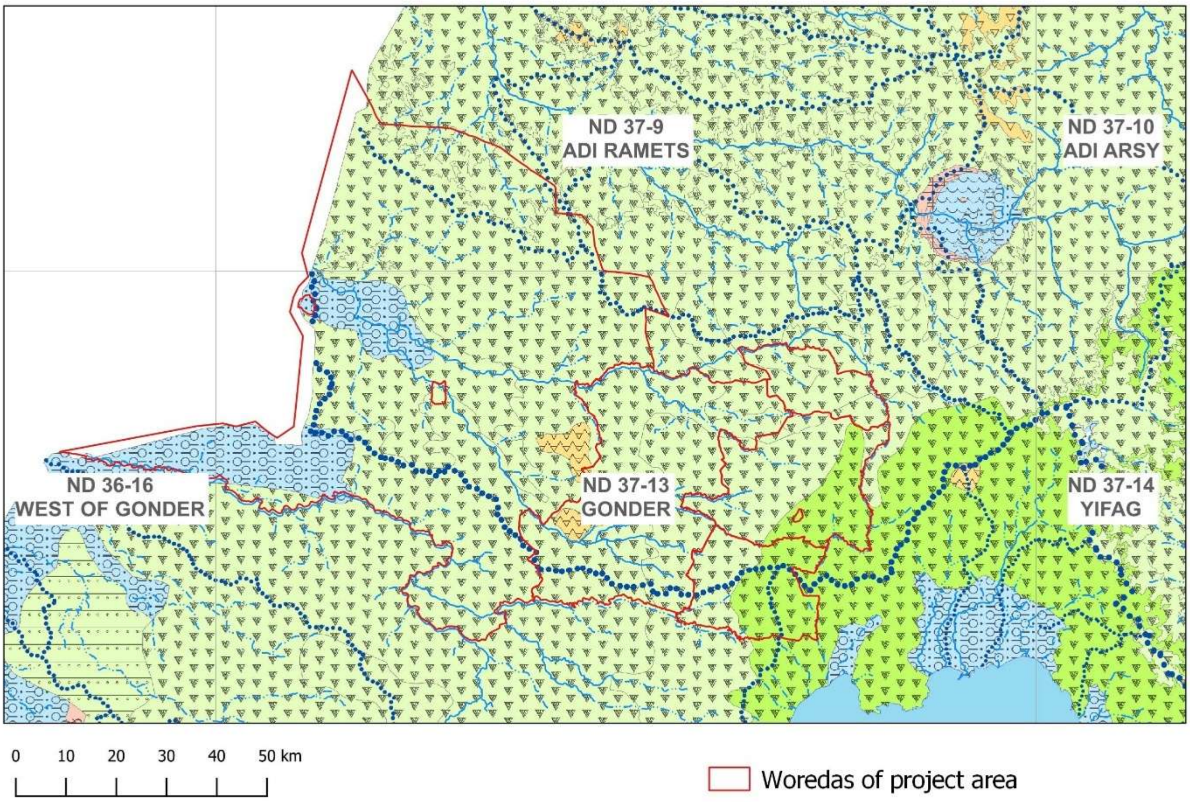
Main deliverables: **Inception report**

Project database

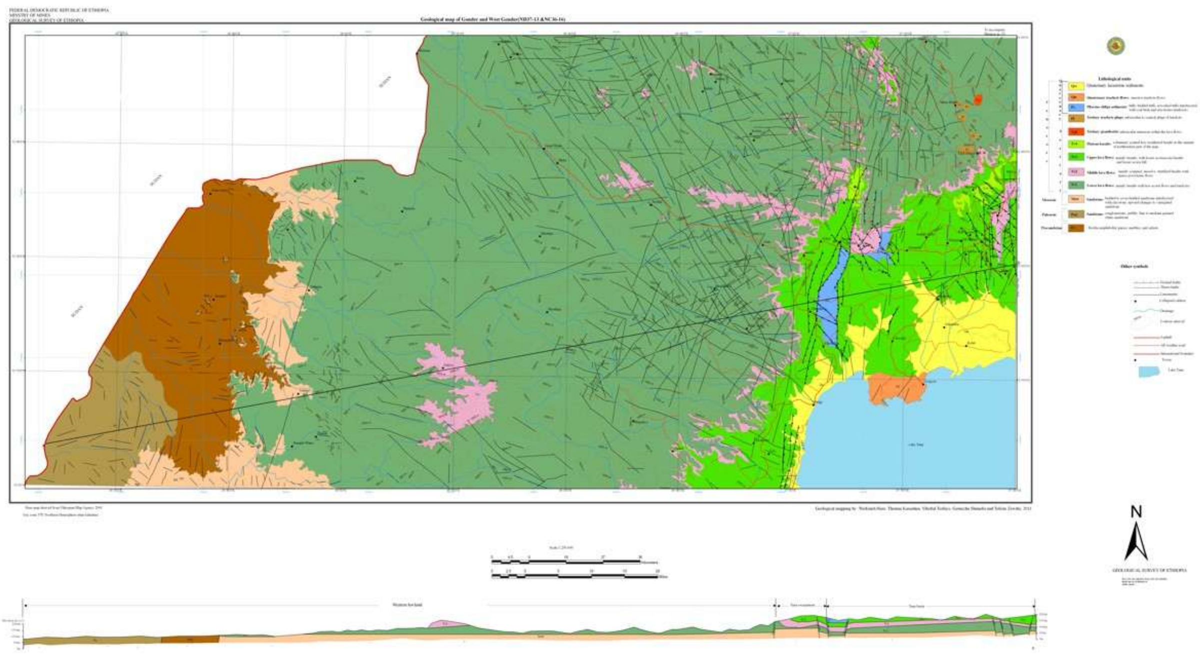
The project database system (see stage 4 for details) will be identified, and proper system of inventoried data filing will be proposed. Data from archival and new field inventory will be transferred to these filling forms to be integrated into the final project – (national) central database system operated by the MoWE.

Main data sources and thematic layers

Geological/Hydrogeological maps. Main data collection will start with existing geological, hydrogeological and hydrochemical maps at a scale 1 : 250 000 GSE and other related maps at a scale 1 : 1 200 000 published in cooperation with MoWE (in archive of the Consultant). The project area is covered by Map of Gonder ND 37-13 and small part of West of Gonder ND 36-16 and Adis Ramets ND 37-9. Based on data collected the first version of geological base and hydrogeological maps of the project area will be prepared using harmonized legend.



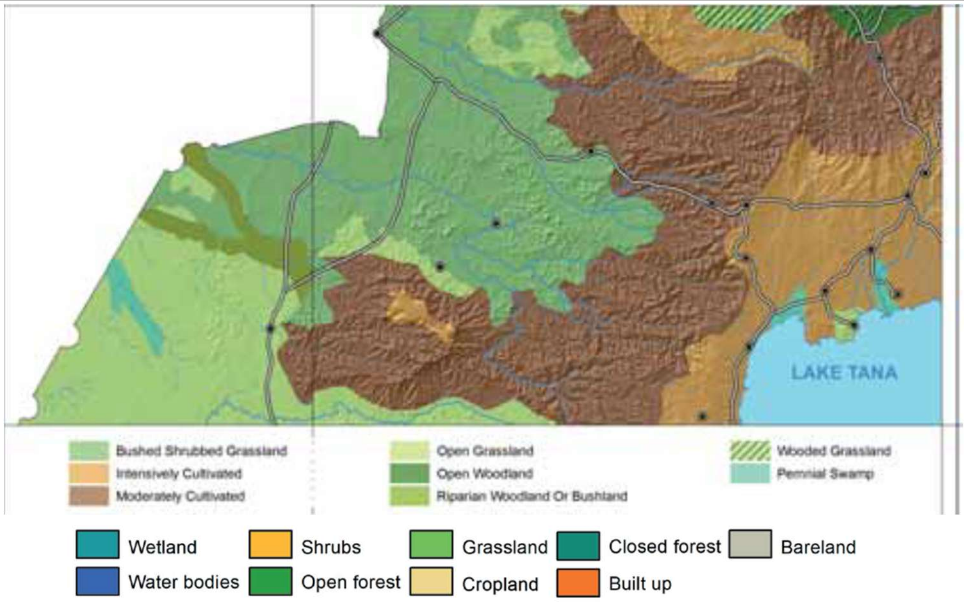
Coverage of existing hydrogeological maps at scale 1:250,000



Existing geological map at scale 1:250,000 (Gonder and West of Gonder)

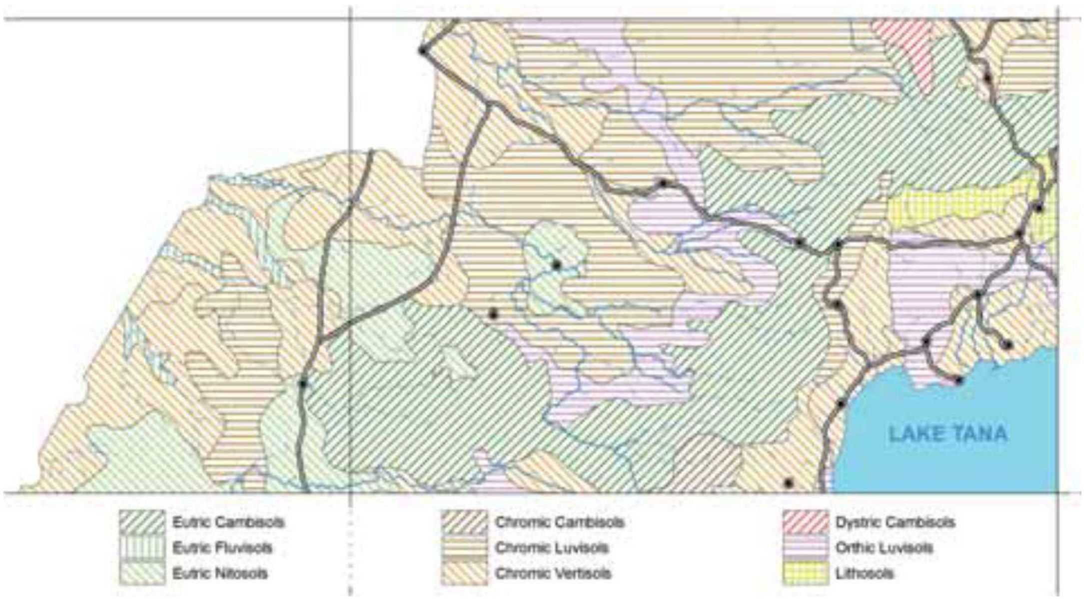
Collection of Land Use/ Land Cover (LU/LC) maps. The landscape of the project area is more impacted by human activities, especially by agriculture of the rural farmers. The density of inhabitants is high. The demands of such a big population are reflected in the landscape by a large area of intensive usage of agricultural land which covers more than half of the total area. Land cover refers to the surface cover on the ground, e.g., vegetation, water, bare soil or other. Identifying and mapping land cover is important for local or global monitoring studies, resource management, and planning activities.

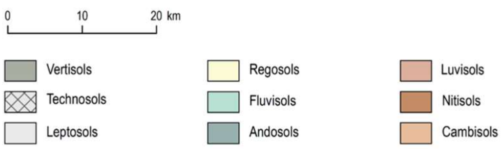
The Global Land Cover Database from Copernicus data services will be used for this purpose. For these global 100 m resolution maps, the main inputs are PROBA-V satellite images, organized into Sentinel-2 tiles. The processing in this tiling grid ensures high quality data and facilitates the continuity with Sentinel-2 from the Copernicus programme. Land use influence perceived hazard levels and zonation of an area where especially land use changes involving land abandonment strongly influence vulnerability of an area that is already adversely disposed for instability or degradation due to other physical factors. LULC data plays a crucial role in groundwater mapping by providing essential insights into the relationship between land activities, surface conditions, and groundwater characteristics (understanding areas of recharge and discharge, surface water-groundwater interactions, sources of contaminants, aquifer vulnerability etc). The initial LU maps will be downloaded from Ethiopia Sentinel 2 LULC2026 global land use map (geoportal). This data set represents the land cover map for the year 2016. All mentioned maps are accompanied by explanatory notes and detailed description of the mapped area and tabular data about hydrogeological features from water point inventory including sampling. Preparation of topographical background for detailed maps based on topo-maps at a scale 1 : 250 000 and 1 : 50 000. A topographic map provides information on the existence, location, and the distance between natural and human-made features on the Earth's surface.



Example of land cover schematic map of the part of the project area (Gonder and W of Gonder map sheet)

Soil Map. Soil map is an important tool because soil represents the frontier between geological, hydrological, atmospheric, and biological interactions. There are five major factors, which in various combinations create a large array of soil characteristics: time, climate, parent material, topography, and organisms. Soil plays an important role in the process of infiltration and forming of initial chemistry of infiltration water. It also plays role in vulnerability of groundwater resources and adopting principles of their protection. The final soil map, however, it is difficult in urban areas, will be based on the results of the soil survey, RS, aerial photos, geological map, topography, and the Reference Soil Groups Map of Ethiopia Based on Legacy Data and Machine Learning Technique: EthioSoilGrids 1.0 (Ali et al., 2022). The soul will be classified based on colour, Structure, texture and silt clay ration.





Example of major soil groups from the project area (Gonder and W of Gonder map sheet)
Major soil groups from the project area

Black cotton soil of the Metema area

Collection of previous surface and well geophysical measurements is important and will be utilized as a primary tool to frame the shallow and deep subsurface architecture of the aquifer systems in order to develop a comprehensive conceptual model of the project area. Existing geophysical well logs will be collected from drilling reports and data reassessment can provide more detailed information about the number of major lithologic/hydro-lithological units in existing wells and help in information about their physical characteristics. Data collected during the inception phase will be used for fine tuning of field geophysical investigation in Stage 2.

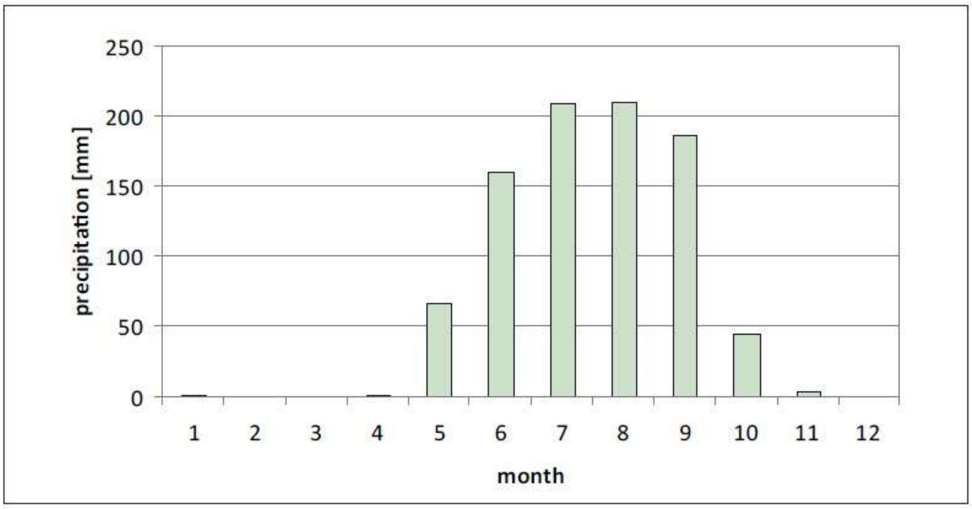
Hydrometeorological data collection will consist of both climatic data from the National meteorology Agency and hydrological data from Hydrological department of Ministry of Water and Energy.

The Kolla zone covers the largest area of western Gonder, and the western lowlands including the Ethio-Sudan border areas. As the climatic conditions of Kolla are less comfortable for people, settlements and population density are scarce. The subtropical (Weina Dega) climatic zone is the second largest climatic zone in the study area and includes almost all the highland area in the west.

The mean temperature of the coldest month is below 18 °C and for more than four months above 10 °C. Precipitation during the driest winter months is less than one tenth of the wettest summer months. The volume and distribution of precipitation varies considerably from one area to the next such that the lowest is about 600 mm and the highest is about 2,000 mm. The project area is characterized by two distinct seasons (dry and wet) and a unimodal precipitation pattern with the wet season during April/May to October/ November.

The project area is drought prone and occurrence of low rainfall and the associated drought over the northern part of Ethiopia is reflected by fluctuations in the level of Lake Tana. The level of water in Lake Tana and the total annual precipitation at the Gonder meteo-station is shown.

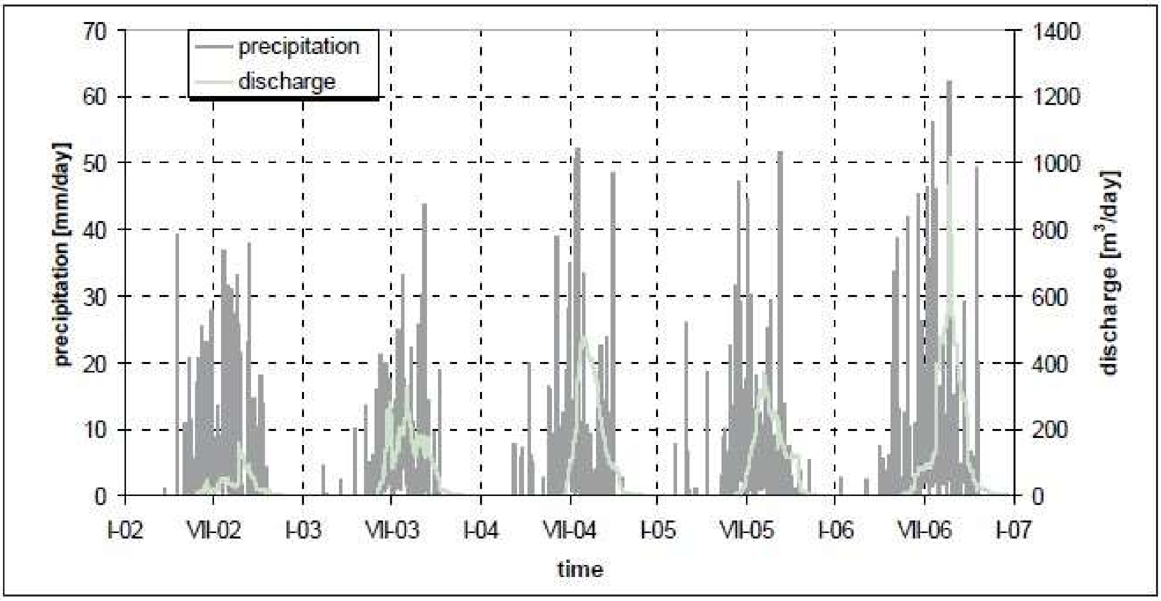
Hydrometeorological data will be used for simplified hydrological map to show the main and local surface water and groundwater divide, the main streams and wadies of the project area and position of meteo-stations and river gauging stations.



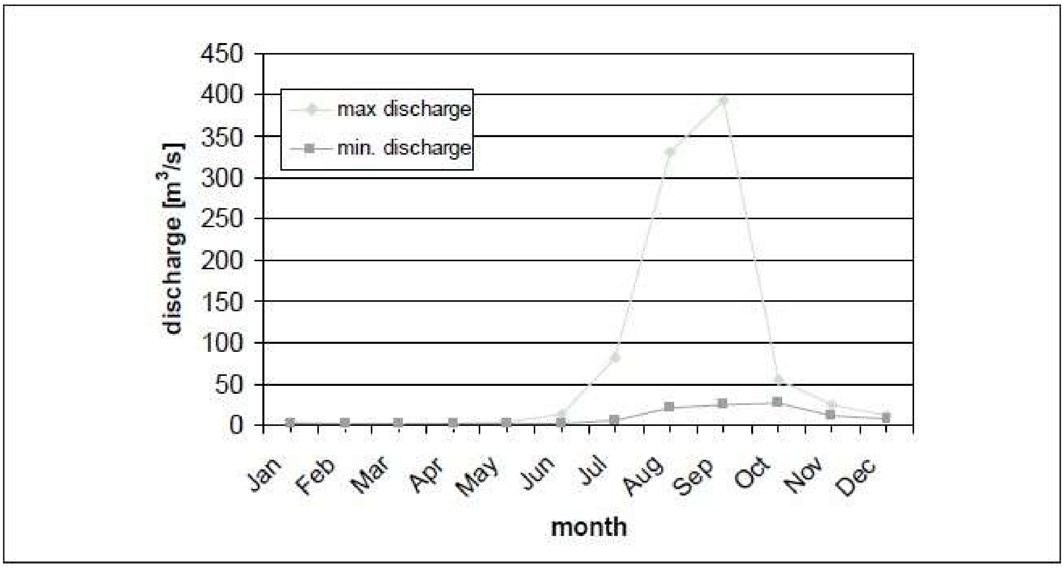
Example of rainfall pattern in of the project area (Metema meteo - station)

The Abay and Tekeze basins occupy the project area. The major perennial rivers flowing from east to west and crossing border to Sudan are the (Shinfa later) the Rahad River (Abay basin) in the south and the (Atbara) Gwang River in the center and the Angereb River (Tekeze basin) in the north. The drainage forms a parallel to subparallel pattern. Rivers in the northern part of the sheet flow directly to Sudan and together with the Tekeze are the source of the Atbara River, a right tributary of the Nile. The Gwang River becomes the Atbara River near the Sudanese border.

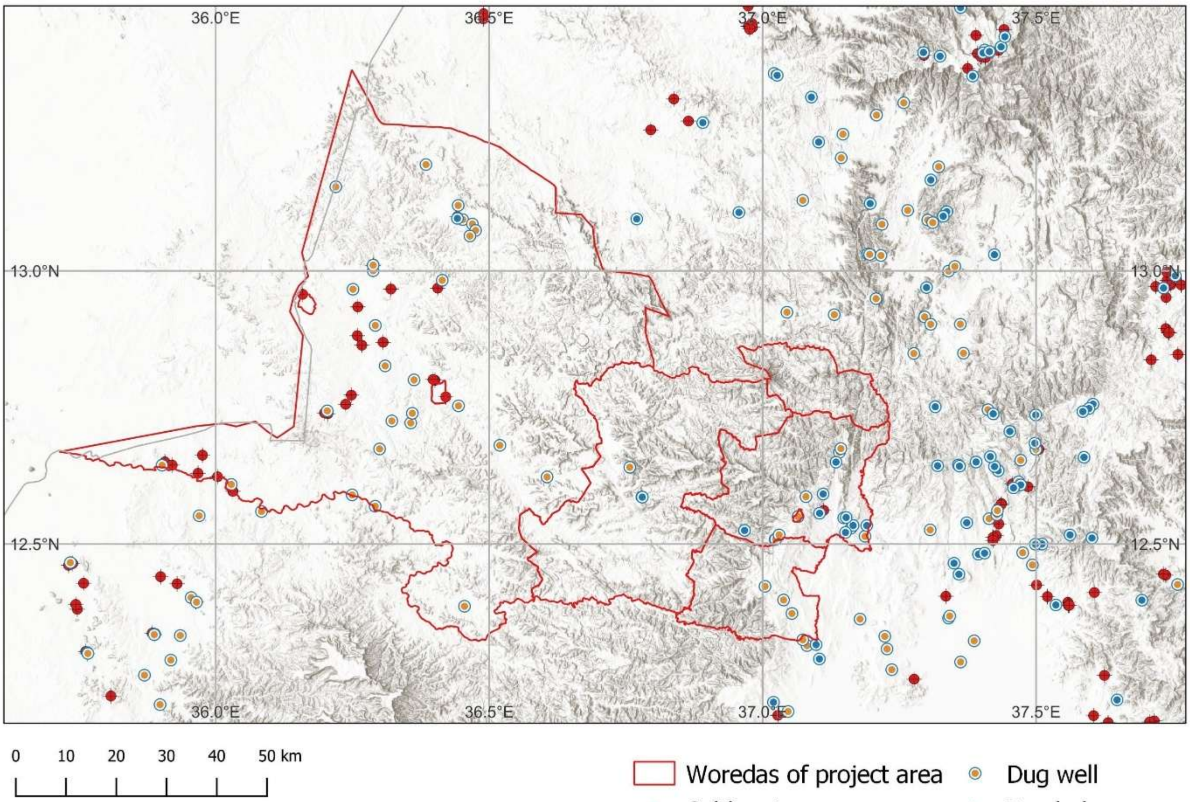
River discharge is monitored in one river gauging station at Gwang in Metama. There are also gauging stations on the Angereb River at Abdefari, Megech near Azezo and the Sanja River at Bebew. These gauging stations are located outside of the project area (to the North – Adi Ramets sheet). The river gauging stations are managed by the Ministry of Water and Energy. Some of them are operational but many of the stations have no continuous data. Gauging stations with existing and reliable flow data will be studied in detail for assessment of runoff and baseflow data. Flow characteristics are similar, with a peak during three rainy months. A short period of very high flow is followed by a period of low flow and most rivers of the area fall dry after December / January. There is one dam constructed upstream of Angereb River which is used for water supply of the Gonder town and is constructed in the year 1975. The water supply of Gonder town from this dam started during 1994.



