Hydrogeological Mapping for Climate Resilient WASH in Ethiopia – LOT 1

23 November 2021

Phase 2 Validation

BDA/ICB/GW01/2021

aquacon ENGINEERING PLC

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Background

- A project agreement was signed between BDA (Ministry of Water and Energy) and JV of Acacia Water (the Netherlands) and Aquacon Engineering PLC (Ethiopia) on May 14, 2021 for hydrogeological mapping of 13 woredas in northern Ethiopia (Tigray, Afar and Amhara Regions).

Project area

S.N	REGION	ZONE	WOREDA
1	Tigray	C. Tigray	Abergele
2	Tigray	C. Tigray	Kola Temben
3	Tigray	C. Tigray	Mereb Lehe
4	Tigray	E. Tigray	Erob
5	Tigray	E. Tigray	Hawzen
6	Tigray	E. Tigray	Saesi Tsaedaemba
7	Tigray	W. Tigray	Tsilemti
8	Afar	Zone1	Kori
9	Afar	Zone2	Afdera
10	Afar	Zone2	Berahle
11	Afar	Zone2	Megale
12	Afar	Zone 4	Yalo
13	Amhara	N. Gonder	Beyeda

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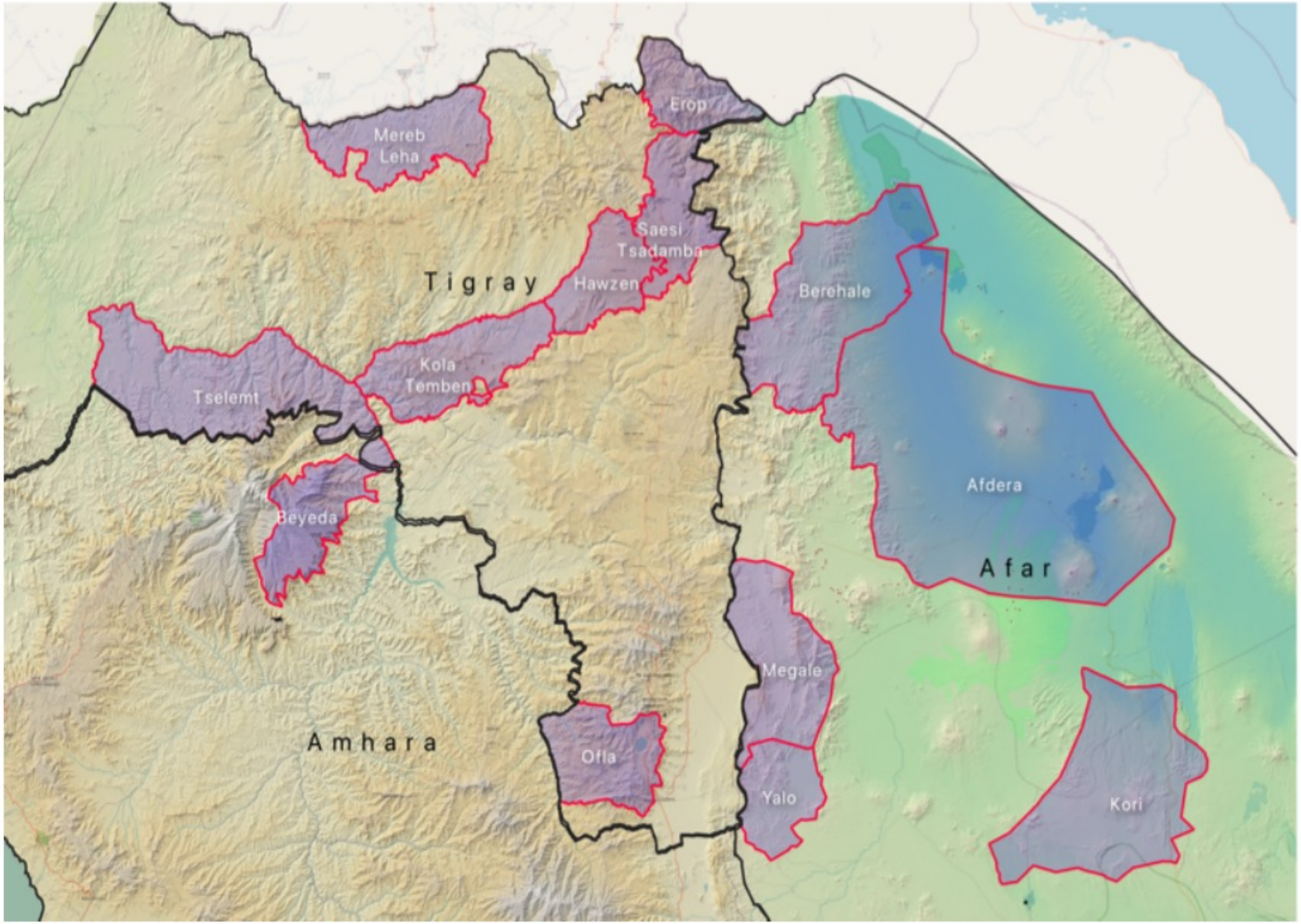

Figure 1 Location of the 13 selected woredas for Lot 1

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The project has been implemented in 3 phases :

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

Phase I has been completed in August 2021. This report covers the result of Phase 2. Phase III will start in December 2021, after the results from Phase 2 have been validated.

The main deliverables of Phase 2 are:

- Groundwater potential map of each woreda at a scale of 1:100,000
- Selection of groundwater potential areas and 2 drilling site per woreda
- Water demand estimation
- Ground water development Risk Mitigation Strategy

Objective

- **The overall objective** of the project is to increase access to safe and sustainable water for the drought affected areas of regions under considerations.

- **Specific objectives:**
- Carry out detail hydrogeological mapping of each woreda
- Identify groundwater potential areas and 2 target drilling sites per woreda
- Specify drilling methodology to be applied
- Provide capacity building trainings on the application of overlay analysis techniques for groundwater potential mapping in Ethiopia

Methodology

- **Collection and review all pertinent existing data and information from various sources :**
- Geological and hydrogeological maps and reports by GSE , MoWE and RWBs
- Post graduate thesis
- Geophysical data
- Borehole data
- Meteorological and river discharge data
- Satellite images

- **Field data collection (???)**
- **Carry out advanced data analysis and interpretation**
- **Carry out layer analysis and identification of potential areas and drilling sites**
- **Validation of results of layer analysis using existing borehole and satellite data**
- **Provide capacity building training**
- **Conduct validation workshop to get feed backs of stakeholders**

Overlay Analysis and GW Potential Maps

Overlay Analysis

The overlay analysis involves **GIS computation of groundwater potential**/suitability by factoring **various indicators** for groundwater and their **weighting factors.**

The **six** indicator parameters that were chosen are: Regional Permeability, Secondary permeability, Topographic location/Slope, Recharge, Land use and soil type.

