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Hydrogeological mapping for Climate Resilient WASH in Ethiopia – LOT 1

Inception Report – Draft BDA/ICB/GW01/2021

ACACIAWATER

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Foreword

More than 90% of all readily available water on earth is groundwater. Groundwater thus plays a crucial role in water availability. It is imperative to treasure this underground water source and to utilize it wisely. Yet this is often not the case. For many water managers and water users, groundwater is still the big unknown (out of sight, out of mind). Surface water is primarily seen as the main water source. Where no surface water is present, you often see groundwater exploitation and in many cases on a non-sustainable way. Without having a scientific and fact-based knowledge of these groundwater resources, groundwater is often pumped and consumed unlimitedly, while the recharge of deep groundwater is complex and very slow, almost inexistent in certain cases. An important explanation for such behaviour, is that knowledge about the groundwater system is often lacking in organizations and governments that are responsible for water management and supply.

Groundwater is also of paramount importance to Ethiopia to supplement the available surface water resources in providing drinking water to its population and for economic development (agriculture, livestock, industry, tourism). Groundwater is especially important in regions with limited or polluted surface water and in areas affected by recurrent droughts. The use of groundwater is hampered by a lack of understanding and information. This leads not only to missed opportunities for groundwater development but also to failures in groundwater investments because of poor siting of wells, inadequate well designs, and poor drilling practices, leading to low or declining production rates and water quality deterioration. It is estimated that 50% of the wells drilled for rural water supply in the drought prone areas is suffering from serious yield reduction within 5 years due to falling water tables, well failures or water quality degradation.

The current project focusses on the mapping of the deep groundwater resources for several priority areas spread over 5 regions of Ethiopia. These so-called 'operational maps' should be an information base for water managers to take decision on locations for sustainable groundwater development. Also, to be calculated the 'water balance' shall give an estimation of the potentially available resources. This innovative project will fine tune existing approaches and deliver a 'mapping methodology' replicable to other areas.

Naturally the methodology, collected data and database, will be shared for future deep groundwater mapping, and benefit various stakeholders outside the current program. However, it must be stressed that the methodology will not be a blueprint, but depending on the area to be mapped, will require additional expert judgement and assessment in the field.
The idea behind this assignment is not only to map groundwater resources in the selected priority areas. Other aspects are involved, namely the sustainability of such enterprise. This is tackled with several activities such as a participatory approach that any project on Integrated Water Resources Management should involve: stakeholders are identified and involved at the earliest stage of the project. The key stakeholders, represented in the peer review committee, are not only involved but play an important role in decision-making, knowledge and data gathering, strategies drafting, etc. By doing so, stakeholders are empowered to play key role in achieving the common objectives and to further work on those aspects, even when the project is finished. Their interests and influence are represented and used throughout the entire process, which makes the outcomes of the project more likely to be accepted.

Moreover, looking at natural resource dependency that is crucial in such arid and climate vulnerable areas, the project has in its core climate-resiliency. This is translated by an open mind-set of stakeholders and experts that look for the most suitable solution depending on the specific context that is under-studied. The idea is not to, from now on, only use groundwater but to offer the opportunity to take water management related decisions based on evidence and scenarios. Watershed management and rehabilitation, stream recovery, spring restoration, natural recharge enhancement through community mobilization and so on are illustrations of possible methods that can be used in the selected areas, and beyond. By having a climate-resilient mindset/goal, the strategy is not to go for one dependency to the other but rather to diversify options to better manage water access within those communities and increase their resilience in the context of climate change.

Mapping groundwater increases the knowledge about this precious resource. Surface water is more likely to be directly affected by drastic changes: pollution, evapotranspiration (in the context of climate change and warmer temperatures, this effect can be expected to increase), or misused. Groundwater can constitute an important substitute to provide clean water in areas where surface water can no longer be used or where surface water is not sufficient. It can also offer alternative source depending on the type of use.

Being protected and stored in the soil, groundwater usually offers good quality water. Moreover, in addition of the mapping assignment, the sustainable use of groundwater must be presented to reach resilience: it is difficult recharge, the priority uses (e.g., offering clean water, domestic uses might be prioritized). By doing so, communities will not rely on one source – traditionally surface water -, increasing their vulnerability in case of changes, but will have the knowledge and the tools to diversify their water sources by using groundwater, or other alternatives that will be studied according to the context. In addition, thanks to these mapping, NGOs and regional authorities will have access to data to take suitable and sustainable decisions and avoid losses when drilling.

Although not a core activity of the project, in case of poor quality and/or low potential of groundwater, the experts involved in the project will present alternatives having the objective of increasing resilience: one example is water harvesting that can be done throughout the rainy season to store water until the dry season. By doing so, the vulnerability of users and water risks decrease, as the dependency to one method or one source may be resolved at least in part.

Glossary of terms

Hydrogeological map: scale 1:1,000,000. It is composite map based on the geological map where geological units having similar hydrological properties have been clustered. It shows aquifer productivity and hydrological features like rivers, springs, wells, structural geological elements, and water quality data. Similar maps have been produced at scale 1:250,000 for every woreda.

Groundwater Suitability map: this is the 1:100,000 scale map produced from the overlay analysis which accounts for all physical criteria and classifies areas according to the potential of drilling positive wells. It is a colour-coded map where colour codes correspond to specific potential classes for the different aquifers and potentially a correlation with the expected water quality. Features which are normally represented in the hydrogeology maps, and which have led to the classification of the suitability zones may not be directly shown on such maps. Major landmarks such as roads and rivers are featured on these maps.

Hydrogeological Operational map: this is the 1:50,000 scale map produced from the overlay of the Groundwater Suitability map and the Demographic map. The map sheets follow the same grid and naming convention as the existing 1:50,000 topographic map series published by the Ethiopian Mapping Authority. The aim of this map is to identify the areas where the water demand is urgent and some potential for groundwater exists. With these maps, the Target area are going to be identified and selected for further investigations.

Target area: the part of the area chosen from the Hydrogeological Operational map that will be the target for additional detailed hydrogeology survey at the scale of 1:50,000. Target areas are chosen for the phase III studies and in the RFP, these are also called priority sites and detailed study areas.

Target site: specific drilling site which bears an X and Y coordinate. The (26) selected sites for drilling the deep groundwater wells. The target site shall be selected after a series of analyses and discussion with BDA and stakeholders. The final choice shall be presented to the steering-committee for validation at the end of Phase III.

Target site drilling maps: a 1:5,000 scale map to help locating the proposed sites. The maps include the exact location of the proposed drilling sites as well as relevant geophysical measurements, profiles and cross sections, and landmarks.

1 Introduction

Drought is the major natural disaster affecting the livelihood of Ethiopians, resulting in water insecurity which in turn causes disruption of livelihoods and loss of life. A significant proportion of the Ethiopian population still lacks access to clean water, even though Ethiopia successfully achieved the Millennium Development Goal (MDG) target of halving the number of people without access to improved drinking water. At the national level, 60 to 80 per cent of communicable diseases are attributed to limited access to safe water, and inadequate sanitation and hygiene services.

The UK Department for International Development (DFID) supports the Government of Ethiopia to improve water security through the One Wash National Programme (OWNP) and other longer-term development and emergency activities. Yet, whilst emergency support is critical, it is also vitally important that resilient WASH development programming takes place in water insecure areas to break the cycle of emergencies. The challenges are greatest in the lowland parts of Ethiopia due to the complex geology and hydrogeology of the areas, which provide challenges to the development of productive groundwater sources. In addition, most regions of Ethiopia lack detailed hydrogeological maps that can be used as a quick reference for siting water wells. As a result, the drilling of dry or low-yielding wells is the main challenge in groundwater development.

Current national mapping is very broad scale and focuses primarily on depth to water and geology. Although an excellent starting point, this level of mapping appears to focus on irrigation, and does not necessarily tie in well with development potential, or range of borehole yields. With accurate borehole attribute data, and accurate geological mapping, hydrogeological characterization and mapping can provide the basis for efficient field verification.

The Ministry of Water, Irrigation and Energy (MoWIE) has received funding from DFID for a three-year project entitled "Delivering Climate Resilient Water, Sanitation and Hygiene in Ethiopia (DCRW)". As agreed by an MOU between DFID and the Government of Ethiopia work stream? two of the four programme areas are being implemented by the Basins Development Authority (BDA).

This project, which runs to 31 March 2022, is part of the UK government's aid strategy to support the poorest people in adapting to climate change, specifically on building climate resilience in water and sanitation services that contributes to achieving Sustainable Development Goal (SDG) 6. The project complements DFID and Ethiopia's significant programming on water and sanitation and supports effective delivery of the Government of Ethiopia's strategy for sustainable water supply in drought affected areas. A key feature of this program involves funding for groundwater mapping and improvement of groundwater data management.

Objectives

Overall objective
The objective of this project is to increase access to safe and sustainable water for the people in drought affected regions by producing hydrogeological maps at the Woreda level and recommend drilling sites which the Government of Ethiopia and other partners can use for developing groundwater.

Specific objectives
A first step of this project is the initial identification of target areas for borehole drilling. The focus of this project will be:

- Create detailed groundwater potential maps for each Woreda.
- Identify one optimal drilling site and one alternative (optional) drilling site per Woreda, using the groundwater potential maps and geophysical field investigation results, and recommend the type of drilling methodology(s) to be employed.
- Build the capacity of the Water Development Commission (WDC), Basins Development Authority (BDA), regional governments, and NGOs to use/apply overlay analysis techniques for groundwater potential mapping and borehole siting in Ethiopia.

1.1 Project Area

The overall project covers a total of 53 woredas throughout the country (Figure 1) which is subdivided into four lots. The current project deals with the 13 woredas from Lot 1 in the Tigray, Afar and Amhara Regions (Figure 2) and a list of selected woredas is presented in Table 2.

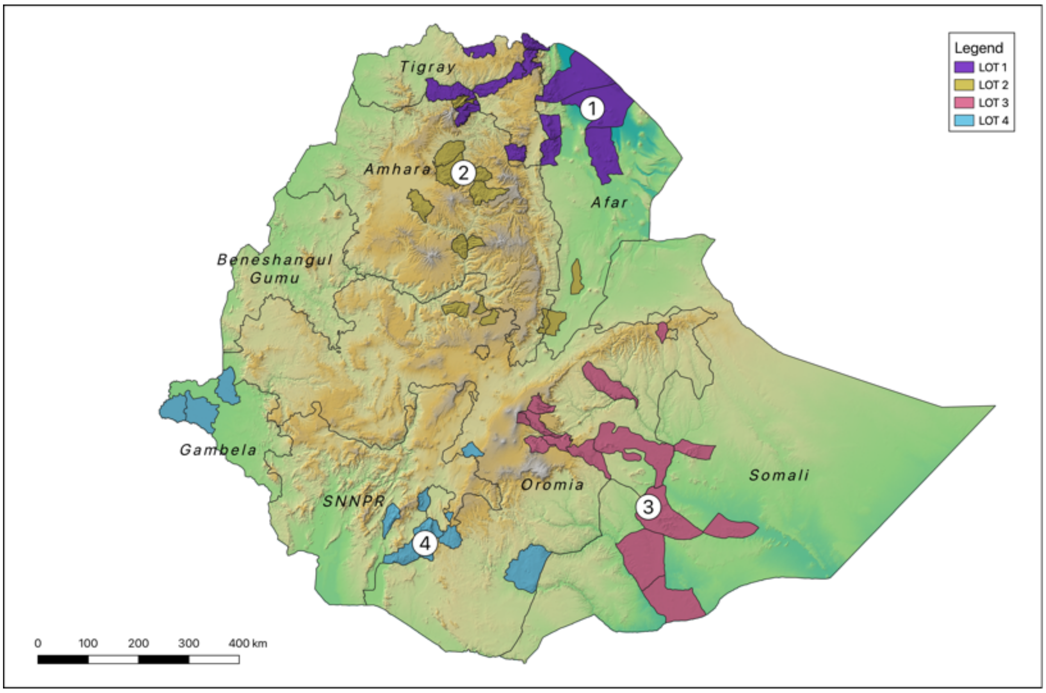


Figure 1 Location of selected woredas for Lots 1, 2, 3 and 4

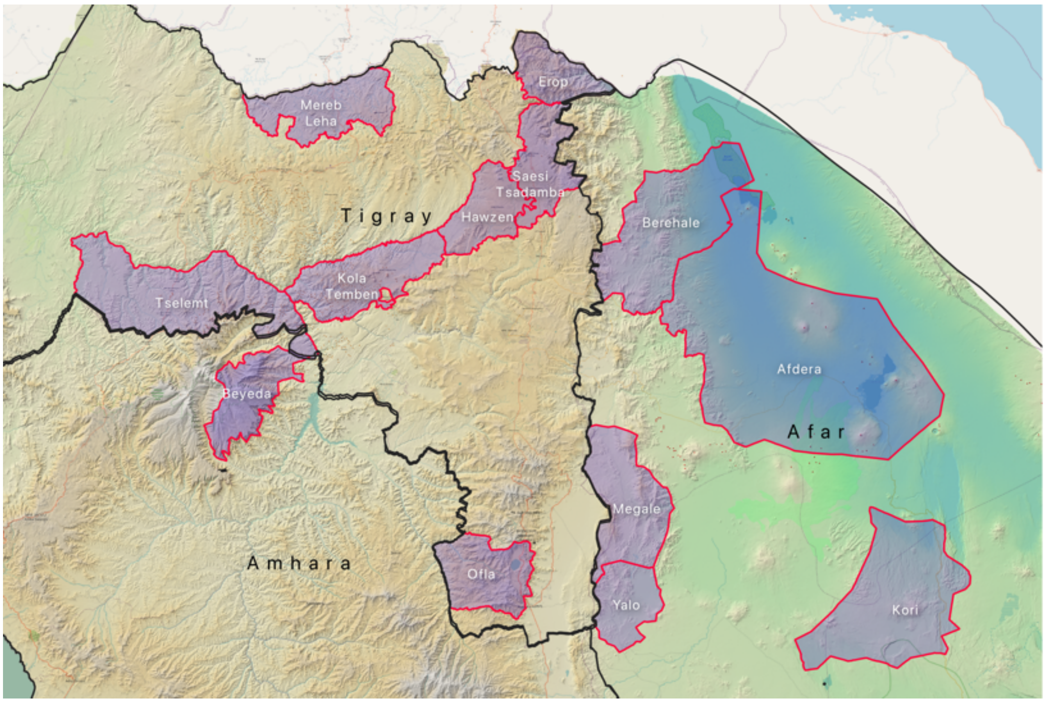


Figure 2. Location of the 13 selected woredas for LOT 1.