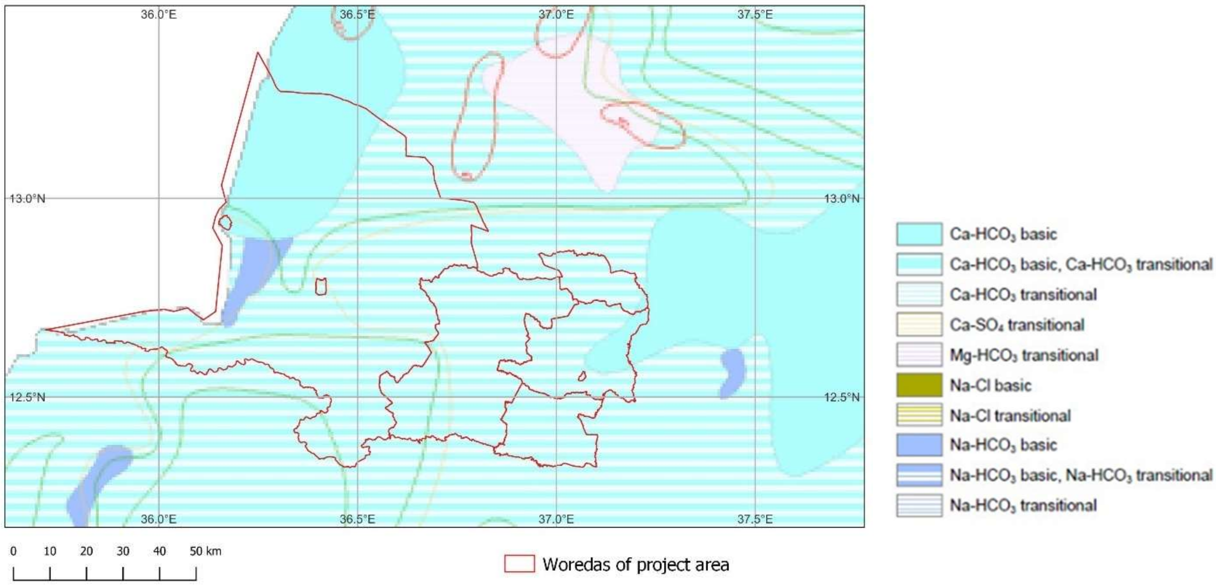
Gwang river precipitation and discharge relationship



Example of flow analysis (the Sanja River)



Preliminary water point inventory in the area



Main hydro chemical types in the project area

Remote sensing

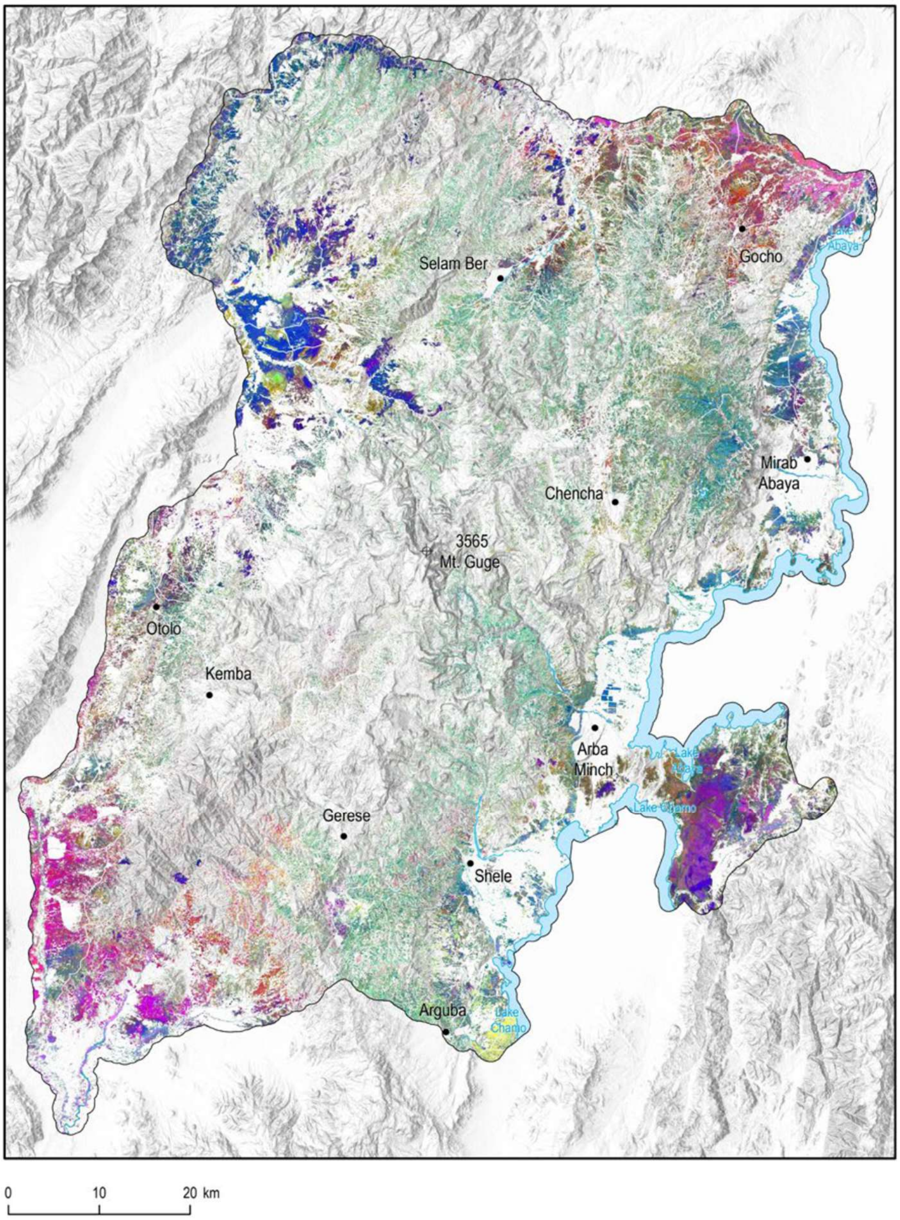
In groundwater mapping, remote sensing provides valuable data such as land use, vegetation cover, soil types, geological formations, lineaments, and surface water bodies, which are crucial for understanding the hydrological environment. The RS methodology provides input for the GIS overlays and supports both the geological and hydrogeological activities, RS data will be collected comprising:

REMOTE SENSING data will be collected from various datasets and will comprising: (a) Sentinel-2 optical data (10-m spatial resolution (Visible-NIR bands)) which is currently highest spatial resolution free optical satellite data; (b) Landsat 8 optical (30-m spatial resolution) and thermal data (100-m spatial resolution) which offers also two thermal bands ideal for geological studies; (c) ASTER optical (15-m spatial resolution) and thermal data (90-m spatial resolution), which offers exceptionally large number of spectral bands in the SWIR spectrum (30-m spatial resolution) and thus is ideal for geological applications; (d) ALOS-PALSAR L-band radar data and potentially also (e) Sentinel-1 C-band radar data coupling with L-band radar will be tested. The pre-processing of the RS optical data will include the following steps: (a) atmospheric correction; (b) band stacking in order to produce a single multiband raster layer; (c) cloud detection and masking; (d) masking; (e) vegetation mapping and masking; (f) built-up area mapping and masking. The pre-processed optical RS data will be further enhanced to provide best possible information about the surface variability using: (a) spectral bands combinations; (b) spectral band indices with focus on geological and lithological mapping; (c) Principal component analysis (PCA) – the transformation of spectral information into new band system enhancing visual appearance of the satellite imagery. The pre-processing of the RS radar data will include steps such as conversion to Ground Range, focusing and geocoding. The preprocessed radar data will be used to complement the optical data for lithological mapping, especially using different radar wave polarization (HH+HV in case of L-band and VV+VH in case of C-band).

CHIRPS - the Climate Hazard Group InfraRed Precipitation with Stations (CHIRPS) dataset provides rainfall maps from 1981 to near-present for almost all the globe. It was developed by the United States Geological Survey (USGS) and Climate Hazards Center of UC Santa Barbara (CHC) scientists and is based on satellite imagery (infrared Cold Cloud Duration) and in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring.

MODIS - Evapotranspiration (ET) and MODIS vegetation indices including Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI) are produced on 16-day intervals at multiple spatial resolutions. They characterize the global range of vegetation states and processes based on daily atmosphere corrected bidirectional surface reflectance in the red, near infrared and blue wavebands, which is acquired by the Terra and Aqua satellites equipped with the Moderate Resolution Imaging Spectroradiometer (MODIS).

The pre-processing of the RS optical data will include following steps: (a) atmospheric and topographic correction; (b) band stacking to produce a single multiband raster layer; (c) cloud/shadow detection and masking; (d) mosaicking; (e) vegetation mapping and masking; (f) built-up area mapping and masking. The pre-processed RS data will be further enhanced to provide best possible information about the surface variability using: (a) spectral bands combinations; (b) spectral band indices with focus on geological and lithological mapping; (c) Principal component analysis (PCA) – the transformation of spectral information into new band system enhancing visual appearance of the satellite imagery. The pre-processing of the RS radar data will include steps such as conversion to Ground Range, focusing and geocoding.



Example from the Gamo area of satellite imaginary (Principal Component Analysis (PCA) transform of the Sentinel-2 imagery)

Overlay analysis

In groundwater mapping, GIS helps integrate, visualize, and analyse various data layers, such as elevation, geology, hydrogeology, rainfall patterns, and soil properties. Overlay analysis in GIS involves stacking different layers of spatial data to identify relationships between them. For example, overlaying soil type maps with rainfall and land use data can help pinpoint potential groundwater recharge zones.

Overlay analysis will be carried out using multi criteria decision method (MCDM) under the GIS environment. After organizing the input thematic layers, the weights will be assigned by a group of experts who have extended knowledge of the regional and local hydrogeological conditions. Due to the large geographical coverage of the area, overlay analysis is very important to identify specific target locations for aquifer recharging sites and first selection of potential target areas for detailed study.

The general steps involve:

- Preparation of physical thematic layers required for multi criteria overlay analysis of the study area.
- Determining the significant layers
- Reclassifying or resampling the data within a layer
- Weighting the input layers
- Adding or combining the layers
- Analyzing the result and delineation of the groundwater potential zones.

The final products, i.e. groundwater potential map, will be prepared on a scale of 1:100,000 with a resolution of 100 m by 100m . The map projection for all overlay layers and the final product is UTM 37N, WGS84. The map will be used for selection of target areas for the next field trip (verification of results) and planning of location of detailed work for stage 2.

The groundwater potential of the area for siting the well will be defined using an automated overlay procedure in GIS using the following primary overlay layers:

1 <u>Regional permeability</u> – primary porosity Rock type, Aquifer classification. The existing hydrogeological maps 1 : 250 000 shows lithological units and their aquifer classification (see chapter hydrogeology).

2 <u>Secondary permeability</u> - Lineament proximity, Lineament density. For the lineament input layer, a combination of the distance to lineaments and (proximity in meter) and lineament density (length of lineaments per km^2). Lineaments will be used from existing 1:250,000 or 1 : 100 000 geological maps or from morphotectonic analysis by RS.

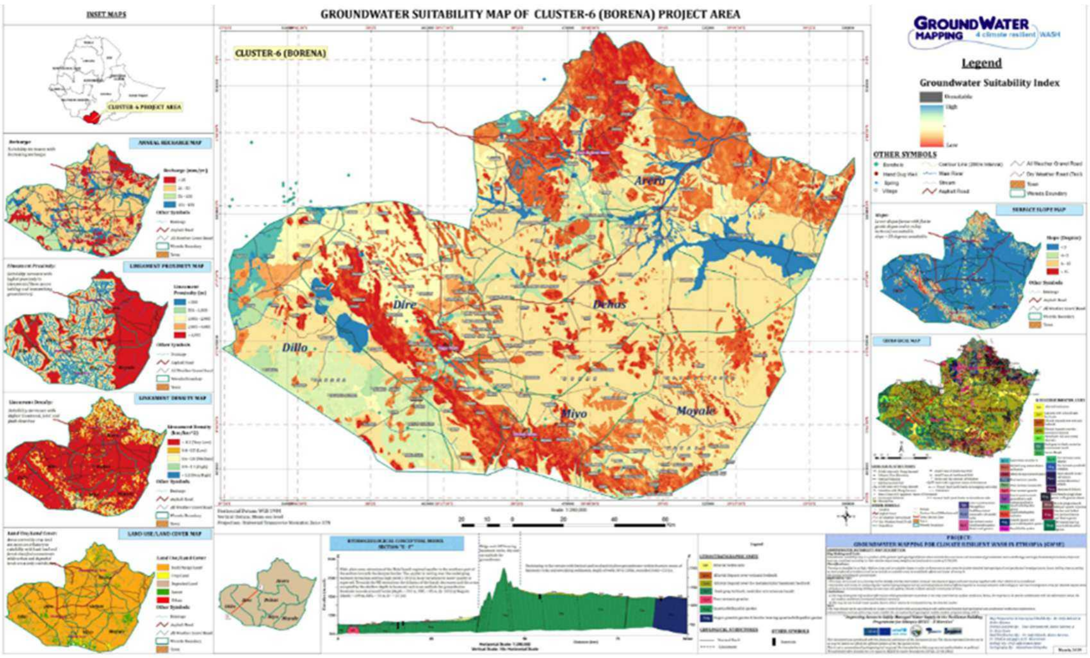
3 <u>Topography</u> (Elevation, Slope), Topographic wetness index is recommended to be used as a primary criterion

4 Recharge - can be estimated from different approaches such as using the annual precipitation (CHIRPS) and infiltration coefficient derived from the lithology, by calculating water balance components, using public data to estimate water balance components and combinations of these approaches

5 <u>Land Cover -</u> European Space Agency WorldCover V2 provides a global land cover map for 2021 at 10 m resolution based on Sentinel-1 and Sentinel-2 data. The WorldCover product contains 11 land cover classes which will be reclassified based on the land cover characteristics of the area.

<u>6 Soil Infiltration capacity</u> - In cases where soil development limits the infiltration, the gross recharge may be overestimated. To correct for the overestimation, the saturated conductivity (Ksat) of the soil will be used which is derived from pedotransfer function of the hydraulic parameters.

<u>7. Stream/surface water proximity</u> - distance from streams is another factor considered for overlay analysis. HydroSHEDS dataset can be used for proximity analysis and for more detailed study, stream network can be delineated from ALOS-PALSAR DEM and used for the proximity analysis.



Example suitability map from Borena, Ethiopia

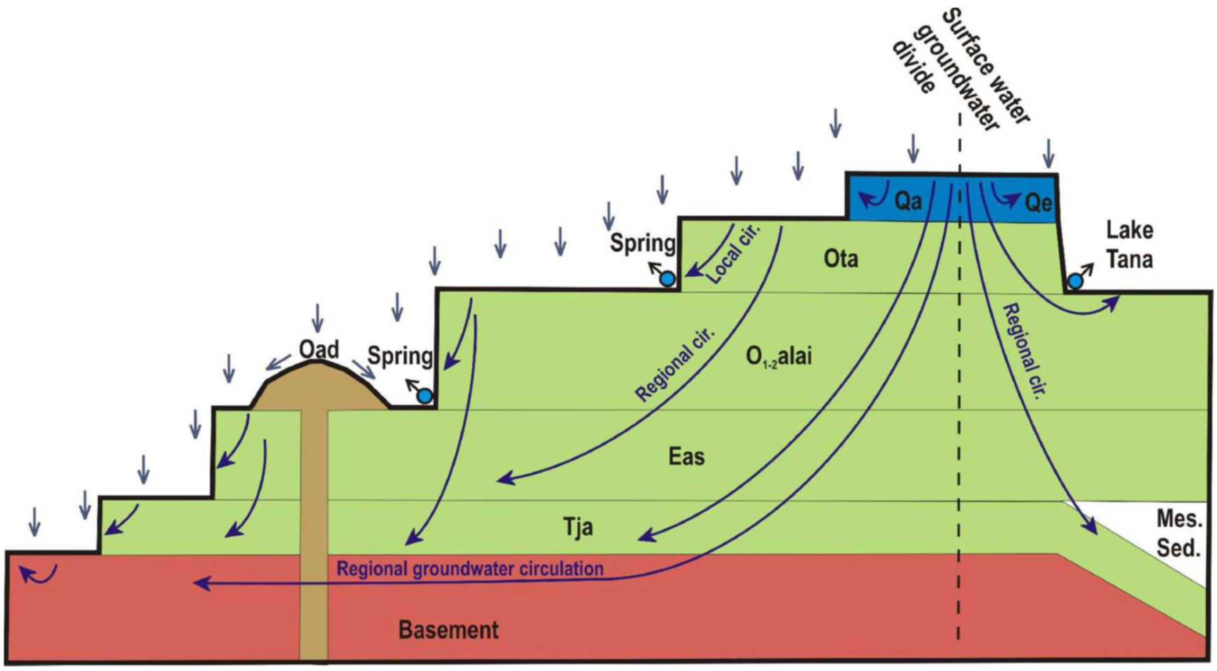
The results of the overlay analyses need to be validated by comparing the groundwater potential map to existing well yields and fields observations, using statistical methods where possible. The stability of the results will be investigated by sensitivity analysis on the weights for the groundwater information layers and the scores for the various value classes within each information layer. Detailed overlay procedure, classification and weighting will be discussed in Inception Report workshop.

Hydrogeological conceptual model

Preliminary regional hydrogeological conceptual models of the study area will be developed to be later implemented in detailed model of target areas together with regional groundwater flow systems map. This model after hydrogeological system analysis shall be a basis for analytical and numerical modeling conceptualizing of the study area, in multilayered aquifers.

Minor aquifers with local and limited groundwater resources (aquitards) are found scattered over the mapped area having limited extent and forming the peak of the volcanic plateau. They are developed along the basin watershed, particularly along the escarpment of Lake Tana. Runoff is relatively fast, and infiltration is limited. The rest of the highland and lowland areas are covered with various volcanic, sedimentary (consolidated and unconsolidated) and crystalline rocks forming rugged terrain as well as a gently undulating plain that receives adequate rainfall and has moderate run-off resulting in good front recharge (infiltration) and formation of extensive and moderately productive or locally developed and highly productive fissured and porous aquifers. Infiltration into hard rock aquifers is particularly good in areas where the plateau is covered by thick eluvial sediments (regolith). Aquifers and/or individual volcanic formations (layers) outcropping in the plateau area also feed deeper fissured aquifers developed in underlying volcanic and sedimentary rocks (sandstone). Infiltration through volcanic aquifers into deep sedimentary rocks of the Abbay basin is not known, but it is theoretically possible as shown in the hydrogeological conceptual model. Outcrops of deeper aquifers can be found only in deep valleys and in the western lowlands therefore the possibility for their direct recharge is limited. These aquifers are recharged from the upper overlying layers and groundwater flow direction is mainly vertical. The vertical groundwater flow changes to horizontal in both the local as well as regional drainage basins. The basement rocks form the regional drainage base (aquitard) for groundwater that changes its vertical flow to horizontal flow and emerges in deep valleys as springs from the sandstone and volcanic rocks.

A preliminary conceptual hydrogeological model of the project area is shown in the following figure.



Example of hydrogeological conceptual model from the project area

The general groundwater flow direction in the whole basin coincides with the topography following the surface water flow direction because small intermittent and particularly perennial rivers as well as Lake Tana form a local drainage level. The tectonic structures also partly control the groundwater flow. Most of the springs emerging from tertiary volcanic rocks are topographically controlled and others emerge along structures confirming that the groundwater flow is controlled by both factors. Local groundwater flow directions vary from place to place according to the local topography. The trachyte of the Adwa Formation mainly forms domes and does not alter the regional groundwater circulation or flow. The intermittent and ephemeral character of rivers in the area contributes significantly to the recharge of the aquifers. Surface water recharges aquifers when it flows permanently and particularly during floods when the river stage is above the groundwater table. This is the typical situation during July, August and September. Most of the recharged water is retained in the aquifer for a relatively limited time before it drains back to the river again during October, November and December. Rivers of the mapped area provide recharge pulses into bank aquifers. This recharge mechanism is important mainly in the lowlands where precipitation is lower, and evapotranspiration is high. A relatively low content of total dissolved solids between 300 and 700 mg/l and Ca – HCO_3 type of groundwater chemistry shown on the hydrochemical map confirms the presence of fresh water in wells located along the rivers.

Groundwater is under water table conditions; however, artesian conditions are also known from the fissured aquifers north from the project area.

The principles of the general conceptual model of the project area are based on the 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 from neighboring aquifers
- direct discharge by springs from outcropping aquifers
- direct discharge to rivers
- indirect discharge from one aquifer to another (vertical as well as horizontal)

Preliminary field visit

Field visit (1 week) for the expert team will be focused on two main components:

1. Further data acquisition and verification.
2. Meeting and engaging stakeholders in the project area.

Collection of new data from Regional, Zonal, and Woreda Water Bureaus. Data collection will be concentrated in drilling reports with complete data about geology, hydrogeology, hydraulic of aquifer and groundwater quality.

At the same granularity from Zone to Woreda level, representatives of the respective communities and experts from Water bureaus will be engaged to ensure smooth project implementation. In the meetings project goals, extent and benefits will be communicated to the stakeholders and their feedback will be collected. Possible risks and limitations will be identified for planning of subsequent stages.

Inception report and Workshop 1

The inception report will be prepared in several steps:

1. Draft inception report prepared by consultant.
2. Submission and presentation to client.
3. Receiving client´s feedback through review and comments.
4. Validation workshop organized by client – presentation of outcomes, further discussions and feedback collection.
5. Incorporating relevant comments, feedback and requirements into final Inception report.
6. Final inception report submission to client.

Report basic contents:

- Results of preliminary review and analysis of collected data.
- Identification of target areas based on overlay analysis and planning of detail work in the areas.
- Preparation of possible conceptual models of the flow system.
- Prepare water inventory and database uploading forms for enhancing existing database and upload collected data.
- Compile preliminary geological, hydrogeological potential and other relevant maps at a scale 1 : 250 000 / 1 : 100 000.
- Identify data gaps and suggestions for planning and execution consequent stages.

2. Stage 2 - Field survey

Main activities: **Comprehensive multidisciplinary study**

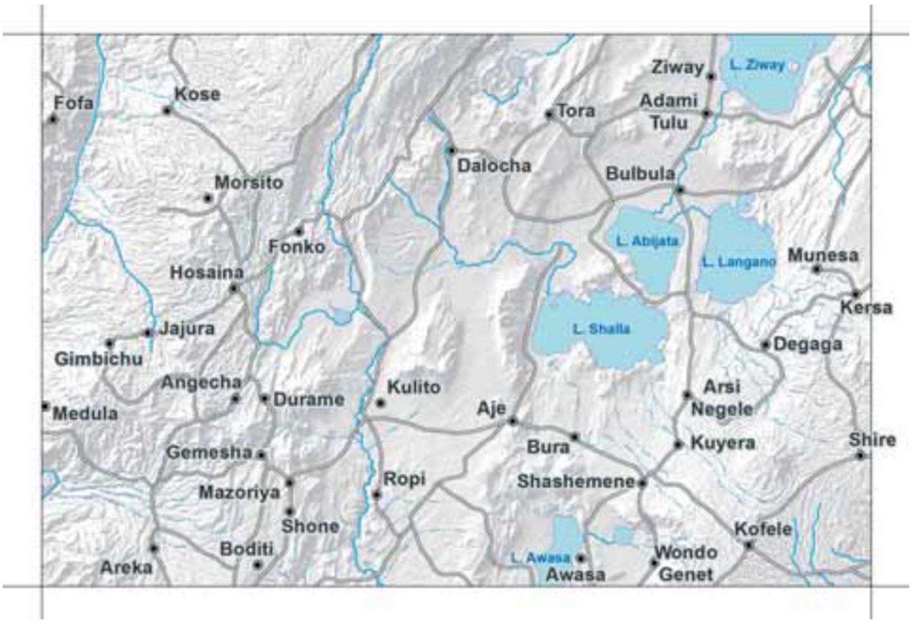
Main deliverables: **Drilling specifications and tender documents, Field survey report**

Comprehensive multidisciplinary study

A topographic map provides information on the existence, location, and the distance between natural and human-made features on the Earth's surface. It also indicates variations in the terrain, heights of natural features, and the extent of vegetation cover.

Topographic maps can be of various scales which incorporate a variety of information. In short, it can be said that a topographic map is a graphical representation of the three-dimensional configuration of the Earth's surface in two dimensions. The features in topographic maps can be divided into four major groups:

1. Relief: Depicted with contour lines or by shaded relief. A shaded relief will be used for terrain representation that uses colours and shading to show heights and features on the map. Shading on a topographic map is used to give it a more realistic view. Mountains actually look like mountains instead of just contour lines.
2. Water features: they represent oceans, lakes, rivers, streams, swamps, springs etc. A river network is a mandatory feature that makes it easy to navigate the map.
3. Vegetation: they represent wooded and cleared areas. Topography for geological maps is usually used without forests, because the green colour of forests would distort the colours of individual geological unities.
4. Cultural features: they represent all the human-made features: buildings, roads, railroads, land boundaries, etc.