The **groundwater potential** maps have been constructed using an automated GIS overlay procedure in **Quantum GIS** using the following primary overlay layers:

Overlay Analysis

Table 1 Overlay layers

Layer	Criteria	Indicators
1	Regional permeability	Rock type, Aquifer classification
2	Secondary permeability	Lineament proximity, Lineament density
3	Topographic location	Slope, Topographic wetness index
4	Recharge	Recharge rate
5	Land use	Recharge potential
6	Soil type	Infiltration capacity

1.Regional permeability

Table 2 Lithology, infiltration coefficients and aquifer classes

Code	Lithology	Infiltration coefficient	Aquifer class	Class description
M12	Low grade metamorphic rocks – phyllite and slate - metavolcanics rocks - intermediate and basic lavas, tuffaceous slate, agglomerate, rhyolite and metasediments - black slate, limestone, sandstone, siltstone and greywacke	0.08	B5	Fissured aquifers, low productive
M19	Medium grade metamorphic rocks – schist - phyllitic schist, metagreywacke and metaconglomerate	0.06	B5	Fissured aquifers, low productive
M29	Amphibolite	0.05	B5	Fissured aquifers, low productive

The **1:250,000** hydrogeological map that was composed during the inception phase contains **29** different **lithological codes** and **9 aquifer classes**. The aquifer classes (B1 to B9) are used as a proxy for the permeability layer, and the lithology code is used to derive the recharge layer

2.Secondary permeability (lineaments)

Used a combination of:

- the distance to lineaments (proximity in meter) and
- lineament density (length of lineaments per km2).

To prepare these two indicators, **fault lines** have been extracted from the **1:250,000** geological maps from the Geological Survey and **enhanced** the result with lineaments extracted from **multispectral** and **radar imagery (Landsat-8 and Sentinel1).**

3.Topographic location

- In both **literature** and **previous work in Ethiopia**, the **slope** of the terrain has been used for the topographic location criteria, while the **topographic wetness index** (TWI) has been used as a secondary criterion (Type II layer). During a meeting with BDA, DFID, Montrose, and the consultants in august 2021, it was decided to use the **TWI as a primary overlay layer** instead of slope.

4. Recharge

- estimated from the **average annual precipitation** (2000-2014) Climate Hazards Group InfraRed Precipitation with Station data **(CHIRPS)**. and **infiltration coefficient** related to the geology.
- For the recharge calculations, use is made of the study by MoWIE, BCEOM, ISL and BRGM in 1999 for the **Abbay River Basin Integrated Development Master Plan Project**. In the study, an infiltration coefficient was assigned to all lithological units appearing on the geological map of Ethiopia.
- The final recharge layer has been obtained by **multiplication** of the **annual precipitation** by the **infiltration coefficient**

5.Land use

- For the land use overlay layer, the **Sentinel-2 land use classification by ESA's CCI (2016)** was used. This dataset contains **10** land use classes on a 20 m resolution. The data has been **resampled** to 100 meter and reclassified to **6 land use classes** for the overlay analysis.

Table 3 Land use reclassification

ESA Land use		Overlay	
Class	Description	Class	Description
1	trees	3	forest
2	shrubs	2	bush/range land
3	Grassland	2	bush/range land
4	cropland	1	cropland
5	vegetation aquatic or regularly flooded	6	irrigated
6	lichen and mosses / sparse vegetation	4	degraded land
7	bare	4	degraded land
8	built up	5	urban area
9	snow and/or ice	n/a	
10	open water	6	irrigated

6.Soil type

The **recharge layer** has been prepared using annual precipitation and the infiltration coefficient derived from the lithology on the geological maps. In cases where a soil has developed that **limits the infiltration**, the recharge may be overestimated.

To **correct for the overestimation**, the saturated conductivity (Ksat) of the soil is used.

Ksat of the soil was derived using the **Rosetta pedotransfer function version 2 (Schaap et al. 2004)** which was applied to the soil clay, silt and sand content obtained from the SoilGrids dataset (Poggio et al. 2021) to estimate soil hydraulic parameters, such as hydraulic conductivity, using soil properties that are easily measured in the field.

Table 4 Saturated conductivity classes

Ksat cm/d	Class
< 28	Low
28 – 31	Low to medium
31 – 34	Medium
34 – 37	Medium to high
> 37	High

Classification and scoring of Input Layers

Table 5 Class scores

Permeability			
Aquifer class	Eigenvalue	Normalized weight	Relative score
B1	4.12	0.35	1.00
B2	2.06	0.18	0.50
B3	1.85	0.16	0.45
B4	1.15	0.10	0.28
B5	0.52	0.04	0.13
B6	0.33	0.03	0.08
B7	0.21	0.02	0.05
B9	1.49	0.13	0.36
		Consistency Index	0.06

Recharge			
Recharge in mm/y	Eigenvalue	Normalized weight	Relative score
<25	0.25	0.03	0.06
25 - 50	0.49	0.06	0.12
50 - 100	1.00	0.13	0.25
100 - 200	2.04	0.26	0.52
>200	3.94	0.51	1.00
		Consistency Index	0.06

Topographic location			
Slope in degrees	Eigenvalue	Normalized weight	Relative score
>15	0.34	0.05	0.12
10 - 15	0.58	0.09	0.20
5 - 10	1.00	0.15	0.34
2 - 5	1.72	0.26	0.59
<2	2.91	0.44	1.00
		Consistency Index	0.01

Topographic location (alternate)			
TWI	Eigenvalue	Normalized weight	Relative score
<2	0.25	0.03	0.06
2 - 5	0.49	0.06	0.12
5 - 10	1.00	0.13	0.25
10 - 20	2.04	0.26	0.52
>20	3.94	0.51	1.00
		Consistency Index	0.06

Land use, land cover			
Landuse	Eigenvalue	Normalized weight	Relative score
urban	0.32	0.03	0.08
bare	0.55	0.05	0.14
bush/rangelan(	1.00	0.09	0.26
forest	2.03	0.19	0.53
cropland	2.79	0.26	0.72
irrigated	3.85	0.37	1.00
		Consistency Index	0.02

Soil			
Ksat	Eigenvalue	Normalized weight	Relative score
<28	0.34	0.05	0.12
28 - 31	0.58	0.09	0.20
31 - 34	1.00	0.15	0.34
34 - 37	1.72	0.26	0.59
>37	2.91	0.44	1.00
		Consistency Index	0.01

Lineament density			
density in km/km2	Eigenvalue	Normalized weight	Relative score
<0.2	0.25	0.03	0.06
0.2 - 0.5	0.49	0.06	0.12
0.5 - 1.0	1.00	0.13	0.25
1.0 - 2.0	2.04	0.26	0.52
>2.0	3.94	0.51	1.00
		Consistency Index	0.06

Lineament proximity			
proximity in meter	Eigenvalue	Normalized weight	Relative score
>4000	0.25	0.03	0.07
2000 - 4000	0.53	0.07	0.15
1000 - 2000	1.05	0.14	0.30
500 - 1000	2.04	0.28	0.59
<500	3.47	0.47	1.00
		Consistency Index	0.03

Analytical Hierarchy Process **(AHP)** has been used (Saaty, 1977, 1982). Has been used to determine the **class scores**