Table 1 Selected woredas Lot 1

Region	Zone	Woreda	Area (km2)
Afar	Zone 1	Kurri	2,870
Afar	Zone 2	Afdera	7,435
Afar	Zone 2	Berahile	2,509
Afar	Zone 2	Megale	1,548
Afar	Zone 4	Yalo	823
Amhara	North Gonder	Beyeda	973
Tigray	Central	Kola Temben	1,365

Tigray	Central	Mereb Leke	1,259
Tigray	Eastern	Erob	773
Tigray	Eastern	Hawzen	869
Tigray	Eastern	Saesie Tsaedaemba	963
Tigray	Northwestern	Tselemti	2,656
Tigray	Southern	Ofla	1,085
		Total	**25,128**

1.2 Remarks from the Inception Phase

The inception phase was carried out in the period May – June 2021 and will be finalized with the Inception Workshop/kick off meeting in Addis Ababa on July 15, 2021.

The current report is based on dialogue among the project team and the BDA. Several missions have been carried out by the international team to Addis to set up contracts, establish the first contacts with the local authorities and discuss the methodology and planning.

In the various documents (RFP, ToR, Contract) different names and definitions occur for the same project concepts and elements. We propose to harmonize and redefine the technical terms to avoid confusion and have prepared a *Glossary of Terms,* which can be found at the beginning of this report.

Administrative boundaries

The output of this project is organized by woreda and the woreda and kebele boundaries are subject to change. Considering the current volatile situation in the project area, it is essential that consensus is reached with BDA about the administrative boundaries to be used for this project.

The map with selected woredas for this project (figure 3) has been prepared using data from the Central Statistics Agency (CSA), and is based on the 2007 census. The administrative boundaries are yearly updated by CSA and Regional Bureau of Finance and Economic Development (BoFED). The data is published by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) through the Humanitarian Data Exchange (HDX) service. The current version dates from October 2020 and differs from the 2007 version as shown in table x and figure x below. Most woreda boundaries have changed and some woredas have been split.

In this project, the administrative boundaries from CSA (2007) will be used as published by EthioGIS (https://www.ethiogis-mapserver.org).

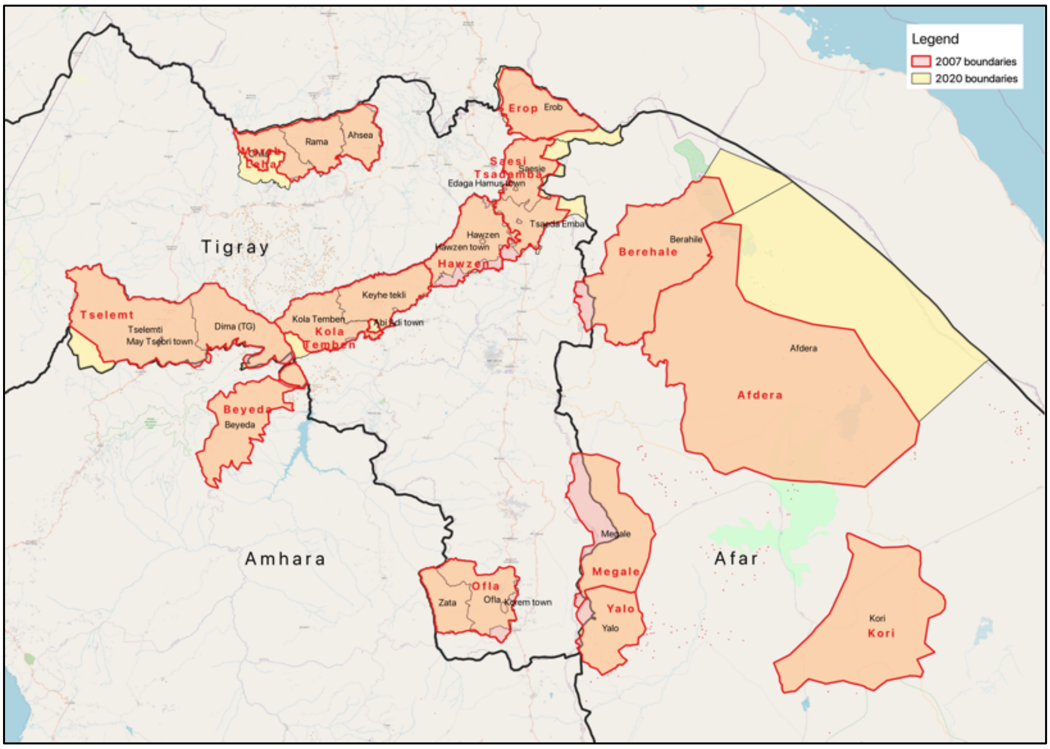


Figure 3 Changes in administrative divisions between 2007 and 2020

Table 2 Selected woredas (2020)

Region	Zone	Woreda	Woreda (2007)	Area km2
Afar	Awsi /Zone 1	Kori	Kori	2,869
Afar	Fanti /Zone 4	Yalo	Yalo	764
Afar	Kilbati /Zone2	Afdera	Afdera	12,494
Afar	Kilbati /Zone2	Berahile	Berahile	2,916
Afar	Kilbati /Zone2	Megale	Megale	1,129
Amhara	North Gondar	Beyeda	Beyeda	968
Tigray	Central	Ahsea*	Mereb Leke	362
Tigray	Central	Chila*	Mereb Leke	591
Tigray	Central	Keyhe Tekli*	Kola Temben	715
Tigray	Central	Kola Temben*	Kola Temben	718
Tigray	Central	Rama*	Mereb Leke	479
Tigray	Eastern	Erob	Erob	919
Tigray	Eastern	Hawzen	Hawzen	740
Tigray	Eastern	Saesie*	Saesie Tsaedaemba	606
Tigray	Eastern	Tsaeda Emba*	Saesie Tsaedaemba	509
Tigray	Northwestern	Dima*	Tselemti	853
Tigray	Northwestern	Tselemti*	Tselemti	1,928
Tigray	Southern	Ofla	Ofla	638
Tigray	Southern	Zata*	Ofla	420
*New woredas have been marked with **			Total	30,616

1.3 Project Team

The first weeks were used to get the team in place and integrate the working program. All partner's roles have been consolidated during the inception phase and are described below.

1.3.1 Acacia Water bv

Acacia Water is leading the partnership in deploying international experience in groundwater investigation and mapping using remote sensing, data management modelling, and in the application of a range of geophysical methods.
This role will enable the identification of the groundwater potential and propose locations for production wells based on a strong technical methodology. Acacia Water is responsible for the project management (content and financial), reporting and formal communication with the client.

1.3.2 Aquacon Engineering plc

Aquacon is providing local support on hydrogeological assessments, groundwater mapping, water resources assessment and monitoring, geophysical measurements, and plays a role in the later phases of development and monitoring.

Furthermore, Aquacon is providing logistical support for the team in organizing field work, and provides local expertise on hydrogeology, geology, geomorphology, and geophysics.

The professionals are also engaged in collecting the large amount of data and information necessary for carrying out the technical assessment.

1.3.3 UHL and Associates

UHL will provide technical support in (a) the development of drilling ToRs and borehole design elements; (b) Risk Mitigation Strategy development; and (c) Remote Sensing data acquisition and processing particularly focused on fracture analysis.

1.3.4 Engaged professionals

The following personnel will be engaged in the project (Table 1):

Table 3. Overview personnel engaged in the Inception Phase.

Name	Position	Tasks assigned
Dr. Arjen de Vries	1. Project manager (1st)	Overall project management (organizational and financial) and official contacts with client, the Peer Review Committee, and other stakeholders.
Mr. Zenaw Tessema	2. Project manager (2nd)	Together with the PM, responsible for overall project management and official contacts with client, the Peer Review Committee, and other stakeholders. Represents Arjen de Vries as program manager if needed
Mr. Jiri Sima	2. Team leader (1st)	Day to day management of project. Responsible for overseeing all reporting
Mr. Abebe Ketema	2. Team leader (2nd)	Together with the TL, responsible for day-to-day management of project, and field activities specifically. Represents Jiri Sima as project leader if needed.
Dr. Tilahun Azagegn	3. Senior hydrogeologist	Data integration, guiding field data acquisition by all experts, guiding water point inventory works, designing and validation of GIS overlay analysis, Water quality survey supervision and geochemical data interpretation and integration in the hydrogeological models.
Dr. Maarten Waterloo	4. Senior hydrologist	Surface water hydrology, specialized in the links between land use, soils and water flows. Will be

		responsible for water balance modelling and assessment of climate change impacts.
Prof. Bekele Abebe	5. Senior geologist (1st)	Responsible for the geological map production and lead the identification and mapping of key geological and geomorphological features. He will further be responsible for harmonization and standardization of map products across the various districts so that uniformity is maintained.
Vincent Uhl	5. Senior geologist (2nd)	Data integration, guiding field data acquisition by all experts in form of geological map and conceptualization of lithological units for interpretation and integration in the hydrogeological models. Development of drilling ToRs and Risk Mitigation Strategy
Dr Shimeles Fisseha	6. Senior Geophysicist (1st)	Will lead the VES and ERT data acquisition of phase III activities.
Dr Yigrem Asefa	6. Senior Geophysicist (2nd)	VES and ERT data acquisition and interpretation during 3rd phase
Mr Theo Kleinendorst	7. Senior RS expert (1st)	Remote sensing and satellite image processing and the validation of the weighing criteria for the overlay GIS analyses
Mr Ashish Daw	7. RS expert (2nd)	Remote Sensing data acquisition and processing, water balance modelling input
Ms Anouk Gevaert	8. Modelling expert	GIS and Remote Sensing modelling, water balance modelling and overlay analyses
Dr Erimias Hagos	Hydrogeologist	Field hydrogeological survey and mapping at various scales
Dr Abdelwassie Hussien	Hydrogeologist	Field hydrogeological survey and mapping at various scales
Shiferaw Ayele	GIS expert	Cartography

1.3.5 Quality Control

Projects in the water sector are becoming more and more complex. The many Different stakeholders have different interests and varying goals, requiring a comprehensive Quality Management System (QMS).

By means of a QMS, Acacia Water and Aquacon ensure that the expectations of all participating parties are fully met, potential problems and conflicts are identified in time, and respective mitigation measures are introduced when and where necessary. Lack of an appropriate QMS often leads to partial or even complete failure of the project. Our approach to quality management for successful project management using a QMS therefore enables the following assurances to be delivered:

- accurate estimation of project duration and costs
- appropriate planning of resources, activities, and scheduling
- co-ordination of resources and activities
- communication with/among involved parties, leading to the results needed and avoiding unintended results.
- sufficient measurable indicators
- progress control so that exact project status can be determined.
- quality control, resulting in appropriately acceptable and usable products (reports).
- financial control

The team is working within a Quality Management System based on ISO 9001:2015 standards, aiming at optimizing internal processes and eliminating errors during project implementation. Acacia Water has developed and applies a QMS for all its projects undertaken.

A Quality Management Handbook has been put in force, describing processes and priorities, identifying responsibilities, and regulating the follow-up of activities.

Through clearly distributed and identified responsibilities, as well as standardized processes of the QMS, project achievements of the required quality and within the anticipated timeframe can be ensured. Project planning is enforced by guidance through the company's management. Project procedures and documentation are set up in line with respective instructions in the QM Handbook. Qualifications of personnel are continuously developed to meet rising demands and expectations.