Example of hill shade, road and settlements that will be used as a basis for topographical background in the project area (Hoseina map sheet) The topographical maps will be used for background information of other maps.

Geomorphological and Geological survey as background data for hydrogeological survey and groundwater resources assessment as well as for groundwater modeling.

The geomorphology of the area is variable, and it is generally the result of repeated volcanic and tectonic events with the associated erosion of outcropping 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.

The maximum elevation is 2,871 m.a.s.l. in the highlands (plateau area north from Gonder) and the minimum elevation of 525 m.a.s.l. in the Quara and Metema lowlands along the Sudanese border, for example. Mountains on the plateau are the result of volcanic activity. Tectonic activities resulted in development of ridges and depressions and erosion activities associated with tectonics resulted in formation of deep gorges and incised valleys. Deposition of sediments in valleys at lower altitudes is due to erosion in the uplands and transportation into the lowlands that has formed the plain area of the sediments. The depositional landforms are mainly found in the western part of the Ethio-Sudanese border and in the Lake Tana graben.

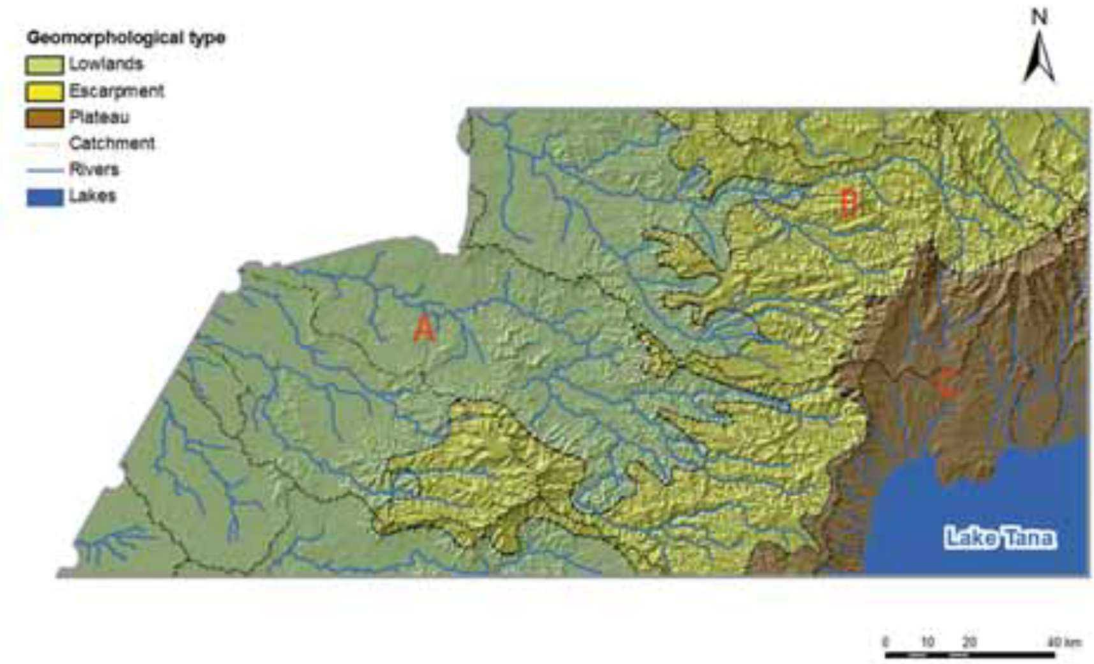
The topography slopes toward the northwest and toward the south and southeast in places. Physiography can generally be divided into three physiographic zones (shown in following figure).

The flat land topography

- of the lowland area at the extreme western part of the western Gonder map sheet (zone A) which is a continuation of the Sudanese plain to the west and covers a vast area on the map sheet,
- of the highland area which is the southeastern part of the Gonder map sheet (zone C) including the marshy area of lacustrine sediments surrounding the northern part of Lake Tana (Dembia plain).

The mountain escarpments in the central southern part of the area (zone B) are characterized by different volcanic rocks with relatively different topography, especially the Ashengi and Aiba basalts.

Rugged topography where the pre-Tertiary formations constitute the rugged topography which is relatively elevated comparing the flat land areas in the West of Gonder map sheet (part of zone A) and steep mountain chains formed by volcanic rocks and sandstone formation.



Example of schematic map of morphological map (Gonder and W of Gonder map sheet)

The geology of the area has been mapped at a scale 1 : 250 000 / 1 : 1 200 000 (and 1 :50 000 for Chilga sedimentary graben) and these maps will be will be collected in stage 1. The combination of old geological mapping with Remote Sensing (geomorphology and boundary of lithological units), geophysical survey and field data collection will be used for preparation of harmonized legend to geological map compilation of detailed geology. maps of the project area at a scale 1 : 100 000 and 1 : 50 000 for target areas in stage 2 and 3.

The geological map will depict and interpret the geological structure of the Earth's surface, including sediments forming the Quaternary cover and anthropogenic deposits. It will be a compilation of lithological, stratigraphic and structural observations of the bedrock and the overlying Quaternary deposits, supplemented by selected tectonic, (paleontological Chilga Formation), geodynamic data, etc. Information depicted on the geological map of the project area will include:

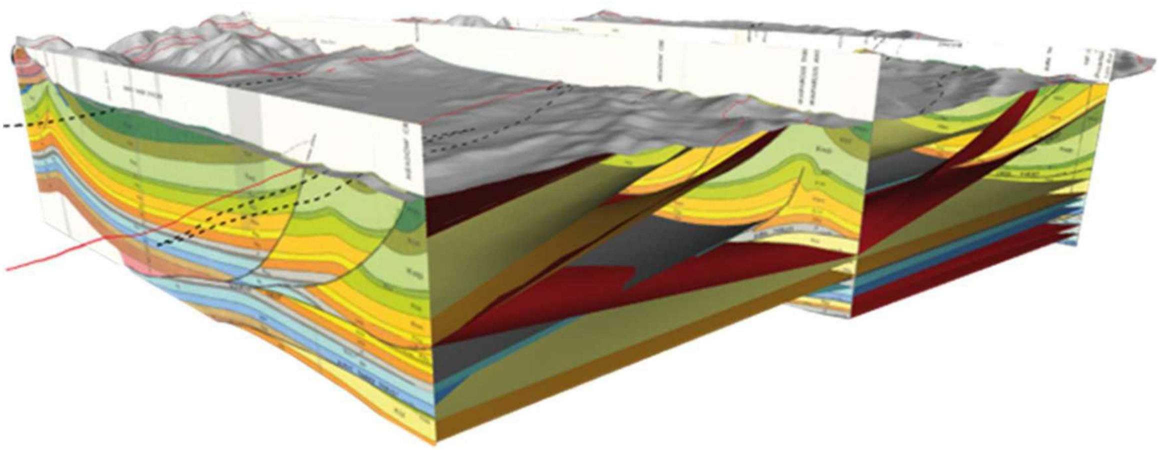
- Areas of rocks units defined in terms of lithostratigraphy, chronostratigraphy, petrology, tectonics, and the geological contacts between them.
- The lines of faults and other tectonic elements on the Earth's surface.
- Important geodynamic phenomena.
- Lines of geological cross-sections.

1. The legend will include all features shown on the geological map, the geological cross-section and the lithostratigraphic column. If some of these features appear only in the lithostratigraphic column or in the geological cross-section, then this should be indicated in the text describing the individual items of the legend.
2. A geological cross-section without vertical exaggeration is constructed to depict the inferred geological structure to a depth of 1–2 km (according to scale). This will vary depending on the characteristic features of the geological structure of the mapped area.
3. Text information like map mane, authors, projection, copyrights etc.
4. Good illustration and photographs complete the geological description of an outcrop in the field, but the most important role of a picture is to display the relationship of rocks,
5. Geological maps will be accompanied by appropriate text that will provide and extend information about the important geological features identified during the geological mapping.

Pre rift volcanic provinces (Ashangi and Aiba units) characterize the project area. These are covered by eluvial and other Quaternary sediments. There are small outcrops of Palaeozoic sediments along the border with Sudan and in Chilga graben.

Basalts of the Gonder area

3D Simplified GEOLOGICAL MODEL can be applied **b**ased on an existing set of geological data from drilling reports the 3D geological models will be created in the MOVE software (Petex - https://www.petex.com/pe-geology/move-suite/). The 3D models will be the basic input for the processing of groundwater spatial variability. In the next stage geological 3D model will be verified by virtual boreholes (proposed new wells and/or well fields) in regular network, whereas the geological pattern is extracted to virtual boreholes and virtual borehole database is used as input data for groundwater flow models.



3D Geological model „Move“

Hydrological study will be concentrated integration of data and information collected during inception phase, particularly in assessment of (10 years data) rainfall, runoff, baseflow, and water balance implementing various methods including Wet-pass model. All-important hydrological features will be shown in hydrological map at scale 1: 250 (100) 000. Climate characterization will be conducted using meteorological data analysis from meteorological stations within the mapped area and several others located in the nearby surroundings, operated by the National Meteorological Service Agency (NMSA) and WMO.

The project area It was found that the area lies mainly in in Kolla (tropical) region tha eastern limit lies in the subtropical (Weina Dega) climate zone.

The meteorological stations operated by the Meteorological Institute within the project area and surroundings are Delgi, Gonder, Gorgora, and Metema have rainfall data available for a period of 10 – 40 years. The daily rainfall data available for Aykel covers the period 1981 – 2006.

The rainy season within the area passes from March to May and from July to October The rain station in Meteme (1^{st} class sation) is situated in elevation of 803 m.a.s.l. and its rainfall average is of 885 mm.

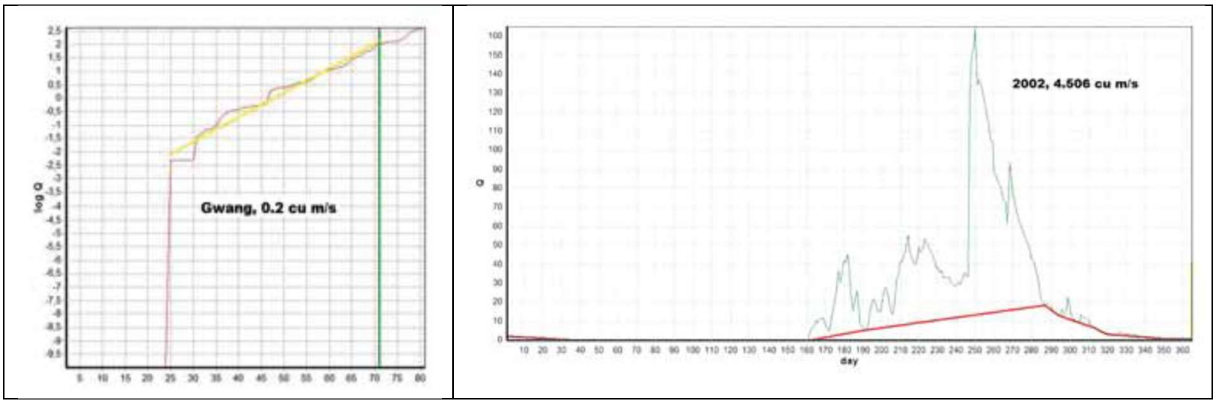
The project area is located within the Tekeze and Abay basins. Surface water is drained by several rivers crossing Ethiopian border to Sudan where they form the Nile River with other rivers of the area. There are several river gauging stations in the project areas and their surroundings that can be used for hydrological analyses, however the river gauge on the Gwang River at Metama will be principal for the project.

The following methods will be used for partial recharge calculation:

- Baseflow assessment using
    - Kille method
    - Hydrograph separation
- Model of water balance using
    - WetSpass or SWAT
    - Infiltration coefficient

There are many river gauging stations in the study area. Other river gauging stations are located within the neighbouring areas from where the data can be also used for the assessment of the surface as well as for the baseflow values. The stations will be also used for comparison and for correction of the data reflecting the fact that the river discharge is directly proportional to the intensity of rainfall within the project area. The annual variability in runoff is high particularly in the last several years showing increasing extremes in weather / climate due to climatic changes (see example following figure).

Examples of baseflow separation using of Kill and hydrograph separation methods is in following figures. Example of data from river gauging station that can be used for assessment of run-off and baseflow are in following table.



Example of Kille and hydrograph separation of baseflow for the Gwang River at the Metema river gauging station

Example of assessment of hydrological data

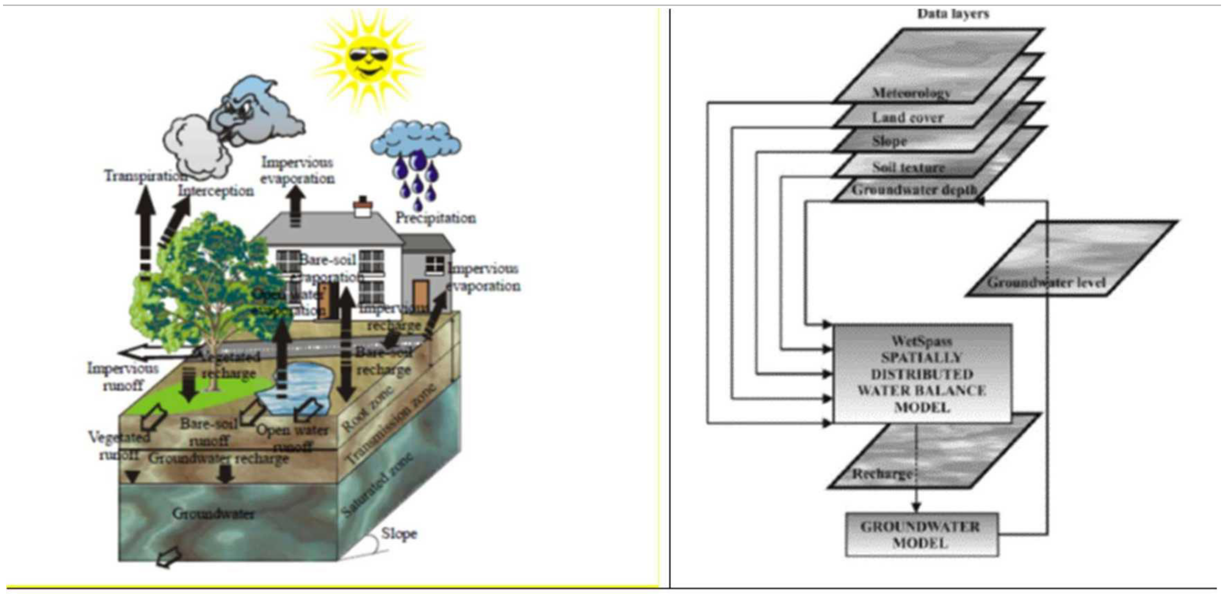
River	Area (km^2)	Average flow in m^3/s	Specific runoff [$l/s.km^2$]	Base flow in m^3/s	Specific baseflow [$l/s.km^2$]
Megech River near Azezo	513	8.2	16.0	2.0	3.0
Gwang River at Meteme	6,816	17.0	2.5	2.3	0.3

Water Balance is based on principles that precipitation is partly evaporated, partly transpired and part of the water flows to rivers as runoff (surface runoff and baseflow). The rest of the water recharges the aquifers.

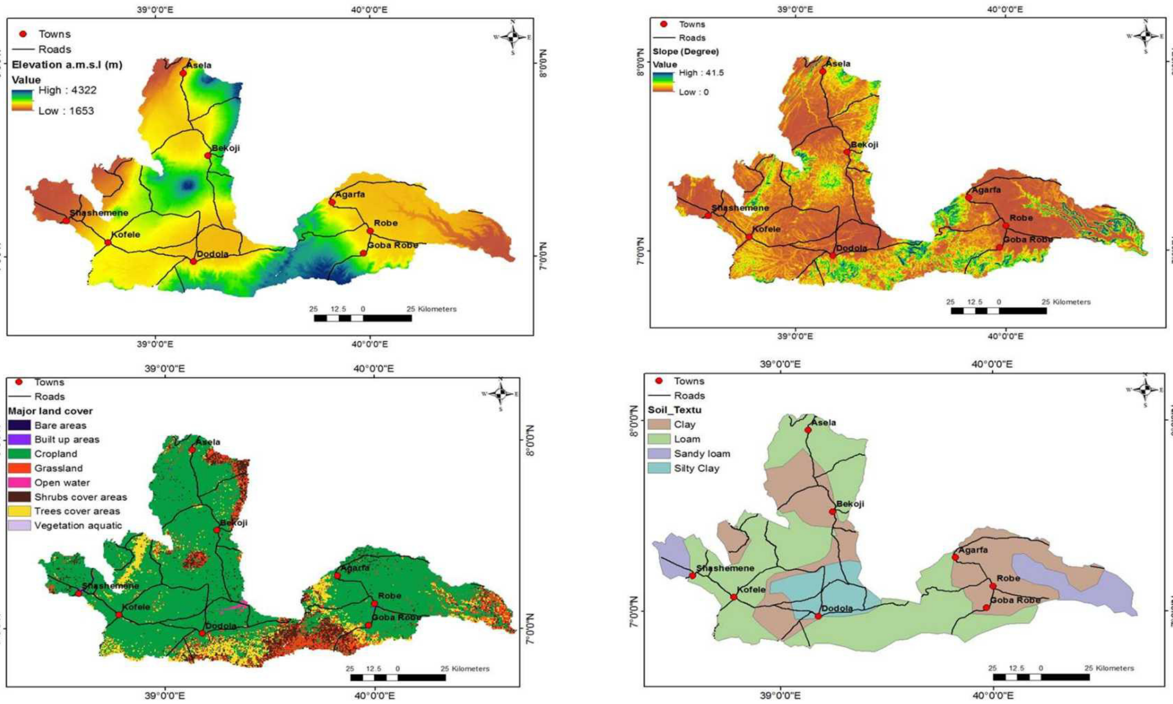
WETSPASS model is based on Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady State (Batelaan and De Smedt, 2001). It is a steady state spatially distributed water balance model for simulating yearly or seasonal averages of groundwater recharge, evapotranspiration (soil evaporation and transpiration also as separate outputs), runoff, and interception. WetSpass yields spatially varying groundwater recharge using spatially varying meteorological, land use, and soil inputs. WetSpass is completely integrated in GIS as a raster model.

Inputs for this model include grids of land use, groundwater depth, precipitation, potential evapotranspiration, wind-speed, temperature, soil, and slope whereby parameters such as land use and soil types are connected to the model as attribute tables of their respective grids. Since the model is a distributed one, the water balance computation is performed at a raster cell level. Individual raster water balance is obtained by summing up independent water balances for the vegetated, bare soil, open water, and impervious fraction of a raster cell. The total water balance of a given area is thus calculated as the summation of the water balance of each raster cell.

All hydro-meteorological (rainfall, temperature, humidity) data used in this model was taken from FAO, 2005 global database. Land use data was modified from 8km global land cover map derived from AVHRR data and FAO UN SDRN. Depth to water table estimated from the inventory work under this project was used to obtain depth to water table information required by the model. Soil data is modified from the Harmonized World Soil Database, Version 1.2 of FAO. Slope and topography data has been derived from SRTM 90m resolution. The model was then run on monthly time step to obtain gridded recharge value for the entire project area.



Structure of WetsSpass model



Example of WetsSpass model: elevation (upper left), slope angle (upper right), Land cover (lower left) and soil texture (lower right)

An infiltration (recharge) coefficient will be assigned to all lithological units appearing on the geological map of Ethiopia. These infiltration coefficients will be assigned to the units of the geological maps. The final recharge layer will be obtained by multiplying the annual precipitation by the infiltration coefficient (see example in following table)

Lithology	Infiltration (recharge) coefficient	Class description
Basalt with minor trachyte, (rhyolite) and pyroclastic (based on geomorphological position and age)	0.13 – 0.15	Fissured aquifers, moderate productive
Ignimbrite	0.10	Fissured aquifers, moderate productive
Alluvium	0.17	Intergranular aquifers, moderately productive

The dataset can be obtained from the FAO Water Productivity Open-access Portal (https://data.apps.fao.org/wapor/) and is based on the ET-look algorithm. The WaPOR product is based on the Penman Monteith equation and uses satellite soil moisture data to estimate the evaporative stress terms of the equation (Bastiaanse et al., 2012). The WaPOR dataset described above was used as an alternative to the SEBAL methodology. While the SEBAL methodology can be applied to Landsat imagery to obtain evaporation at a slightly higher spatial resolution (30m) than WaPOR, the revisit time of Landsat imagery is 16 days. In practice, the time period between useful scenes can be even longer due to the dependence of the algorithm on thermal infrared data, which is not available when there is cloud cover. This means that the instantaneous evaporation flux that the SEBAL algorithm provides must first be translated into a daily total, and then at minimum into a 16-day total to fully cover the period between Landsat scenes. In contrast, the ET-look algorithm is driven by soil moisture data. Remotely sensed soil moisture is insensitive to cloud cover and is available every 1-2 days, depending on latitude. Therefore, this algorithm is more capable of capturing daily fluctuations in evaporation and thereby gives a more accurate annual total. For this reason, the WaPOR dataset is more suitable than the SEBAL methodology for this study.

A simple water balance approach was used to estimate recharge based on average annual precipitation depth and a calibrated infiltration coefficient. For the recharge analysis, the average annual precipitation was calculated over the period 2009 – 2018. The data was downscaled to 100m resolution using bilinear interpolation. The total surface water resource of the RVLB is estimated by Halcrow (2008) at just over 5,300 Mm^3/year, calculated from total annual average river flow into the lake systems under 'natural' conditions – without human abstractions. This amounts to a per capita water availability of 597 m^3, per annum which is well below the threshold of 'water scarcity', of 1,000 m^3/capita/annum. This van decline to 232 m^3/capita/annum by the end of 2034 because of population growth – a situation of extreme water scarcity.

Finally hybridized recharge will be calculated of the area and used in calculation of groundwater resources and as an input to mathematical model of groundwater flow.

Hybridized Recharge Estimation based recharge will be estimated by comparing output of the previous methods. The final recharge value is either an average of the various estimates or is chosen from the result of one single method. In doing so certain criteria have been applied. Finally, one recharge map for the entire project area has been derived from the application of the following criteria:

- The recharge result from any method is not considered if the recharge exceeds 15% of the rainfall. Please note that the rule of thumb for humid areas reveals recharge is about 10-12% of rainfall, in semi-arid areas it is around 5% of rainfall, and in arid areas it varies between 1 to 2% of rainfall;
- If one or two of the recharge estimates out of the five turns to be outliers (lowest or highest), the mean of the other three methods is considered; and

- If all the recharge estimates give significantly different values from each other, the recharge estimate which gives the median value is considered.

Geophysical study

Geophysical study in site will implement two independent geophysical methods and will be concentrated in answering the following tasks.

1. Explore and identify the nature and conditions of geological and groundwater characteristics by using three geophysical methods (Magnetics and VES).
2. Investigate the ground water conditions of the proposed sites; estimate the optimum drilling depth.
3. Make investigation to sufficient depth for all sites.
4. Use other possible primary and secondary techniques and collect data that are available.
5. Use suitable and appropriate data processing models and analysis methods and presentations to obtain satisfactory results.
6. Produce and submit the hydro-geophysical study report made for all sites. The report consists of general information about the area (location, Woreda, Kebele, Village; site locations of recommendable wells and existing wells as well (GPS), produce reports for each of the site both in hard and electronic copies.

Owing to the general litho-stratigraphic conditions of the survey area and climatic conditions, groundwater occurrence is generally expected to be associated with geological structures, weak zones and weathered and fractured volcanic rocks. Therefore, the identification of geologic structures, determination of extent of structures, thickness of weathered and fractured rock units as well as thickness and nature of lateritic and alluvial deposits will be important. To this end, the most suitable methods, which includes Magnetics and Vertical Electrical Sounding (VES) methods were proposed. The proposed integrated geophysical investigations will be conducted on all hydro-geologically selected sites.