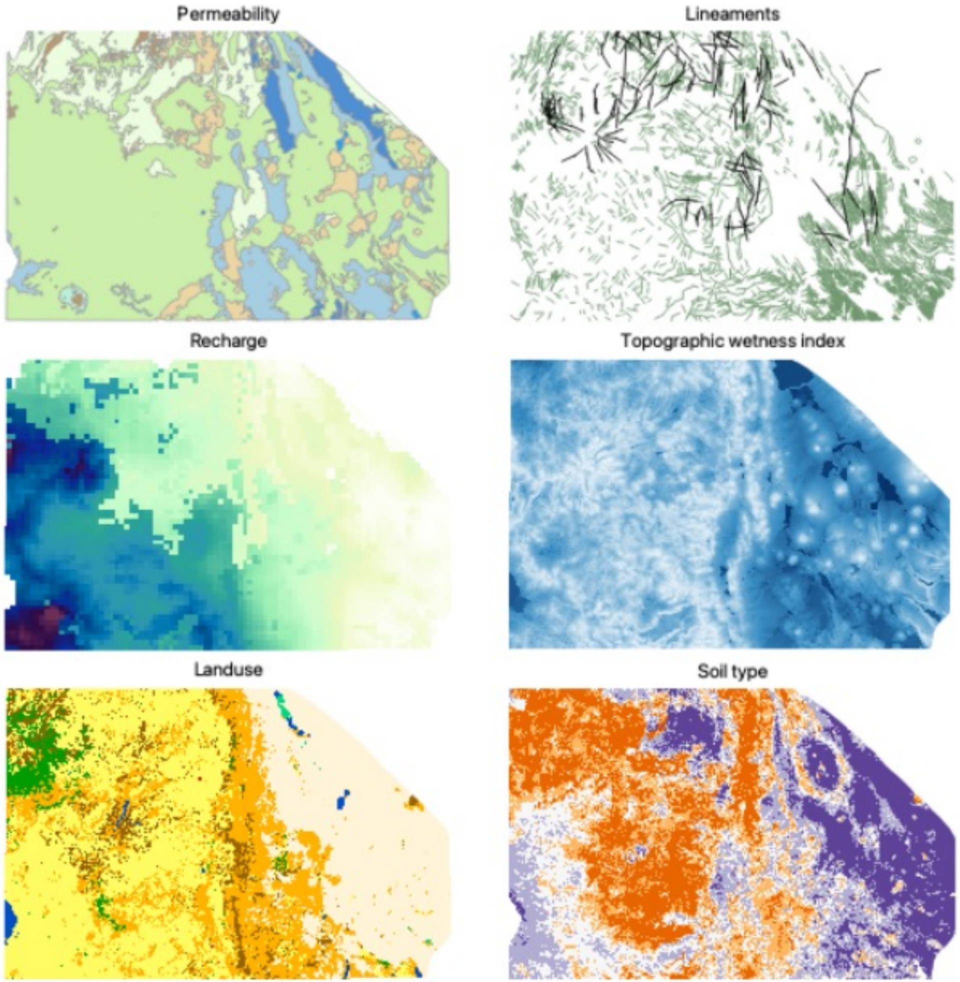


Figure 2 Input layers

Permeability and **topographic location (TWI)** are considered most significant for **all regions**. In **Tigray,** the topographic location, recharge, and occurrence of lineaments are considered more significant **than in Afar**, whereas in **Afar** the **regional permeability** alone determines one third of the suitability score

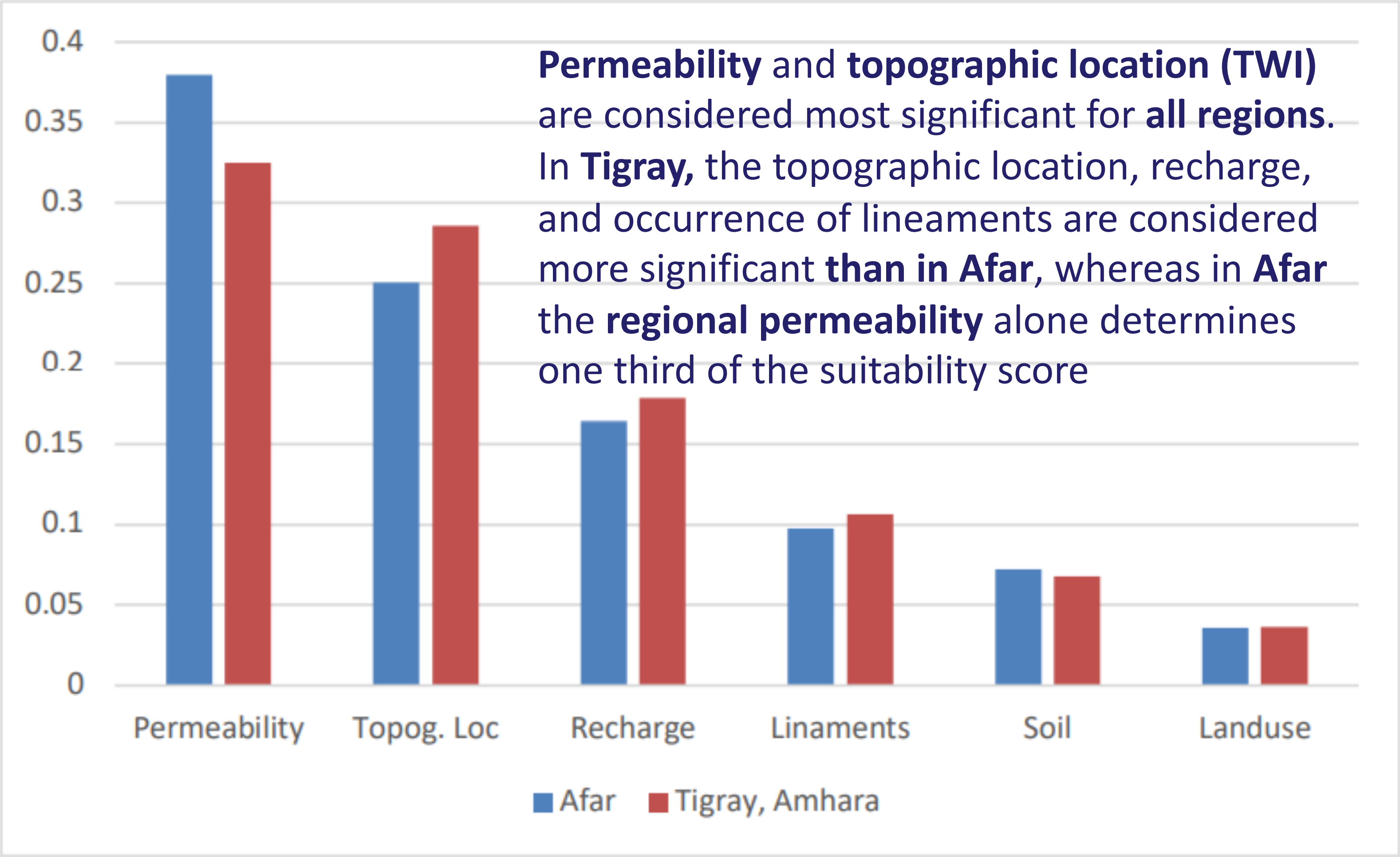


Figure 3 Layer weights per region

Regional Layers

Regional layer weights - Afar

Lithology class	score
Land use	0.04
Soil	0.07
Recharge	0.16
Topographic location	0.25
Lineaments	0.10
Permeability	0.38