Lessons learned from various projects are circulated among Acacia Water staff as and when beneficial to promote continuous development. Capitalizing from past projects and lessons learned through information dissemination encourages an exchange of valuable knowledge and effective use of it, developing Acacia Waters' project management standards and continuously embracing new concepts and innovative techniques.

2 Methodology

2.1 Overall workplan and methodology

The project is designed in 3 phases:

- Phase I (Inception Phase)
- Phase II (Mapping Phase)
- Phase III (Siting Phase)

Figure 4 below provides a detailed overview of the project activities.

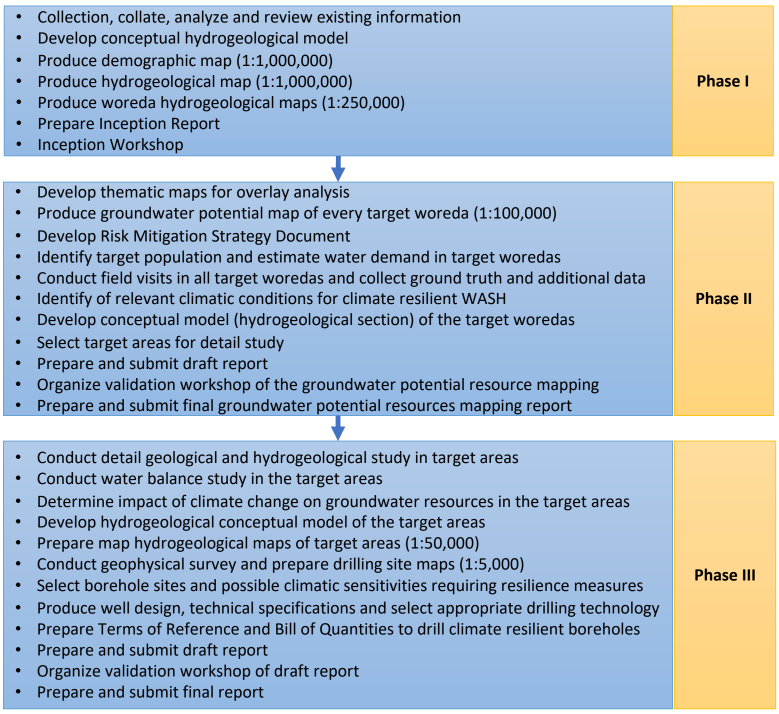


Figure 4. Overview of the different activities per phase

Our approach largely follows the flowchart in the RFP which is based on the methodology of previous successful experiences during the UNICEF project "Groundwater Mapping for Climate Resilient WASH in arid and semi-arid areas of Ethiopia" (GW4E). The proposed methodology includes but is not limited to geological and geomorphological exploration, geophysical exploration, Remote Sensing and GIS application, hydrological application for recharge estimation, geochemistry and isotope hydrology application, statistical approaches for validation of overlay analysis and data integration through conceptual model development.

These methods will be utilized as appropriate according to the specific characteristics in each woreda.

Several outputs are foreseen from the mapping activities as shown in Table 3.

Table 4: Deliverable maps

Map	Project Phase	Scale	Count	Description
Hydrogeological map	Inception Phase	1,000,000	1	Harmonized geology and unified hydrogeological classification for entire project area
Hydrogeological maps	Inception Phase	250,000	13	Harmonized geology and unified hydrogeological classification per woreda
Socio-economic map	Inception phase	1,000,000	1	Based on available data from CSA census (2007)
Groundwater Potential maps	Phase II	100,000	13	Groundwater potential map for every woreda
Hydrogeological Operational maps	Phase III	50,000	13	Hydrogeological map for target areas including geophysical surveys
Drilling site maps	Phase III	5,000	26	Detailed map of the selected drilling sites. Geophysics cross-sections added.

Table 5 Deliverable documents

Document	Project Phase	Count	Description
Monthly progress reports	Throughout Project	2	Describing progress in project activities and outputs
Inception report (IR)	Inception phase	2	Based on available data from CSA census (2007)
IR Minutes	Inception phase	2	Minutes of the presentation to Peer Review Committee of the draft inception report for review and Minutes of workshop with national experts and other relevant stakeholders to finalize weighting criteria
Mapping report (MR)	Phase II	2	Validated report with identification of potential sites and submission of groundwater potential maps at 1:100,000, results of geophysical and hydrogeological investigations, identification of drilling sites for each woreda and drafting of TOR for drilling
MP Minutes	Phase II	2	Minutes of dissemination workshop of the groundwater resources mapping exercise and results among the main WASH stakeholders in Ethiopia
Final Report (FR)	Phase III	2	Describing and summarizing findings of the project and conclusions and recommendations for drilling phase
FR Minutes	Phase III	2	Minutes of training workshop to Ethiopian Federal and regional governments, NGO partners and other relevant stakeholders.
Training materials	Phase III	20	Explain the steps of remote sensing work and overlay analysis, ground water mapping, and the final interpretation of the maps for targeting well prospects, integrating borehole and surface geophysical information and migration of all existing groundwater resources information, including RS data into the central database

Figure 5 presents a general overview of the flow path for the project deliverable maps. The methodology strategy starts at developing and gathering two information baselines, one physical and the other socio-economic. The first will be the base for developing the Groundwater Suitability maps (1:100,000) and the second will provide the necessary information to set the first steps towards selecting the demand hotspots. The overlay of this information and adding results from the field investigations will result in Operational Hydrogeology maps (1:50,000) for every woreda. Hereafter, and by deploying expert judgment and stakeholder's engagement, a selection will be made of the most promising sites to follow up with detailed geophysical analyses. The Target Drilling Site maps (1:5,000) will be prepared for the final drilling sites.

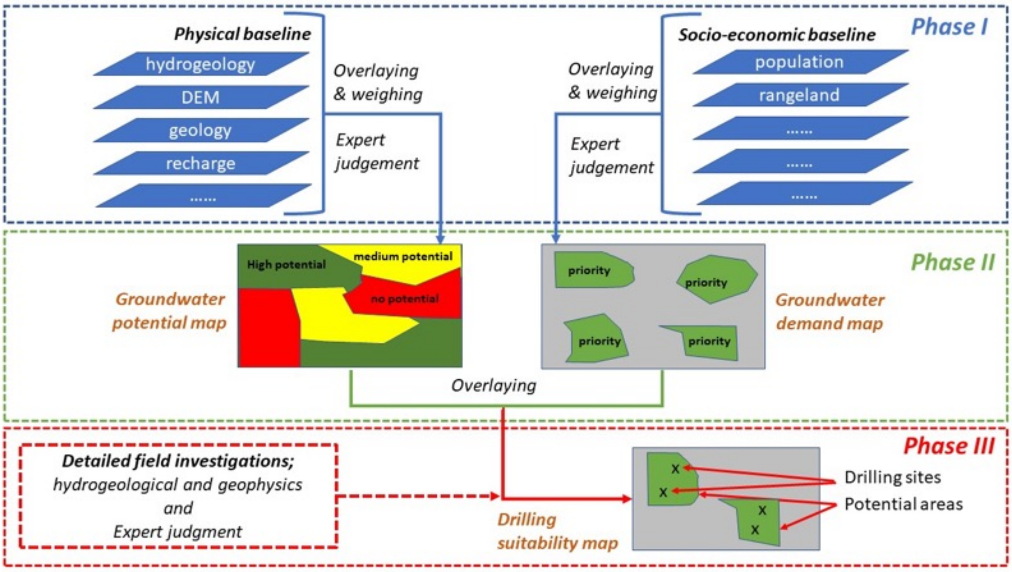


Figure 5. Diagram of output maps production

In the following section our methodology and approach are presented to assess and integrate the key parameters: geology, hydrogeology, geophysics, remote sensing-GIS, and geochemistry. We also explain how we will integrate this information in the overlay analysis to select the target areas and potential drilling sites. These investigations will be carried out in Phases II and III after the physical baseline from Phase I has been completed.

2.1.1 Dissemination

All maps and documents produced by this project will be delivered as two hard copies. The spatial data, such as maps, GIS layers, raw imagery, remote sensing products will be stored in a spatial database that will be physically transferred to BDA at the end of the project. The imported water points inventory data, water quality and results of the hydrogeological inventory carried out by this project will be stored in this database.

During the execution of the project, raw data, intermediate layers, and interim results will be stored on our private cloud server to facilitate data sharing between team members, the Client, and designated stakeholders.

To facilitate dissemination and access to the results of the project, the produced maps and data will be published/provided through a web application and database that will be developed under LOT 5 of this project.

2.2 Phase I

The following activities will be undertaken in this phase:

- Collection, collate, analyze and review existing information
- Develop conceptual hydrogeological model
- Produce demographic map (1:1,000,000)
- Produce hydrogeological map (1:1,000,000)
- Produce woreda hydrogeological maps (1:250,000)
- Prepare Inception Report
- Inception Workshop

Phase I

Phase I consists of a desk study to collect and harmonise all information available (maps, reports, water quality and quantity data, meteorological information, demographic data, socio-economic maps, etc). The results on the inventory will be presented in two 1:1,000,000 maps: a hydrogeological map and a socio-economic map. In addition to the 1:1,000,000 hydrogeological overview map, a hydrogeological map 1:250,000 will be produced for every woreda (13 in total). This phase will be concluded with an Inception workshop and an Inception Report (this report). A detailed description of the results of the Inception Phase is presented in chapter 3.

2.3 Phase II

The following activities will be undertaken in this phase:

- Develop thematic maps for overlay analysis
- Produce groundwater potential map of every target woreda (1:100,000)
- Identify target population and estimate water demand in target woredas
- Conduct field visits in all target woredas and collect ground truth and additional data
- Identify of relevant climatic conditions for climate resilient WASH
- Develop conceptual model (hydrogeological section) of the target woredas
- Select target areas for detail study
- Prepare and submit draft report
- Organize validation workshop of the groundwater potential resource mapping
- Prepare and submit final groundwater potential resources mapping report

Phase II

Figure 6. Activities planned in Phase II

The following deliverables are planned for Phase II:

- Overlay analysis criteria and weighting criteria
- Peer review meeting and minutes
- Water balance study and recharge estimations per target area
- Groundwater Suitability map (1:100,000) at woreda level (13 maps)
- Hydrogeological cross sections in each woreda
- Phase II dissemination workshop and minutes
- Validated Phase II report

In this Phase, deliverables will be produced for all woredas and will combine general (hydro)geological features with zones of groundwater suitability, indicated by certain overlay textures. The groundwater suitability classes result from the overlay analysis and field verification.

2.3.1 Basic groundwater information layers

The following groundwater information layers will be prepared to conduct the regional overlay analysis, characterize the area, and identify zones for the hydrogeological groundwater suitability maps.

- Lithological/geological map
- Lineament and lineament density
- Drainage and drainage density
- Classified lithological map indicating inferred permeability
- Geomorphology and slope
- Precipitation and recharge rate
- Yield of boreholes
- Water quality data

For the preparation of the above layers some sub-layers need to be prepared, such as land use, landcover, soil type, soil moisture and vegetation indices. These sub-layers will also be stored in the spatial database for easy reference and retrieval.
For the overlay analysis of the fundamental hydrogeological parameters, overlay criteria (scores and weights) will be established and GIS overlaying techniques will be applied.

2.3.2 Familiarization field visits

The first field recognition campaign will take place at the beginning of phase II. The field teams will visit the area to establish a first contact with the local authorities, partners, and stakeholders. During the field visit, initial tests will be carried out on the geophysics methods to test suitability of the equipment and reach (vertical) of the methods. During the visits, updated information regarding pertinent socio-economic and demographic aspects will be gathered to assist in the finalization of the demographic layers for the overlay analysis.

In concert, a water point inventory will be initiated in each of the project areas.

The familiarization visit is intended to
a) Validate the various conceptual models proposed during the inception phase for the various woredas
b) To observe the geology, topography, drainage, access road and accessibility of the project area
c) To establish links with local authorities and gather recent socio-economic and demographic data

2.3.3 Validation of overlay analysis

The results of the overlay analyses need to be validated. First some filtering needs to be applied to convert pixels to homogeneous areas. Then groundwater potential areas will be validated by comparing these to existing well yields and fields observations, using statistical methods where possible. The validity of the results will be investigated by sensitivity analysis on the weights for the various groundwater information layers and the scores for the various value classes within each information layer.

The RFP makes a distinction between type 1 and type 2 groundwater information layers: Type 1 include slope, lineaments, recharge, and permeability. Type 2 include NDVI, TWI, flow accumulation, drainage network, true and false colour Landsat 8. The idea in these reports is to use the type 2 layers to refine the results of the overlay analysis of the type 1 layers. There is another approach we are also considering which is to aggregate (according to certain weights) the numerous information layers (or sub criteria) and produce a restricted number of information layers (criteria) describing the most important conditions like direct (focused) and indirect (diffuse) groundwater recharge, transmissivity, shallow groundwater or groundwater seepage and others. On the basis of these higher order layers (criteria) the groundwater potential can be determined.
Refining these criteria will be done in phase II.

2.3.4 Water Demand layers

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 as GIS layer. We will use the 2007 census data as a starting point for the demographic maps which are available down to the woreda level.