Magnetics

Field Procedure and Instrumentation

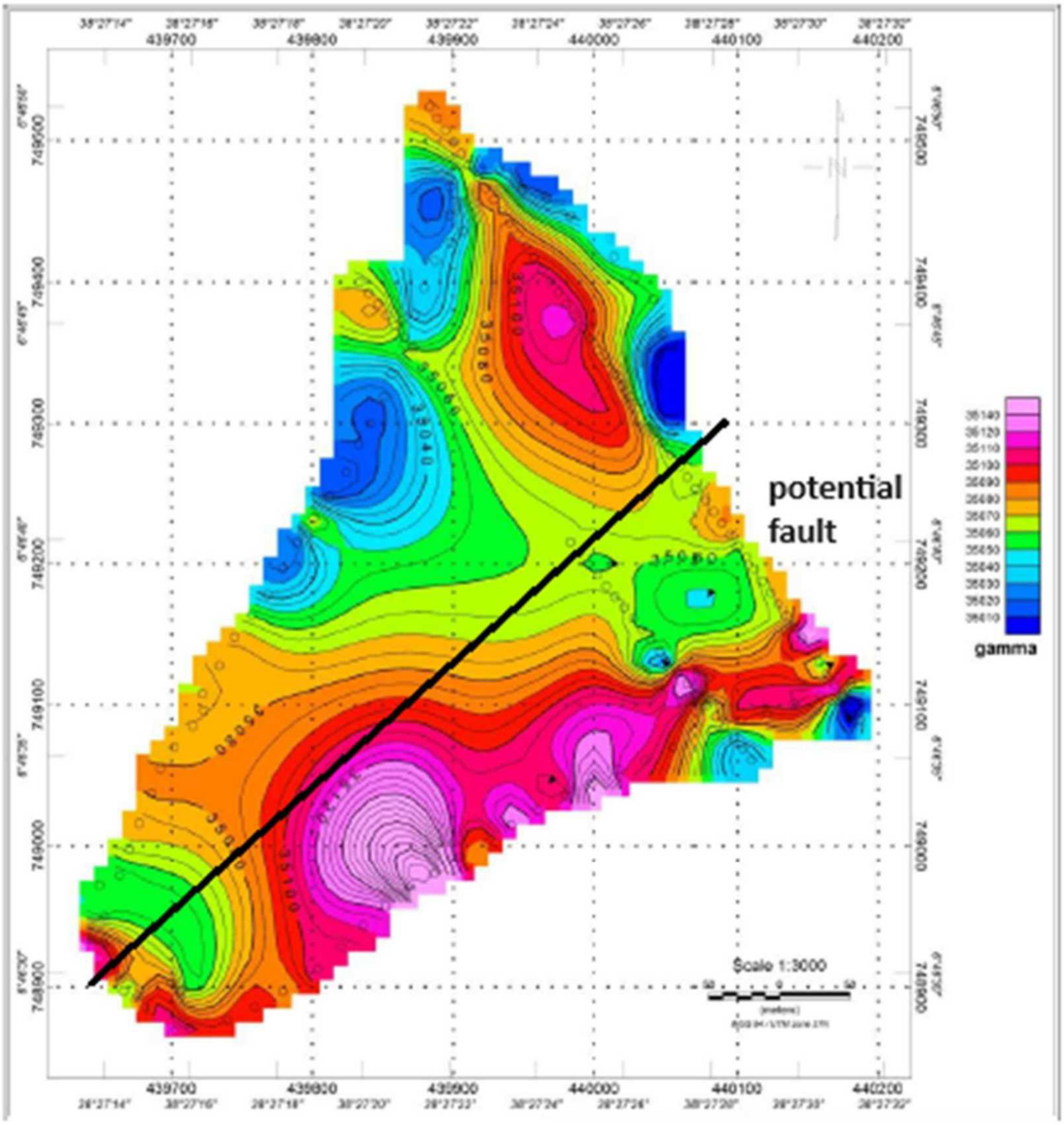
The Magnetic method will be conducted in the present survey to verify the geological structures mapped with VES methods in the volcanic terrains of the project area. The magnetic survey will be conducted along the selected line for the geophysical investigations. The station interval for the magnetic survey shall be 15m, having a length of 500m (51 stations) for each site. A total magnetic survey at three VES lines with a total of 60 km.

A field magnetic survey will be carried out using a total field magnetometer (G-856 - proton precession magnetometer, Geometrics Inc., USA). The G-856 proton precession magnetometer displays six-digit magnetic field to resolution of 0.1 nT in average conditions.

Data Processing and Presentation

The field observed magnetic data will be corrected for diurnal variations using the base station readings taken at the beginning and end of the magnetic survey.

The diurnal corrected total field values will be then smoothed using a moving average program and the results will be plotted at a reasonable scale using Geosoft Mapping System (Oasis Montaj). The results of the magnetic survey at all sites will be presented as magnetic maps.



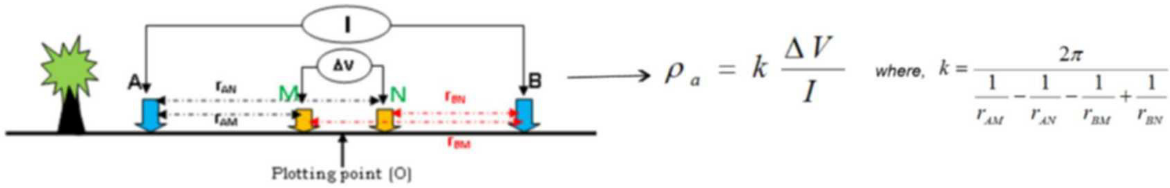
Example of magnetic map of well siting (Total Field), with interpretation of potential fault (black line)

Vertical Electrical Sounding (VES) survey

Field procedure and Instrumentation

VES in measurements will be conducted using Schlumberger array with a minimum current electrode spacing of AB/2=1,000 m, at 2 km interval in several traverse lines, which enables to attain the minimum depth of investigation (400m) with an interval of 200m. A total of 120 VES observation points shall be carried out for the project area in hydro-geologically selected sites. In addition, to calibrate the VES results parametric VES will be conducted at one/two existing borehole locations. Data quality will be controlled by plotting and analyzing the VES data in the field.

The Vertical Electrical Sounding (VES) survey will be carried out using the Advanced Geophysical Instruments (AGI) SuperSting R1/IP electrical resistivity unit having a maximum current output of 2A. Data acquisition will be done with higher accuracy (below 0.5%).

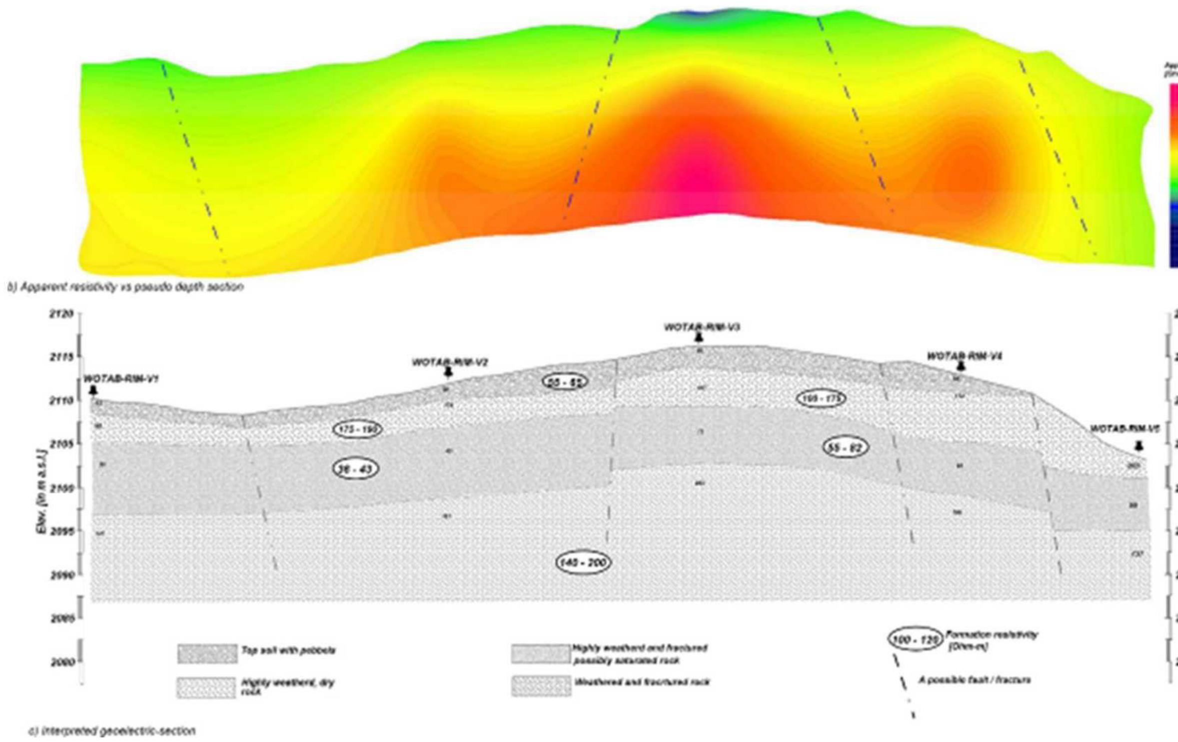


Example of arrangement of VES measurements

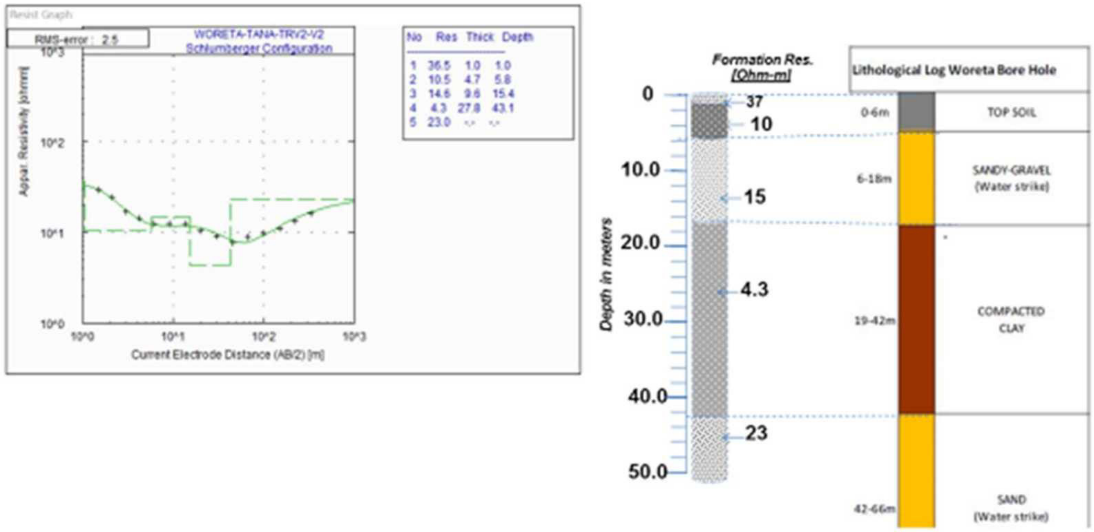
Data processing and presentation

The observed apparent resistivity at each VES point will be plotted against half current electrode separation (AB/2) on a double logarithmic paper of modules 62.5mm. The raw data will be initially smoothed to remove noisy signals. The VES interpretations will then be processed manually using partial curve matching techniques where two-layer master and auxiliary curves (Orellana, 1972). Here, the plotted apparent resistivity curves will be compared with pre-calculated theoretical curves for given earth model until the best fit obtained (curve-matching procedure) from which, layer parameters, resistivity, and thickness, will be calculated. These parameters and the field data will be used as input data for the forward and inversion computer program (RESIST). In addition, the effect of anisotropy will be considered, and the necessary adjustment shall be made. Interpretation is done to a depth of about 400m. (see example of assessment)

Such visualization can routinely be obtained by plotting pseudo-depth sections using the measured apparent resistivity (ρa) and pseudo depth (AB/2) values which depict the overall resistivity picture on a vertical section along the survey line.



Example of typical approach in compiling the final geo-electric section of a 5-VES line - apparent resistivity pseudo section (top) and geoelectric section (below)



Example of comparison of geoelectric layer parameters with a lithology log from a parametric well

Well Geophysics

Reassessment of geophysical well logs can provide more detailed information about the number of major lithologic/hydro-lithological units in existing wells and help in information about their physical characteristics.

Logging measurement carried out in the project area using a methodology that enables basic precision, or reinterpretation of the lithological profile of the borehole. Individual rocks (basalt, trachyte, tuff, clay) are characterized by different levels of natural radioactivity (Gamma Log method). Rock damage (tectonic damage and weathering) is manifested by a decrease in electrical resistances (Normal LN-SN method), low specific electrical resistances are typical for some rocks (for clays, tuffs). Conversely, high resistance values are registered in sections of compact, intact rocks.

By comparing the Gamma Log and Normal LN curves in seven selected wells, the correlation of individual rock positions is performed and the interpretation of the storage ratios in the section can be performed (see example in next figure). Physical and chemical properties (temperature, conductivity, pH) were also monitored on the wells during drilling these wells.

Environmental and social impact Analysis (ESIA)

Regarding socio economic and environmental impact analysis, preliminary evaluation of the study area and practice from similar and analogous projects shall be referred and possible study outcome shall be visualized.

The objectives of the ESIA study includes review of the existing policy, institutional and administrative capability related to environmental matters; to identify the current state of the environment of the project area; to examine the major potential environmental impacts induced by the project and to propose mitigation measures for the potential adverse impacts of the project on the environment. Implementation of the project, thus, must be in alignment with a legal requirement of EISA proclamation (Proc. No. 299/2002) declared by the Federal Democratic Republic of Ethiopia. The study approach & methodology adopted include screening and scoping to determine the extent of the project and secondary data search and analysis for the baseline of bio-physical and social environmental parameters of the project area. In addition, a field survey was conducted on the surrounding environment of the project areas to collect site specific baseline environmental data for the project influenced areas. Sensitive environmental components that could be significantly affected by the drilling and operation of the wells.

Regarding socio-economic data most of the (validated) information with regard to administrative boundaries, gazetteer data (towns, roads, rivers), population data, water demand (drinking, livestock), geographical distribution of water use, is known and available to the project team. Coverage, cost and accessibility of current water sources and infrastructure, especially from a socio-economic point of view, are still unknown to the project team and form a data gap. Future water demand gaps for different water users, such as domestic and livestock, can be projected with a design horizon 2050.

Information on socio-economic aspects relevant for decision making on the target areas will be supported by data from the Central Statistical Agency of Ethiopia. The water demand is used to match areas demonstrating high suitability of groundwater abstraction with areas that have a high-water demand, and which have an insufficient water supply. Other socio-economic information required by guiding decision makers in selecting target areas, such as accessibility or water supply for schools and health care facilities are:

• Boundaries of kebeles and woredas with their names

• Population densities and numbers (see example map)

• Localities of villages and built-up areas

• Schools

• Health facilities

• Water points: springs, well

• Existing irrigation systems

• Roads

• Rivers

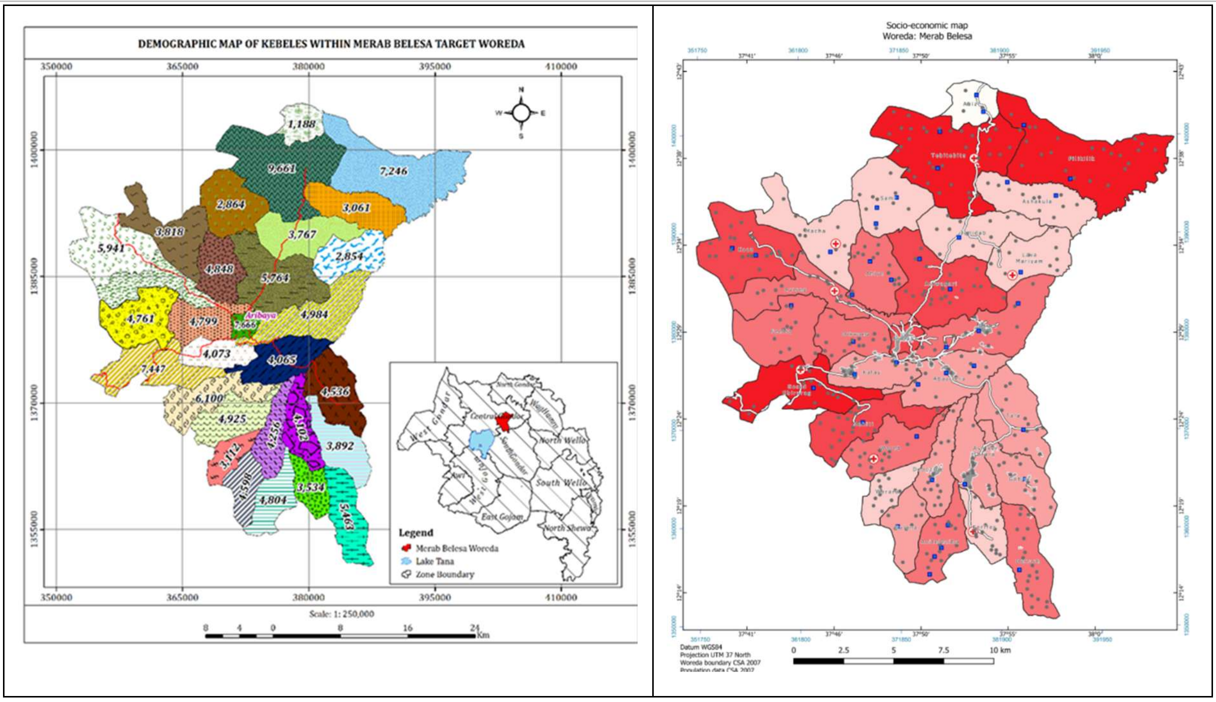
Example of socio-economic map is in following figure. The water demand maps can be derived from the population data of the Central Statistical Agency of Ethiopia as of 2007 and which are available on a Kebele level.

Water Demand in the form of a demographic map will also be prepared in this phase to aid the selection of target areas. The methodology aims at identifying the hotspots for water demand based on human and livestock population and livestock corridors. The rangeland maps prepared by the PRIME consortium will be used for the data collection, where available.

The most recent Population and Housing Census of Ethiopia was conducted in 2007 under the auspices of the Population Census Commission that was established by proclamation No. 449/1997. Tabular data is available per woreda from the Central Statistical Agency and has been published by OCHA as a GIS layer. We will use the 2007 census data as a starting point for the demographic maps which are available at the woreda level.

In 2013, CSA published population projections for 2007 to 2037 and the projection data per woreda will be processed into GIS layers and refined using Remote Sensing land use and landcover products. We can estimate the spatial distribution and dynamics of the population if a relation exists between areal extent of built-up area and the population count.

Alternatively, we may use the population projections as published by the Socio-Economic Data and Applications Centre (SEDAC). SEDAC provides global population projection grids based on Shared Socio-economic Pathways (SSPs) for 2010 to 2100. The spatial resolution is 15 km.



Examples of maps used for socioeconomic study (population and water demand)

Environmental and social impact assessment will be based on Socio-economic data on population distribution, health facilities, schools and waterpoints was obtained from CSA (2007), aggregated to woreda level, and processed into GIS layers. These GIS layers for the basis for the development of the 1:1,000,000 scale socio-economic map.

Water quality survey

Water quality assessment will be done on two basic levels 1. Integration and updating hydrochemical maps (scheme) collected in Inception phase and 2. comparison of analytical data with standards for drinking water and for agricultural use. Assessment of the groundwater quality of the different aquifers (geological formations) in the project area as well as various parts of the water circulation system (rainwater, surface water, and groundwater) was carried out. The results of the hydrochemical study have greater implication on developing the conceptual model of groundwater circulation within the aquifers.

There are large sets of data from previous reports and mapping projects. In addition to the existing archival data. A new set of up to 100 analyses will be taken during field study of the project.

The low TDS (between 300 to 600 mg/l) and calcium-bicarbonate type dominates the project area; however, sodium-bicarbonate type of groundwater also occurs in the area. This type indicates the fast hydrogeological regime of the area where rainfall is the main source of aquifer recharge. Groundwater flows relatively fast in the fractured volcanic rocks of the area from east to west. Content of total dissolved solids (TDS) increase from east to west following groundwater flow direction.

<u>Water Quality</u>

The water quality in the mapped area was assessed from the point of view of drinking and agriculture 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 published in the Drinking water – Specification CES 58, (ICS: 67.160.20, Published by Ethiopian Standards Agency, © ESA, Fourth Edition 2021) and is conform with WHO standards for drinking water.

High concentrations of fluoride in one well in the Metema area can indicate some local enrichment of groundwater by fluoride.

Particular interest will be paid to the content of nitrates in groundwater. The content of nitrates is not related to the rock composition (type) but it reflects lack of sanitation and 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 decomposition of various plants and other organic material. The nitrate content in archival samples of the project area varies from 0.0 mg/l to 222 mg/l in drilled wells, but reaching 3,012 mg/l in dug well. Nitrate pollution is an important factor particularly in vulnerable groundwater resources (shallow aquifers). This fact also must 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.

Groundwater chemistry of new samples compared to drinking water specification CES 58

Substance or characteristic	**Range in analyses (min–max) [mg/l]**	**Maximum permissible level**	**Number of analyses exceeding maximum permissible level**
TDS		1,200	
pH		6.5 - 8.5	
Na		200	
Ca		150	
Mg		100	
Fe		0.3	
Mn		0.4	
Cl		250	
SO4		400	
NO3		50	
NO2		0.5	
F		1.5	
Total hardness		300	
Total alkalinity $CaCO_3$		600	
(B) HBO_2		0.3	

Suitability of surface and groundwater for irrigation will be compared to SAR and USSL standards.

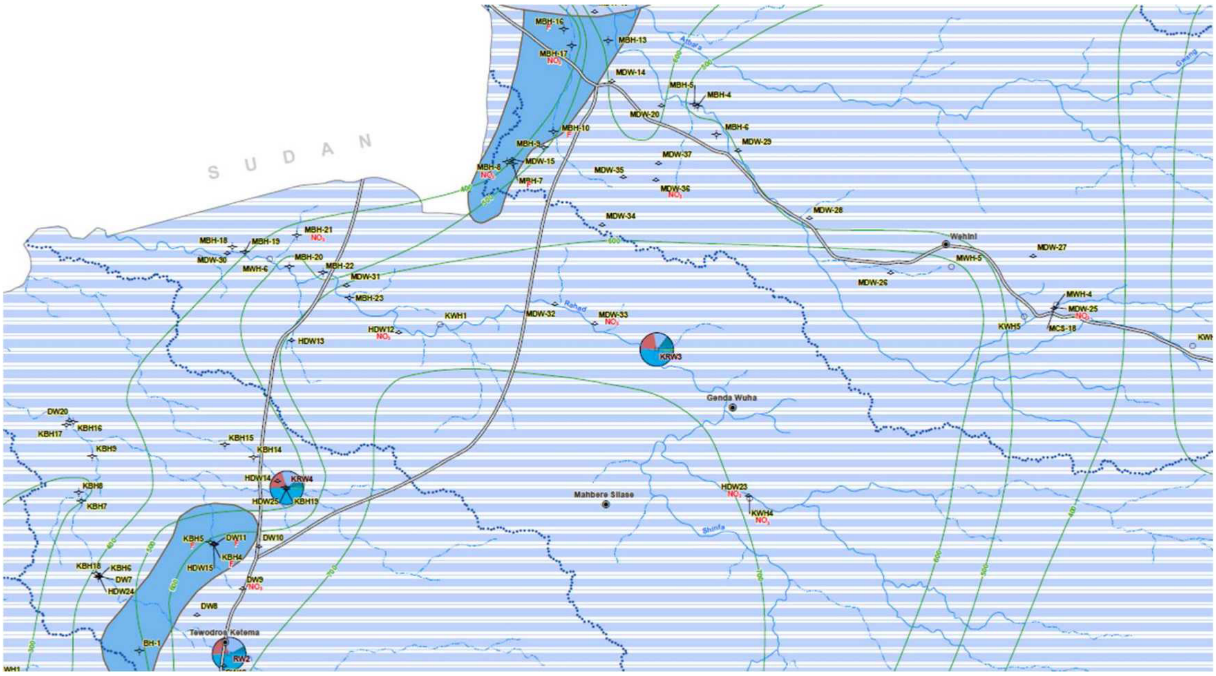
Suitability of water for irrigation based on SAR criteria

SAR Value	Class	Remark	No of case	Percentage
<10 (s1)	Low	Good		
10-18 (s2)	Medium	Good for coarse-grained permeable soil unsatisfactory for highly clayey soil with low leaching		

18-26 (s3)	High	Suitable only with good drainage, high leaching organic addition		
>26	Very high	Unsatisfactory		

Water quality analysis result based on the US salinity criteria

EC (µs/cm)	**Class**	**No. of sample in range**	**Remark**
<250	Low salinity (C1)		Good
250-750	Moderate (C2)		Good for soils of medium permeability for most plant
750-2,250	Medium to high (C3)		Satisfactory for plants having moderate salt tolerance
2,250-4,000	High (C4)		Satisfactory for salty tolerant crops on soils of good permeability with
>4,000	Very high (C5)		Not fit for irrigation



Extract from published hydrochemical map of the project area (1 : 250 000)

Hydrogeological study of target areas

Hydrogeological study will be divided into three main parts 1. Integration of data collected for hydrogeology in Inception Phase – compilation of hydrogeological maps of the project area at scale

1 :250 000 and 1 : 100 000 scale and retrieval of existing data about springs dug a d drilled wells) 2, Field trip with data collection and sampling from institutions and field trip (including sampling) and integration of data in form of hydrogeological map accompanied by explanatory text. 3. Compilation of final hydrogeological maps at scale 1 : 50 000 of target areas, hydrogeological cross sections and definition of hydrogeological conceptual model and hydrogeological characterization of target areas for preparation of tender documents and mathematical model.