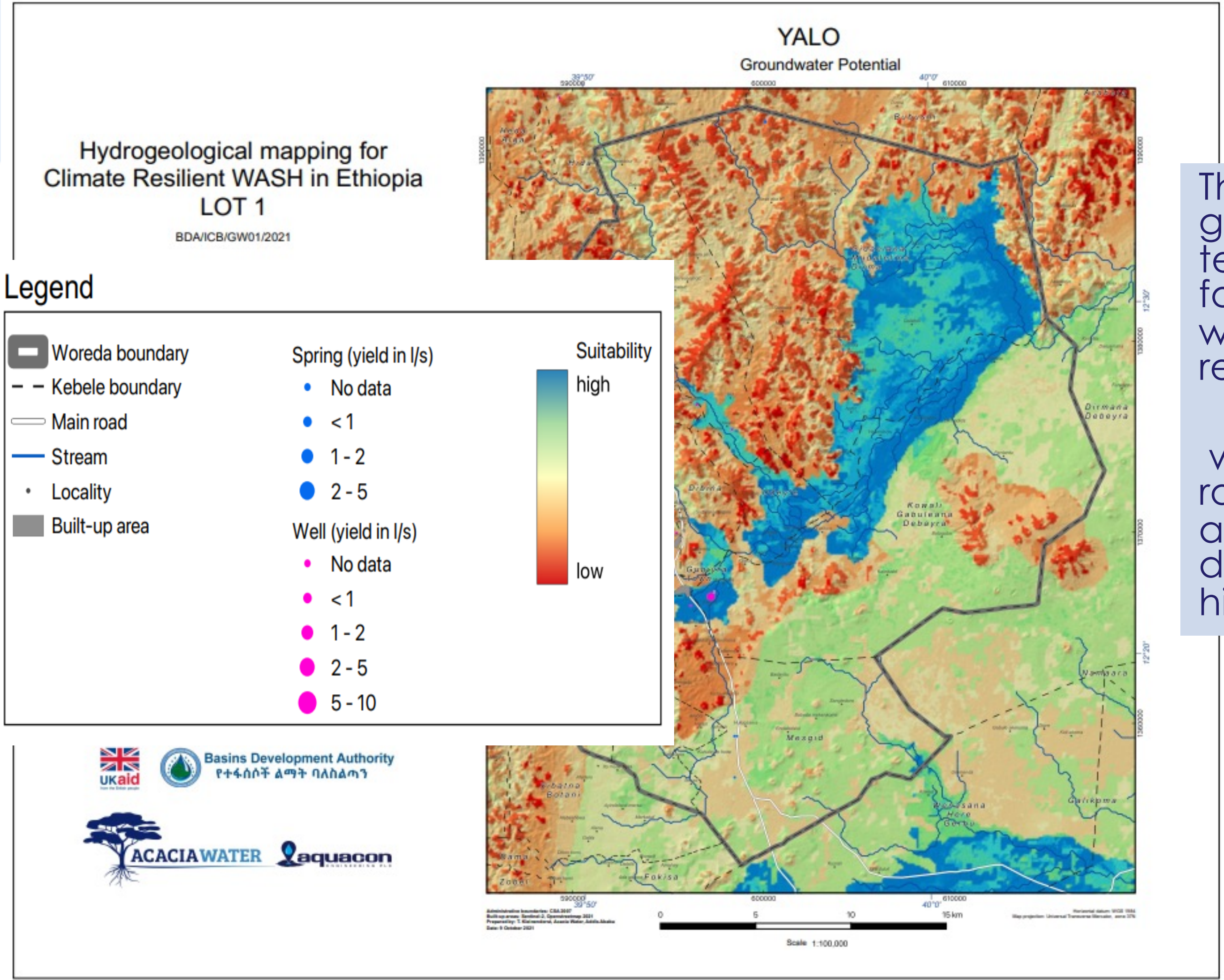
Regional Layers

Regional layer weights – Tigray and Amhara

Lithology class	score
Land use	0.04
Soil	0.07
Recharge	0.18
Topographic location	0.29
Lineaments	0.11
Permeability	0.32

Overlay Analysis Results

GW Potential Maps



The **maps show** the groundwater potential in terms of **relative suitability** for drilling productive water wells, and show relevant features like:

wells, springs, streams, roads, villages, built-up area, and administrative divisions on a backdrop of hill-shaded terrain.

Hydrogeology and conceptual models

Conceptual models

- Two transects along Hawzen – Berehale and Ofla – Yalo (Plateau to Rift valley) have been discussed here .

Hawzen

- Hawzen woreda is located in Eastern zone of the Tigray Region and has an area of 869 km2. It is located at the Western plateau (highlands). Its southern and western borders are formed by Tsaliet and Werei rivers (the Tekeze River tributaries).

Geology

- The northwest part of the woreda is covered mainly by basement rocks of low grade metamorphic rocks penetrated by intrusive rocks. The northeast part covered mainly by Edaga Arbi glacial. The southern part consists of Enticho sandstone additional to large strip of Edaga Arbi glacial and noncontiguous outcrops of Antalo limestone.

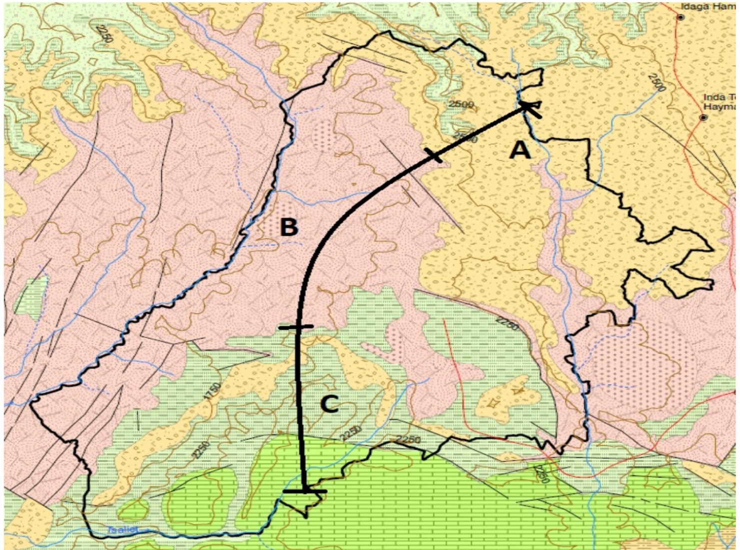
Hydrogeology

- Highly productive aquifers (T = 10.1 – 100 m2/d, q = 1.1 – 10 l/s·m, Q = 5 – 25 l/s for wells and/or springs) where groundwater is stored in and flows through the fractured and weathered parts of **limestone** and where the productivity could be enhanced by **karstification** along some fissures

- Moderately productive aquifers (T = 1.1–10 m2 /d, q = 0.011–0.1 l/s.m, with spring and well <u>yield Q = 0.51–5l/s</u>) where groundwater is stored in and flows through the fractured and weathered parts of **Adigrat sandstone**.
- Low productive fissured aquifers (T = 0.11 - 1 m2/d, q = 0.0011 - 0,01 l/sm, <u>Q = 0.05 -0.5 l/s</u> for wells and/or springs) in **Precambrian basement complex**

Water quality

- Groundwater is soft with TDS between 400 and 500 mg/l and no ions exceeding standards for drinking



Berehale Woreda

- It is located in the Afar Zone 2 and has an area of 2,509 km2.