CSA has 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 assuming that a relation exists between areal extent of built-up area and population count.

2.3.5 Preparation Groundwater Suitability maps

The suitability maps will be developed based on the existing Geological and Hydrogeological maps and overlain by detailed Remote Sensing products. It is a colour-coded map where colour codes correspond to specific potential classes for the different aquifers and potentially a correlation with the expected water quality. Features which are normally represented in the hydrogeology maps may not be directly shown on such maps.

In addition to the maps, hydrogeological cross sections will be developed. The suitability maps will also contain information on the location and size of the villages and urban centres as well as main landscape features.

2.3.6 Ground truthing and validation of suitability maps

Ground truthing and validation of the suitability maps will be primarily done using the water point inventory data. The groundwater suitability maps will be checked against the productivity of successful boreholes already drilled in the areas. In data rich areas statistical approaches may be applied to validate the overlay analysis and select the most important parameters among the used indicators.

2.3.7 Dissemination workshop end Phase II

At the end of Phase II, a one-day workshop will be held with the peer-review committee, BDA and NGO's involved to present the results achieved and discuss the criteria for selecting the target areas for the hydrogeological operational mapping (1:50,000) in phase III.

The criteria for selecting the target areas will depend on the outcome of the overlay analysis and actual water demand. At this stage, the selection process is governed by physical properties only (overlay analysis). The dissemination workshop is expected to be consultative rather than prescriptive for the siting of drilling locations.

2.3.8 Report writing and submission

The report writing and submission after phase II will consist of a summary technical report per woreda containing the main findings. The content of these reports will reflect the steps undertaken, both in the field and during the desk study. A short descriptive report will be prepared for each published map.

2.4 Phase III

The following project activities will be carried out in Phase III:

• Conduct detail geological and hydrogeological study in target areas • Conduct water balance study in the target areas • Determine impact of climate change on groundwater resources in the target areas • Develop hydrogeological conceptual model of the target areas Prepare map hydrogeological maps of target areas (1:50,000) • Conduct geophysical survey and prepare drilling site maps (1:5,000) • Select borehole sites and possible climatic sensitivities requiring resilience measures • Produce well design, technical specifications and select appropriate drilling technology • Prepare Terms of Reference and Bill of Quantities to drill climate resilient boreholes • Prepare and submit draft report • Organize validation workshop of draft report • Prepare and submit final report	**Phase III**

Figure 7. Activities planned in Phase III

The following deliverables are planned in Phase III:

- Hydrogeology Operational maps (1:50,000)
- Detailed geological, hydrogeological and geophysical study in each target area
- Determination of target drilling sites in the target areas, including drilling sites maps (1:5,000) and geophysical profiles
- Phase III final report per target area
- Capitalisation report and knowledge dissemination activities in a workshop provided by the project team towards the end of the project
- Minutes of the training on Groundwater Mapping Methodology provided by the project team

2.4.1 Water balance studies and recharge estimation

Establishing groundwater recharge rates is perhaps the most elusive parameter to estimate in arid and semi-arid setting. This is because of the episodic nature of recharge, lack of monitoring data and the fact that many (some) recharge models account parametrization that would work in humid environments.

In this project, multiple recharge estimation methods will be utilized, and a hybrid recharge map will be produced during the Phase II The following recharge estimation methods will be considered initially and a subset applied in the final analysis, depending on the suitability of the method and availability of data:

- Recharge estimation based on assumed percentage of rainfall
- Recharge estimation based on infiltration coefficient
- Recharge estimation based on chloride mass balance
- Recharge estimation based on hydrology models (such as WETSPSS) for selected areas
- Recharge estimation based on baseflow separation method (Chernet, 1982)
- Recharge estimation from literature surveys (e.g., Scanlon et al, 2006; Healy 2010 for global picture and a fair number of recharge studies by Ethiopia scientists).
- Recharge estimation from Remote Sensing data (WAPOR)

The hybrid recharge estimation shall be used as the basis of aquifer sustainability assessment.

2.4.2 Improving existing geological maps

Geology forms the basis of the hydrogeological and water potential maps. During phase III of this project, detailed hydrogeological maps (1:50,000) will be prepared. The available 1:250,000 geological maps need to be updated and refined to the 1:50,000 scale. We will harmonize the existing geological maps and studies in terms of stratigraphy and nomenclature, refined assessment of remote sensing data and field verification. Existing geological maps will be updated where necessary using supervised classification of Landsat-8 or Sentinel-2 imagery. We suggest doing the structural analysis (lineament studies) based on remote sensing images in phase II. Lineament extraction is performed using PCI Geomatics software and directional hill shades of SRTMGL1 data or Sentinel-1 SAR imagery. The results of the structural analysis will be incorporated in the mapping products of phase II and will also be used in the overlay analysis and the selection of the target areas.

The improvements and additions with respect to the existing hydrogeological maps are:

- the groundwater suitability map as defined by the overlay analysis
- harmonization of the geological stratigraphy and nomenclature
- production of new maps in areas where such maps do not exist
- apply updated geology and hydrogeology knowledge in Ethiopia to produce the maps

2.4.3 Selection of target areas

A pre-selection of target areas will be done during the dissemination workshop at the end of phase II. At the beginning of phase III, the actual water demand will be matched with the pre-selected target areas and the combination of water demand and potential availability will be discussed with the regional stakeholders. The outcome of the discussions (reality check) will be a final selection of target areas.

2.4.4 Map production

The field studies in the target areas in phase III will produce hydrogeological maps at the scale of 1:50,000 including proposed target sites. These maps display the same features as the phase II maps but in more detail and new information acquired during the field studies, like water points (wells, springs, tanks). An important feature of these maps is information on the demand side, like location and perimeter of the villages, zone(s) with maximum distance to new waterpoints, population, village facilities like schools and medical posts, livestock. Finally, proposed well sites will be presented on these maps.

As a basis for these hydrogeological maps, we propose to use the existing 1:50,000 topographic maps issued by the Ethiopian Mapping Agency wherever available. We will produce 1:50,000 hydrogeological maps with the same sheet numbering and projection as the topographic map sheets.

2.4.5 Geophysical Methodology

Based on the result of Phase II work and geological and hydrogeological assessment, a combination of Vertical Electrical Sounding (VES) and magnetics (spell out) will be recommended, and ground geophysical surveys conducted as required. The Schlumberger array will be employed for the VES surveys. In this configuration, the current electrodes spacing (AB) is systematically increased about a central point – the sounding point for deeper penetration. A maximum half-current electrode separation (AB/2) may extend up to 750 – 1000 m in order probe the subsurface to greater depths.

For each VES measurement, the readings (along with the current and potential electrode separations) will be carefully recorded on a data sheet and simultaneously stored in the instruments' internal memory. By concurrent plotting of the data in the field and studying the tendency of the curves, the field crew can monitor the adequacy of the current electrode spacing and the data quality. Written remarks will be taken for any anomalous observation on the numerical data and/or from the surrounding geology.

For the ERT survey, the Wenner–Schlumberger configuration will be utilized to guarantee deeper penetration, reliable stability, and ability to detect both horizontal and vertical subsurface features. The configuration is based on fixed spacing between potential electrodes while, the spacing between current electrodes is logarithmically increased for number of dipole lengths. Then the spacing between potential electrodes is increased in to obtain more deep penetration.

At least, two field teams will be deployed for the survey. The available list of equipment includes:

- IRIS Electro Pro IP/Resistivity receiver with VIP5000 transmitter and 6.5KVA Honda motor generator: This is a 10-channel powerful unit.
- SARIS (Scintrex Automatic Resistivity Imaging System)
- Abem, Terrameter – SAS-4000 Imaging system comprising of supplemented with an automated multi-electrode system for collecting the 2D electrical resistivity data.
- SYSCAL R1 Plus Switch 72 (Resistivity/IP measurement and 2D Imaging unit) – of the IRIS Instruments.

The list of major accessories includes cables on reels (steel alloy cables for current lines and copper wires for potential terminals), adequate number of steel electrodes. Other ancillary accessories include hammers, GOS, multi-tester, etc.

Navigation and the exact positioning of sounding points and ERT survey lines will be determined using hand-held GPS devices (GARMIN-60S).

In case very deep (>400m) exploration is deemed necessary, the traditional geo-electrical methods may not be appropriate. In these cases, alternative geophysical methods such as Controlled-Source Audio Magnetotellurics (CSAMT) or gravimetry may be considered.

2.4.6 Data processing and interpretations

The electrical resistivity survey data will be processed and presented utilizing different software packages, and up on the demand the programs to be utilized in this project will include the following:

- WinResist and IPI2WIN software packages - for processing of DC electrical resistivity sounding data and generation of earth models
- RES2DINV program - for 2D inversion of resistivity data and determination of resistivity and depth of subsurface layers
- Geosoft (Oasis Montaj) – for processing, presentation and analysis of wide range of geophysical data
- Surfer – for production of maps.

2.4.7 Result compilation and reporting

In addition to the above listed processing tools, for compilation and final presentation of the results we will employ other software packages such as ArcGIS, QGIS, CorelDraw, MapInfo and/or AutoCAD software. These are powerful vector-based drawing program useful to produce different composite plots.

For your quick insight, exemplary figures 8, 9 and 10 can be found below on qualitative and quantitative geo-electrical sections from our anonymous previous endeavours.

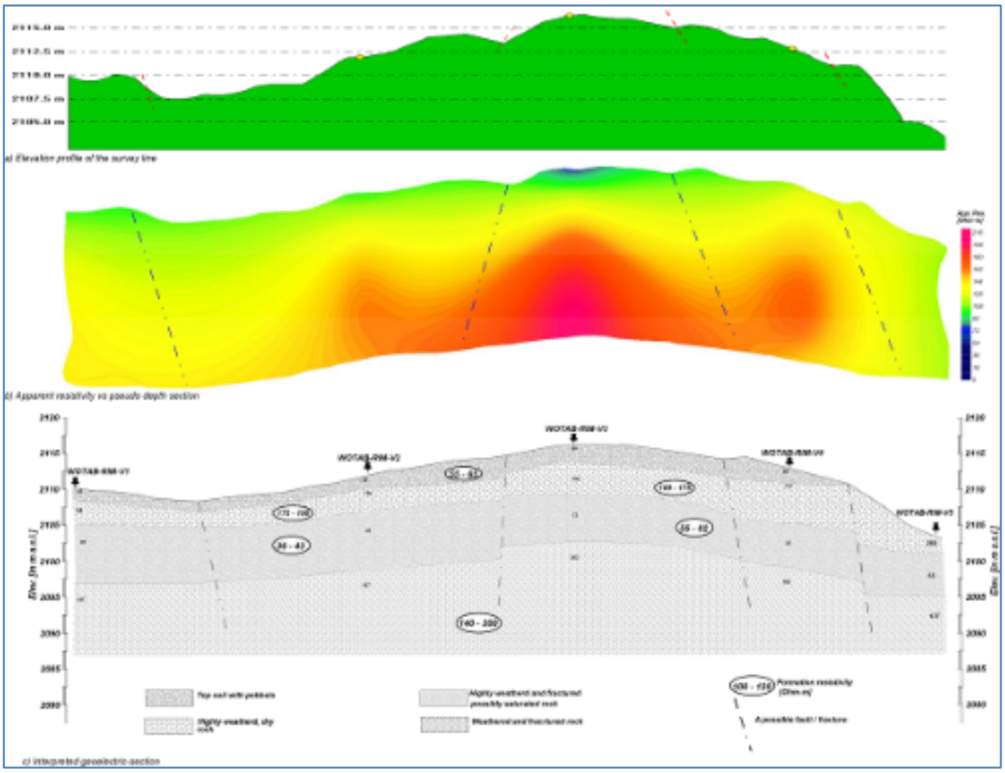


Figure 8. *A panel showing a typical approach in compiling the final geo-electric section of a VES line, topographic profile (top), elevation constrained apparent resistivity pseudo-section (middle) and interpreted geoelectric section (bottom).*

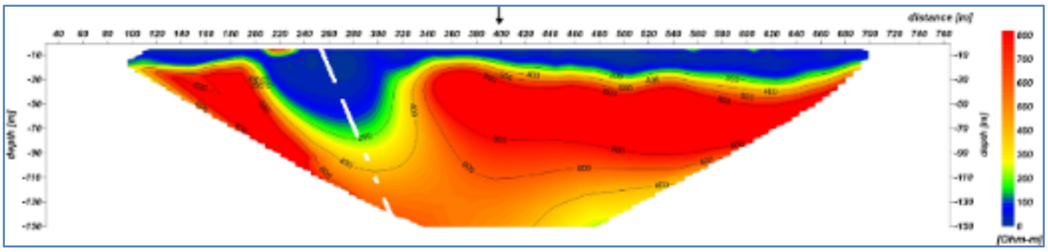


Figure 9. *The subsurface model obtained from inversion 2D ERT data.*

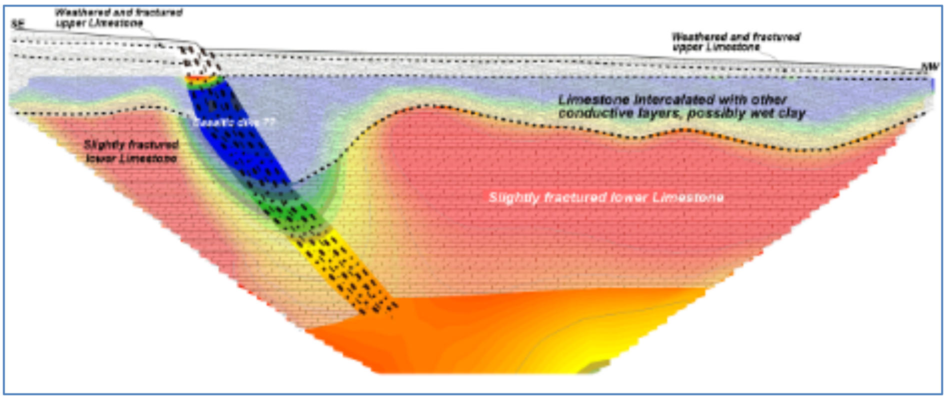


Figure 10. *Composite subsurface model obtained from combining the models obtained from the conventional geoelectric section (1D) and the 2D inversion model of the ERT data along same Line.*

2.4.8 Waterquality

Geochemical analyses will be conducted in the target areas during phase II. This will support the design of the conceptual model development for each target area.