The hydrogeological maps will express the main hydrogeological units-based integration of hydrogeological character of the main geological units. In the case of hydrogeological map, the permeability of hydrogeological units will be the main information shown on the map. It will be compiled based on combination of two basic types of data and information: (a) type of permeability – qualitative characteristic (e. g. intergranular, fissured aquifers) map, or (b) value of Transmissivity (T= m^2/d), specific yield o wells (q = l/s.m) and yield (Q = l/s) for wells and/or springs – quantitative characteristic. The type of permeability will be expressed by a specific color and quantitative characteristic are expressed by intensity of the color using principle the higher value the intensive is color (see article legend).

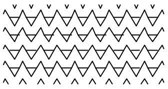
The legend will be mainly based on provisions for the International Legend to the Hydrogeological by Wilhelm F. STRUCKMEIER and Jean MARGAT (1995). The legend to the hydrogeological map is standardized for each hydrogeological unit of the Ethiopian territory.

The items of legend to the hydrogeological maps include four main groups of graphical information: lines, colors and hatching (patterns). Each item has a number, graphical expression and text description. The graphical expression of legend is presented in four main sections as follows:

A. Background information (black color) representing topographical data (names of villages and towns, roads, state and regional boundaries, latitude grids, etc.)
B. Lithology (Gray color ornaments)
C. Groundwater and rocks - aquifers and non-aquifers (various colors)
D. Water points (wells, dug wells, springs, rivers, etc.)

Lithological units will be derived from the project geological map. The geological units will be simplified and examples of proposed ornaments for individual lithological units are shown in the following table.

No.	Ornament	G-symbol No.	Lithology
C8		Q 22	Clayey sand with gravel – Alluvial sediments in general
C78		V 12	Pyroclastic rock without distinction (including scoria)
C81		V 17	Basaltic rocks
C92		V 44	Ignimbrite
C93		V 45	Rhyolite and other siliceous (acid) volcanic rocks

C94		V 46	Trachyte

Legend to hydrogeology will primary express the relationship between groundwater and rocks. All lithological units that appear on the geological map are shown in color, whether aquifers or non-aquifers. The color and its intensity depict the basic qualitative and quantitative characteristics of hydrogeological units. The hydrogeological units are arranged (lined up) from the most potential (porous) aquifer to the most impermeable aquiclude and aquifers with specific conditions in concordance with the description in the explanatory notes. The general legend for groundwater and rocks is shown in the following table and will be used accordingly.

No. in library	Specification	Aquifer / non-aquifer characteristics (definition)
B1	Dark blue	Highly productive aquifer (T = 10.1 – 100 m^2/d, q = 1.1 - 10 l/s.m, Q = 5 - 25 l/s for wells and/or springs) or locally extremely productive aquifer in which flow is mainly intergranular
B2	Light blue	Moderately productive (T = 1.1 - 10 m^2/d, q = 0.011 - 1 l/s.m, Q = 0.51 - 5 l/s for wells and/or springs) or local or discontinuous (smaller than 100 km^2) but highly productive aquifer in which flow is mainly intergranular
B3	Dark green	Highly productive aquifer (T = 10.1 - 100 m^2/d, q = 1.1 - 10 l/s.m, Q = 5 - 25 l/s for wells and/or springs) or locally extremely productive aquifer in which flow is mainly through regularly developed system of fissures of sedimentary rocks and karst openings
B4	Light green	Moderately productive (T = 1.1 - 10 m^2/d, q = 0,011 - 1 l/s.m, Q = 0.51 - 5 l/s for wells and/or springs) or local or discontinuous but highly productive aquifer in which flow is mainly through regularly developed system of fissures and joints of sedimentary and volcanic rocks
B5	Brown-red	Low productive (T = 0.11 - 1 m^2/d, q = 0.0011 - 0,01 l/s.m, Q = 0.051 - 0.5 l/s for wells and/or springs) fissured aquifer in which flow is mainly developed in irregular system of fissures and weathered mantle of a crystalline rock (intrusive and metamorphic rocks) with local and limited groundwater resources
B6	Light brown	Aquitards - Minor aquifer with local and limited groundwater resources (T = 0.01 - 0.1m^2/d, q = 0.0001 - 0.001 l/s.m, Q = 0.005 – 0.055 l/s)
B7	Dark brown	Aquicludes - Formation with essentially no groundwater resources (aquifuge – solid rocks / blind rocks)

B8	Combination of two aquifer colors	Aquifers with alternating layers of fissured and porous permeability (mixed aquifers) the appropriate aquifer colors should be used in horizontal 5 mm stripes	

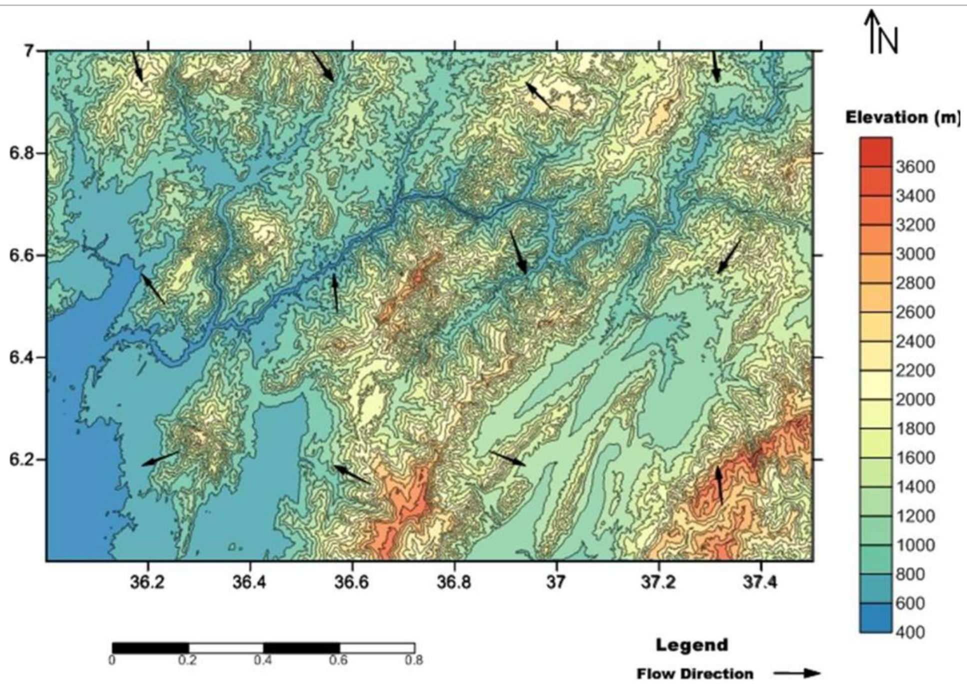
The method for drilling site location will combine of the overlay analysis, conceptual model, socio-economic study, geological, hydrogeological and geophysical surveys will finally result in a map with proposed drilling locations. The locations will be ranked according to the potential. The accompanying report contains a detailed description of the target sites, including exact location, proposed drilling method and depth.

Groundwater flow, recharge and discharge

Just as surface water tends to flow downhill, groundwater tends to move down gradients from water table areas of higher elevation to water table areas of lower elevation i.e. groundwater levels within all aquifers appear to follow the topography. Gravity is the dominant driving force for groundwater flow. Due to the limited water level data available for existing boreholes and springs, the groundwater flow direction in the study area is determined based on topography, geology and structures.

- Topographically, groundwater flows from the highest elevation (the plateau) through escarpment to the lowest elevation (bottom of MER and finally to lakes)
- Lithologically, groundwater flow in hard rocks is practically through fractured zones and their weathered mantle (regolith).
- Structurally, groundwater flows along fractures, faults and lineaments. The positions of springs, which are controlled by topographic breaks, are indicators of the possible groundwater flow.

In shallow groundwater, the movement and flow direction are dependent on the inclination of the topography of the area. The depth to water levels in shallow wells is near the surface and represents the local groundwater subsystem in the unconfined aquifer, which discharges to the nearest surface water bodies or infiltrates downwards. Therefore, the elevation of the ground level in shallow wells and deep boreholes shows that groundwater tapped by shallow wells and deep wells are in different flow systems. Examples of the regional groundwater flow directions are shown on the following map.



Example of regional groundwater flow directions metric maps

Groundwater Recharge areas

Practically all groundwater originates as rainwater. In the case of the study area, the principal source of recharge is precipitation in addition to stream flow. Lakes and reservoirs can also play their role in the recharge mechanism. The amount of groundwater recharge is controlled by the amount of precipitation, prevailing temperature, terrain (slope gradients), land cover (vegetation) and types of rocks (permeability). The study area is a good recharging zone due to the favorable lithology of the upper and lower Jima volcanics and regional as well as local structures.

Groundwater Discharge areas

Groundwater appears at the surface in the form of spring in the escarpment areas and in dug wells and shallow wells in the stream valleys. The main discharge of groundwater is in the form of baseflow to perennial rivers. Groundwater with its level near the surface may return directly to the atmosphere due to evapotranspiration from the soil and by transpiration from vegetation. Groundwater abstraction from wells constitutes the major artificial discharge of groundwater.

Map showing estimation of distribution hydraulic parameters for selected aquifers (groundwater potential areas) will be constructed based on data from pumping test shown in drilling reports of existing wells and will be updated after drilling of new test well for purpose of groundwater flow mathematical model.

Direct river flow discharge measurement

Direct river flow discharge measurements will be conducted using the newest equipment by OTT Hydromet FM Water Flow Meter. It is a handheld electromagnetic water flow meter with automatic discharge calculation. Measured data will be used to:

1. Measuring water flow and discharge to determine the amount of water flowing through an open channel for calibration (verification) of existing data, predicting water availability and flood events, allocating watering, and collect the latest data for hydrological analysis. In dry periods

2. Assessment of section of gaining streams, where groundwater seeps out into the streams and losing streams, stream where water moves into groundwater system. This information and data can be used for groundwater-stream interactions explanation and groundwater flow model.

Example of discharge measurement with OTT MF Pro in Gofa zone.

Selection of target areas and drilling sites

Will start with potential maps from overlay analysis and will be incorporated with data from geological, hydrogeological, and hydrochemical maps and schemes. Selection of target areas will consider detailed geophysical measurements (XZ location) and results of socio-economic (water demand) and environmental studies.

Finaly all integrated data and information will be shown in the form of following table (example)

SN	Target area code	Region	Zone	Woreda	Kebele	x	Y	Remark
1	M1	Amhara Regional State/CER	Semien Gondar Zone	Metema	Metema town	999999	888888	xxxxx
Moderately productive fissured basalt intercalated with tuffs with low, but relatively good recharge. Groundwater resources can be developed by deep wells drilled into / nearby faults and lineaments (higher discharge). Groundwater is soft with TDS between 400 and 600 mg/l and no ions exceeding standards for drinking and irrigation (fluoride and nitrate under question)								

Additional work

- Overlay analysis - groundwater resources potential maps will be updated by incorporation of new data from field work.
- The same principles will be used to compile hydrogeological maps of target areas (potential areas) at a scale 1 :50 000 in stage 3, however the draft maps will be prepared in this stage.
- The hydrogeological conceptual model of the area will be updated based on collected data and detailed information.

Tendering documents

Bidding documents will be prepared for each individual test well. For the borehole drilling, the BoQs will be prepared with confidential cost estimations, technical specifications, detailed drawings and list of required equipment. It will also include work plans, as well as listing all the necessary steps for getting approvals by every relevant authority. BOQs and tender documents will be prepared as lots that will be specified by the Client. The Client together with Contractor will review all tender documents as a preliminary review to ensure adherence to the technical requirements, reasonable and accurate costing of the proposed works, inclusion of appropriate ES, health and safety requirements, and completeness of documents. If costing is deemed to be above the available financing the Client will request a revision of the proposed works. Three weeks should be estimated for this round of review by the Client and Consultant.

The format of the bidding documents will follow the World Bank format and will be in line with national guidelines. The content of the bidding documents will at least include sections on instructions for bidders and data sheet; evaluation and qualification criteria; bidding forms; general conditions; and particular conditions. Tender documents should include bills of quantities, technical specifications and drawings.

In line with Word Bank standards, the Drilling company will prepare the Environment, Social (including issues of sexual exploitation, abuse, gender-based violence, and gender role/involvement), Health and Safety (including security for personnel) (C-ESHS) Works Requirements. The Consultant will include costs for staff, measures and works related to the implementation of required ESHS measures in the overall cost estimation and in the BoQs. This document will be reviewed by the Client and Consultant.

Borehole drawings will be provided in a separate volume, with drawings using suitable scale. The size of the volume will be dictated by the scale of the drawings. The scale of the drawings will be chosen according to degree of derail to be displayed in order to avoid misunderstandings" In case A3 print outs are needed, drawings will be arranged in a way to print the needed scale on A3 format. To the extent possible, drawings will be presented in about A3 format to facilitate reproduction. The scale will not be reduced to the extent that details are rendered illegible.

Borehole drawing books will contain drilling maps and situation plans (overlaid on satellite image background) in relation to local geography: longitudinal profiles and plan views - including natural terrain and plans of construction works. All units will be using a metric system, elevations will be meters above sea level with the WGS 84 datum, and the coordinate system will be UTM Zone 37N.

During the tender procedure for the contracting a Drilling Contractor, technical support will be provided to UNICEF during the pre-ender meeting, in which the details and expectations as well as questions from suppliers can be discussed and clarifications made.

The support will be provided in awarding Construction and installation contracts through provision of as needed technical assistance/advice for evaluation of bids and contract negotiations with regards to technical, financial, and C-ESHS aspects, review of the BoQ and budgets/cost estimates received from bidders.

Field survey report and validation workshop 2

Draft field survey report contents will be as follows:

- Description and list of inventoried points
- Identification of aquifers
- Existing resources description

- Rate and mechanism of recharge and discharge conditions
- Geological and hydrogeological maps (1 : 100 000 with cross sections)
- Results of geophysical survey with geo-electrical and pseudo-sections
- Regional as well as local groundwater flow systems
- Estimated hydraulic properties of identified aquifers
- Surface-groundwater interaction conditions
- Maps showing selected sites for test and/or pilot production wells drilling and testing (updating groundwater resources potential maps)
- Specification and borehole drilling bid documents

The final filed survey report will incorporate comments/feedback from workshop 2.

3. Stage 3 - Drilling and Groundwater resources evaluation

Main activities**: Test well drilling supervision, GW resource evaluation, GW model**

Main deliverables: **Quality assurance manual, Progress & drilling supervision reports, Test well drilling completion report, Final GW Resource evaluation report**

Stage 3 combines activities of Phase 1 (GW study and design) and Phase 2 (Drilling supervision) of the project. The work will be led by Project manager nominated for Drilling supervision part of the project. The work will be performed by two senior supervising hydrogeologists with support of two junior supervising hydrogeologists.

Drilling supervision will be organized in four sub – activities:

1. Preparation of quality assurance manual and support of the Client In selection of drilling companies
2. Filed supervision of drilling
3. Preparation of drilling reports
4. Final report on test well drilling

Quality assurance manual

The QA manual defines the quality management system and sets the standards for obtaining quality and safety. Number of Operating Procedures should provide the minimum technical requirements for drilling works including surveying of drill hole, sampling and logging of drilling chips, validation and storage of results and geological data in a computer database, basic environmental considerations and handling of potentially hazardous materials.

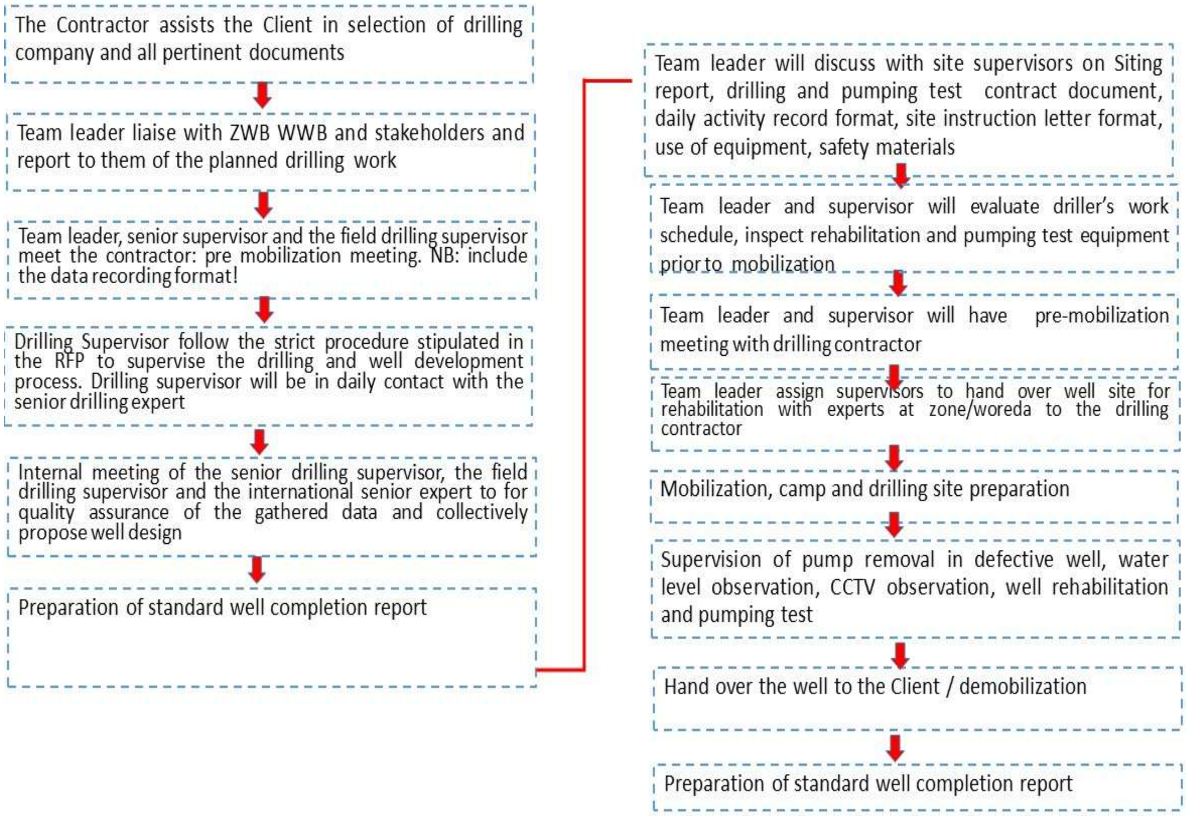
Overall considerations of supervision

The supervisor always needs to be watchful and is expected to display great professionalism and act with honesty and impartiality in any dispute over the contract.

During the whole drilling process and pumping test phases the Supervisor will liaise with the supervisor from the Regional Water Bureau (RWB) or any other relevant institution. Experts from RWB or Zonal Water Bureau (ZWB) or woreda could be on site during the construction. This will help keeping good relationship with local authorities and also help for any administrative issue.

Field supervision of drilling

Basic scheme of supervision of drilling of new well work process is in following scheme.



Wells drilling supervision workflow

Levels of supervision

Competent groundwater expert(s) will be employed to carry out the supervision of siting, drilling, pad construction and installation of pumps. Full-time supervision will be implemented. On completion of the borehole construction and related activities, the Supervisor will carry out a final borehole inspection.

The Supervisor will be totally independent of the Drilling Contractor. In other words, the Supervisor for any technical questions regarding the aquifer/geologic as a GPS, dip meter, measuring tape, stopwatch, magnifying glass, and borehole camera.

Full- time supervision

Borehole drilling will be done by the Drilling Contractor. The Supervisor stays with the drilling team throughout the drilling process, from the inspection to demobilization and handover. An on-site supervisor will be deployed at each borehole drilling site, and they stay in the camp of the Drilling Contractor and go out with them each morning.

The supervisor will be available at any time. The Drilling Contractor needs approval from the Supervisor for any technical questions regarding the aquifer/geology.

Site instructions

The technical specifications for the borehole drilling include the procedure for site instructions and the consequences for not abiding by them. Site instructions issued to the Drilling Contractor by the supervisor will be in writing and in duplicate. The Drilling Contractor will sign on the original and the duplicate instructions. The original is handed over to the Drilling Contractor, and the supervisor will keep the duplicate (paper copy).

Reporting progress of works
It is of utmost importance that the progress of the work be in accordance with the programmed work since the timely implementation of the project calls for strict adherence to the approved timetable. The Client will be advised continually as to work progress and will be informed if and when any deviations from the work schedule occur.

Check that the works will be carried out in a safe manner and report all breaches of safety requirements and monitor the corrective action taken to ensure unsafe practice does not continue.

The transport facilities for supervisors and also transport for the RWB, ZWB and woreda experts if requested will be arranged.

Final borehole inspection
An inspection is an official visit to the works in order to verify that all specifications have been adhered to and that the works are in proper condition. On completion of the Works by the Drilling Contractor, the inspection of boreholes, pads, pumps and surroundings and identification of any defects that need to be corrected during the Defects Liability Period will be carried out by supervisors. The defects will be listed in the Certificate of Substantial Completion which is issued at this stage.

The supervisor will monitor the correction of the defects. When satisfied that the defects have been corrected. The Supervisor, along with the Client Designated Representative, will issue a Certificate of Final Completion.

Planning and inspection (step 1)

In order to verify the capabilities of the Drilling Contractor before the Drilling Contractor's contract is signed, the Supervisor will conduct pre-qualification inspection of Drilling Contractor's equipment and personnel as a pre-requisite for mobilization, or as part of the tender process. This may be undertaken by in collaboration wilt the Client for any measures or arrangements.

Planning

- The Supervisor will study the project duration, time schedule, sequence of activities and verify them accordingly prior to the actual commencement of the work.
- The procurement of materials, transportation of equipment, materials and manpower will be analyzed by the Supervisor together with the Drilling Contractor.
- The Supervisor will show the selected sites to the Drilling Contractor.
- The Supervisor will check the Drilling Contractor's resource mobilization and will prepare a report for it.

Inventory
- Prior to the commencement of the works the Supervisor will inspect the drilling rig and the pumping test equipment of the Drilling Contractor.
- A detailed inventory of the materials to be supplied by the Drilling Contractor (equipment, materials, drilling tools compressor, welding plain, casing and screens, pumps, generators etc.) will be conducted.
- lf any item of the inventory is rejected during the inspection; the Supervisor must make sure that the items have been replaced as soon as possible.

The supervisor will request the Drilling Contractor to submit a report with:

- A work plan: project duration, time schedule, sequence of activities.
- Materials to be used, procurement of materials, and transportation.
- Equipment and transportation.
- Manpower and transportation

After inspection this report will be reviewed and signed by the Supervisor before being validated by the Client.

Confirmation of the borehole site (step 2)

The supervisor will check the borehole site prior to mobilization so that the borehole is drilled in the right place and location. The Supervisor will be responsible for checking accessibility of the sites and the eventual handing over of the drilling site to the Drilling Contractor. The final site handover will involve consultation with the Zonal Water Bureau and the local community with regard to land ownership and land use.

Pre-mobilization meeting (step 3)

The purpose of the mobilization meeting is to ensure that the Drilling Contractor and Supervisor are fully aware of their exact roles and responsibilities and contract details.

Once the contract of the Drilling Contractor has been signed, and prior to mobilization, a meeting between the Client (RWB), the Drilling Contractor, The Client, and the Consultant will be essential. At the meeting, all three parties go over the design, materials and procedures for each step in the contract. Roles and responsibilities need to be clarified in detail. This provides an opportunity for any ambiguity to be resolved, and the contract amended as necessary. This meeting will result in a memorandum of understanding (MoU), for each region, written by the supervisor and signed by all parties.

Mobilization (step 4)

Mobilization takes the drilling project from contract signing to deployment of the drilling crew and equipment on site. Mobilization includes the following activities:

i. **Contract:** All borehole projects and supervision are based on a contract agreement.
ii. **Programmed work:** The Supervisor will discuss the technical specifications and drilling procedure with the Drilling Contractor and will discuss and agree the target depths. Then the supervisor will ask the Drilling Contractor to submit a program of works, though the Supervisor needs to be flexible in case of unforeseen technical difficulties and/or social or environmental issues.
iii. **Community liaison:** It is essential that, before the Drilling Contractor arrives on site, the Supervisor will organize at least one discussion wilt the Community about the project and details of the drilling process and their expected obligations and contributions with the main contact persons or Community representatives- The Drilling Contractor's representative should meet with the Community and agree a start date.
iv. **Equipment checks**: All the equipment, including safety equipment that will be used by the Drilling Contractor will be checked to make sure that it is all in working condition, and the same as, or equivalent to, what was examined in the inspection step. The suppliers, manufacturers, or sources of the material to be used, such as drilling fluid, casing and screens, will be specified. The Drilling Contractor should submit samples of the materials for the Supervisor's approval. The slot size and wall thickness will be checked.

v. Because of their fragility, plastic casings should be stored and shipped with care. Stack the materials properly in shade (not direct sunlight), because the plastic is susceptible to degradation and deformation by heat and degradation by natural ultraviolet radiation.

vi. **Data collection forms:** The format of drilling data collection to meet the contract requirements will be agreed on. The final version for copying will be agreed on site between the Drilling Contractor and the Supervisor and signed by both parties once all the stages of the contract are completed. The drilling data will comprise description of cuttings, drilling progress, borehole logs, well completion log with position of screens and casings, daily reports of operations, changes in drilling plan, failures, and repairs.

vii. **Project filing system:** Most of the data could be stored electronically, but hard copies are required for field use. A file (in duplicate) should be opened for every well and all records and data for the well stored in the file. Checklists for all stages of borehole construction will be printed inside the flap of the folder and ticked as construction progresses. The original is kept in the Contractor’s office and the duplicate in the Drill Camp or site office.

