Shallow Groundwater Atlas for Household Irrigation, Southern Ethiopia Oromia Regional State

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Ministry of Agriculture

Ethiopian ATA
Agricultural Transformation Agency
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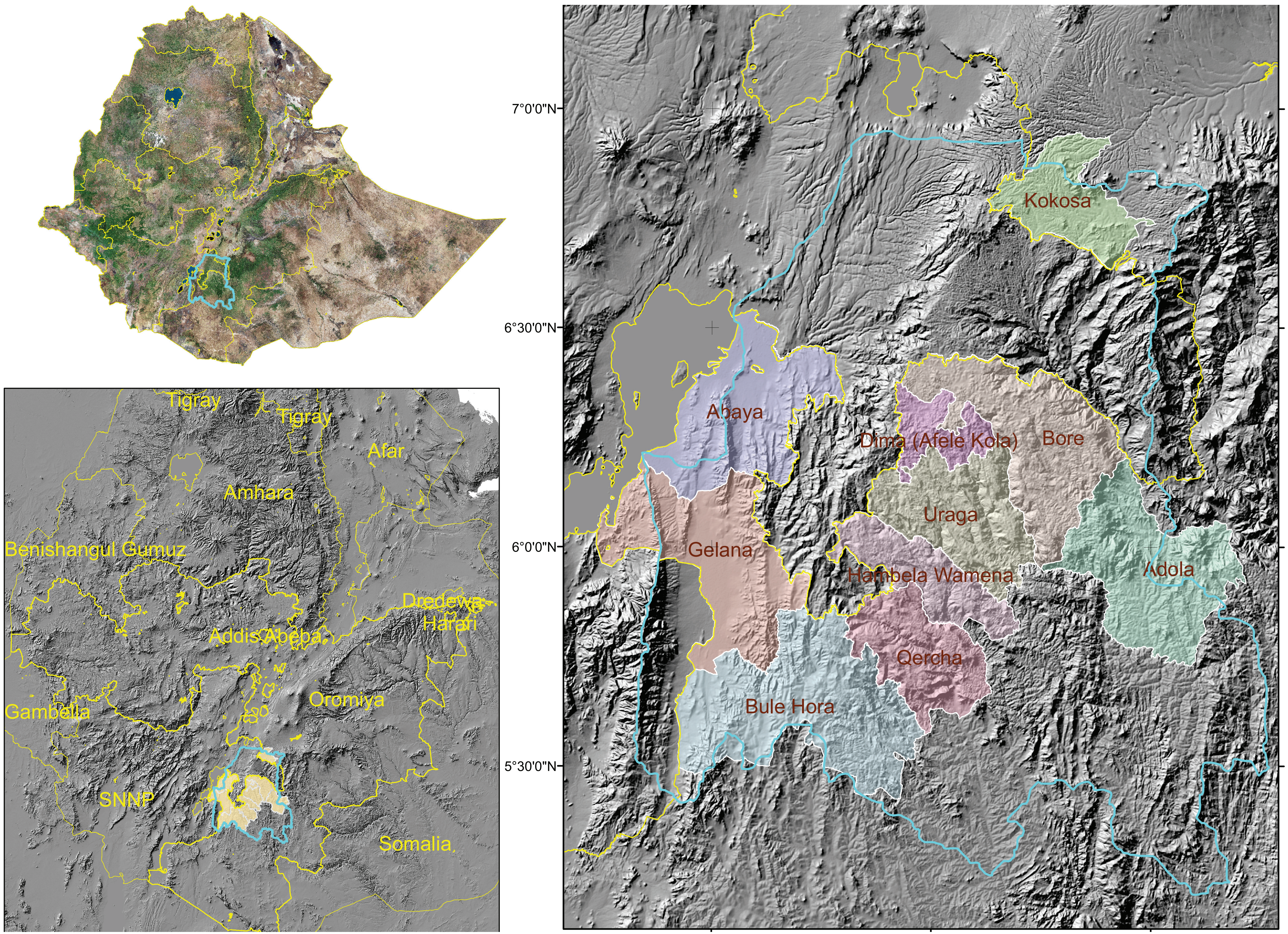

Tigray
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Addis Abeba
Oromiya
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Kokosa
Abaya
Dima (Afele Kola)
Bore
Uraga
Gelana
Hambela Wamena
Adola
Qercha
Bule Hora