The geochemical analyses will also investigate the suitability of groundwater in target area for multiple use such as drinking and irrigation. Parameters will be specified for:

1. Potable use
2. Irrigation use (Sodium Adsorption Ratio (SAR) and Salinity hazard)
3. Langelier Index and Ryznar Stability (corrosivity or scaling)

The geochemical analyses will be used in determining specific constituent levels that might pose health concerns, notably fluoride and arsenic. The parameters that will be analysed include TDS, EC, pH, Alkalinity, Ca, Mg, N, K, Cl, NO3, SO4, F, As. It is envisaged to take a total of 20 samples at pertinent locations, relevant to the study.

2.4.9 Other field assessment activities

Detailed hydrogeological and geophysical investigations will be done over the selected target areas identified from phase II activities involving:

- Water point inventory: as per the pre-defined format, an exhaustive inventory of all accessible groundwater sources (boreholes, springs, hand dug wells) with location, and giving an appropriate code to provide accurate data for the hydrogeological interpretation and project data base establishment.

- Detailed geological and structural observations of geological units of the area will be done to characterize and classify them according to their relevance to the groundwater study. Such observations include but are not limited to type of lithological units, their extent and distribution, weathering and fracturing characteristics, texture, cementation, porosity, nature and extent of the geological structures and their hydrogeological implications (faults, dykes, etc.).

- Map and verify hydrogeological boundaries and units (hydrogeological mapping), identify major aquifers, define their extent based on the available data and field inspection and combining with the geological and geophysical data.

- Hydrological/hydrogeological observations and measurements: water levels (groundwater level observations), discharge measurements (wells and springs), groundwater manifestation horizons like seepage zones, springs etc.

- Observations on the geomorphology, land use and vegetation.

- Assessment/evaluations of recharge conditions for the area for its sustainable utilizations.

- Identifications of specific potential locations for verifications to recommend water well drilling by the help of geophysical investigations.

- Preparation of hydrogeological sections along zones of likely high groundwater flow paths

In preparation for the data collection in the field, the project team have prepared a data collection sheet to be used in the field. These forms are provided in the annex of this report.

2.5 Risk Mitigation

Measures which will be employed during the project implementation to address and mitigate identified categories of risk, as well as recommendations for long-term post-project measures are provided in this section. More detailed risk mitigation planning will be developed in Phase II, as appropriate, for the discrete project areas.

The major areas of risk associated with the planned boreholes have been identified as follows:

1. Borehole Yield
2. Borehole Water Quality
3. Borehole Functionality
4. Borehole Monitoring

2.5.1 Borehole Yield

The principal risks with respect to borehole yields include:

- Borehole yields that are unable to meet present and future demands
- Borehole yields that decline over time

Mitigation Measures:

- Borehole siting in areas where focused recharge takes place by reliance on technical tools (i.e., fractured areas in the basement rock and volcanic areas).
- Optimizing borehole depths to account for water-level fluctuations – seasonal, long term, and induced by climate change.
- Optimizing borehole designs by:
    - Developing detailed borehole drilling and construction specifications for the drilling contractor and professional drilling/construction oversight.
    - Using materials (casings, borehole screens, filter packs, grout) that meet applicable standards.
    - Scientifically designing borehole screen slot size openings and filter pack sizing to prevent sand pumping.
    - Borehole testing to analyse data for long-term sustained borehole yields for both current and future populations.

2.5.2 Borehole Water Quality

The principal risks with regard to borehole water quality include:

- Anthropogenic groundwater quality issues, such as bacteriological (E coli, Total Coliform; Faecal Coliform) and elevated Nitrates.
- Natural groundwater quality issues, such as elevated Total Dissolved Solids (TDS), Fluoride, or Arsenic.
- Nearby land uses that might impact groundwater quality.
- Releases, spills or leaks, such as of petroleum substances powering the borehole pump.

Mitigation Measures:

- Borehole siting that takes into account nearby land use and establishing protective distances to potential groundwater contamination sources.
- Wellhead drainage works, land use control, and housekeeping in a protection area around the borehole.
- Proper borehole construction with sanitary protection against artificial pathways for contaminant migration, e.g. casing annulus infiltration, by installing a protective column of grout (15 m minimum) in the borehole-casing annulus.
- Fuel storage and spill control plans for fuels.

2.5.3 Borehole Functionality

The principal risks with regard to borehole functionality include:

- Operational risks related to:
  - Borehole/pumping system malfunctions or breakdowns
  - Availability of power for pumping, i.e. fuel or electricity
- Risk of damage due to location, poor security, and theft.

Mitigation Measures:

- Contracting professional firms for borehole and pumping system construction.
- Training borehole operators by means of on-the-job training and workshops.
- Instituting formal O&M procedures.
- Developing Wellhead Protection Programs using a tiered approach:
  - Tier 1 (within ~25m radius of the borehole):
    - Security fencing.
    - Daily Wellhead Inspection.
    - Housekeeping.
    - Avoiding unauthorized system intrusions.
  - Tier 2 (within ~100 to 500m radius of the borehole):
    - Review and input to proposed land-use changes.
    - Creation and operation of water reserves or conservation districts
    - Emergency response to spills, releases or leaks.
    - Education of the community regarding wellhead protection

2.5.4 Borehole Monitoring

System monitoring is critical for the smooth operation of the borehole and pumping system, including identification of types/points/causes of decline or failure, and timely mitigation intervention and troubleshooting. The types of data which should be collected include:

- Condition of equipment via routine inspection
- Daily pumpage (rate (Q), duration, volume)
- Water levels (static and pumping)
- Water level drawdown (s) to evaluate decline in specific capacity (Q/s)
- Water quality (E. coli – monthly, colour, odour, turbidity, air bubbles)
- Rainfall

Indicators of need for borehole operation modification include:

- Decline in pumping/static levels
- Decrease in borehole pressure
- Cascading (air entrainment)
- Sand pumping/turbidity
- Reduction in well yield and specific capacity (Q/s)
- Colour, odour, turbidity changes in the pumped discharge

A formal plan should be established to specify the parameters and frequency of data collection and analysis.

2.5.5 Data sources

We foresee to use the following data sources:

1. Borehole and Spring Inventory Data:
   a. Depths
   b. Borehole Yield Range and Spring Flow Range
   c. Static and Pumping Water Levels
   d. Available drawdown range

2. Groundwater Quality Data from Field Reconnaissance and Inventory:

3. Water Demand – Present and Future (2040)
   a. Human
   b. Livestock
   c. Irrigation
   d. Commercial

4. Aquifer Resiliency:
   a. Dynamic Reserve – annual recharge (shallow and deeper aquifer systems)
   b. Static Reserve - storage
   c. Ratio of Static Reserve to annual demand

5. Precipitation Data:

a. Annual
b. Trend analysis

6. Geologic and Hydrogeologic Mapping Products

3 Inception Phase

The following activities were undertaken in this phase, which was comprising mainly desk data collection and first assessment:

Task	Status
Creation of the project team, including changes in team composition as a reaction on recent character of the project	completed
Collection of basic data about existing geological and hydrogeological maps, reports, water quality and quantity data, meteorological information, demographic data, socio-economic maps produced before project started	completed
Compilation of hydrogeological map at scale 1:1,000,000 showing hydrogeological condition of each Woreda	completed
Developing conceptual hydrogeological models to complement data scarcity.	completed
Compilation of demographic map (1:1,000,000) showing demographic data for each Woreda	completed
Preparation of field survey and investigation plans and base maps with information to be used for the Type 3a layers.	completed
Drafting inception report detailing proposed methodology and final work plan for the assignment.	completed
Presenting to stakeholders the draft inception report for review by Peer Review Committee.	completed
Submitting the final inception report for validation by Peer Review.	completed

3.1 Data collection and review of information

- Geological maps
- Hydrogeological maps
- Reports
- Water point inventory data (from RWB, MoWIE)
- Hydrometeorological data
- Remote Sensing products

3.1.1 Summary of previous hydrogeological works

The first regional hydrogeological reports and maps were published by Tefaye Chernet (1985)

- Tesfaye Chernet, (1985) Hydrogeology of Ethiopia (explanation of the hydrogeological map of Ethiopia, 1:2,000,000), EIGS Note 225.

The summarizing hydrogeological report accompanied by map at scale 1:1,000,000 was published by Bayissa Asfaw (2003)

- Bayissa Asfaw (2003) Regional Hydrogeological Investigation of Northern Ethiopia, Ministry of Mines, Geological Survey of Ethiopia, Addis Ababa.

The study area was fully covered by hydrogeological and hydrochemical maps accompanied by explanatory notes) of the Geological Survey of Ethiopia at scale 1 : 250 000

- Mulat Alemayehu and Yewubdar Abebe, Jiri Sima editor (2018) Hydrogeological and hydrochemical map of Afrera Yechew Hayk ND 37 – 12, Geological Survey of Ethiopia, Addis Ababa / AQUATEST a.s., / AquaCon plc /Geotest a.s. /Czech Geological Survey, Czech Development Agency, Prague.

- Webanchi Fekadu and Alemayehu Tadesse, Jiri Sima editor (2018) Hydrogeological and hydrochemical map of Axum - Adigrat - Dafta Meda ND 37-6, ND 37-7 and ND 37-8, Geological Survey of Ethiopia, Addis Ababa / AQUATEST a.s., / AquaCon plc /Geotest a.s. /Czech Geological Survey, Czech Development Agency, Prague.

- Yonas Mulugeta, Yewubdar Abebe and Mulat Alemayehu, Jiri Sima editor (2018) Hydrogeological and hydrochemical map of Afrera Yechew Hayk ND 37 – 12, Geological Survey of Ethiopia, Addis Ababa / AQUATEST a.s., / AquaCon plc /Geotest a.s. /Czech Geological Survey, Czech Development Agency, Prague.

- Tesfaye Chernet and Gebretsadik Eshete, Jiri Sima editor (2018) Hydrogeological and hydrochemical map of Mekele ND 37-11, Geological Survey of Ethiopia, Addis Ababa / AQUATEST a.s., / AquaCon plc /Geotest a.s. /Czech Geological Survey, Czech Development Agency, Prague, second amended edition.

- Thomas Agezew and Aschalew Gurmu, Jiri Sima editor (2018) Hydrogeological and hydrochemical map of Maychew ND 37 – 15, Geological Survey of Ethiopia, Addis Ababa / AQUATEST a.s., / AquaCon plc /Geotest a.s. /Czech Geological Survey, Czech Development Agency, Prague.

- Webanchi Fekadu and Nejat Bekele, Jiri Sima editor, (2018) Hydrogeological and hydrochemical map of Urikemam Terara ND 37-16 and Alelu Meda ND 38-13, Geological Survey of Ethiopia, Addis Ababa / AQUATEST a.s., / AquaCon plc /Geotest a.s. /Czech Geological Survey, Czech Development Agency, Prague.

Some parts of the study area were covered by detailed hydrogeological studies of the Geological Survey of Ethiopia at scale 1:50,000 and Agricultural Transformation Agency

- Mesfin Kidanemariam and Degefom Areaya (2020), Detail Groundwater Resource Investigation in Mekele and Surrounding areas, Groundwater resource assessment directorate, Ministry of Mines, Petroleum and Natural Gas, Geological Survey of Ethiopia.

- Sadam Ebrahim, Mehari Tadesse and Tinsae Mammo (2020) Hydrogeology and hydrochemistry of Mekelle and Southern Mekelle Area, Groundwater resource assessment directorate, Ministry of Mines, Petroleum and Natural Gas, Geological Survey of Ethiopia.

- Sima J., editor (2019) Hydrogeological Mapping of the Shallow Groundwater in the digrat Abergele, Chancho-Mehal Meda, Kofele-Goba and Harari Identified Areas – Part – Adigrat Abergele, AQUATEST for Ethiopia Agricultural Transformation Agency.