Drilling supervision (step 5)

The aim of drilling supervision is to ensure a high-quality borehole is drilled in a way that is safe and well-documented.

Before drilling the Supervisor will provide a predictive log of the geological strata and aquifers and the expected water level.

The drilling Supervisor will make sure the following conditions are met and will provide weekly reports:

Safety: The Supervisor will ensure that the Drilling Contractor takes all precautions for the safety of the personnel, the public and the equipment on the drill site. The Supervisor will check and ensure that the Drilling Contractor has a properly equipped first aid kit on site and has adequate preparation for dealing with emergencies. All personnel on the site, both the Supervisor and the drilling crew, shall put on protective clothing, proper boos, hard hats and gloves. The supervisor will be constantly vigilant to prevent accidents, and to minimize injuries should accidents occur. Spectators must be kept behind a clearly defined barrier and prevented from staring at the welding arc where welding is carried out.

The Supervisor will look after his/her own safety and be aware of risks to the Drilling Contractor's crew and the public and check for the availability of hygienic facilities such as: latrines (30m away from drilling site), hand washing sites, showers, etc. as well as medical kits.

Rig position: The drilling Supervisor will be responsible for checking rig positioning- i.e. horizontality of the rig and the verticality of the mast. Verticality of the drill pipe should be checked with a spirit level. The rig should be jacked on a robust wooden block so that verticality remains throughout. The rig should be positioned exactly over the pegged site.

Well diameter and drilling method: The well diameter and drilling methods will be checked by the Supervisor in accordance with the contract specification.

Monitoring drilling depth: The supervisor needs to always know the depth of the drill bit to ensure that proper data logging is being done, to know the depth at which to tell the Drilling Contractor to stop and to compare the drilled depth with the depth recommended in the contract.

Sampling and logging:

- The Supervisor will give site instructions for sampling methods, storage, and sampling frequency.
- The Supervisor will carry out sampling himself, make and make descriptions and take photographs of the samples.
- The Supervisor will be responsible for proper litho-logical and/or electrical logging as appropriate and draw up the geological sections of the boreholes.

Plumpness and alignment: The Supervisor shall check and control the plumpness and alignment of the boreholes by close observation during drilling and by checking the possible causes.

Penetration rate: This is the time taken to drill a particular interval. A fast penetration rate can indicate an aquifer, although this is not always the case. Less porous strata, such as massive rocks are often slower to drill through. The Supervisor will record the penetration rate.

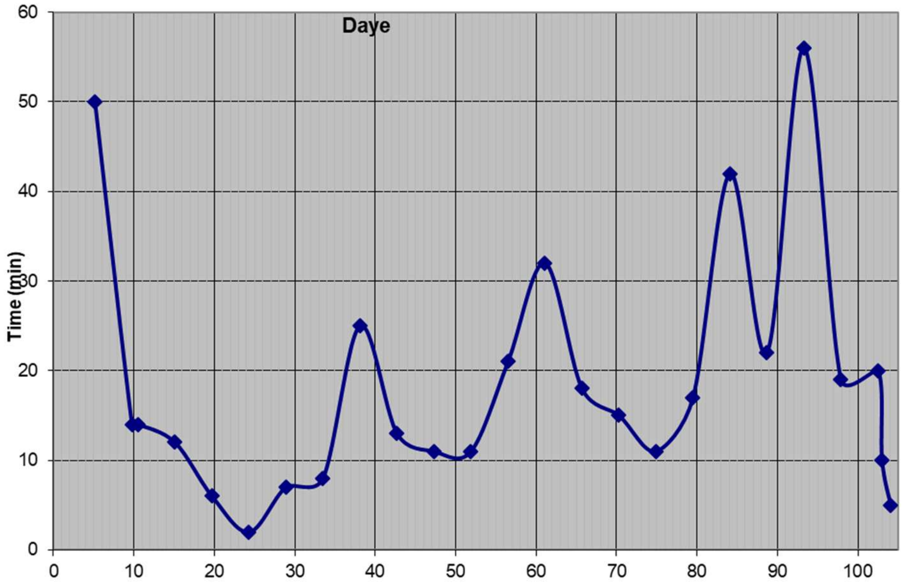


Figure 2 : Drilling rate for well at Daye

Example of drilling rate diagram

Drilling fluids & air-lift yield: The Supervisor will inspect and will make sure appropriate drilling fluids have been utilized. The type of fluid should match the drilling method:

- The preferred method is down the-hole-hammer using compressed air, water (with air) or foam,
- Only if DTH (down-the-hole) drilling is not possible rotary drilling can be carried out. For the drilling mud no chemicals are allowed.
- Monitoring the drilling fluid color and viscosity is the responsibility of the Drilling Contractor. Viscosity is checked by measuring the flow rate of the drilling fluid through a Marsh Funnel. The Supervisor will ensure the Drilling Contractor has a Marsh Funnel and it is properly used.

Drill cutting samples: The Supervisor will be responsible for sampling drill cuts. The drill samples should be bagged in strong transparent bags, labeled with indelible ink, and stored in a position that they will not be contaminated by site conditions or drilling operations. The label should contain the borehole number based on national borehole numbering system, location, sample number and depth. The sample could be collected and stored in a sample box. A photograph of the samples will be taken as a permanent record. In mud drilling the samples would have mixed with the drilling fluid. The samples should be washed before bagging. But care should be taken in washing soft rock material, such as clay, as they could disintegrate in water.

Cutting samples during air drilling are usually obtained by pushing a shovel under the drill table alongside the conductor pipe. As the samples are blown out rock fragments collect round the pipe and some land on the shovel. At the prescribed sampling interval, the shovel is withdrawn with the fresh sample. The Supervisor will make sure the cuttings are sampled as prescribed in the drilling TOR.

The depth interval of collecting samples might have been stated in the Technical Specification but drilling conditions may require that this is reviewed. It might have been specified that samples should be taken at every meter interval. However, in a deep borehole where the formation does not change rapidly, the interval could be increased to two or three meters.

Equally, where there is rapid change in lithology, the Supervisor may change the interval to a meter.

Groundwater strike: Careful observations and recording of position of groundwater strike is necessary. Water strikes made during mud rotary drilling are usually indicated (unless they are very minor) by a rapid dilution of the mud mix. The interception of an aquifer during air drilling is much more obvious, as the machine will begin blowing out waste fragments of rock instead of dry dust.

Strata Log: Drill samples will be described, and a strata log will be prepared by the Supervisor. From the strata description, the supervisor will prepare a graphic strata log which will form the pad of the final borehole report. For a borehole to be properly logged, the driller and Supervisor need to always know its exact depth. This is necessary for the calculation of drilling charges, and while designing the borehole. First, the Supervisor will make a note of the length of the drill bit and of any other tools that may be used to drill the hole. Put the bit on the ground and make a chalk mark, '0,' on the first drill pipe against a suitable fixed point on the rig and at a known height above ground level. Such as the drilling table (which centralizes the drill pipes in the hole). From then on, marks can be made on the drill pipe at regular intervals - say, every half meter - to record the depth of drilling and to assist in the logging of penetration rates. However, because drillers often forget to make these chalk marks, the Supervisor will also keep count of the number of drill pipes going into the hole. The total length of these, plus the length of the drill bit, is the correct depth (beware of drill pipes of slightly differing lengths). The main attributes of a borehole log are accuracy and consistency; a good set of logs is an essential resource.

Final borehole depth: It will be the responsibility of the Supervisor to instruct the Drilling Contractor to stop drilling when the right depth has been reached. Supervisor will decide to end drilling will depend on the information gathered while drilling. The factors will include: what has been stipulated in the contract, which may be based on Client guidelines with respect to the average borehole depth in the area, depth of the water strikes/aquifer, static water levels, estimated seasonal fluctuations in water levels i.e. changes in waiter levels as a result i.e. recharge in the wet season(s) and groundwater discharge during the dry season(s), the estimated yield from the borehole, once the final depth of the well is reached. The depth of the borehole will be checked by a weighted plumbline, in order that an accurate construction design may be drawn up.

Drill Report: The data from the drilling will be recorded both for the final design and as a reference for future borehole projects. The Drilling Contractor needs to keep a daily drilling log which will be signed by the rig operator and the Supervisor at the end of each day. The Supervisor should insist that this is done - The Supervisor will keep the record of the drilling activities and all measurements in a field notebook. The most important data will go into the well completion report.

Well design and construction (step 6)

The data from the drilling will be recorded both for the final design and as a reference for future borehole projects. The Driller drilling rate and observations on water levels the data can be used for well design.

Well Design: The Supervisor will be responsible for the final design of water well construction, which shows settings of casings and screens, gravel packing, and well head structure. The Supervisor will do:

- Inspection and approve the timely conditions casings and screens proposed
- Decision whether casings and screens are need for the well
- Preparation casing and screen arrangements (well design) as per the requirements of the technical specification and drilling results.

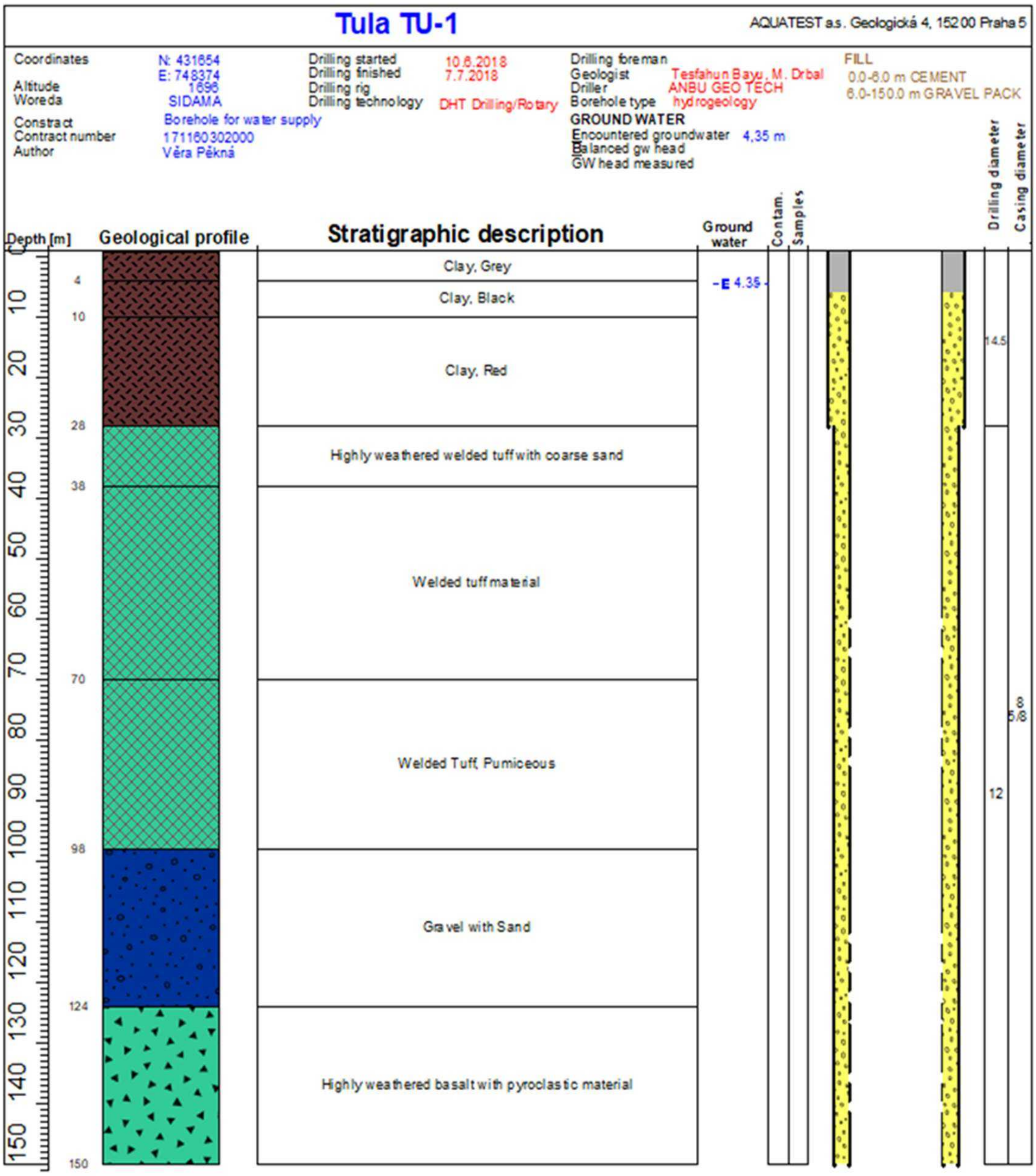
Screen slot size: The total open area of the screen governs the amount of water that flows into the hole. Slot sizes will be checked by the Supervisor.

Installing casing and screen: It requires great care and attention as it is easy to install blank casing in the aquifer horizon. Once the depth of the borehole and the depth interval for screening are known, a sketch of the proposed assemblage of casing and screen will be prepared by the Supervisor. A 3m length of sand trap should be part of the well design when boreholes are cased to the bottom and the bottom casing sealed with an end cap.

The Supervisor will inspect the screens and screen slots and verify whether they comply with the prescribed technical specifications:

- Supervise screen and casing setting shown in the well design for each borehole.
- Check and approve whether casings are driven to the bottom of the well.

If there are two distinct aquifers with different water quality, only one of the aquifers shall be screened to avoid mixing of different water types.



Example of documentation of the well design (the Tula well

The Drilling Contractor might arrive at site with a number of odd lengths of steel casing, which the Drilling Contractor would attempt to weld together. In such instances, the Drilling Contractor must not use angle grinders to cut the casing, which might, as a result, be left without very straight or square ends. This may result in breakage at the interior weld in the borehole. The Supervisor will check also that the Drilling Contractor is using the correct type of welding rod. If mild steel, mild steel, mild steel stainless steel or stainless steel/stainless steel joins are required, different types of welding rod may be necessary, Using wrong welding rods could cause parting of the casing in the borehole and develop rust.

Gravel pack: is installed in the annular space between the borehole screen and the wall of the drilled hole. The rest of the annular space of the borehole above the screen shall be filled with bore whole cuttings or gravel. The Supervisor will do

- Decision about the necessity of gravel packing

- Checking the size, uniformity and quality of the gravel proposed
- Checking sand bridging
- Appropriate instruction for gravel packing
- Checking the gravel packing method

Care will be taken in that the Drilling Contractor may bring on site whatever she/he assumes to be suitable gravel, which may be irregular stone chippings or "building aggregate". It is then up to the Supervisor to check and control on the size and quality of the gravel pack material to satisfy the conditions in the drilling specifications.

Well development (step 7)

The aim of well development is to prepare the borehole for use and install the pump and ancillary headwork and structures.

The Supervisor will give instructions for appropriate well development and will check that the well is developed to the required standard.

Borehole Development Method: Borehole development is about cleaning the area of the aquifer immediately around the screens. The method of development will be stated in technical specification.

Borehole Development Success: The Supervisor will ensure that eventually the water coming out from the borehole is clear of mud and is sand free; Samples of the water will be collected in a clear container and checked to see that there are no sediments collecting at the bottom of the container. As part of this, the Supervisor will decide whether a borehole should be accepted or declared abortive.

lf the borehole is to be aborted. The supervisor will also determine whether the Drilling Contractor should re-drill the borehole at his or her own expense or not, this depends on the time it takes for the water to be clean (maximum should be a turbidity of 10 NTU). Development should continue until the Supervisor is satisfied that the water coming out of the borehole is clean and sand free.

Sanitary seal

The Supervisor will ensure that a sanitary seal is placed at the top (6m) to prevent surface water which may be polluted from flowing down the borehole annulus into the aquifer. (Example: the sanitary seal will be the cement slurry in the mixture of 25 1 of water to 50 kg of neat cement, or betonies, to be define with RWB or ZWB or woreda expert).

Pumping test and water quality determinations (step 8)

Pumping test provides the means to determine the likely success of the borehole in terms of yield and drawdown. It provides information on the properties of the aquifer and on the borehole itself. Three types of pumping test will be conducted: a step-drawdown-test, a long duration test and a recovery test (refer to ICRC guidelines "Technical review" land information needed according to UNHCR spreadsheet).

1. The Supervisor will make a proposal and will follow a step-drawdown-test to determine the hydraulic performance of the well. The data from a step-drawdown-test will be used to calculate the well efficiency" During the test the discharge of the pump will be increased stepwise 4 to 5 times. The duration of the different steps is one to two hours.
2. A constant discharge or aquifer test gives information about the drawdown resulting from a specific pumping role (10 to20% larger than the design discharge). The long duration pumping test should be continued for at least 72 hours. The Supervisor will decide the duration of pump testing as per the specification and nature of the aquifer and will collect the water samples for analysis on water quality parameters: pH, EC, macro-parameters, fluoride, arsenic, turbidity, bacterial quality (total coli form bacteria) and isotopes (tritium, radiocarbon and stable water isotopes), Between

the step-drawdown-test and the long-duration test, at last three hours are required to let the water level recover and come to rest at its static level.

lf there are other wells nearby (400 m), water levels in these wells will also be measured at regular intervals to investigate the mutual influence between the wells and the aquifer dynamics.

The Supervisor will make a proposal and will follow a constant discharge test to provide information about the aquifer in the vicinity of the well and determine the short-term performance.

After the long duration pumping test, the recovery of the water level will be measured. Based on this recovery test the aquifer transmissivity can be calculated.

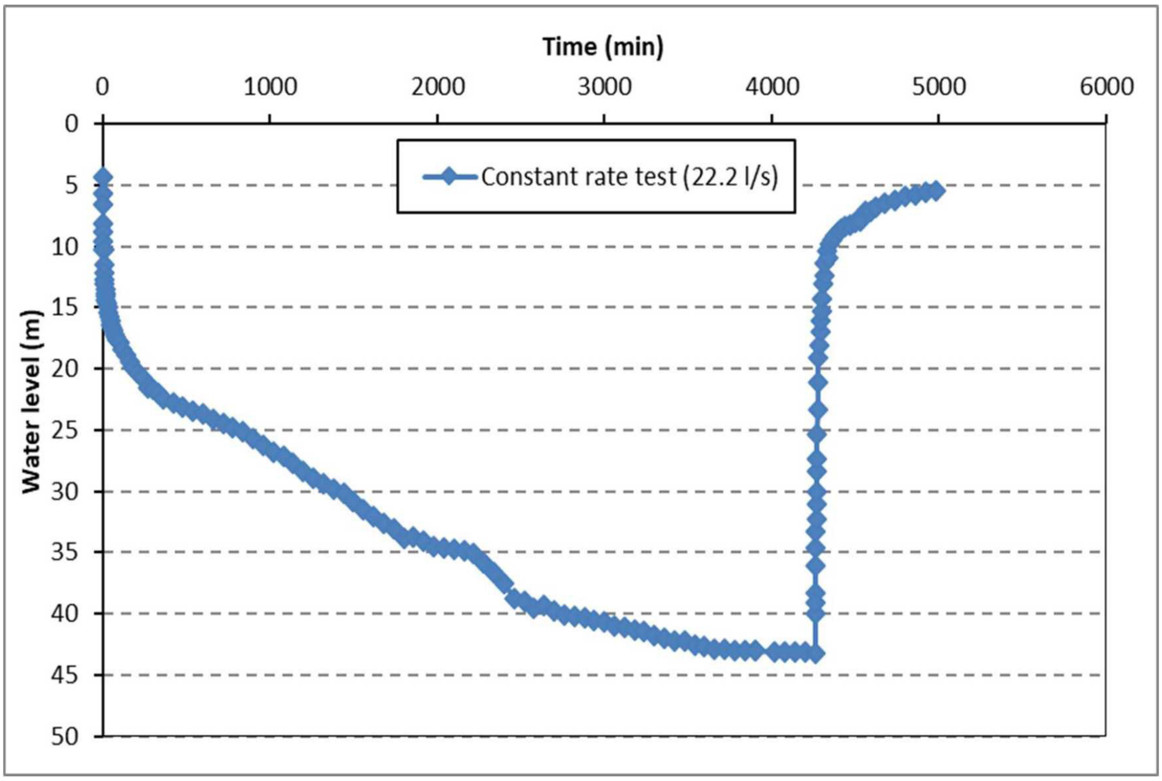
During the pumping test operation, the Supervisor will handle the following tasks:

i. Check equipment and materials for conducting pumping test. These may include the pump, source and capacity of power, riser pipes. And water level meter and discharge measurements devices, hand tools data collection formats.

ii. At the end of the long duration test the Supervisor will assist in collecting the water samples for analysis on water quality parameters (pH, EC. Macro-parameters, fluoride. arsenic, turbidity, bacterial quality (total coli form bacteria) and isotopes (tritium, radiocarbon and stable water isotopes)

iii. Follow up pumping tests, analyze data, make recommendations on optimum yield, sample water laboratory test and pump settings. Ensure water quality analysis is carried out and the results received, studied and advised upon by the Supervisor.

iv. Make recommendations on submersible pump type, power source (electric grid, type and number of solar panels, generator, or hybrid system) rising main, electric cables, borehole sensors, and control equipment.



Example of pumping test analysis (Tula well)

Grouting and well head construction

It is essential to prevent contamination of the aquifer and to ensure that the users obtain safe, clean drinking water. When the Supervisor will be satisfied with the yield, and development has settled the gravel pack, then the annulus of the borehole is back filled with the cuttings, or clayey soil, up to 6m below the ground surface or as specified by the specification.

At the end of the completion of the sanitary seal, the Supervisor will check the construction and labeling of the well head in a standard way and as per the design. Labeling will follow the national borehole numbering system and be approved by the RWB. Attention will be given to the following:

- Supervision of the sand bridge above the gravel pack so that infiltration of cement grouting is prevented from entering into the gravel pack.
- Checking the cement, sand and gravel mix for the well head construction.
- Ensuring protection of surface flooding around the well
- Checking fencing around well and meeting with RWB to clarify fencing distance.

Water sampling analysis and well disinfection

The Supervises will ensure that water samples are taken by the Drilling Contractor in a clean bottle and send it to the laboratory for the analysis as specified in technical specification and according to the laboratory specified timeframe. Where the facilities are available, the sample should be analyzed on site and then taken to an approved laboratory for further analysis, note that some parameters change between sampling and reaching the lab and need to be tested as soon as possible after sampling, or close to the site (including pH, EC, dissolved oxygen. iron and microorganisms). In this work attention will be given to the following:

- Ensuring water samples are taken according to the proper procedures (see handbooks) and in any case according to instructions of the laboratory.
- Controlling possible contaminant source during drilling
- Supervision the well disinfection using appropriate chemicals (chemicals approved by the Client according to analysis results).
- Supervision of final sealing (closing) of the well.

Drilling site re-instating (step 9)

At the end of the drilling work, the site must be re-instated to its original condition by removing all dirt generated as a result of the drilling activity, mud pits or any other excavations made around the area should be filled and site is re-instated properly.

Demobilization (step 10)

During the demobilization stage the Supervisor will make sure to leave the site clean, safe and ready for use on completion of all works when the Supervisor will issue a Final Completion Certificate. For this, the supervisor has to ensure that the Drilling Contractor has complied with all the stages, including the final ones, of the contract specification.
Before demobilization, the supervisor will check that the borehole record has been completed, and all information filled in.

Drilling reports

Drilling report is prepared based on data and information collected during drilling by hydrogeologist of drilling contractor or by supervising hydrogeologist. Drilling reports will be presented for all well separately to make their use of various stakeholders easier. Drilling reports will have uniform contents and annexes. The report information can be enhanced by several photographs.