Geology

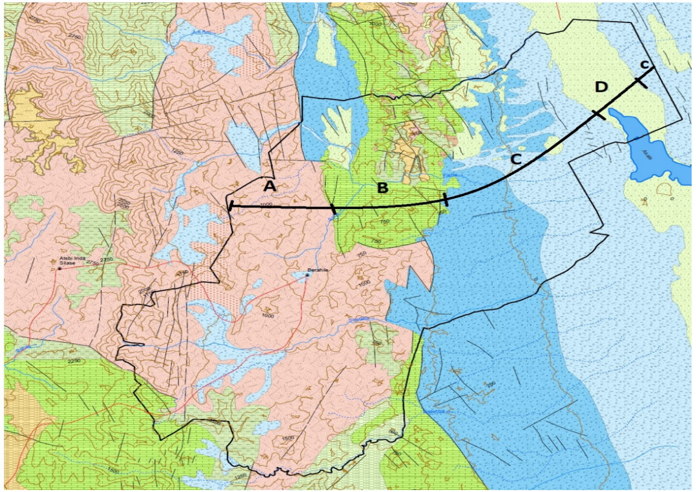
- Large part of Woreda is covered by basement of low grade metamorphic rocks .Central part is represented by sedimentary rocks (mainly limestone) and by high terraces fluvial deposits in its southern part.

Hydrogeology

- The Quaternary alluvium along rivers and at floor of Afar Depression, lacustrine sediments, and some volcanic material represent the main aquifers.

Water quality

- Groundwater is hard with TDS between 1000 and 2000 mg/l with content of sulphate and fluoride above standards for drinking water in the eastern part of Woreda (foot of escarpment).



Ofla

- Ofla Woreda is located Southern zone of the Tigray Region and has an area of 1,085 km2 .The area is located at the Western plateau (highlands) west of the surface water divide between Tekeze and Danakil basins.

Geology

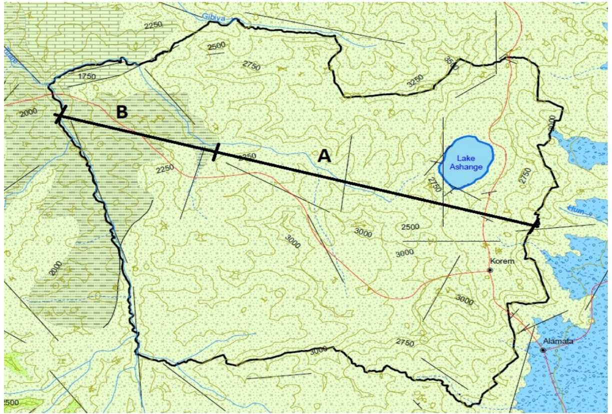
- The area is covered by volcanic (Ashangi basalts) and sedimentary (Upper sandstone) rocks.

Hydrogeology

- Hydrogeological units with porous permeability and moderate and locally high productivity (T = 1.1–10m2/d, q = 0.011–0.1 l/s.m, with spring and well yield Q = 0.51–5l/s) consisting of basalts and sandstone.

Water quality

- Groundwater is soft with TDS between 400 and 500 mg/l and no ions exceeding standards for drinking



Yalo

- Yalo Woreda is located in the Afar Zone 4 and has an area of 823 km2 .The area is mainly located at the Western Afar margin - hilly terrain (escarpment) and the Afar floor.

Geology

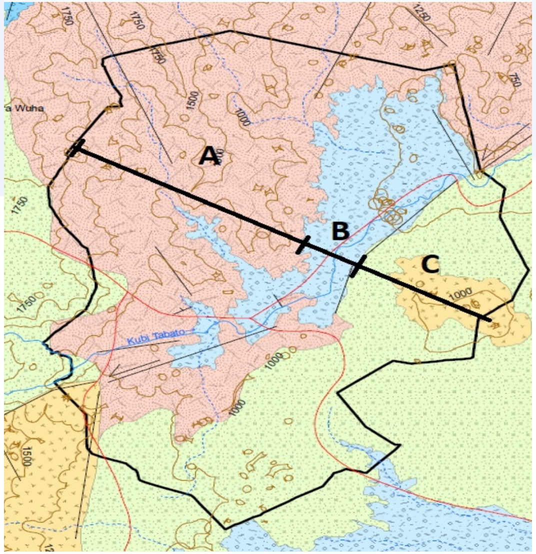
- The Woreda consist dominantly metavolcanicc rocks, volcanic rocks overlain by alluvial sediments and some outcrops of sedimentary rocks .

Hydrogeology

- Hydrogeological units with porous permeability and moderate productivity (T = 1.1–10 m2/d, q = 0.011–0.1 l/s.m, with spring and well yield Q = 0.51–5l/s) where groundwater is Stored in unconsolidated material.
- Hydrogeological units with fissured permeability and moderate productivity (T = 1.1–10 m2/d, q = 0.011–0.1 l/s.m, with spring and well yield Q = 0.51–5l/s) where groundwater is stored in and flows through the fractured and weathered parts of volcanic rocks.
- Low productive fissured aquifers (T = 0.11 - 1 m2/d, q = 0.0011 - 0,01 l/sm, Q = 0.05 -0.5 l/s for wells and/or springs) in Precambrian basement complex consisting of mainly metavolcanics.