There are a lot of drilling reports providing detailed information about individual wells and summarizing datasheets of Tigray Regional Water Bureau. Specific hydrogeological characterization of the study area is in thesis of students of the Mekele University as well as Addis Ababa University and other publishers.

- Tamiru Alemayehu (2006) Groundwater Occurrence in Ethiopia, Addis Ababa University, Ethiopia / UNESCO.

- Seifu Kebede (2013) Groundwater in Ethiopia Features, Numbers and Opportunities, Springer-Verlag Berlin Heidelberg.

3.1.2 Geological data

Geological data and information were collected from archive of GSE and MoWRI. Existing maps at scale 1: 250,000 were used for preparation of harmonised geological map: emphasis was given to lithological units that have important water bearing properties such as lateral and vertical extents of lithologic units, contact and spatial relationships, and degree of weathering and alteration.

It was found that fracture analysis: tracing of major faults and lineaments in previous maps; collection of representative structural data on major joint orientations from all lithological units (and then fracture analysis) needs to be improved by using the most recent RS methods as well as and verification of lineaments and faults in the field. Fracture analysis and structural maps used to define the structural regimes of the basin and to determine their influence on hydrogeological and hydrological processes (e.g., flow regimes).

The recent findings in geologic of the area mapping is shown in simplified geological map (no- in scale) that is presented as an inset map on the hydrogeological map at scale 1:1,000,000. Short description of geological units is in chapter 3.2.1 and detailed description of geological units is in Annex 2. The geology of the area will be compiled in scale 1:100,000 for each Woreda in phase II.

3.1.3 Hydrogeological data

The hydrogeological map of the project area at scale 1:1,000,000 was compiled based hydrogeological maps available at the server of Geological Survey of Ethiopia at scale 1:50,000 (http://gis.gse.gov.et/hg_maps/index.html). Hydrogeological map of the Project area shows hydrogeological condition of each Woreda. The hydrogeological characteristics and groundwater potential of the area are highly affected by the complexity of the geology, physiography, climate, and geological structures. The classification of different lithological units is based on the qualitative and quantitative parameters of the hydrogeological characteristics of various rocks. Since quantitative data such as permeability, yield, aquifer thickness and transmissivity are not sufficient or evenly distributed throughout the area, it was essential to apply a qualitative approach to achieve a complete and detailed potential classification. Qualitative investigation includes field observations of the geological, hydrogeological, geomorphological, physical, and geographical setup. Hence, the lithological units are characterized as having porous or fissured permeability, or they are impermeable.

An explanatory text to the hydrogeological map of the Project area is in chapter 3.2.2 to chapter 3.2.5. Detailed description of hydrogeology of the Project area is in Annex 3. Hydrogeological map at the scale 1:1,000,000 is attached to this report. The map will be used of further analyses in Phase II.

During the validation workshop it was decided that 1:250,000 hydrogeological maps should be produced for every woreda instead of one single 1:1,000,000 map. The 13 woreda maps for Lot 1have been attached in the Annex and contain essentially the same information as the 1:1,000,000 map but on a larger scale.

3.1.4 Hydrometeorological data

Climatic data collection consists of list and basic data from climatic stations of the 1st and 2nd class of The National Meteorological Service Agency. The data has different length and accuracy (e.g., data from Addis Ababa climatic station starts in 1994 and ends in 2017).

River flow gauging data, measured by the Hydrological Department of MoWIE, that will be used for assessment of baseflow (one method for recharge estimation) was collected from the Tekeze Basin.

First series of water point inventory data were collected from Mekelle Water Bureau and from RWB, MoWIE.

3.1.5 Remote Sensing data

Most relevant remote sensing data and global datasets were gathered in preparation for the phase II overlay analysis. Further data still needs to be collected during phase II. For details of all required data see Table 6. In phase II this table will be further developed, and will include indicator (derived from data), criteria (GIS layers), preliminary weights for criteria, indicator classes and preliminary weights for indicator classes. We envisage to produce at least the following maps from Remote Sensing Data: precipitation, evapotranspiration, evaporation, soil moisture, vegetation indices, digital terrain model, watershed boundaries, flow accumulation, slope, wetness index, classified lithology, lineaments, soil type, land-use and landcover.

For some layers, the changes over time are most essential. This is especially the case for precipitation, evaporation, soil moisture, vegetation, and land-use. For these layers, the long-term average, significant trend, standard deviation, and seasonality will be determined using statistical methods.

Table 6: Databases and data collected, and to be completed during Phase II.

Layer	Data Source	Type	Remarks
1. **Groundwater**	MoWIE Others	Water points, water quality	Secondary data collection in progress
2. **Hydrometeorology**	MoWIE NMA	River flow records Rainfall Evaporation Temperature Relative humidity	Data collection in progress
3. **Maps and Reports**	GSE, AAU, MoWIE Others	Geological and hydrogeological maps and reports	Collected

Table 5a Remote Sensing data.

Layer	Source	Resolution		Availability	Phase
		Spatial	**Temporal**		
Precipitation	GPM	0.1 degree	2014-2021, daily	Available	2
	CHIRPS	0. 05 degree	2000-2021, daily	Available	2
Surface reflectance	MODIS MOD09	500 m	Dec 2020	2017 Available	2
	Landsat-8	30 m	Dec 2020	2017 Available	2
	Sentinel-2	10 m	-	To be collected	3
NDVI	MODIS MOD13	250 m	2000-2021, 16 days	Available	2
	Landsat-8	30 m	Jun 2021	To be collected	2
	Sentinel-2	10 m	Jun 2021-	To be collected	3
Landcover + dynamics	MODIS MOD12	500 m	2001-2012, yearly	To be collected	2
Land use/land cover	Sentinel-2	20 m	2016	Collected	2
Evapotranspiration	MODIS MOD16	500 m	2000-2020 (8 days)	Available	2
Structural lineaments	SRTMGL1	30 m	2014	Available	2
	Landsat-8	30 m	Dec 2017	Available	2
	Sentinel-2	10 m	Tbd	To be collected	3
	Sentinel-1	10 m	Tbd	To be collected	2
Surface geology	Landsat-8	30 m	Dec 2017	Available	2
	Sentinel-2	15 m	Tbd	-	3
Elevation	SRTMGL1	30 m	2014	Available	2,3
Flow accumulation	SRTMGL1	30 m	2014	-	2,3
TWI	SRTMGL1	30 m	2014	-	2,3
Slope	SRTMGL1	30 m	2014	-	2,3
Catchments	SRTMGL1	30 m	2014	-	2,3
Drainage network	SRTMGL1	30 m	2014	-	2,3
Soil moisture	GLEAM	0.25 degree	2003-2020	Needs processing	1
	SMAP/Sentinel-1	1000 m	2017, daily	-	1
	SMAP/Sentinel-1/Sentinel-2	100 m	Tbd	-	2

3.1.6 Socio-economic data

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.

3.1.7 Data gaps

During the Inception Phase water point data has been requested from MoWIE (BDA, RWB), CSA, OCHA and UNICEF. Not all existing water point information has yet been received. During the next project phases, we will complete the inventory in the selected woredas. Obtaining most recent data from Tigray Region may turn out to be difficult or even impossible because of security issues. We will have to rely on existing information in these areas.

During Phases II and III 1:50,000 toposheets are required for the 1:50,000 operational hydrogeological maps, and 1:5,000 drilling site maps. The toposheets may not be digitally available for some target woredas, notably Afar. In these cases, we will revert to online maps to provide the necessary topographic details.

In order assess the climate resilience of the target sites, access to detailed hydrometeorological data is essential, both historical and recent. We will complement meteorological data from the National Meteorology Agency of Ethiopia (NMA) with satellite products such as CHIRPS (precipitation) and WAPOR (evaporation).

Lacking gauging stations or incomplete records may affect the availability of hydrologic data like stream flows and thereby the quality of the water balance estimations. We envisage to complement missing data using flow modelling.

The available socio-economic data is outdated as it originates from the 2007 census. Recent data on service level, water demand, and population distribution is needed to prioritize the demand areas in the target woredas. During Phase II more recent data will be obtained from the selected target woredas.

3.1.8 Weighting criteria

The weights of the criteria or map layers for the overlay analysis are non-unique and vary from one hydrogeological environment (or conceptual model) to another. Therefore, during the inception phase we looked into the hydrogeological models relevant for the woredas in question. In the table on the next page, the weighting criteria are described and classified according to the different hydrogeological conceptual models.

The classes can be descriptive (e.g., lithology, soil type) but the class scores and layer weights need to be numeric. Scores need to be agreed upon, and layer weights will vary per Lot. We will calculate a Consistency Index (CI) for the weights of the criteria and will verify that the CI is below 0.1.

During phase II detailing of the criteria will be done. The project team proposes to present the criteria to the peer review committee during the phase II workshop and we shall converge and produce a set of class scores that is commonly agreed upon. The final selection of the criteria shall be discussed during the Peer Review Workshop in Phase II. During a Technical Meeting with BDA, DFID, and the consultants for Lots 1, 2, 3 and 4 on 4 August 2021, it was proposed to use Topographic Wetness Index as criterium for topographic location instead of slope.

Table 7: Preliminary weighting criteria

Weighting criteria											
Layer	**Criteria**	**Indicator**	**Key assumptions. Yield potential increases...**	**Quantification Method**	**Weight factor**	**Class and class Weight**					
Main Criteria											
						1	**2**	**3**	**4**	**5**	**Total**
1	Regional permeability	Rock type	...with higher regional permeability.	Group formations with similar regional permeabilities		High	Medium	Low-Med	Low	Very low	
											100
2	Secondary permeability	Lineament and geologic structure density	...with higher lineament, joint and fault densities.	1. Map geological lineaments and structures. 2. Group areas with similar lineament densities		High	Medium	Low-Med	Low	Very low	
											100
3a	Topographic location	Slope (Angle of slope)	...in areas with gentle slopes and in valley bottoms.	1. Generate a slopes layer (in degrees) from the DEM. 2. Group areas with similar slopes		Flat (0 - 5°)	Gentle slopes (5 - 10°)	Moderate slopes (10 - 25°)	Steep slopes (>25°)		
											100
3b	Topographic location	Topographic Wetness Index	...in areas with high flow accumulation and low slope	1. Generate a TWI layer from the DEM. 2. Group areas with similar index		Very High	High	Medium	Low	Very Low	
											100
4	Recharge	Recharge rate	...with increasing recharge.	1. estimate recharge by various methods 2. Develop a recharge layer(map) 3. Group similar recharge values		Very High	High	Medium	Low	Very Low	
											100

5	Land use	Recharge potential	…with certain land use types such as irrigated cropland.	Group land use types by recharge potential		High	Medium	Low			
											100
6	Soil type	Infiltration capacity	...with increasing infiltration capacity of the soil.	1. Group soil type by infiltration capacity 2. Indicate presence of obstructing layers in the soil profile that prohibit recharge to the groundwater		High	Medium	Low	Very low		
											100

Weighting criteria											
Layer	Criteria	Indicator	Key assumptions. Yield potential increases...	Quantification Method	Weight factor	Class and class Weight					
Sub- Criteria											
1	Flow Accumulation	catchment run-off	With increasing in flow accumulation, high chance of recharge, indicate flow paths	From satellite data processing		High	Medium	Low			
2	Net precipitation	Length of dry season, net precipitation depth and precipitation intensity	Shorter dry season, higher precipitation depth and low intensity increases chance of recharge	From satellite data processing		High	Medium	Low			
											100
3	NDVI	vegetation cover	With high NDVI, indictor of soil moisture, SGW, consideration of Evapotranspiration	From satellite data processing		High	Medium	Low			
											100
4	TWI	Elevation, flow accumulation and slope	With increasing TWI, potentially soil moisture and shallow groundwater recharge	From satellite data processing		High	Medium	Low			
											100
5	Drainage density	Density of drainage	High drainage density implies poor permeability	From drainage map		High	Medium	Low			
6	Soil moisture	Change in soil moisture during wet season	Water balance component used for recharge estimation	From satellite data processing		High	Medium	Low			
											100

3.2 Conceptual hydrogeological model

3.2.1 Geological setting

The project area lithological units can be divided into two macro structural domains: units of the north-western plateau and adjacent western escarpment and units of the Afar Depression. A simplified geological map is presented as an inset map in the hydrogeological map at scale 1:1,000,000.

Northwestern plateau and escarpment

The stratigraphic succession of the north-western plateau and adjacent western escarpment can be divided, in general, into 10 units (from the oldest to the youngest one): Precambrian basement and intrusive rocks, Enticho Sandstones, Edaga Arbi Glacials, Adigrat Sandstones, Antalo Limestones, Agula Shales, Amba Aradam Formation, Trap series, Mekele Dolerites and Axum-Adwa Plugs.

The Precambrian basement of the Mekelle Outlier is made of low-grade Metavolcanics Tsaliet group consisting dominantly metavolcanics (green schist, which was originally mainly volcanic rocks with associated sediments) and Tambien group consisting dominantly metasediments (slates, phyllites, greywacke, limestone and quarzitic dolomites). Intrusive rocks are represented by syenite, tonalite, granodiorite, gabbro as well as Mekele dolerite (black andesine dolerite) usually dolerite is forming dykes 4 to 18 m thick.