TABLE OF CONTENTS of Drilling report:

1. INTRODUCTION
2 LOCATION AND ACCESSIBILITY
Table 1: GPS Coordinate of the Borehole
3 OBJECTIVE AND SCOPE OF THE WORK
4 MACHINERY AND EQUIPMENT
Table 2: Drilling Rig, Equipment and Accessories
5 DRILLING AND COMPLETION HISTORY
5.1 DRILING HISTORY OF THE WELL
5.2 DRILLING POROBLEMS ENCOUNTERED
6. FORMATION SAMPLING
7. CASING DESIGN AND WELL COMPLETION
Table 3: LITHOLOGICAL DESCRIPTION OF THE WELL
8. WELL DEVELOPMENT, CLEANING & WELL HEAD CONSTRUCTION
9. PUMPING TEST
9.1 PURPOSE
9.2 EQUIPMENT USED
10 DATA RECORDING AND INTERPRETATION
10.1 METHODOLOGY
10.2 PUMPING TEST OPERATION AND ANALYSIS
11 SUMMARY OF WELL DATA
12 WATER QUALITY TEST
13 WATER RESOURCES QUANTITY AND QUALITY PROTECTION
14 CONCLUSION AND RECOMMENDATION

ANNEX 1: LITHOLOGY AND WELL CONSTRUCTION
ANNEX 2: CONSTANT PUMPING TEST DATA AND ANALYSIS
ANNEX 3: RECOVERY OF CONSTANT PUMPING TEST DATA AND ANALYSIS
ANNEX 4: RESULT OF CHEMICAL AND BACTERIOLOGICAL ANALYSES

Final report on test well drilling

The final report will summaries data of individual wells (see chapter 11 of Drilling report) and is accompanied by summary of financial audit, showing:

INTRODUCTION
DRILLING INFORMATION
CASING INSTALLATION
GRAVEL PACKING & WELL DEVELOPMENT

Basic information about wells

S/n	Site Name	UTM	Elivation	Date Started	Date Completed	Depth (m)	W.S.D (m)	Aquifer Type	E.Y L/sec	screen pos. (m)	G.P M³	Pump type	p.p (m)	Remark
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*

Geological Logs of individual wells

Depth (m)		Lithological description	Hydrogeological description
From	To		Aquaifer / non aquifer

Groundwater resources evaluation

The groundwater resources assessment will be prepared in three basic steps 1. Assessment of dynamic groundwater resources using baseflow separation (baseflow concept), 2 Recharge data from hydrological study 3. Hydraulic model for specific target sites in major aquifers of the project area.

Baseflow concept

Specific baseflow has been calculated in stage 2 (hydrology). The area of the project of 1,724 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 of porous and fissured permeability cover a substantial area of project.

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 project 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 and specific baseflow in $l/s.km^2$ for aquifers in the project area will be used for assessed water resources of the project area as shown in following table.

	Input	Area (km^2)	Resources total (Mm^3)	Remark
Precipitation – project area	mm	1,724		
Total water resources – project area	$l/s·km^2$	1,724		% of rainfall
Renewable groundwater resources active aquifers	$l/s·km^2$			% of rainfall
Static groundwater resources of fissured aquifers	5 % porosity 100 m thickness			
Static groundwater resources porous aquifers	15 % porosity 100 m thickness			

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.

Recharge data

Hydrological study provides hybridized infiltration data using model of water balance using WetSpass and balance equation using FAO data. Data in mm of infiltration will be incorporate with data from baseflow separation. All available data will be used as a input to the mathematical model of ground flow and its variations.

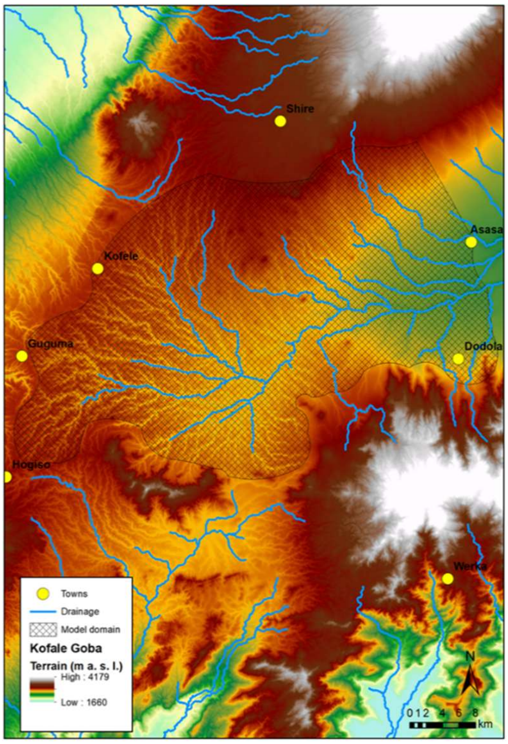
Suitable and sustainable groundwater resources in the project area active aquifers will be defined based on extensive hydrological study including water balance modelling, which revealed that total of infiltration (groundwater resources) of the project area is X.XXX Mm^3 with an average infiltration depth of XXX mm/year. Later on, the active aquifers will be overlain with drinking groundwater area, land use / water demand and recharge. Resulting data will be clipped to individual woredas and number of households that can be supplied will be calculated for future development.

Mathematical groundwater model

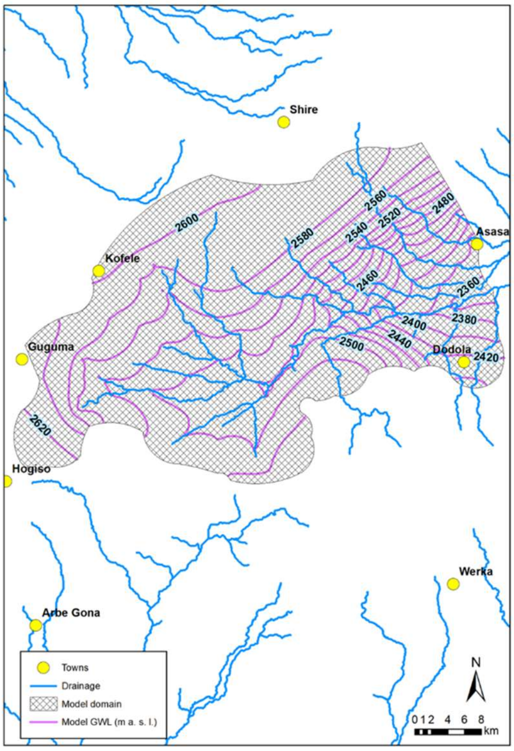
We will use MODFLOW6 as the primary model code for running the groundwater model. This finite-difference code is free, extensively error-checked, peer-reviewed, and utilized world-wide. ModelMuse is the suggested Graphical User Interface GUI for this project because it is supported by the United States Geological Survey, is free and openly available for use by future project Stakeholders, is easy to use, and is supported with robust training sources and user manuals. Additional water budget processing will be conducted using Zonebudget or Flo-Py (Python computer code for interfacing with MODFLOW). Results will be presented using not only graphs and figures but also animations and/or three-dimensional visualizations to aid in stakeholder engagement and understanding of modeling results.

The construction of model will be based on

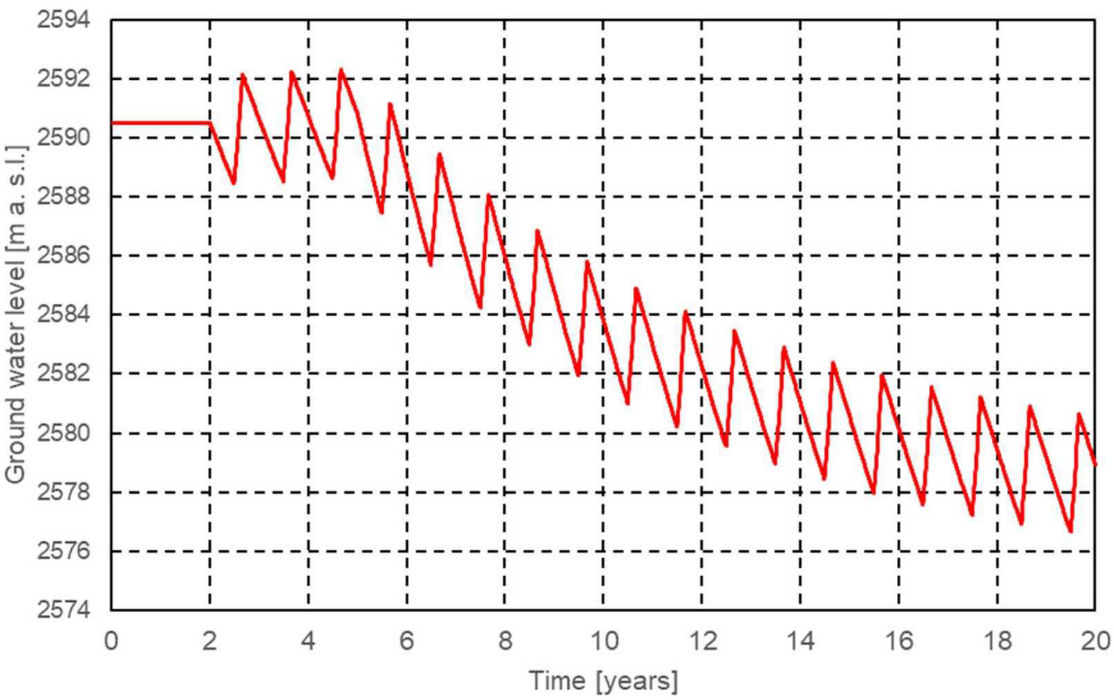
- Aquifer boundaries and conceptual model including 3D aquifer geometry, distributions of hydraulic properties, reference groundwater levels, recharge and discharge zones, known well fields and recharge projects, etc;
- Defining of boundary on all the model boundaries, based on the conceptual model defined under Task 1.6, ensuring not to impose unrealistic recharge or discharge flows;
- Calibration of the mathematical groundwater model in steady and transient state, to evaluate most likely recharge and discharge flows.
- Simulation of the aquifer evolution until 2050 under different water use and climate scenarios (with a maximum of 6), predicted by IPCC or ICPAC, to assess likely responses of the aquifer to increased use and impacts of climate change.
- Stochastic (i.e. uncertain or random input variable) modeling considering uncertainty in input parameters such as recharge rates, heads, and other boundary conditions, aquifer properties, and stresses such as pumping and managed recharge.



Example of model domain – the Assasa plain



Example of groundwater levels – the Assasa plain



Example of prediction of groundwater fluctuations – the Assasa pain.

Climate change and natural risks considerations

Ethiopia's climate risk is very high due to the potential of the hazards and the fragility of the exposed environment. The impacts of recurrent seasonal phenomena, especially floods and droughts, are intensified by rapid population and urban growth, as well as environmental degradation. The lowlands of the project area are more vulnerable to rising temperatures and prolonged droughts. A climate study by the World Bank (2021) also documented a rise in mean annual temperature of 0.2 °C to 0.28 °C per decade over the last 40-50 years. Rainfall intensity, depth, and distribution changes as well as an accelerating rate of evaporation due to increasing temperature, directly impact the amount of rainfall and recharge rates for groundwater, increasing water stress and freshwater vulnerability. The entire Ethiopian territory is often affected by recurring droughts causing famine. For the IPCC mid-range (A1B) emission scenario, the mean annual temperature will increase in the range of 0.9–1.1 °C by 2030, in the range of 1.7–2.1 °C by 2050 and in the range of 2.7–3.4 °C by 2080 over Ethiopia compared to the 1961–1990 norm. A small increase in annual precipitation is also expected over the Awash Basin.

Floods have a direct relation to an increase in temperature as the warmer air potentially contains more moisture resulting in heavier rainfall. Intense rainfall events are likely to recur more frequently, raising the flood risk. Ethiopia Disaster Risk Management Commission (EDRMC), the 2020 floods were one of the most severe in decades. Climate change cause extreme heat (and the impact on embankment materials) as well as extreme flows (for example). The well documented floods in the project area happened in 1993, 1994,1995 and 1996 the flood of 2020 was one of the most severe in decades.

Our climate risk and vulnerability assessment will be focused on available water resources and based on a territorial approach using a GIS-based methodology of water services and climate change vulnerability assessment. Based on the available data and existing studies, current and future measures to preserve water services assets will be analysed. Trends of future developments will be also assessed. Once local and regional datasets have been obtained, data compilation for building a geodatabase will be performed. Regarding climate risk assessment, the CMIP6 model of the latest IPCC report AR6 will be used, with two specific objectives: (i) conducting a rapid and comprehensive detailed climate change risk and vulnerability assessment in the Borana area for the water resources; and (ii) identifying suitable adaptation options to strengthen the climate resilience of catchments to improve water services for livelihoods and people.

Given their direct relation and impacts on water resources, the key elements that the assessment will focus on are, but not limited to:

- Drought analysis, taking into consideration precipitation and temperature
- Extreme temperature analysis
- Groundwater availability and accessibility – as far as these data are available
- Heavy precipitation and flood hazard analysis
- Soil moisture analysis

While open-access databases and global climatic models can be considered as potent inputs for hydrological modeling and climate risk assessments, their resolution, even after downscaling, presents certain challenges. This is because at each downscaling step, several assumptions are made. These assumptions are often associated with uncertainties that will in fine affect the resolution of the final output. Therefore, calibration with observed data is often needed to ensure the validity of the approach and the integrity of the simulated results. The same principle is applicable for hydrologic modeling inputs/outputs where cross checking with observed data (for example rain gauges, weather station data and flow measuring stations) is needed to calibrate the model and ensure the finest possible outcome. Prior to output optimization, quality inputs are needed to ensure accurate representations and minimize deviations from reality. For instance, accurate information on land cover, particularly those that are field validated, are an important example.

The analysis of current simulated data with respect to observed measurements will allow an establishment of explanatory variables to map future scenarios of change, hence ensuring a sufficiently accurate representation of upcoming conditions. Through this approach, accurate proactive planning for safeguarding Ethiopia's resources and socioeconomic welfare can be promoted.

Nine climate indicators can be used to assess the water availability and climatic conditions of the region, at the scale of the project area zone and each sub-catchment within the region. For each indicator, we computed the reference period (i.e., existing current condition), and projected two climate scenario trends (SSP2-4.5 and SPP5-8.5) for three temporal horizons (2030, 2050, 2070)

- Number of hot days with T max > 42 ºC
- Days with precipitations > 50 mm
- Days with precipitations > 20 mm
- Average precipitations (mm)
- Warm Spell Duration Index (WSDI)
- Yearly average of minimal temperatures
- Yearly average of maximal temperatures
- Standardized Precipitation Evapotranspiration Index (drought analysis)
- Maximal numbers of Consecutive Dry Days (drought analysis)

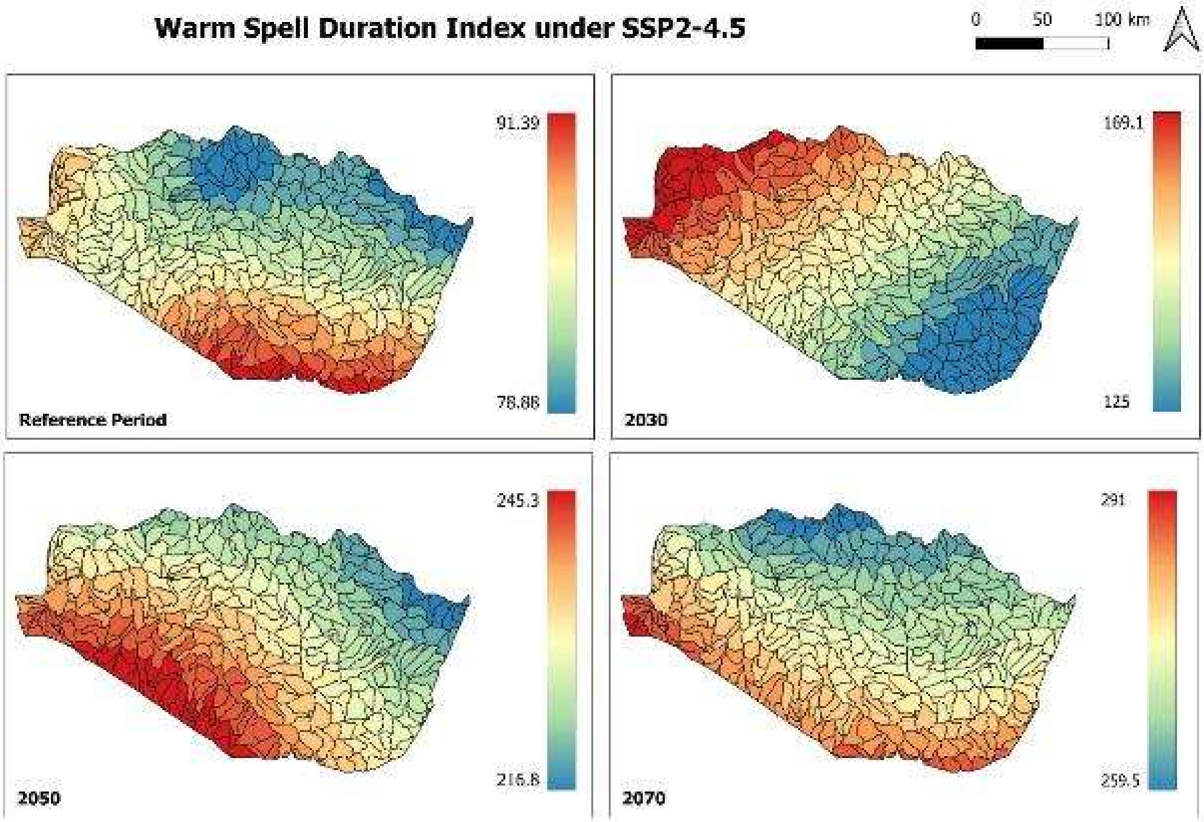
For each indicator, we will compute the reference period (i.e., existing current condition), and project two climate scenario trends (SSP2-4.5 and SPP5-8.5) for three temporal horizons (2030, 2050, 2070)

Hazard refers to the potential occurrence of a phenomenon (e.g., heatwaves, drought, flood) that can cause harm to people, property, or the environment.

To estimate climate variability and drought risk, we will compute 3 indicators, at 3 temporal horizons (2030, 2050, 2070) under two different climate scenarios. Namely, the warm spell duration index, the maximum number of consecutive dry days, and the Standardized Precipitation Evapotranspiration Index (SPEI). The outcomes of the SPEI for the Borana zone shows a trend of worsening of the situation for the 2 scenarios with a more unfavourable situation by 2070 for the SSP5-8.5 scenario (due to the increase of temperatures in general and the quasi-stability of precipitations).

To project future rainfall pattern and trends, we will compute 3 climate indicators, namely, the average precipitation, the number of days with precipitations > 20mm, and the number of days with precipitation > 50mm.

The WSDI is a measure used to quantify warm spells or periods. It represents the annual count of days with at least 6 consecutive days when daily maximum temperature is above the calendar day 90th percentile of maximum temperature centered on a 5-day sliding window during the base period. A higher value (red) indicates that warm spells or heatwaves are (and will be) more persistent and will last for longer periods, which can have significant impacts on human health, agriculture, and other sectors sensitive to temperature. Figure below shows an example of warm spells across Borana in 2030, 2050 and 2070.



The Maximum Number of Consecutive Dry Days is a climatological index that measures the longest period of consecutive days without any measurable precipitation (rain, snow, sleet, or hail) in a particular location. This index is often used by meteorologists, hydrologists, and water resource managers to help understand the frequency and duration of dry spells and drought conditions in a region. This indicator is most often read together with WSDI. To calculate the Maximum Number of Consecutive Dry Days, we will analyze precipitation data collected over several decades and identified the longest period of consecutive days without any measurable precipitation. This index helps identify regions that are particularly prone to drought conditions and assess the potential impacts of prolonged dry spells on agriculture, water supply, and /or industries

GW resource evaluation report and validation workshop 3

Groundwater resources evaluation report will cover manly

- Interpretation and calibration of geophysical survey results vs drilled and parametric wells
- Results of detailed investigation of hydrogeological system with delineation, characterization of aquifers at a scale 1 : 50 000 for potential (drilling) areas
- Assessment of groundwater resources quantity and quality and sustainable exploitable volume
- Economical way of water development
- Seasonal variability and trends in groundwater levels and resources (recharge)
- Consideration of possible climate change impact under different IPPC scenarios.

Final groundwater resources evaluation report will incorporate also comments/feedback from workshop 3.

4. Stage 4 - Groundwater Database Preparation

Main activities: **Database Review & Update**

Main deliverables: **Data Upload to client´s Database**
The activities will be divided into four basic steps:

- Review of the existing Groundwater Information System
- Establishment of a project database / repository
- Entering the archival and new project data into the project database and
- Migration of project data into current database at MoWE

The previous existing databases has been reviewed and MoWE has two software packages for storage, retrieval, and analysis of groundwater data - ENGDA (USGS) and ENGWIS (Schlumberger Water Services). Both packages are outdated and dysfunctional. However, existing data in databases were able to retrieve the data stored in ENGDA during BDA project Acacia – Aquacon 2021. Based on the review of the existing systems there was a developed functional design of the database and its front-end that provides central storage for dissemination of the project's results and existing groundwater data.

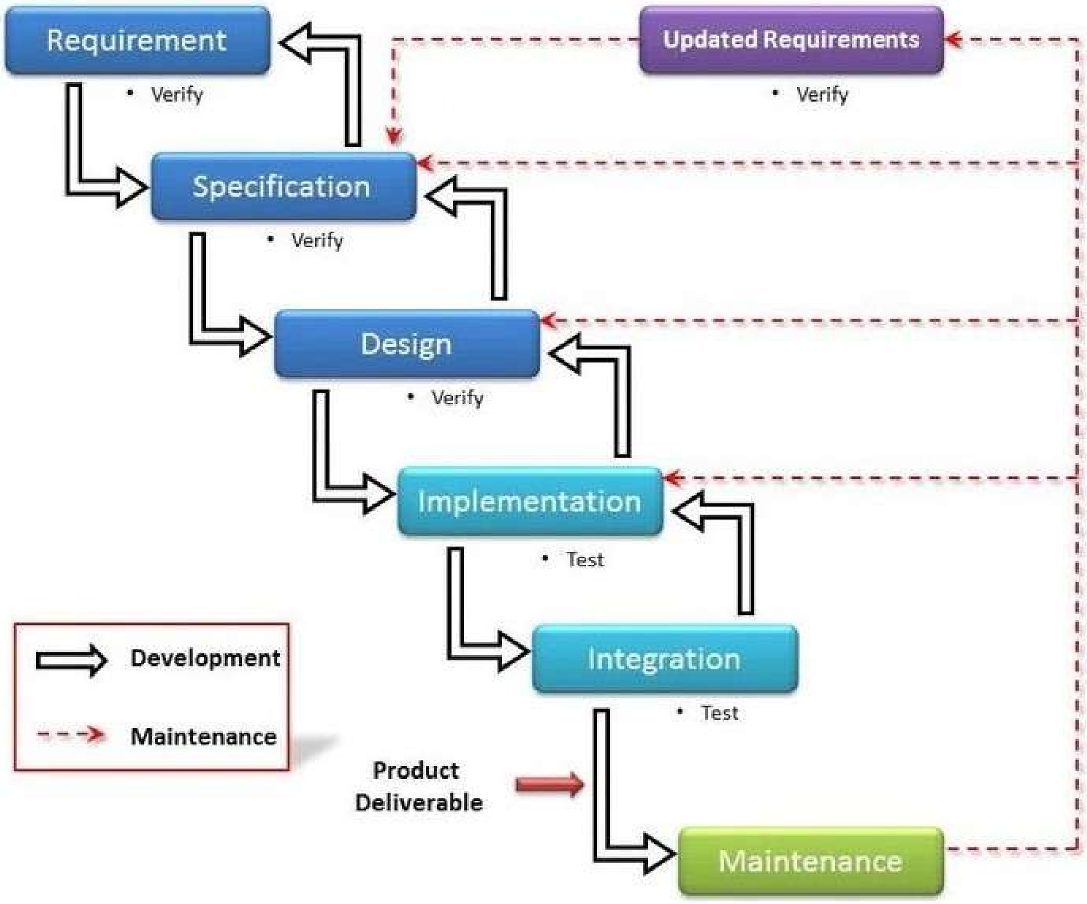
The project will develop a preliminary functional database repository design, suitable for migration of the existing data to running database. Because the system is web-based, there are no installation, hardware, or software requirements for the end-users and data integrity is guaranteed though automatic backups in the cloud. Users can access the system (with appropriate credentials) on any device using any major Internet browser like Edge, Chrome, Firefox, Safari and Opera. It will be accessible from computers, tablets, and smartphones.

During the database design special emphasis will be given to create a detailed, structured representation of data that ensures efficient storage, retrieval, and management. Proper database design helps to maintain data integrity, avoid redundancy, and support scalability and performance. It involves steps like requirement analysis, conceptual and logical design, normalization, implementation, testing and refinement. This method ensures databases meet user needs while maintaining integrity and performance. User documentation will be prepared to summarize the listing of available datasets as well as simple instructions about accessing, setting up, operating, maintaining and troubleshooting the database.

Validated maps, reports, row and processed data acquired for this project will be uploaded in the database. For ease of access, similar attribute templates will be used for the project data, open-access data and data provided by all the stakeholders. Attributes include physical and chemical hydrogeological parameters, more specifically borehole locations, yields water strike levels, water rest levels and water quality parameters. All the data will be grouped in a file system per drainage basins or administrative regions for efficient accessibility and management.