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Acronyms

AAU	:	Addis Ababa University
ADLI	:	Agricultural Development Led Industrialization
AGP	:	Agricultural Growth Program
ATA	:	Agricultural Transformation Agency
BH	:	Borehole
CEO	:	Chief Executive Officer
CDA	:	Czech Development Agency
CHAMP	:	CHAllenging Minisatellite Payload
DEM	:	Digital Elevation Model
DMT	:	Density Mapping Technology
EATA/ATA	:	Ethiopian Agricultural Transformation Agency
EC	:	Electrical Conductivity
ECSA/CSA	:	Ethiopian Central Statistical Agency
GENS	:	Groundwater Exploration Navigation System
GDP	:	Growth Domestic Product
GIS	:	Geographical Information System
GOCE	:	Gravity Field and Steady-State Ocean Circulation Explorer
GoE	:	Government of Ethiopia
GPS	:	Ground Positioning System
GRACE	:	Gravity Recovery And Climate Experiment
GSE	:	Geological Survey of Ethiopia
GTP	:	Growth and Transformation Plan
GWRAD	:	Ground Water Resource Assessment Directorate
HDW	:	Hand Dug well
HHI	:	Household Irrigation
HVC	:	High-value crops
K	:	Hydraulic Conductivity
MDG	:	Millennium Development Goal
MoWIE	:	Ministry of Water, Irrigation and Electricity
MoANR	:	Ministry of Agriculture and Natural Resource
NGO	:	Non-governmental Organization
NMSA	:	National Meteorological Service Agency
NRMD	:	Natural Resources Management Directorate
PET	:	Potential Evapotranspiration
PHHS	:	Potential Household number to be served
PPOPS	:	Potential Population to be served by Small scale Irrigation
R	:	Recharge
RGW	:	Renewable Groundwater
RBOA/BOA	:	Regional Bureau of Agriculture
RS	:	Remote Sensing
RWH	:	Rainwater harvesting
RWP	:	Rope-and-washer pump
RTI	:	Radar Technology International
Q	:	Discharge of Water
SGW/SGWM	:	Shallow Groundwater Mapping
SLM	:	Sustainable Land Management
SMF	:	Smallholder Farmer
SNNP	:	Southern Nations Nationalities and Peoples’
SP	:	Spring
SRTM	:	Shuttle Radar Terrain Mission
SSI	:	Small-scale irrigation
STE	:	Senior Technical Expert
T	:	Transmissivity
TDS	:	Total Dissolved Solids
TP	:	Treadle Pump
UTM	:	Universal Transverse Mercantile
VES	:	Vertical Electrical Sounding
VSGW/SGW	:	Very Shallow Groundwater
WATEX	:	Water for Every X (Everyone and Everywhere)
WETSPASS	:	Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady State
WHO	:	World Health Organization
WMO	:	World Meteorological Organization
WOA	:	Woreda Office of Agriculture
WS	:	Water Supply
WT	:	Water Table
WOA	:	Woreda Office of Agriculture
ZOA	:	Zonal Office of Agriculture

Foreword by H.E. Minister of Agriculture & Natural Resources

Given that agriculture is the dominant economic sector of Ethiopia, the Government is truly committed to agricultural and rural development. The Ministry of Agriculture and Natural Resources (MoANR) is the federal organization responsible for maintaining the country's agricultural growth. The Ministry is charged with developing and refining national agricultural and rural development strategies and policies, with input and support from the regional administrations and other significant stakeholders. One such strategy is the Agricultural Development Led Industrialization (ADLI) strategy that aims to transform the country's economy into a well-developed and prosperous one. This strategy is based on the realities of the country and its prime objective is to accelerate agricultural production and productivity at all levels. Since the launch of this timely national strategy, the agriculture sector has come to drive Ethiopia's overall economic performance.

The first five-year Growth and Transformation Plan (GTP I) and the Agricultural Growth Program (AGP) within the MoANR have both contributed to great progress made in the country's economic growth. Building on the progress made under GTP I and setting strategic directions, GTP II continues to put emphasis on economic sector development, led by agricultural and rural transformation. Development of smallholder production of crop and livestock products will be further enhanced, and hence, will remain the main source of growth and rural transformation during GTP II. In order to achieve these goals, natural resources will need to be adequately identified, developed, and managed]to make Ethiopian agriculture sustainable. This will be done through aligning the plan for agricultural development with the green economy development strategy, coupled with an expanded irrigation use.

The country has enormous groundwater resource that can be utilized for irrigation. GTP II intends to increase farmers' production and productivity through improved utilization of agro-ecological based irrigation schemes, so that farmers can grow a wider variety of crops year round. Over four million hectares of land can be cultivated by strengthening irrigation activities that can be undertaken by smallholder farmers: the objective is to increase the area of land covered by irrigation from 2.34 million hectares in 2014/15 to 4.14 hectares by the end of 2019/20, (thereby irrigating 1.74 million hectares of additional land). GTP II also aims to provide access to at least one alternative water point for 80% of smallholder farmers, pastoralists, and semi-pastoralists, of which 50% are users of the full irrigation farming package are the major targets set to irrigation development during GTP II.[1] If these targets are achieved as planned, this will contribute to the realization of the irrigation potential of the country.

The Sustainable Irrigation and Watershed Development program that is part of the Transformation Agenda has been identified as a key opportunity to transform the lives of smallholder farmers, increase incomes, and ensure food security at the household and national levels. The Small Scale Irrigation Development Directorate of the MoANR and the ATA jointly take ownership and coordinate implementation of this program in collaboration with the irrigation offices at Regional, Zonal, and Woreda Bureaus of Agriculture and Natural Resources (BoANRs), and Regional Irrigation Development Authorities. Through this partnership, SGW potential in Southern Ethiopia thas been assessed and mapped in this Atlas, which can be used to identify locations ideal for HHI.