Sedimentary units are composed by poorly sorted Edaga Arbi glacials and Enticho Sandstone which is the lowermost sedimentary unit exposed in the mapped area. Sedimentation continued by deposition of fine to medium-grained grained Adigrat (Lower) sandstone and by Antalo limestone consisting of white (and rarely black) finely crystalline to lithographic, well-bedded and fossiliferous limestone interbedded with yellow marl and sandy limestone. The Agula shale conformably overlies on the Antalo formation with a very thick sequence of marls and shales. The Amba Aradam (Upper) represent the sea regression and is composed by sandstone siltstone, and argillite.

The latest stratigraphy divided volcanic rocks of the Plateau to 4 units as follows:

1. the basal basalt sequence forming gentle and rugged terrain corresponding to the Ashengie,
2. the upper basalt sequence forming the plateau proper corresponding to the Aiba-Alaji-Termaber sequences,
3. broad based shield volcanics capping the plateau and
4. Quaternary scoria basalts associated with the shields

The Adwa plugs penetrate the trap volcanics and have an alkaline trachytic and phonolitic composition.

Quaternary cover consists of lacustrine and river sediments which are exposed along the Tekeze River. The specific unconsolidated sediment composed of sand, gravel and boulders are developed in Kobo and Alemata marginal grabens.

Afar Depression

The geological units of the Afar Depression consist of epimetamorphic basement in Danakil Alps, volcanic rocks and sedimentary rocks represent lithological units of the Afar Depression. Early in the Pliocene the sea invaded Afar from the north, depositing gypseous and saline sands and clays. There was some submarine volcanic activity towards the end of the Pliocene. Tectonic uplift during the pluvial is associated with formation of terraces.

The sedimentary units can be in general divided into four formations:

1. Red Formation consisting of several hundred meters of conglomerate, sand, sandstones and red, green or multicolored clays interbedded with volcanic rocks
2. White Formation which is a series gypsum layers with rare calcareous intercalation
3. Dallol Formation with evaporitic rocks such as bedded halite, gypsum, anhydrite, potash salt and shale
4. Afdera Formation which contains lacustrine sediments, limestones and diatomite.

Specific sediments are represented by continental conglomerate and high fluvial terraces of the Upper Pleistocene with dominant gravels and sands at foot of escarpment and region. Low topography is covered by alluvium, silt, clay sand, dunes and other aeolian deposits.

A large area of the Afar Depression is covered by volcanic rocks of various composition. The basaltic volcanism is represented by Afar Basalt, Basic pyroclasts of sub aerial origin and basic lava flow lava fields and related spater cones mainly of basaltic composition (submarine and sub lacustrine) and stratoid basaltic lava and ignimbrite sheets. This basalt is characterized by fine texture vesicular surface and showing moderate to high degree of weathering.

Volcanic rocks of intermediate composition are dark trachyte, mugerite, hawaite, andesine basalt, ferra basalt, picritic basaltic flows and spater cones, alkaline over-saturated trachyte, alkaline and peralkaline rhyolite as well as Intermediate and silicic lava of Afrera volcano.

Silicic massifs ignimbrites, pumice flow and layers, mostly of rhyolitic composition forms ridges, hills as well as gentle slopes. The Dalha Formation is forming north-west trending ridges and consists of series of basaltic flows with some intercalation of ignimbrites, detrital deposits, lacustrine sediments. Kemissie rhyolite is exposed in the central southern part along the western margin of the Afar rift (eastern horst of Maycho graben).

3.2.2 Hydrogeology

The hydrogeological characteristics and potential yield of water points of the area are highly affected by the complexity of the geology, physiography, climate and geological structures. The classification of different lithological units is based on the qualitative and quantitative parameters of the hydrogeological characteristics of various rocks. Since quantitative data such as permeability, yield, aquifer thickness and transmissivity are not sufficient or evenly distributed throughout the area, it was essential to apply a qualitative approach in order to achieve a complete and detailed potential classification. Hence, the lithological units are characterized as having porous or fissured permeability, or they are impermeable.

3.2.3 Hydrogeological classification

Based on the hydrogeological character of the lithological units and their topographical position, the study area can be divided into hydrogeological units as follows:

- Highly productive porous aquifers developed in the High fluvial terraces and Continental conglomerate at the foot of the escarpment and filling the lowlands and the Danakil depression, Red Formation reddish in color and mostly coarse grained, poorly cemented conglomerate and sandstone beds outcropping along the western margin of the Danakil Depress and highly permeable and highly recharged sediments filling of the marginal grabens (Maychew graben) and are composed of clay, sand, gravel and boulders.
- Moderately productive porous aquifers in Quaternary alluvial, lacustrine and eluvial sediments and Afdera Formation. There are two types of alluvial sediments are recognized: (a) those spread out in alluvial plains, and (b) those which occur as thin strips along permanent and intermittent streams. These aquifers are exposed along permanent rivers of the plateau area and filling the Afar rift floor, forming the flat morphology.
- Highly productive fissured and karstic aquifers in karstified Antalo limestone (particularly in the western part of the area where karst features are common) and the Upper basalts and trachyte (upper part of Aiba, Dessie, Tarmaber- Megezez basalts, and Stratoid basalts).
- Moderately productive fissured aquifers developed in Paleozoic to Mesozoic sedimentary rocks (Paleozoic low grade metamorphosed limestone and dolomite, non-karstic Antalo limestone, and Enticho, Adigrat and Amba Aradom sandstones), Tertiary and Quaternary volcanic rocks (lower and middle part of Trap basalts – Koetsa, Alaje and Debre Tabor basalts, trachyte and pycoclastics, Mekele dolerite and recent Afar basalts, basic and intermediate volcanic rock, basaltic fissure flows.
- Moderately productive aquifers of the Dalha Formation with alternating layers of fissured (basalts and rhyolite) and porous permeability (detrital and lacustrine sediments).
- Low productive fissured aquifers developed in Precambrian basement rocks (metavolcanics and non-carbonate metasediments), epimetamorphic basement of Danakil Alps and intrusive rocks (Syenite and foliated and massive granite) of the area.
- Aquitards consisting of Agula shales which are at places hard and well jointed, while in others it is soft and powdery, Edaga Arabi glacials consisting of angular, poorly sorted grains of quartz and lenses of conglomerates and Hamsho tuffaceous sediments with quartzite, arkose and agglomerate, Kemissie rhyolite, White and Dallol Formations with dominant evaporites, where groundwater moves through and collects in solution cavities. Alkali trachyte and rhyolite and tuff as well as and Trachyte and rhyolite and other silicic lavas of Afera volcano and silicic centers and domes of the Afar Depression
- Aquicludes consisting of dome forming phonolite / trachyte and gabbro and metagabbro and metapyroxinite (aquifuge – solid rocks / blind rocks. These units outcrop in the study area only in localized exposures, they are very massive and hard with very slight weathering.

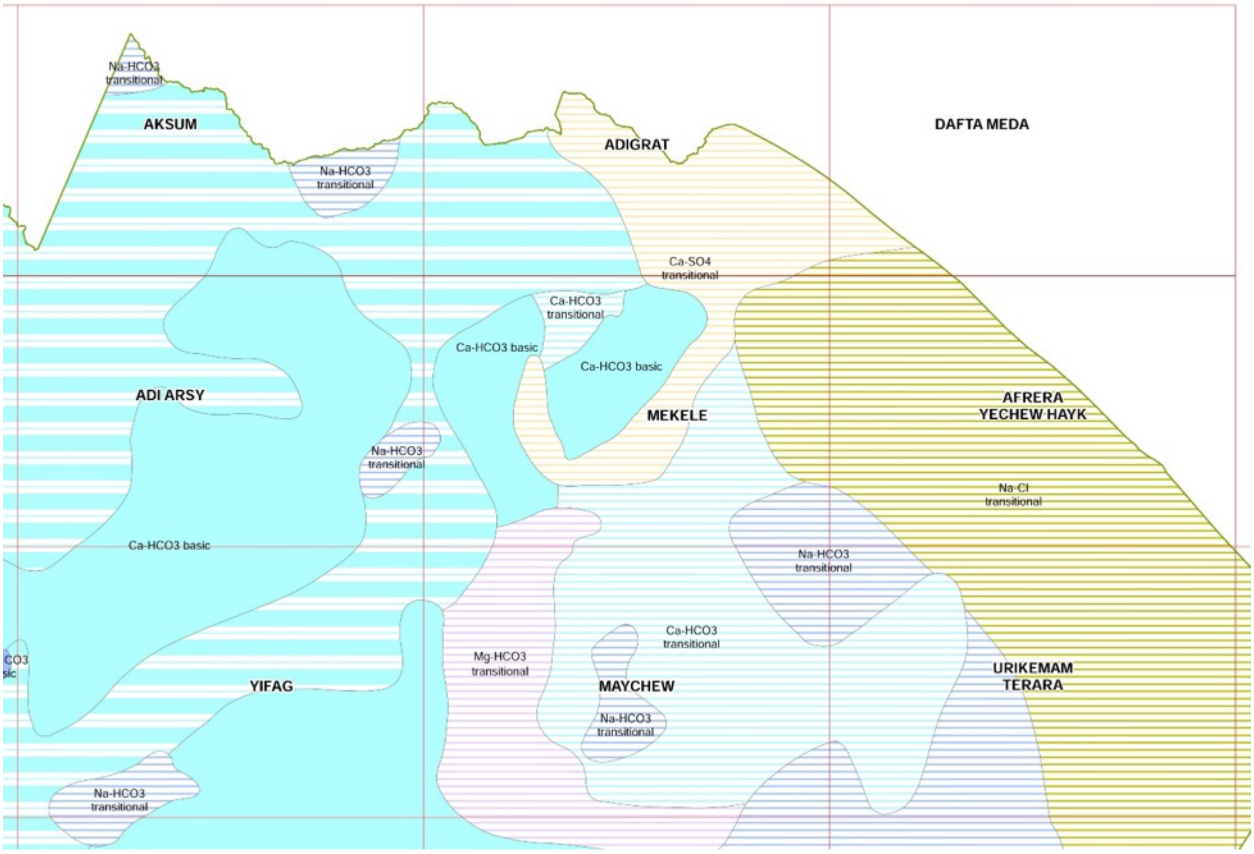
3.2.4 Hydrochemistry

Plateau and escarpment

Groundwater chemistry of the Plateau is characterized by calcium and magnesium bicarbonate types, with total dissolved solids (TDS) lower than 500 mg/l or varying between 500 and 1,000 mg/l, showing fast groundwater circulation in fissured aquifers. Groundwater of the area is, in general, convenient for drinking, agricultural as well as industrial purposes.

Afar Depression

Groundwater chemistry of the Afar Depression is characterized by sodium bicarbonate types, with TDS lower than 1,000 mg/l or varying between 500 and 1,000 mg/l, showing alteration of groundwater by hot springs along the western escarpment. The eastern part of the area is characterized by calcium sulphate and sodium chloride types with TDS above 1,500 mg/l. This water quality shows that groundwater is affected by evaporation and dissolution of evaporites (gypsum and halite). In this area TDS in groundwater exceeds maximum permissible level for drinking water.



3.2.5 Hydrogeological conceptual model

The major surface water divide between the Tekeze and Afar basins separates the project area conceptually into a eastern and western part.

East of the water divide

Here the steep topography leads to rapid run-off and fast-flowing streams, and most of the recharge occurs in valleys in alluvium or other permeable rocks. This is the case in both major basins. Most of the run-off from the escarpment infiltrates into the fluvial fans at the western margin of the Afar (Danakil) Depression, whence it travels as shallow groundwater to replenish the evaporating basins of Lake Asale and Lake Bakili in the north and to Lake Afdera to the south-east of the study area. The rainfall in the Afar (Danakil), though many times less than the potential evaporation in the area, partly infiltrates due to the favourable permeability of the coarse-grained gravel, sands and vesicular basalts and the high intensities of the infrequent rainstorms, adding to the groundwater reserve in the area (Fig 1).

In the southern part of the study area the groundwater flows from the western mountain chain to the east in the Kobo basin and Alamata sub-basin. Existing data generally show groundwater flow to the south-east in the Mehoni sub-basin in the north. Local groundwater flows towards the west from the escarpment to the graben without changing the regional groundwater flow direction, which is minor except for in the Mehoni sub-basins. Finally, groundwater flows through the eastern horst into the Afar Depression (Fig 2).

West of the water divide

West of the surface water divide highly jointed aquifers of the highland area provide opportunities for direct infiltration. The limestones in the Giba valley, the Trap Series volcanics and the Enticho sandstone are regions of such direct recharge. However, the highest rainfall area along the major watershed is on low productive aquifers, resulting in relatively low recharge at the watershed. West of Antalo, at Feleg Hafo Terara, a patch of sandstone rests on Agula Shale and dolerites. Five springs discharge at the base of the sandstone. In addition, the topographic position of this sandstone encourages both run-off and immediate baseflow. Therefore, it is assumed that infiltration of 20% of the annual rainfall occurs on good aquifers, whereas poor aquifers probably have infiltration of less than 3%.