Harmonization is necessary to ensure consistency in units and coordinate systems. Data that do not pass the basic validation tests will not be migrated. This is to warrant the quality of the data stored in the database. For the validation, a set of rules will be developed from existing inventories of hydrogeological and hydrochemical maps at scale 1 : 250 000. that will enable automatic validation of incoming data. The rules identify possible problems/inconsistencies with:

- Coordinates and coordinate systems
- Units (for water quality, discharge, and depth)
- Duplications of entries
- Topology errors



Database development and maintenance process

The project deliverables will be stored in the document repository, organized by the project Lot number. The deliverables are:

<u>Maps:</u>

- Hydrogeological map 1:250,000;
- Socio-economic map 1:2500,000;
- Groundwater potential maps per woreda (1:100,000);
- Conceptual model of each woreda;
- Hydrogeological maps per target area (1:50,000);
- Hydrogeological cross sections per target area;
- Geophysical survey maps with proposed sites (1:5,000).

<u>Groundwater data:</u>

The groundwater data are subdivided into four main classes:

- Waterpoint data (inventory data);
- Well construction data;
  - o Casing arrangements;
  - o Screen setting;
  - o Pump details ;

• Groundwater data (individual analytical results and time series of quality and quantity);
  - o Well logs (driller's logs, lithological and geophysical logs);

    - Water samples and analyses, and
- Pumping tests.

Recently, MoWE has made a server available at the data center in Hawassa. The detailed technical specifications are unknown, but a general description of the system and conditions including future activities and plans can be collected during the inception phase and the project database will be designed accordingly.

5. Stage 5 - Capacity Building and Information Dissemination

Main activities: **Training manual and training preparation**

Main deliverables: **Training manual dissemination and training execution**

The Client will organize 5 days training for 20 participants. The training program will concentrate in hydrogeology particularly in groundwater mapping, remote sensing and overlay analysis, geophysical investigation and its interpretation for hydrogeology, groundwater/recharge modelling to ensure that hydrogeological investigation can continue in the way in the country.

Consultant team comprises professional including university lecturers.

Preliminary Training program:

Day	Program
1 – Morning	Introduction and program / Geological mapping
1 – Afternoon	Hydrogeological mapping
2 – Morning	Remote sensing and overlay analysis (components and weights)
2 – Afternoon	Surface geophysical measurements and their hydrogeological interpretation
3 – Morning	Meteorological and hydrological measurements (including RS data)
3 – Afternoon	Recharge assessment on baseflow concept and water balance model (Wetspas)
4 – Morning	Hydrogeological conceptual models – basis for mathematical flow models
4 – Afternoon	Groundwater resources assessment and Modflow groundwater flow model, pumping test assessment
5 – Morning	Groundwater resources quantity and quality protection (sanitary zones)
5 – Afternoon	Closing workshop and material handover

Expected workshop materials:

- Training manual corresponding to training program.
- Existing hydrogeological maps and explanatory notes to the project area.
- Guidelines for Basic principles of geological and thematic mapping, Czech Geological Survey, Geological Survey of Ethiopia, 2018.
- Presentations in digital form (USB).

SECTION B – WORK PLAN

The workplan (refer to TECH 5) is adjusted to generally follow the expected schedule of deliverables as indicated in TOR with some modifications suggested by the consultant and commented on below. The final workplan should be revised during negotiation process and Inception stage.

At this stage the following items are highlighted:

1. In general, all the time assumptions in stages involving field surveys and especially drilling could be influenced by the season of project commencement in respect of possible accessibility issues during rainy season.
2. Drilling specifications and tender documents could be prepared depending on the client's need at almost any time during Stage 2. But the level of detail from the local survey incorporated in the document could only correspond to the progress of the actual field surveys. The highest level of detail could be incorporated only along with the final Field survey report. Especially the final well sitting.
3. Time consumption of the tendering process for Test well drilling and possible capacity limitations of the drilling companies can heavily influence commencement of the Stage 3 and depending on components of stage 4.
4. Stage 5 – Capacity building & Dissemination could be on the other hand commenced earlier than suggested in TOR especially not to interfere with the finalization process of the Test well drilling completion report, GW database and Final GW resource evaluation report and validation workshop 3.

Project Implementation Plan and Deliverables

The project implementation plan is organized in stages, as per the ToR; the list below provides the main activities, deliverables, and workshops divided by Stage:

- **Stage 1 - Inception**
    - Main activities: Data collection & Overlay analysis, Preliminary field visit
    - Main deliverables: Inception report
    - Workshops: Validation workshop 1
- **Stage 2 - Field Survey**
    - Main activities: Comprehensive multidisciplinary study
    - Main deliverables: Drilling specifications and tender documents, Field survey report
    - Workshops: Validation workshop 2
- **Stage 3 - Drilling and GW resource evaluation**
    - Main activities: Test well drilling supervision, GW resource evaluation, GW model

- Main deliverables: Quality assurance manual, Progress & drilling supervision reports, Test well drilling completion report, Final GW Resource evaluation report
- Workshops: Validation workshop 3

- **Stage 4 - Preparation of GW database**
  - Main activities: Database Review & Update
  - Main deliverables: Data Upload to client´s Database

- **Stage 5 - Capacity building & Dissemination**
  - Main activities: Training manual and training preparation
  - Main deliverables: Training manual dissemination and training execution

The detailed list of deliverables is as follows.

ID	**Deliverable**	**Month**	**Note**
D-1.1	**Inception report**	End of Month 1	level of detail corresponding to scale 1:100k – 1:250k
D-2.1	**Drilling specifications and tender documents**	Month 5	
D-2.2	**Field survey report**	Month 4 (Draft) Month 5 (Final)	level of detail corresponding to scale 1:50k – 1:100k, for drilling sites 1:5k – 1:10k
D-3.1	**Quality assurance manual**	Month 6	
D-3.2	**Progress & drilling supervision reports**	Month 8-10-12	Periodical report
D-3.3	**Test well drilling completion report**	Month 13	
D–3.4	**Final GW Resource evaluation report**	Month 13 (Draft) Month 14 (Final)	
D-4.1	**MoWE database updates**	Month 13	
D-5.1	**Training manual**	Month 12	

SECTION C – ORGANIZATION AND STAFFING

Organization and Logistical Set-Up

JV companies nominate key and non-key experts for the project performance. A summary of experts and their capsule CV follows. Detailed CV of the key experts in T6 format are attached in Tech-6.

Nomination of experts is based on following principles:

- Adequate qualification and experience relevant to the project
- Complementarity (coupling) of national and international experts
- Equivalence in national languages

For the project performance, organization and staffing is divided into groups consisting of international and national experts:

1. Project Management
2. GIS, Remote sensing, Database, IT
3. Geology
4. Geophysics
5. Hydrogeology, GW Modelling, Hydrology, GW Management
6. Social-Environment

Project Management

The Consultant will rely on a proven experience in leading complex projects through an effective Project Management in all critical aspects: Initiation, Planning, Execution, Monitoring & Controlling and Closure.

Office

The Consultant can count on the local presence of Aquacon Engineering PLC –the member JV partner- which has adequate permanent office facilities located in Addis Ababa, as well as Acacia, with sufficient space for key experts and support team to carry out their desk work. This is an important ‘logistic hub’ and asset to better coordinate any necessary fieldwork in the country.

Logistics to conduct the assignment

Our local JV member partners owns four-wheel drive vehicles that will be used in combination with hired vehicles to support the fieldwork in the target area and routine running of field project activities.

Web-repository

Besides the Database previously described, the Consultant will organize a specific web-repository to be utilized during the project development to store correspondence client/consultant, deliverables, minutes of the meetings, presentations.

Staffing

Key staff

The team has been composed to involve a number of highly qualified regional and international experts with a long-standing experience of working in groundwater sector projects, climate change and social and environmental risk assessment, and in supporting governmental institution managing water resources.

With that perspective the team can guarantee the ideal assignment development, base of the efficiency and the optimization of the long-track experience of the experts in developing such type of Projects.

The team of key experts is composed by the following personnel:

Table: Key staff degree, nationality and experience

EXPERTS		DEGREE	INTERNATIONAL/ REGIONAL	YEARS OF EXPERIENCE IN THE PROJECT SECTOR
K-1 Project Manager / Team Leader	Zenaw Tessema	MSc in Hydrogeology	National	> 45 years
K-2 Senior Hydrogeologists	Robert Michek	MSc in Hydrogeology and Engineering Geology	International	> 30 years
K-3 Senior Geophysicist	Yigrem Assefa Dingo	MSc in Applied Geophysics	National	> 20 years
K-3 Senior Geophysicist	Shimelis Fisseha Woldemichael	PhD in Geophysics	National	37 years
K-4 Senior Geologist – volcanologist	David Buriánek	MSc Department of Mineralogy and Petrology PhD Department of Mineralogy and Petrology,	International	> 20 years
K-5 Senior Hydrologist	Jan Jelinek	MSc in Physical Geography and Hydrology	International	> 15 years
K-6 Senior RS and GIS expert	Samuel Hailu	MA in GIS, Remote Sensing and Digital Cartography	Regional	10 years
K-7 Senior Sociologist	Tesema Tolera Feyissa	MSc in Regional and Local Development Studies	National	> 20 years
K-7 Socio-Economist	Demie Abera Gemeda	MSc in Social Anthropology	National	> 15 years
K-8 Senior Environmental Specialist	Zeleke Chafamo Shashore	MSc in Environmental Science	National	> 35 years

EXPERTS		DEGREE	INTERNATIONAL/ REGIONAL	YEARS OF EXPERIENCE IN THE PROJECT SECTOR
K-9 Project Manager / Team Leader	Shiferaw Lulu Wondimagegnehu	MSc in Hydrogeology	National	> 40 years
K-10 Senior Hydrogeologist / Senior GW modeler	Dessie Nedaw Habtemariam	PhD in Hydrogeology	National	> 30 years
K-11 Supervising Hydrogeologists	Gashaw Gebey Addis	M.Sc. in Hydrogeology	National	13
K-11 Supervising Hydrogeologists	Dawit Tsegaye		National	
K-12 Senior Social-safeguard expert	Tesema Tolera Feyissa	MSc Degree in Regional and Local Development Studies	National	> 25 years
K-13 Senior Environmental	Zeleke Chafamo Shashore	MSc in Environmental Science	National	> 35 years
NK-1 Senior RS & GIS (backstop)	Theo Kleinendorst	MSc in hydrogeology	International	>35 years
NK-2 Senior Hydrogeologist (backstop)	Abebe Ketema Aredo	MSc in Water Resources Surveys, BSc in Geology, Faculty of Geology	Regional	30 years

While here for the key staff only short bios are provided, the detailed CVs are presented in the relevant sections of the technical proposal.

K1 – Zenaw Tessema, Team Leader

Mr. Zenaw Tessema graduated with B.Sc. degree in Geology from Addis Ababa University in 1984. He then received his M.Sc. degree in Hydrogeology from the University of Birmingham, UK in 1998 and did a postgraduate diploma in applied geological survey with emphasis to hydrogeology at ITC, the Netherland in 1987. In addition, he has participated in several water related short post graduate courses in Ethiopia, Egypt, UAE, Uganda, Ghana, South Africa, Austria, Norway and USA.

Over the last forty years, he has been working for the Geological Survey of Ethiopia, Ministry of Water Resources, IAEA, UNESCO, Agricultural Transformation Agency and Aquacon Engineering PLC as a hydrogeologist, project manager, head of groundwater division, program manager and technical officer. Along with this, he has worked for several private consulting firms and NGOs as individual groundwater consultant.

He has participated in several groundwater mapping and assessment projects throughout the country and has taken several project coordination and management assignments

K2 – Robert Michek, Senior Hydrogeologist/Senior Groundwater Modeler

MSc. in Hydrogeology and Engineering Geology at VSB – Technical University of Ostrava, Faculty of Mining and study course for GIS and groundwater flow modelling - University of Denmark, Lyngby, Department of Geology and Geotechnik Engineering, study course for groundwater flow modelling and water protection - University of Granada, Department of Sciences. He is cooperating with Geotechnika in studies where FIDIC procedure is applied for water infrastructure. Regional hydrogeological investigation water development Groundwater flow modeling GIS and DSS for water management Water protection Project of regional hydrogeological investigation / Works for the Czech National Water Master Plan Projects of regional hydrogeological investigation. Project manager for water infrastructure projects groundwater and surface water supply and protection and management, groundwater flow modeling GIS and DSS for water management as well as design for water and municipality infrastructure implementing FIDIC. Recently he has been working in water management studies for water retention in the landscape and multi-criteria analysis for selection of the best variant. He participated in hydrogeological and hydrochemical mapping (1 : 250 000) in western Ethiopia in period 2001 – 2005 – map sheets Adi Ramets - Gulch (Humara area), Gondar and Gonder and West of Gonder (Metema area).

K3 - Yigrem Assefa Dingo, Senior Geophysicist

Yigrem Assfa has obtained a M.Sc. Degree in Applied Geophysics in 2007, BSc. degree in applied Physics both from Addis Ababa University and MSc degree in Environmental Engineering from University of Connecticut, USA. He has been working as a senior geophysicist for various organizations including Water Works, Design and supervision Enterprise and Husky Engineering PLC. He has ample experience in groundwater, Geotechnical, Mineral, Geothermal explorations using several geophysical methods.

K3 - Shimeles Fisseha Woldemichael, Senior Geophysicist

Dr. Shimeles Fisseha is a senior exploration geophysicist (Associate Professor of Geophysics) at the Institute of Geophysics Space Sciences and Astronomy, Addis Ababa University. He has a specialization in Electrical and EM induction studies and has been a focal person and lead expert in a wide range of scientific research and development Projects. With more than 37 years of experience, he has been involved in numerous exploration projects for natural resources; hydrocarbon potential, mineral (ore) deposits and groundwater. In the past several years, he played key roles as an expert, leading the geophysical components of multi-disciplinary projects for the development of shallow and deep groundwater. Among many others, his recent endeavors in diverse geological environments include: “Groundwater mapping of the Tana-Beles and Maychew Tarmaber areas” (NW, N and central Ethiopia); “Assessment of the groundwater potential in Borena”, South Oromia; “Groundwater supply for Woredas in Diredawa administration and Somali regions”, Eastern Ethiopia.

K4 -David Burianek, senior Geologist

Graduated from the Department of Mineralogy (Ph. D. 2003). Member of the Czech Geological Society since 2004. Working in regional geological mapping, petrology, and mineralogy. Project leader for geological mapping of the Czech Republic 1:25,000. Active collaboration on international project focused on geological mapping in Nicaragua, Mongolia, Ethiopia (coordinated by Czech Geological Survey).

Reference to relevant projects:

- Basic geological mapping of the Brno region on a scale of 1:25,000,
- Basic geological mapping of the territory of the Czech Republic 1:25,000,

- Geological mapping 1: 50,000 and evaluation of the economic potential of the selected region of Western Mongolia, duration of the project: 2013-2015), cooperation with Mineral Resources Authority of Mongolia (development projects Czech Republic)
- Regional geological research for the definition and prediction of natural hazards in the central part of Central America, duration of the project: 2007-2009), cooperation with INETER Nicaragua (development projects Czech Republic
- Ensuring Sustainable Land Management in Selected Areas of Ethiopia on the Basis of Geoscientific Mapping - development projects Czech Republic

K5 – Jan Jelinek, Senior hydrologist

Mr. Jelinek has more than 15 years of experience with both surface and groundwater studies including field surveys, mapping, monitoring, data processing, database management, geospatial analysis (GIS) and modelling, in both academic and private sector. As well as applying practical and legal measures in auditing, water protection and management. Since 2022 active participant in several studies and projects in water sector in Ethiopia. Co-author of new hydrogeological map of Ethiopia in scale of 1:1,200,000 (2024).

Master degree – Physical Geography (specialization in hydrology), Charles University in Prague (2006–2008)

Bachelor – Cartography and Geography, Charles University in Prague, (2003–2006)

Main activities:

- Modelling of natural processes and perils (floods, windstorms, earthquakes)
- Reporting and consultancy on natural hazards
- Data processing and analysis
- Geospatial analysis (GIS) and database management
- Surface and groundwater monitoring system installations
- Open channel discharge measurements
- Supervision over the enforcement and compliance of Water Act legal framework – water management and protection
- Supervising groundwater contamination surveys and remediation process on contaminated sites and supervising waste-water treatment
- Inspections and audits of water pollution sources in municipal, industrial and agricultural sectors

K6 – Samuel Hailu, GIS & RS Expert

Mr. Samuel Hailu is a highly motivated GIS & Remote Sensing specialist and Geologist with accomplished logic, problem solving, and project management skills that enhance the ability to address technical problems and process-related issues. Working with multi-disciplinary teams for environmental assessments, training of staff and provision of data collection and management while maintaining the ability to quickly learn new concepts, develop and execute schedules, providing status reports, data, maps and analysis while meeting deadlines in a fast-paced, quality-oriented environment. He has in-depth skill and experience in the application of GIS & RS technologies using proprietary and open source platforms, programming languages and web GIS technologies. He has been contributing to the development and regular updating of data management and governance guidelines, data dictionaries, data models, and other documents required to support effective spatial data dissemination. Mr. Hailu can lead database structuring and management, including regular acquisition and integration of data from partners and remote sensing data, data validation, data cleaning and processing, and release to user including training and troubleshooting. Samuel Hailu Habtemichael holds a MSc degree in GIS, Remote Sensing & Digital Cartography (2015–2017) and a BSc degree in Earth Science (2001–2005), both from Addis Ababa University.

K7/K12 - Tesema Tolera Feyissa, Senior Socio-Economist

Tesema Tolera Feyissa obtained an MA in Regional and Local Development Studies from Addis Ababa University in 2003 and has over 25 years of relevant experience of working for various organizations as a sociologist.

Over the last 25 years has participated in socioeconomic baseline study, Environmental and Social Impact Assessment(ESIA) study; Environmental and Social Management Plan(ESMP) Preparation; Resettlement Action Plan(RAP) preparation; Livelihood Restoration Plan(LRP) preparation; Occupational Health and Safety Management Plan(OHSMP) preparation; Stakeholders' Engagement Plan(SEP) preparation, Gender Action Plan(GAP) preparation; Vulnerable Group Assistance Plan (VGA) preparation; coordinating/conducting stakeholders` and public consultation; development program/project planning and coordination and compliance monitoring of a diverse set of programs/ projects. He has demonstrated highly skillful work in various sectors including dam and hydropower, water supply and sanitation, irrigation, and road network social and gender related risky identification and management in both private and public agencies. Exemplary roles successfully accomplished include consideration of social and gender issues for masterplan projects, expert consultations during implementation stages, and advising and training of project stakeholders and engineers on appropriate social and gender considerations during program/project design and compliance with during their implementations. Over these years, he has developed the experiential acumen for working efficiently in constrained situations and collaborating effectively with multi-disciplinary teams using excellent communication skills.

K7 - Mr. Demie Abera, Socio-Economist

Mr. Demie Abera has an MA in Social Anthropology and over twenty years relevant experience. His activities include water board and human resource analysis, utility capacity gap assessment, end-line survey, project identification, preparation of rural water management proclamation, regulation & guidelines, mid-term and terminal evaluation of urban & rural water supply projects. Besides he has conducted terminal evaluation of integrated development projects such as Kobo -Raya Valley Integrated Development & productive safety net, financial analysis, workshop & training facilitation, stakeholders mapping and preparation of business plan for urban water supply and management of WASH Projects. He also conducted the National WASH Portfolio Baseline Survey on the Water, Sanitation and Hygiene (WASH) Status, KAPB- Knowledge, Attitude, Practice and Belief Study on Water Sanitation and Hygiene Practices for Pastoralist Community and Assessment of Aid Environment in WASH Sub-sector. He has worked as community management specialist and socio economic and social Impact analyst and Resettlement action planer for several dams that serve for irrigation, hydropower and urban and rural potable water supply financed by different funding Agency using different data collection and analysis methods.

K8/K13 - Zeleke Chafamo, Environmentalist & SESG Specialist

Zeleke Chafamo received his B.Sc. degree in Biology in 1987 from Addis Ababa University and received his M.Sc degree in Environmental System Analysis and Monitoring from ITC, the Netherlands, in 1996.

He has extensively worked as environmentalist in several water, irrigation and hydropower projects in Ethiopia.

K9 – Shiferaw Lulu, Project Manager / Team Leader

Shiferaw Lulu is a senior hydrogeologist with M.Sc. degree in Hydrogeology from Roorkee University (India) and with over 40 years of relevant experiences in groundwater exploration, development and management including ample experience in hydrogeological mapping. He has worked as a hydrogeologist for many governments and private organization both in Ethiopia and aboard including Water Supply and Sewerage Authority, Water Well Drilling Enterprise, Tropics Consulting Engineers, Ag Consult, Aquacon Engineering PLC and SMEC. He has produced and co-authored several groundwater reports and maps.

K10 – Dessie Nedaw Habtemariam, Senior Hydrogeologist/Senior GW modeler

Dr. Dessie Nedaw is an Associate Professor of Hydrogeology at Addis Ababa University. He got his first and second degree from Addis Ababa university in 1991 and 1997 respectively and PhD in Hydrogeology from the University of Natural Resources and Life Sciences, Vienna, Austria in 2003.

He has quite a lot of relevant experience in water balance modeling, Hydrogeological mapping and groundwater vulnerability identification. He has led and participated in several groundwater study projects, groundwater surface water interaction studies, surface and groundwater course teaching and research. He has published several articles in reputable journals in addition to preparing several technical reports as a consultant.

K11 - Gashaw Gebey Addis, Supervising Hydro-geologist

Gashaw Gebey is a practitioner hydrogeologist with M.Sc. in Hydrogeology from Mekele University and about 13 years of relevant experience. He has worked for several organizations including Amhara Design and Supervision Works Enterprise, the World Vision and Aquacon Engineering PLC from where he has acquired ample experience in drilling supervision and contract administration. With assignment from Aquacon Engineering, recently has supervised drilling and construction of 500 meters deep well in Amhara Region.

K11 - Dawit Tsegaye, Supervising Hydro-geologist

Mr. Dawit Tsegaye holds his M.Sc. degree in Water Resources Engineering and Management in the stream of Groundwater Management and the research thesis emphasis on 'Sustainability of Groundwater Use Using Integrated Methods: The Case of Atebala Catchment: Upper Awash Sub-Basin', and B.Sc. in Earth Science (Geology) specialization in Hydrogeology with Chemistry minor.

He has over 10 years of extensive practical experiences as a Hydrogeologist in Groundwater investigation, water point site selection, bid and technical specification document preparation, evaluation, deep water well consultancy, supervision, pumping test analysis and water supply network construction at different projects around the country.

Addition, Mr. Dawit Tsegaye also received professional competency certificates from authorized government bodies:

- Registered professional consultant as a "Practicing Hydrogeologist" from Construction Works Regulatory Authority of the Ethiopian Water Resource Ministry.

- Certificate of competence as a consultant in “Environmental and Social Impact Assessment Studies as Water Resource Use Expert” from Ethiopian Environmental Protection Authority.

NK1 – Theo Kleinendorst, Senior RS & GIS (backstop)

With 36 years working in international hydrogeological consultancy, Mr. Theo Kleinendorst brings significant expertise on groundwater. His expertise and activities include groundwater development and management, water resource management, groundwater modelling, monitoring networks, well siting and well design and geophysical prospecting. Working flexibility and context-driven at national, regional and grassroots levels, Mr. Kleinendorst is able to translate hydrogeological and conceptual approaches into pragmatic solutions and to the language of policymakers and those of different water users. He has over 20 years of relevant working experience in Sub-Saharan region, including specific experience in the Horn of Africa/East Africa region and in Ethiopia specifically. Gradually, his interests moved towards the integration of water resources assessment and management with GIS and Remote Sensing development, with specialization in Management Information Systems (MIS), relational databases, GIS (ArcGIS and QGIS developer), software design and development. He combines his vast hydrogeological experience with the latest remote sensing techniques, Internet of Things and development of smart participatory mobile applications.

NK2 – Abebe Ketema, Senior Hydrogeologist (backstop)

Abebe is a senior hydrogeology consultant holding an MSc. Degree and practical experience of over 35 years. His experiences are mainly in water resources survey and investigation works focusing on groundwater resource potential assessment and exploration with the help of advanced as well as conventional geological, hydrogeological, and geophysical methodologies; followed by supervision of water wells drilling and construction operations. He has been involved in many Land and water resources master plan studies, small and large scale urban and rural water supply and sanitation projects; conducted in Ethiopia including surveys on evaluations of WASH projects status, through physical inspections of schemes as well as using KII and FGD survey methodologies as a tool. His appreciable caliber in project activities coordination and execution for timely delivery of outputs could be mentioned as one of his strong sides in project management. Similarly, he has extensive experience in the preparation of project proposals and supervision of large-scale water well drilling and construction activities vis-a-vis contract administration. Mr. Ketema has also worked as a local consultant for UNICEF Ethiopia on several projects independently, as well as jointly with UNESCO/UNICEF, the European Union Joint Research Committee (EU-JRC) and UNICEF Addis staff and currently with Acacia Water.