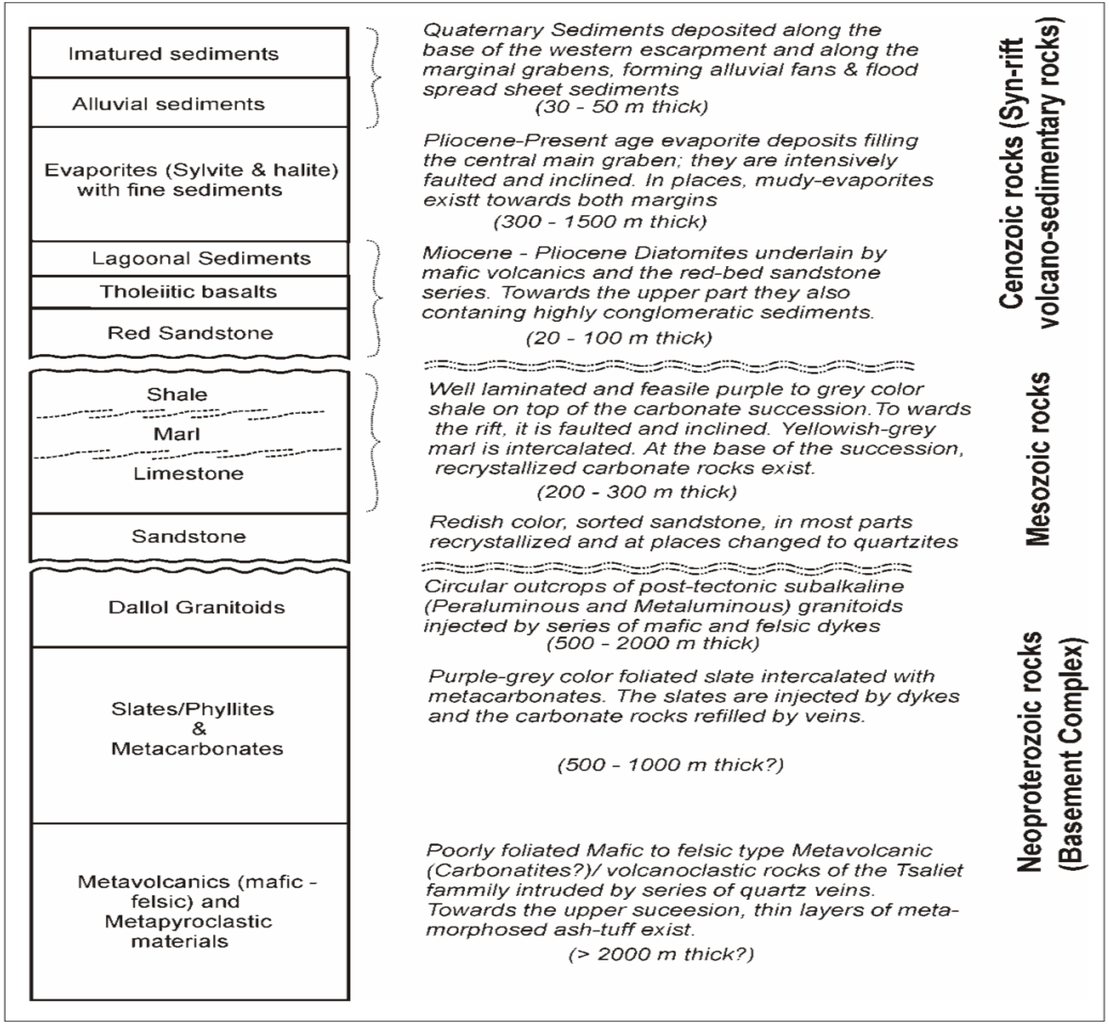
Water quality

- Groundwater TDS below 1000 mg/l and no ions exceeding standards for drinking.



Summary:

- TDS increases up to 5 fold along the flow path from Tigray highland to Afar depression because of long residence time and solubility of aquifer materials
- Groundwater discharge rate increases considerably from the plateau to the rift valley



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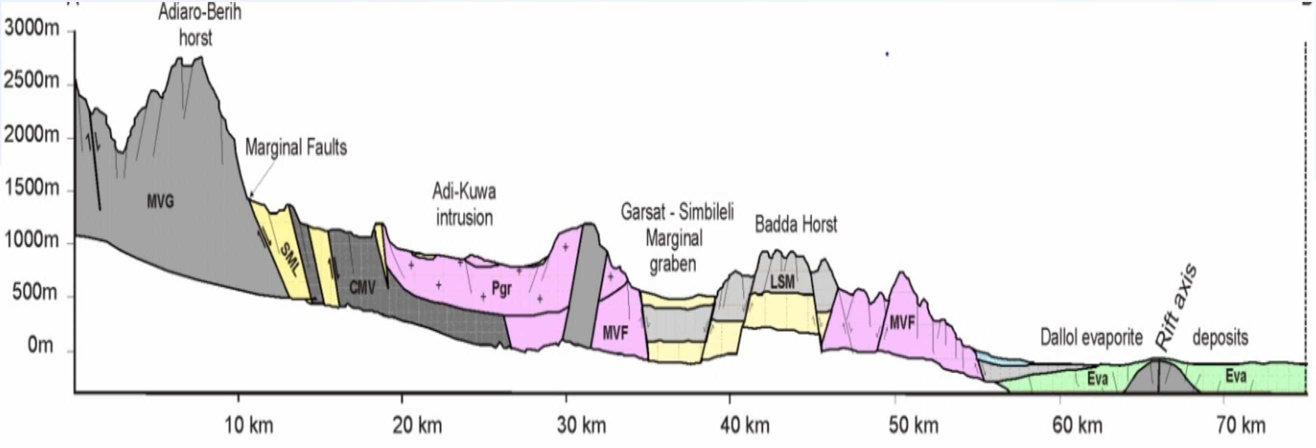


BPS	Boulder-gravel-sand-clay size deposit (alluvial fan), minor fossiliferous limestone	Quaternary to Miocene rock series
PS	Pebble - sand - clay size sediments, sheet flood terraces	Quaternary to Miocene rock series
DG	Diatomites and gypsum with thin lagoonal sediments	Quaternary to Miocene rock series
EvM	Evaporite deposits mixed with fine-grained sediments (mud and clay)	Quaternary to Miocene rock series
Eva	Evaporite deposits (Halite, Silvite, Carnallite) mixed with thin layers of anhydrite, gypsum and shale	Quaternary to Miocene rock series
LCG	Lagoonal sediments with calcite and gypsum	Quaternary to Miocene rock series
MaV	Mafic volcanics, intercalated with the underlying Red bed series,younger conglomerated and alluvial fans	Quaternary to Miocene rock series
RSA	Red Sandstone (Red bed series) overlain by poorly matured alluvial sediments	Quaternary to Miocene rock series
LSM	Moderatly recrystallized limestone and coquinated layers, intercalted with variegated shale, marl and in places, with recrystallized siltsone and fine to medium-grained sandstone (Quartzites).	Mesozoic rock series
FeV	Light-yellow colored felsic volcanics (Trachytes) intruding the post tectonic granitoids	Late Proterozoic rock series
Pgr	Post-tectonic Pinkish granite,intensively intruded both by mafic and felsic dykes	Late Proterozoic rock series
SML	Purple-grey color slate,interupted by meta-carbonates and mafic dykes	Late Proterozoic rock series
MVS	Veined metavolcanics interbedded with grey-purple slates, carbonates sandstones	Late Proterozoic rock series
MVF	Highly sheared mafic to felsic metavolcanics, intruded by felsic-mafic dykes	Late Proterozoic rock series
CMV	Massive metavolcanics with carbonitite origin	Late Proterozoic rock series
MVG	Weakly foliated metavolcanics, intercalated with meta-greywacke	Late Proterozoic rock series