The relative inexperience of Ethiopia in using groundwater for irrigation presents a challenge to the development of the resource, especially exploration at a scale of 1:50,000; in addition, the development and management of SGW makes the challenge more prominent. Nonetheless, the Ministry understands how SGW irrigation can impact agricultural transformation, and therefore the country's overall economic growth. As such, developing HHI using SGW resources is a priority agenda item for Ethiopia's transformation.This Atlas is the culmination of a project to which the ATA, the Sustainable Irrigation and Watershed Development team, the Czech Development Agency (CZDA), AQUATEST, and Addis Ababa University (AAU) have all contributed greatly. The Ministry is grateful to all partners for their expert input and the excellent application of technology. We are confident that the Atlas will positively impact the country's agricultural growth, and we are committed to ensure that the development of SGW for HHI is utilized to transform the agriculture sector.

With the tremendous potential of SGW for HHI in mind, we encourage all stakeholders and actors to undertake their utmost efforts in the timely implementation of the intervention contained herein. Together, we will be able to improve the livelihoods of smallholder farmers while contributing to Ethiopia's overall vision of achieving middle income status by 2025.

Dr. Eyasu Abreha
Minister of Agriculture and Natural Resources, FDRE

Foreword by H.E. Ambassador of the Czech Republic

In recent years, Ethiopia has made great progress in the achievement of the Millennium Development Goals. It succeeded, inter alia, to reduce extreme poverty of its population to less than 24%, to reduce child mortality by two-thirds between 2000 and 2015, and to secure sustainability of environment. Food security and access to safe drinking water play a significant and truly elementary role in this regard. As an agricultural country, Ethiopia depends on its groundwater resources; an irreplaceable role in mapping the groundwater resources is played by the Ethiopian Agricultural Transformation Agency.

The Czech Republic has been assisting Ethiopia in mapping the groundwater resources for some thirty years, while assistance and transfer of know-how in the sectors of agriculture and water resources management are indeed in the spotlight of the Czech Development Cooperation Program. Since its foundation, the ATA has been considered a key partner due to its important role in the transformation of the Ethiopian agricultural sector. The ATA's Sustainable Irrigation and Watershed Development program gives opportunity not only to family farmers but also enables true experts to grow, who will participate in large-scale irrigation projects in near future.

The report on Shallow Groundwater Mapping in Pilot Area in Southern Ethiopia was prepared in the form of a feasibility study for identification and assessment of shallow groundwater for household irrigation within the framework of the Partnership Program designed and financed by the Czech Development Agency of the Government of the Czech Republic. The study was launched based on a Memorandum of Understanding between the Agricultural Transformation Agency, Ministry of Agriculture of Ethiopia and Czech Company AQUATEST in July 2015, and finalized in April 2016.

The study is not a conventional hydrogeological study or mapping but rather deliberately focused research identifying and assessing aquifers with shallow groundwater suitable for household irrigation. It pertains to the pilot area covering over 20,117 square kilometers in the SNNP and Oromia regions at a scale of 1:50,000, while meeting technological criteria such as scientific and technological merits, accuracy, cost effectiveness and scalability.

A hydrogeological conceptual model and final hydrogeological map were constructed based on an assessment of existing data from the Shuttle Radar Topography Mission DEM, Density Mapping Technology developed in the Czech Republic, photomosaic of optic-satellite photographs and field trips for data collection and provision of ground truth for satellite data assessment.

The irrigation potential in the pilot area is very good: there are shallow groundwater resources of 676.45 million cubic meters with irrigation capacity of 21.422 liters per second, which represents sustainable shallow groundwater resources for irrigation of about 85.689 households in the pilot area.

As Ambassador of the Czech Republic, it gives me great pleasure to see that growing cooperation between my country and Ethiopia represented by the ATA and the MoANR will soon bear fruits for the benefit of family and small-scale farmers and hope that many successful projects implemented in cooperation with ATA will follow in the not-so-distant future.

Karel Hejč
Ambassador of the Czech Republic

Foreword by the CEO of the ATA

Given that agriculture is the most dominant sector of the Ethiopian economy, the Government has developed a clear development investment framework for agricultural growth, with the aim of ensuring food security of its nations, nationalities and people. The majority of the sector is made up of smallholder farmers – thus, transformation of agriculture relies heavily on the transformation of smallholder farming. Although many opportunities exist to accelerate growth and transformation in the sector, a number of systemic bottlenecks also exist that must be overcome.

The Government of Ethiopia established the ATA in December 2010 to promote agricultural transformation by enhancing and supporting existing structures of government, private sector and other non-governmental partners to address bottlenecks in the system and deliver on a priority national agenda to achieve food security, poverty reduction, and human and economic development. The ATA supports the Agricultural Transformation Agenda, which is a set of interventions (called Deliverables) designed and selected to unlock bottlenecks to catalyze growth.

The Transformation Agenda within GTP II has developed 30 programs that fall within four strategic pillars, and one "Anchor Initiative" to integrate the impact of interventions on the ground. These programs target prioritized areas such as increasing crop and livestock production and productivity; driving subsistence farmers to a commercial orientation and developing markets; promoting environmentally sustainable and inclusive growth and national food security; and enhancing the implementation capacity of important stakeholders. The ATA is responsible for coordinating and monitoring implementation of all Deliverables and reporting progress to the Transformation Council. Sustainable Irrigation and Watershed Development is one of the ATA's interventions viewed as an opportunity to transform the lives of smallholder farmers and increase their incomes. Designed to be implemented parallel with AGP II, the program aims to support smallholder farmers by providing information and technical input on using shallow groundwater for household irrigation. A major initiative of the program has been to pilot the SGW mapping project to determine SGW resources and lifting technologies for HHI in Southern Ethiopia, specifically in the Oromia and SNNP regions, and for eventual national scale-up.