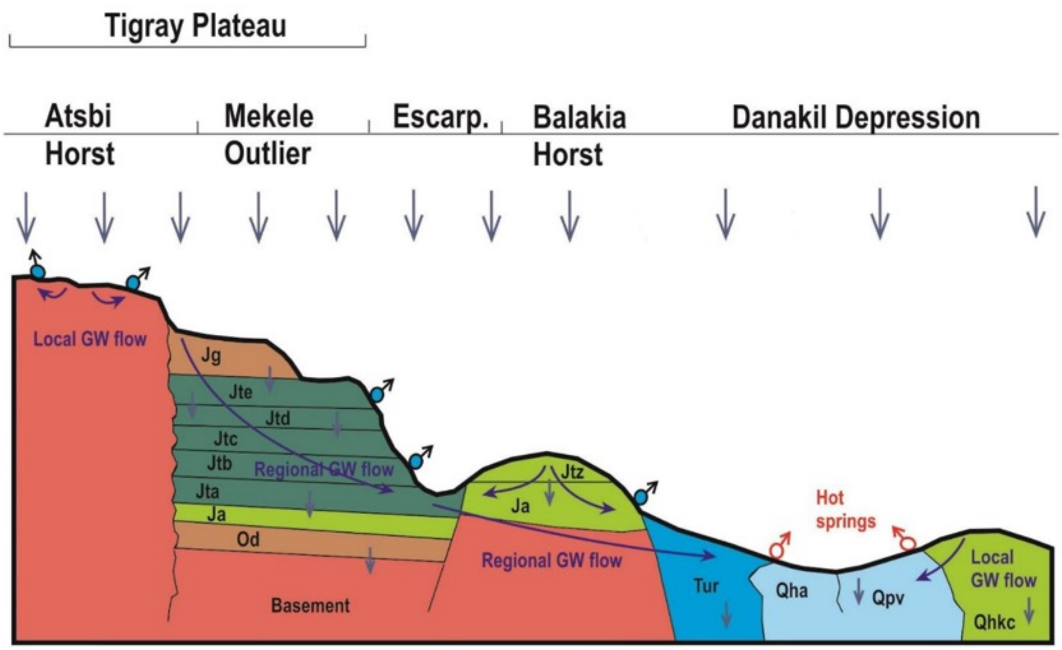


Fig. 1 Hydrogeological conceptual model of the Mekele area

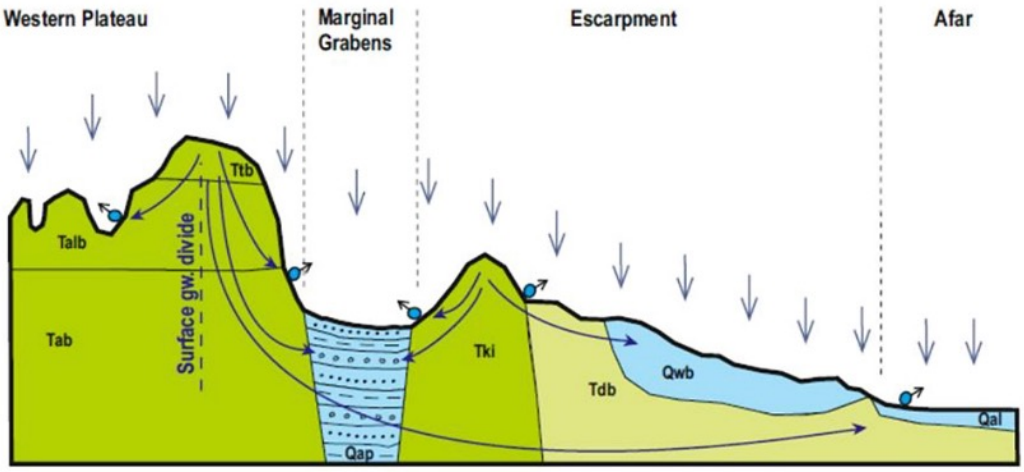


Fig 2 Hydrogeological conceptual model of the Maychew area

3.2.6 Hydrogeological Map

The hydrogeological map of the project area at scale 1:1,000,000 was compiled based on hydrogeological maps available at the server of Geological Survey of Ethiopia at scale 1:250,000 (http://gis.gse.gov.et/hg_maps/index.html). The map shows hydrogeological condition of each Woreda. The hydrogeological characteristics and groundwater potential of the area are highly affected by the complexity of the geology, physiography, climate and geological structures. The classification of different lithological units is based on the qualitative and quantitative parameters of the hydrogeological characteristics of various rocks. Since quantitative data such as permeability, yield, aquifer thickness and transmissivity are not sufficient or evenly distributed throughout the area, it was essential to apply a qualitative approach in order to achieve a complete and detailed potential classification. Qualitative investigation includes field observations of the geological, hydrogeological, geomorphological, physical and geographical setup. Hence, the lithological units are characterized as having porous or fissured permeability, or they are impermeable. An explanatory text to the hydrogeological map of the Project area is in chapter 3.2.2 to chapter 3.2.5. Detailed description of hydrogeology of the Project area is in Annex 3.
A preview of the map is show in figure 11 below. The full resolution map at the scale 1:1,000,000 is attached to this report as Annex 6.

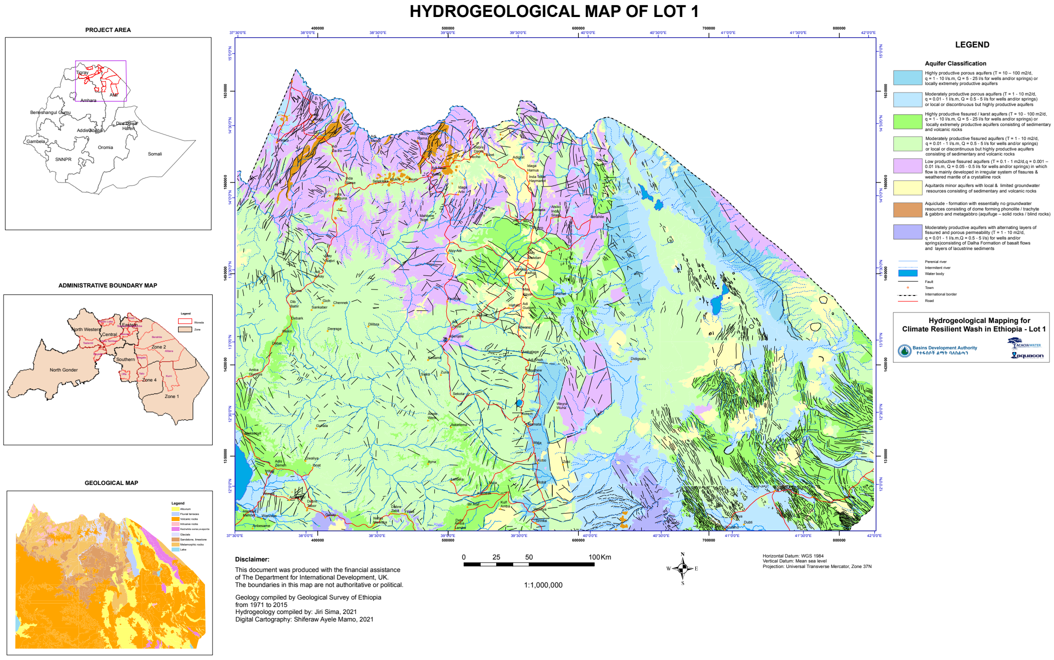


Figure 11 Hydrogeological map

3.2.7 Socio-economic Map

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. The figure below shows the results on a map with the number of beneficiaries per waterpoint and insets with population density, number of schools, number of health facilities and water point density. A full resolution map 1:1,000,000 is attached as annex 6.

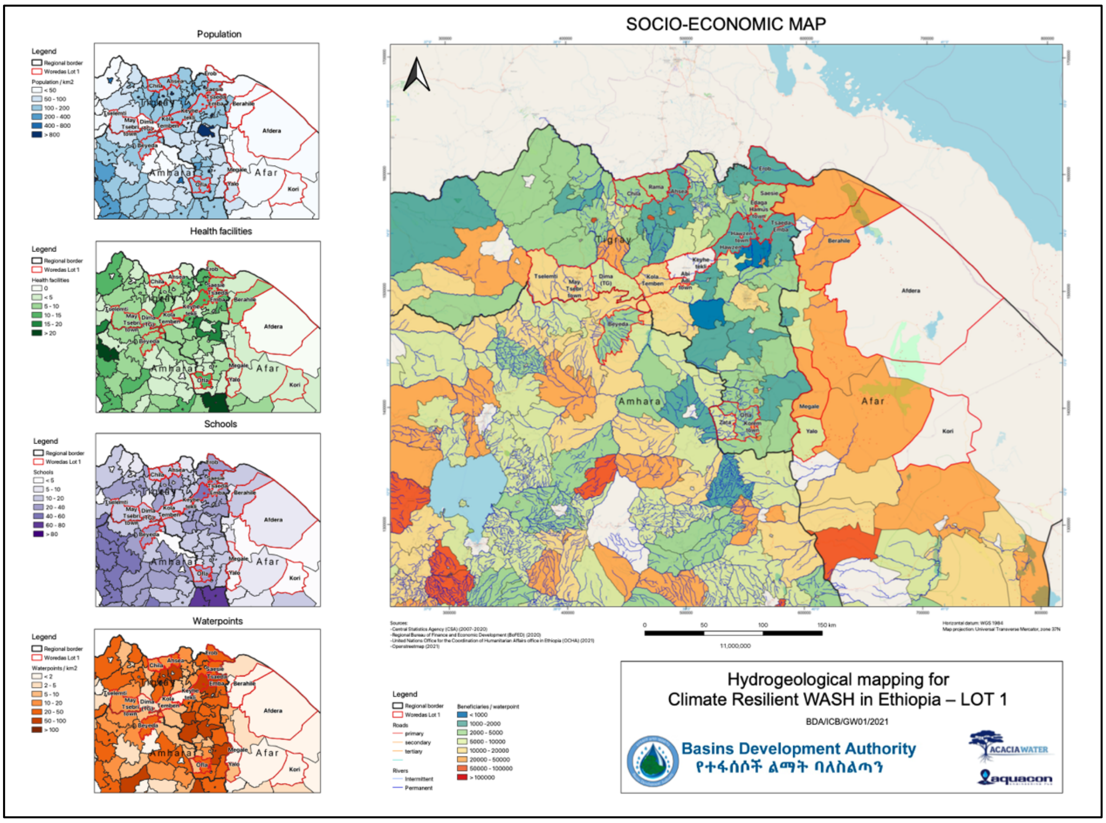


Figure 12Socio-economic map

4 Planning

4.1 Preparation next phases

The overall workplan is given in chapter § 2 'Methodology'. It largely follows the activities in the RFPS but is fine tuned to specific details.

During the Inception Phase, lots of efforts were made to develop a 'tentative planning timeline' for the project activities, which can be found in Annex 5. There are some limitations in preparing more detailed planning given the security issues in the project area.

4.2 Logistical arrangements

The Joint Venture (JV) of Acacia Water (Acacia) from the Netherlands and Aquacon Engineering PLC - Ethiopia (Aquacon) of Addis Ababa, Ethiopia with Acacia Water as lead firm. The JV partners are supported by UHL associates to provide technical support.

The international team and the key national experts will have their main office at the Acacia Water office in Addis. The international team members will present on the basis of short missions. The national project team focussing on the fieldwork will be accommodated in the office of Aquacon Engineering.

4.3 Training and manpower development

The foreseen training consists of two main components:

1. Training courses
2. On job-training

4.3.1 Training courses

Total 2 training courses of 5 days each for 10 and 10 participants will be provided

- Providing tutoring inputs in a 5-day training session for 15 participants and organized to explain the steps of remote sensing work and overlay analysis, ground water mapping, and the final interpretation of the maps for targeting well prospects, integrating borehole and surface geophysical information. Training will be organized for Ethiopian federal and regional governments, NGO partners and other relevant stakeholders. The venue and the agenda will have to be preapproved by DFID and training will be provided in English with translation.
- Capacity building of in 5 days for 10 BDA staff on the migration of all existing groundwater resources information, including RS data into the central database. The Consultant will provide all material and software for the training.

4.3.2 On-job training

Next to the technical activities, capacity building is also a key element of the project. We fully underline the importance of capacity building and training through different information activities including workshop and academic publications. Most of our key experts are university lecturers and have a broad experience in training and manpower development. They will lead the setup of a training plan during the inception phase based on a thorough assessment of the target audience and an assessment of their training needs.

4.4 Work practices

The management of the project consists of:

- International team leader: Dr Arjen de Vries with Mr. Zenaw Tessema as replacement
- National team leader: Mr. Jiri Sima with Mr. Abebe Ketema as replacement

The team will have monthly meetings with BDA designated point of contacts to review progress and discuss any technical or management issues. Minutes of the meetings will be shared with the client and the concerned team members in order to assure follow on agreed actions.

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