Target areas

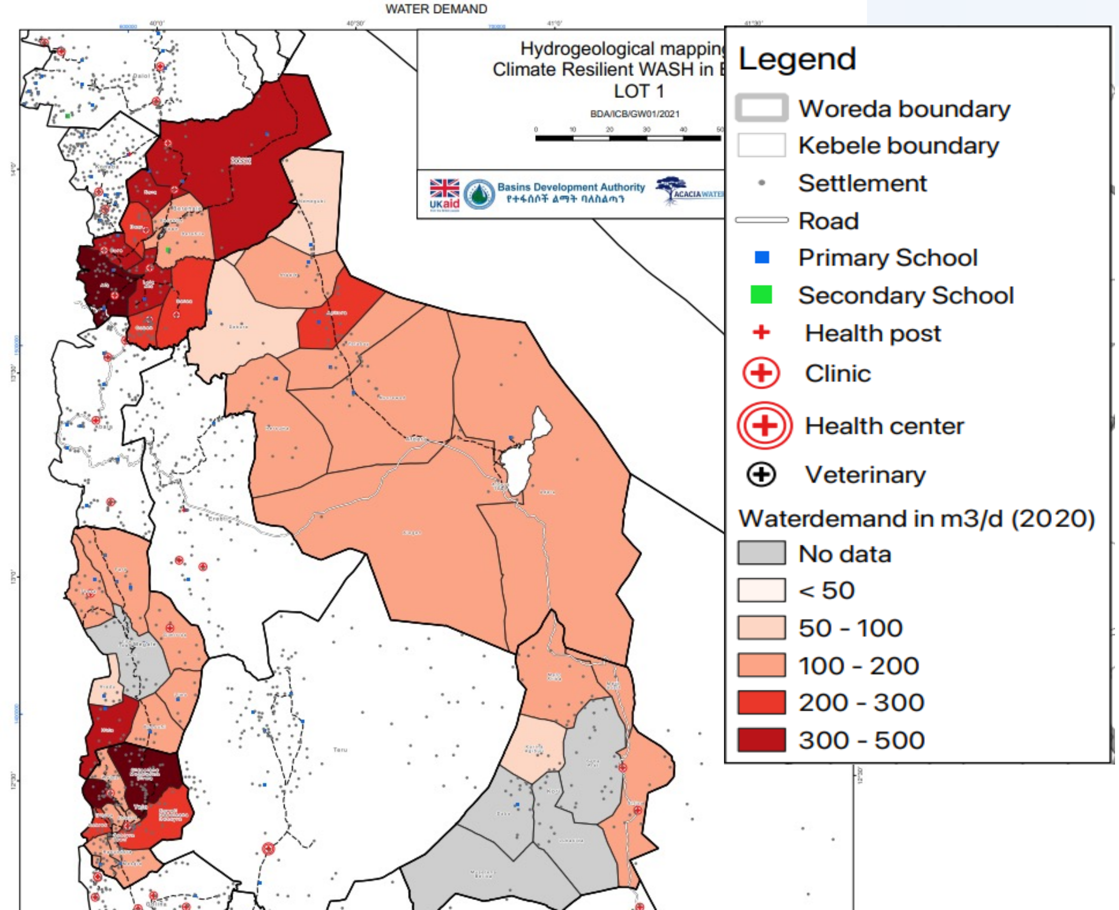
Target areas

Main Selection Criteria/Inputs used:

- Groundwater potential/suitability maps
- Hydrogeological conceptual models
- Socio-economic and water demand maps
- Access

As a result of these evaluations **2-4** potential target areas have been selected for each Kebeles with alternative options for prioritization during the actual field verifications and geophysical surveys. A total of **44 target areas** have been selected within the three regions **(Afar, Amhara and Tigray)**

AFAR



Data Sources and assumptions:

- **Population data:** based on the census 2007 data (CSA, 2017, 2019)
- **Water demand:** According to the GTP II: Rural, 25(lpcd), for Urban Kebeles 50 lpcd.

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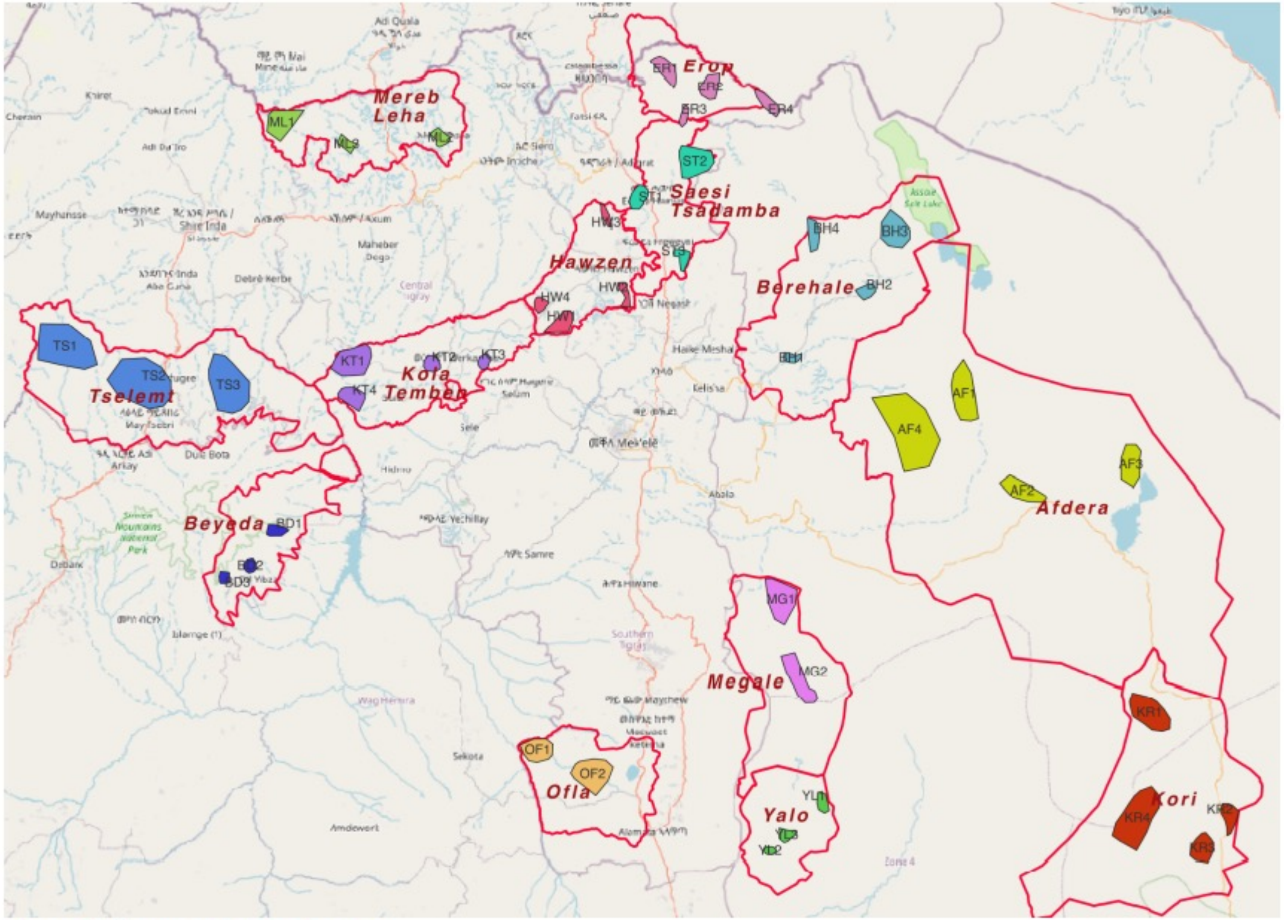

Figure 20 Proposed target areas

Table 8 Target areas

Target Area	Region	Zone	Woreda	Kebele	centerX	centerY	Area (km²)
AF1	Afar	Zone 02	Afdera	Ayitura	656516	1506757	104
Moderately productive porous aquifers where groundwater flowing to the northeast is accumulated by barrier of central massif of Erta Ale and can be developed by shallow and deep wells.							
AF2	Afar	Zone 02	Afdera	Kusrewad	668417	1479526	180
Moderately productive porous aquifers where groundwater flowing to the southeast is accumulated by barrier of central massif of Erta Ale and can be developed by shallow and deep wells.							
AF3	Afar	Zone 02	Afdera	Adela	707743	1485034	63
Moderately productive porous aquifers where groundwater flowing (from Danakil Alps) to the southwest is accumulated by barrier of central massif of Erta Ale and can be developed by shallow and deep wells							
AF4	Afar	Zone 02	Afdera	Debure	638272	1497458	228
Highly productive porous aquifers (high terraces) where surface and groundwater flowing from the escarpment to the east is infiltrating into aquifers and can be developed by deep wells							
BD1	Amhara	North Gondar	Beyeda	Liwaer	444830	1464676	18
Moderately productive fissured aquifers in basalts with high rainfall and good infiltration. Groundwater resources can developed by deep wells drilled into faults and lineaments (higher discharge) and by spring development.							
BD2	Amhara	North Gondar	Beyeda	Abare	436821	1453824	13
Moderately productive fissured aquifers in basalts with high rainfall and good infiltration. Groundwater resources can developed by deep wells drilled into faults and lineaments (higher discharge) and by spring development							
BD3	Amhara	North Gondar	Beyeda	Beya	428874	1450180	11

Risk Mitigation Strategy in Development of GW resources (Zenaw)

The Risk Mitigation Strategy (RMS)

Primarily focus on the steps and processes required to **evaluate and mitigate risks to borehole functionality**.