All technologies identified and experience gained in SGW mapping will assist relevant stakeholders to accurately assess the country's groundwater resources and develop HHI, which provides farmers with tremendous opportunities. With HHI, farmers can cultivate crops during the dry season in addition to the traditional rainy season, as well as be able to grow high value crops for extra earnings. Famers' adoption of effective HHI technologies can increase their incomes and help improve food security throughout the year, thus catalyzing growth in farming communities. The ATA seeks to accelerate this transformation of the agriculture sector, and, in this way ensures that efforts are aligned, activities are coordinated, and an enabling environment is created for farmers to benefit from adopting proven technologies.

It is with the support and contribution of many partners and stakeholders that the project and its output, this Atlas, were completed. This Atlas provides information on the SGW potential available in each woreda, the command area that can be irrigated, and number of beneficiaries in the woredas. I want to express my appreciation for the diligence of the Sustainable Irrigation and Watershed Development program team, whose enormous effort brought the SGW mapping project to its final stage. I would like to thank the development partner Czech Development Agency (CZDA), the consultant AQUATEST, and Addis Ababa University (AAU) School of Earth Sciences experts, who were all involved in exploring and mapping throughout the project. I would also like to extend my gratitude to all international partners, federal, regional governmental and non-governmental organizations who provided the data, insights, and support during the development of the project and Atlas.

I am encouraged by the progress made to date by the Sustainable Irrigation and Watershed Development program team on the Transformation Agenda, and I fully expect the progress to be scaled-up in the coming years with the full engagement of partners and stakeholders. In particular, the diversity of partners engaged in this endeavor contributes to each playing their role to transform the agriculture sector and add to the economic growth of the country.

Khalid Bomba
Chief Executive Officer, ATA

About the Atlas

In Ethiopia, very little effort has been made on shallow groundwater resource exploration, development, and management. SGW resource utilization has been limited mainly to domestic water supply; however, now that there is increasing demand for irrigation, SGW is considered to be a transformational opportunity for smallholder farmers. The Small Scale Irrigation Development Directorate of the MoANR and the Sustainable Irrigation and Watershed Development program of the ATA are promoting small scale irrigation development in which farmers and agro-pastoralists have access to irrigation water sources in a sustainable manner. With this notion, the ATA team is publishing the findings of SGW mapping conducted in Southern Ethiopia in Atlas form for public use.

This Atlas presents the SGW potential of the Oromia Regional State of Ethiopia. The Atlas has identified SGW productive areas for household irrigation (HHI) in 10 woredas with 100% coverage, (the project includes a total of 19 woredas in the region).

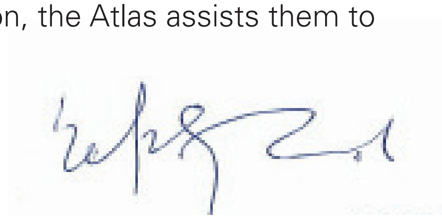
The Atlas has two kinds of maps for each woreda: main and index maps. The main map shows the shallow aquifer characterization of the superficial deposit with the underlying 3D hillshade. It also describes the technologies to use in accessing SGW, and the digability for the lithological units. The four index maps are subsidiary maps that add further information about each woreda:

- The bedrock geology map indicates the distribution of the main geological units (bedrock) that underlie the superficial deposits.
- The superficial deposit map shows the surficial formations over the area. The superficial unit is the aquifer zoning for very SGW and SGW. Both bed rock geology and superficial maps are overlain on the hillshade.
- The rainfall distribution pattern characterizes the geospatial distribution of rainfall with hillshade. In addition, this Index map adds tabular information like sustainable GW recharge, available irrigable land and number of beneficiary households in the woreda.
- The electrical conductivity map illustrates the geospatial distribution of the total dissolved ionic solids in SGW, which, in parallel, indicate the suitability of SGW for agriculture. This map is also inter-bedded with hillshade. Hillshade in the maps helps to understand the topography.

Moreover, the Atlas includes appendices containing AQUATEST and AAU maps. Other appendices contain tables and graphs, which show essential information such as aquifer productivity classification of shallow and very shallow aquifer for HHI; the aquifer's depth, and applicable tools that help to propose potential irrigable area based on the dug well filling rate and column of water; and a tool to propose well spacing corresponding to recharge zones and acreage of land each scheme is intended to irrigate. There are three chapters in the Atlas each covering different administrative zones: Borena, Guji, and West Arsi Zones are each assigned a chapter with edge coloring separation. Administrative boundaries like woredas (districts) and kebeles (sub-districts) used in this Atlas are taken from the Central Statistical Agency's demarcations in 2007. All the maps are presented in 1:50,000 scale, and a common scale bar and Northing arrow are provided. The main map has a full legend, while the bedrock geological and superficial deposit maps have minimized legends to use the workspace of the index map layout. The full descriptions of these minimized index maps are found in the appendix.

The effort and dedication of the Sustainable Irrigation and Watershed Development program team throughout the process of Atlas development was remarkable. Other ATA teams – GIS and Communications – supported the effort and helped give it its final shape.

The efforts of the team in compiling all outputs of SGW investigation and mapping in Atlas form will be invaluable to users who can extract essential information from the woreda maps. By providing stakeholders – government institutions, non-governmental organizations, and individuals – with this information, the Atlas assists them to undertake key measures and hence play essential roles in the development SGW for HHI.



Laketch Mikael
Senior Director, Environmentally Sustainable and Inclusive Growth, ATA

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The Small Scale Irrigation Development Directorate under the MoANR and the Sustainable Irrigation and Watershed Development program team of the ATA would like to thank all governmental and non-governmental organizations, development partners, and individuals who played influential roles, from the commencement of the project to the compilation of all outputs into this Atlas.

We want to acknowledge all staff in the Small Scale Irrigation Development Directorate who were very helpful in all aspects of the project. We would like to express our deep sense of gratitude to Ato Elias Awol (Director of the Directorate) who provided guidance and support throughout the project implementation period and did his utmost to coordinate efforts. We have to give our special thanks Ato Khalid Bomba (CEO of the ATA) for showing keen interest, close follow-up and supportive feedback during the implementation of the project. We are highly grateful to W/zt Laketch Mikael (Senior Director of the ATA's Environmentally Sustainable and Inclusive Growth pillar) for her tireless day-to-day supervision and dedication to the project's outcome.

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With the understanding of how challenging and time-consuming it is to generate a single piece of data, we would like to acknowledge all stakeholders for sharing their valuable data with us. Geological Survey of Ethiopia (GSE), Ministry of Water, Irrigation and Electricity (MoWIE), Japan International Cooperative Agency (JICA), Regional Bureau of Agriculture and Natural Resources (RBoANR), Water Works Design and Supervision Enterprise (WWDSE), Ethiopian Map Agency (EMA), National Meteorology Agency (NMA), Central Statistical Agency (CSA), MoANR, AAU, and many other organizations – we thank you all.

The support we received from all levels of administration, from the SNNP regional administration to the kebele level, and all bureaus of irrigation, is huge and we would like to forward our warm thanks to all.

Finally, we would like to express our gratitude for those individuals who worked with us in providing guidance and support throughout the project implementation period. We would also like to forward our heartfelt gratitude to all stakeholders who participated in the project outcomes' validation workshop and provided their comments to better the results.

Key terms

Alluvial fan – a fan-shaped deposit at the mouth of a mountain canyon, where stream gradient abruptly drops. These are usually coarse grained sediments.

Alluvium - sediments deposited by or in conjunction with running water in rivers, streams, or sheet wash and in alluvial fans.

Aquiclude- a geologic material, stratum, or formation that contains water (i.e., has porosity) but does not transmit it (i.e., has zero or negligible permeability).

Aquifer - a consolidated or unconsolidated geologic unit (material, stratum, or formation) or set of connected units that yields water of suitable quality to wells or springs in economically usable amounts.

Confined (or artesian) - an aquifer that is immediately overlain by a low-permeability unit (confining layer). A confined aquifer does not have a water table.

Leaky - an aquifer that receives recharge via cross-formational flow through confining layers.

Perched - a local, unconfined aquifer at a higher elevation than the regional unconfined aquifer. An unsaturated zone is present between the two unconfined aquifers.

Unconfined (or water-table) - the upper surface of the aquifer is the water table. Water- table aquifers are directly overlain by an unsaturated zone or a surface water body.

Aquifuge - a geologic material, stratum, or formation that neither contains nor transmits water (i.e., has zero or negligible permeability and porosity).

Aquitard - a geologic material, stratum, or formation of low permeability (a confining unit) that transmits significant amounts of water on a regional scale or over geologic time.

Arable - having soil and topographic features suitable for agriculture.

Base flow - (1) groundwater flow to a surface water body (lake, swamp, or stream); (2) that portion of stream discharge that is derived from groundwater flow or the draining of large lakes swamps or other sources outside the net rainfall that creates surface runoff/overland flow.

Basin – (1) an aquifer or aquifer system whose boundaries are defined by surface-water divides, topographic barriers; (2) a structural basin in which the aquifers are isolated from adjacent aquifers; (3) a geographical region drained by a network of rivers and/or streams.

Borehole - a hole drilled into the earth into which well casings or piezometers may be installed.

Capillarity - the action by which water is raised (or lowered) relative to the water surface because of interaction between the water molecules and the solids of the porous medium. Capillarity can also refer to the movement of a fluid into a porous medium due to this interaction; this is also called imbibition.

Capillary fringe (or zone) - the zone immediately above the water table where the medium is saturated or partially saturated by capillary rise from the phreatic zone.

Capillary rise - the height above the water table to which water will rise because of capillarity.

Catchment – the area of land drained by a single stream or river. Catchment and watershed are equivalent terms.

Darcy's Law - the discharge of water (Q) through a unit area of porous medium is directly proportional to the hydraulic gradient (i) normal to that area (A). The constant of proportionality is the hydraulic conductivity (K). $Q=KiA$

Depression storage - surface waters collecting in small topographic depressions that is not part of overland flow.