Steps in the process (**Five steps**):

Step 1: To **develop a ranking matrix** and develop an analysis/probability of current risk levels for each Woreda.

Step 2: Development of risk mitigation strategies for various levels/probabilities of risk that can be implemented in the field.

Steps 3 - 5 are focused on **maximizing sustainable borehole yields** and **minimizing** both **water quality and borehole functionality risks t**hat can be implemented in the **field**

Main focus area is to **outline strategies** to make boreholes/water sources climate resilient.

As a starting point the following "**Mapping Products"** can be used to develop cross-cutting strategies:

1. Precipitation map
2. Recharge map
3. Aquifer mapping
4. Topographic maps, versions updated with DEM and/or LIDAR data
5. Lineaments/siting overlay mapping

The **major technical areas** associated with the **provision of a sustainable long-term groundwater supply sources** include:

(a) borehole yield (initial tested yield and borehole-yield maintenance over time);
(b) borehole water quality (natural and anthropogenic); and
(c) borehole operational functionality.

Step 1: Risk (Vulnerability) Identification and Ranking

The focus of this **initial effort** will be to **outline a methodology and approach** to make boreholes **"climate resilient"**.

development of a ranking matrix to synthesize the **baseline risk factors including**:

1. Aquifer Type: Productive to Marginal (unconfined/confined)
2. Aquifer Static Reserve: High to Low
3. Groundwater Recharge: High to Negligible (0)
4. Current/Future Groundwater Use Comparison to Groundwater Recharge (Analysis of Inputs – Outputs).

A **ranking matrix** will provide an **initial analysis of low to high risk Woredas** and differentiate approaches to risk mitigation

Risk Ranking Matrix Framework

Category	Low Risk	Medium Risk	High Risk
(1). Aquifer Type - Productive to Marginal	B1/2	B4	B5/6
(2). Static Reserve - High to Low	B1/2	B4	B5/6
(3). Annual Recharge – High to Negligible (0)	>150mm/year	50- 150 mm/year	<50 mm/year
(4). Inputs vs. Outputs - Ratio of inputs/outputs	High Ratio – say 5	GW use < or in balance with Recharge	GW use > recharge

1. The Main Aquifer Types in Lot 1 can be broken out into four (4) broad categories including:
    a. B1/2 – sediments/alluvium
    b. B4 – carbonate, sedimentary, basalts, and metamorphic rocks
    c. B5 - basement rocks
    d. B6 - minor aquifers – shale, gypsum, ignimbrite, rhyolite, etc..

Step 2: Risk Mitigation Strategies

Based on the development of risk levels in Step 1, “Risk Mitigation Strategies” may be developed and applied.

Some preliminary examples of identified risks and mitigation strategies are outlined below.

(1) High Existing Risk: examples would include:

- 0 to negligible recharge (<50mm/year)

- Groundwater use>Recharge

Potential mitigation measures might include:

- Water rationing/use restrictions.
- Brackish water resource evaluation and desal applications
- Wastewater reuse for certain applications such as irrigation.

(2)Medium Existing Risk:

- Groundwater use and recharge are in balance.
- Static reserve provides a good drought buffer, i.e. say 30 years for groundwater storage to meet current/future demands.

Example **mitigation measures:**

- Water use restrictions
- Groundwater recharge enhancement (MAR)
- Installation of deeper boreholes in certain aquifer units where fresh groundwater occurrence at depth has been proven out.

(3) Low Existing Risk:

- Productive aquifer systems with large static reserve
- Groundwater recharge much > groundwater use
- Groundwater management systems in place and working.

Step 3: Maximizing Borehole Yields

Key 'Risk Mitigation Measures (RMM)' that will be applied to maximize boreholes yields and make them sustainable in the long run and through wet and extended dry periods are outlined below.

✓ **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 analyze data for long-term sustained borehole yields for both current and future populations.

Step 4: Minimizing Water Quality Risks:

- **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

Step 5: Borehole Functionality Risk Mitigation:

- 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

Phase 3 alternative approach and Methodology

Phase 3 alternative approach

- Field surveys not possible due to access restrictions
- Alternative approach
  - Existing data
  - High resolution satellite imagery
  - Airborne geophysics
  - Climate resilience

Existing data (1)

- Tigray region
  - 16,000 wells
  - 2,600 springs
  - 210 water samples
  - 2,620 analyses
- Afar region
  - 727 wells
  - 101 springs
  - 10 water samples
  - 164 analyses

Existing data (2)

Woreda/region	Wells
Afar	**51**
Afdera	26
Berehale	17
Kori	1
Megale	3
Yalo	4
Amahara	**51**
Beyeda	51
Tigray	**3796**
Erop	251
Hawzen	1136
Kola Temben	256
Mereb Leha	375
Ofla	393
Saesi Tsadamba	1218
Tselemt	167
Grand Total	**3898**

Woreda/region	Springs
Afar	**42**
Afdera	11
Berehale	19
Megale	2
Yalo	10
Amahara	**89**
Beyeda	89
Tigray	**501**
Erop	39
Hawzen	96
Kola Temben	53
Mereb Leha	4
Ofla	139
Saesi Tsadamba	73
Tselemt	97
Grand Total	**632**

Satellite imagery

- Multispectral imagery
  - Worldview (Panchromatic: 0.3 m, Near Infrared: 1.2m)
  - Triplesat (pan: 0.8 m, nir: 3.2 m)
  - IKONOS (pan: 1 m, nir: 4m)
  - Spot 6 (pan: 1 m, nir: 6 m)
  - Sentinel-2 (10 m)
- Radar, soil moisture and water content products
  - Sentinel-1 SAR (3.5 - 10 m)
  - Wapor (30 – 100m)
  - Vandersat (100 m)
- Lineament detection
  - Manual (photographs, Google Earth)
  - Automatic (Radar, Multispectral imagery)

Airborne geophysics

- Geological Survey
  - Gravimetry
    - Deeper aquifers
    - Main structures
  - Magnetometry
    - Main fault lines, lineaments and intrusive
- Mining industry
  - Quite some (airborne) surveys done
  - Accessible?

Climate resilience

- Detailed watershed delineation
- Evaporation, precipitation etc from satellite products
- Soil type, lithology from existing datasets
- Long term trends from climate models
- Abstractions from inventory data
- Stream flow, runoff modelling
- Wetspass, SWAT modelling
- Use GWBSS methodology

Thanks for your attention

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