Discharge – 1) the volumetric flow rate [L3 t-1] of a stream, spring, or groundwater system; 2) the water leaving a groundwater system by flow to surface water, to the land surface, Or to the atmosphere.

Evapotranspiration - the combination of evaporation and transpiration, measured units [L3 /t/L2].

Actual evapotranspiration - the amount of water that actually evaporates and transpires from a surface.

Potential evapotranspiration - the amount of water that would evaporate and transpire from a surface if sufficient water was available to meet the demand.

Fracture - a subplanar discontinuity in a rock or soil formed by mechanical stresses. A fracture is visible to the naked eye and is open (i.e., not filled with minerals).

GENS (Groundwater Exploration Navigation System) - a mobile, wireless GPS-enabled device to assist in conducting field exploration of groundwater resources.

Household Irrigation – Irrigation managed at household level through water lifting/saving technologies.

Hydrogeology – the study of subsurface water, including its physical and chemical properties, geologic environment, its role in geologic processes, natural movement, recovery, contamination, and utilization.

Hydrograph - a chart depicting either discharge or water level as a function of time.

Hydrologic cycle - the circulation of water over, upon, and beneath the surface of the Earth.

Hydrostratigraphic unit - a formation, part of a formation, or group of formations of significant lateral extent that compose a unit of reasonably distinct (similar) hydrogeologic parameters.

Impermeable – (1) impervious to a fluid; (2) a material with zero permeability.

Infiltration - the movement of water from the surface of the land into the subsurface (vadose zone).

Influent stream– a stream that loses water to the groundwater. Also called a losing stream.

Irrigation - application of water to lands for agricultural purposes.

Irrigation return flow – irrigation water that is not used consumptively and then either recharges the underlying aquifer or flows into nearby surface water bodies.

Meteoric water - water that is or has been a part of the atmospheric portion of the hydrologic cycle.

Percolation – gravity flow of groundwater downwards through the unsaturated zone.

Perennial stream – a stream that flows all year. Compare with ephemeral and intermittent streams.

Runoff – 1) water from precipitation, snowmelt, or irrigation running over the surface of the Earth; 2) surface water entering rivers, lakes, or reservoirs.

Recharge - the process by which water enters the groundwater system or, more precisely, enters the phreatic zone.

Shallow groundwater- groundwater body that has a static water level ranging from zero to 30 meters below ground surface.

Saturation zone - generically is considered equivalent to the phreatic zone. It is the zone in the Earth's surface below the water table and the saturated portion of the capillary fringe in which all pore space is generally saturated with liquid water.

Soil moisture (or soil water) - 1) water in (unconsolidated) materials above the water table; 2) in particular, water stored in the root zone.

Spring – a discharge of water from the earth; a natural fountain.

Static water level - the level of water in a well that is not affected by pumping.

Storage - water contained within an aquifer or within a surface-water reservoir.

Total dissolved solids (TDS) – the sum of all organic and inorganic dissolved matter in water. Transmissivity (T) - the discharge through a unit width of the entire saturated thickness of an aquifer for a unit hydraulic gradient normal to the unit width sometimes termed the coefficient of transmissibility [L2 t-1]

Unsaturated - the condition when the porosity is not filled with water.

Water table - a surface at or near the top of the phreatic zone (zone of saturation) where the fluid pressure is equal to atmospheric pressure. In the field, the water table is defined by the level of water in wells that barely penetrate the phreatic (saturated) zone.

WATEX (Water for every X) - an algorithm used by RTI (Radar Technology International) that help to process radar and other images to produce groundwater resource maps.

Wetland - areas under or contiguous to open water or with a shallow water table.

Yield – the amount of water pumped from a well (or bore), the units, volume per time [L3 t-1].

Field capacity - the amount of water a soil can hold under natural conditions by capillarity and thesuction of plant roots. If the water content is greater than the field capacity then gravitational flow can occur. Also called field moisture capacity.

Map for very shallow and shallow groundwater resource

Introduction

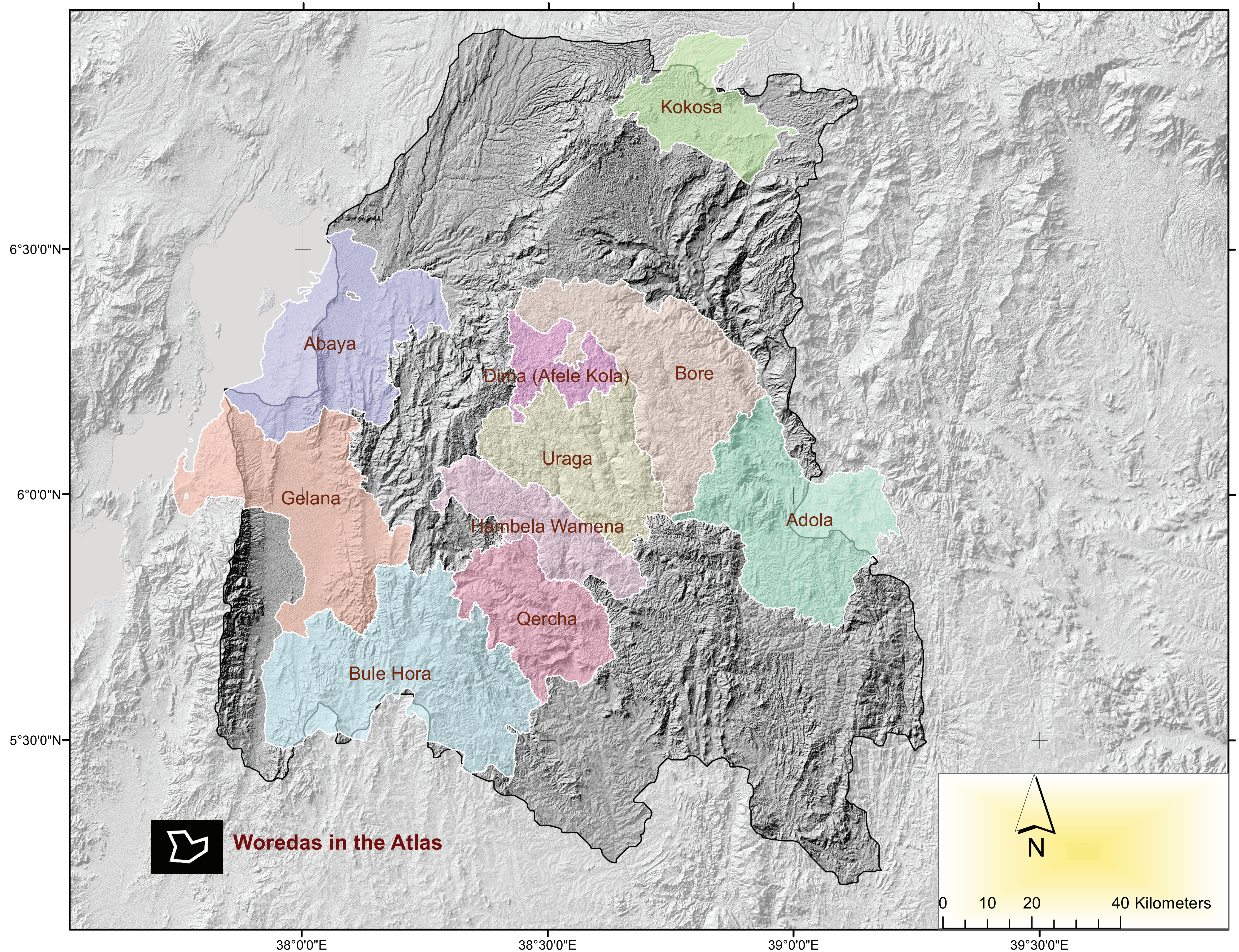
The Ethiopian Agricultural Transformation Agency (EATA/ATA) has been working since 2012 to assist the transformation of Ethiopia's agricultural economy by providing scientific and technological inputs and solving bottlenecks in the agriculture sector. One of the systemic bottlenecks in the sector is lack of information on SGW potential to promote irrigation practices.To address this bottleneck, a shallow groundwater mapping pilot projects have been conducted since 2013. At the central part of Ethiopia, in 32,000 KM² covering 89 Woredas Shallow groundwater mapping for household irrigation conducted by US consultant called Radar Technologies International (RTI) and its sub-contractor Addis Ababa University (AAU). RTI uses WATEX™ technology that helps to process radar and other images, supported and calibrated by observed data. AAU, School of Earth Sciences has been involved in field data collection, analysis and interpretation, mapping, identification of pilot project area, development of tools and report preparation. Feasibility of Technological Package for Identification and Assessment of Shallow Groundwater for Household Irrigation project conducted at the Southern part Ethiopia in 2015. The project area covers 20,117.8 KM² and 47 Woredas (19 Oromia and 28 SNNPR Woredas). One of the development partner for ATA, Czech Development Agency (CDA) funded the project. Consultant AQUATEST a.s. granted the project and worked on the feasibility of the technology package validated during the technology scanning of shallow groundwater resource assessment for household irrigation. AQUATEST used new technology for the exploration that is Density Mapping Technology (DMT) based on Geophysical Satellite Imagery analysis. In addition Radar and Optical Satellites Imageries analysis were also part of the technology package. Intensive field work also incorporated in the investigation. Integration of both technology package input and conventional hydrogeological investigation gave the outputs great accuracy. AAU, School of Earth Sciences experts involved at the project and gave critical and high level of expertise input to the project. The integration of international and local team helped to get high level of accuracy to SGW resource mapping that was confirmed by ground-truthing.

The project considered potential irrigable land which has a slope of less than 4-7% and where irrigation projects can be surely developed. All shallow groundwater resource maps have been produced at a scale of 1:50,000 with depth and yields indications. Shallow groundwater form HHI context refers to groundwater with a maximum depth of 30 meters while very shallow groundwater refers to groundwater within the top 6 meters from the surface. Shallow groundwater resource is abundant in the project area. 676.45 Mm³ sustainable shallow groundwater resource can be potentially developed for smallholders farmers with farm land of 0.01 to 1ha using shallow and very shallow groundwater. The available renewable groundwater recharge has 21,422 l/s irrigation capacity which can support about 85,689 households (428,443 household persons) considering the need of groundwater for irrigation of 1ha is equivalent to 1 l/s.

Shallow and very shallow groundwater resource maps show distributions of water bearing units, yields and recharge rate. The mapping was based on innovative approach whereby the geology of superficial materials covering the top 30m was superimposed on slope map to identify regions of shallow and very shallow groundwater. It is found out that shallow groundwater occurs in five aquifer units, each classified based on their productivity. A new guideline for classification of aquifers has been proposed for the project area and this guideline could eventually be used for Ethiopia. Available renewable groundwater resources, available land for irrigation, and the number of beneficiary population in each Woredas have been estimated.

Groundwater management and development tools have been developed in this work. The first tool is a decision support tool for determining water column thickness required in a Hand Dug Well (HDW) to irrigate a specific area of land or for determining the well design and pumping so as to regulate water use from individual HDW, and finally how to determine the size of irrigable land from available water column in a HDW. The second tool is also a decision support tool which helps to determine spacing between water schemes so as to avoid depletion of the groundwater resources. The spacing is dependent on recharge rate and yield of aquifers or acreage of land to be irrigated. Technology options for accessing and lifting groundwater have also been the subject of this study. Corresponding to each aquifer unit, appropriate technology to lift and access groundwater has been proposed. The annually available and renewable groundwater recharge in the project area could irrigate around 21,422ha of land. Unregulated groundwater development could lead to rapid decline in the groundwater levels. After a detailed calibration management tools developed in this work, the tools could be used to regulate groundwater abstraction in the project area so as to judiciously develop the shallow groundwater for household irrigation. Thus step wise development is required so as to monitor the impact of the development and step wise approach of accelerating shallow groundwater use in high potential areas and gradually development progress to the low yielding areas could be advantageous.

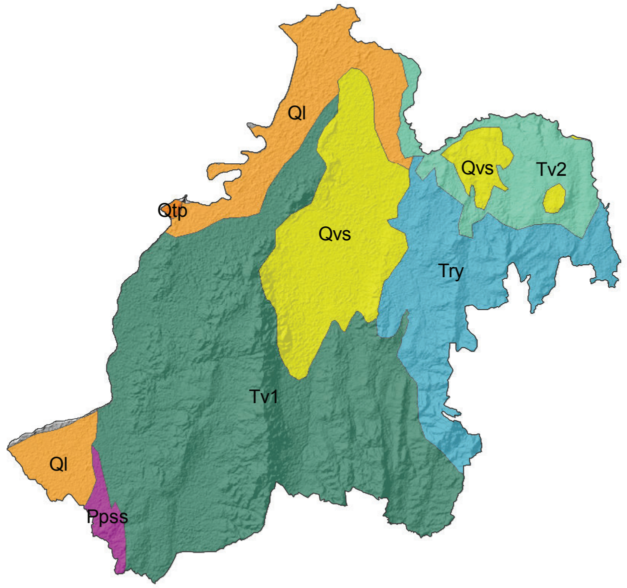
All outcomes of the Feasibility of Technological Package for Identification and Assessment of Shallow Groundwater for Household Irrigation project were uploaded to field tablet with external GPS via Bluetooth connectivity. These field tablets are navigational tools with geo-database of the project. These tools will be delivered by ATA to Oromia and SNNP regions and one for each atlas Woredas. The tool can be used by irrigation experts from Regions, Zones and Woredas to collect valuable data from the field and to determine areas of groundwater potential, whether available groundwater resources can be used for irrigation purposes and to inform borehole drilling and other irrigation activities at household level.



Map for very shallow and shallow groundwater resource

Abaya Woreda

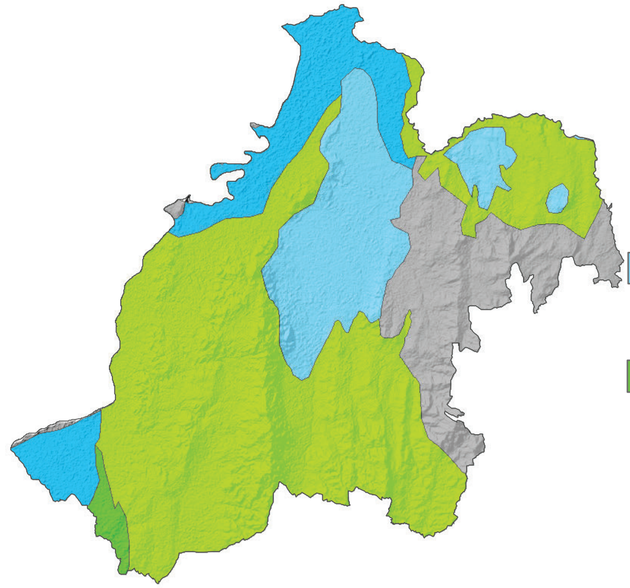
Bed rock Geology



Geological units

- Qvs — Black Cotton soil, Lacustrine sediments, Pyroclastics and Tuffs
- Ql — Lacustrine sediments, Volcanoclastic sediments and Tuffs
- Qtp — Ptroclastics, ignimbrites, unwelded Tuffs, and Pumice fall
- Tv2 — Vesicular Basalt and Trachyte
- Try — Trachyte and rhyolite and pyroclastics
- Tv1 — Basalts and Rhyolites
- Ppss — Adola Group: Phylite, Metasiltstone and Metasandstone

Superficial Deposit



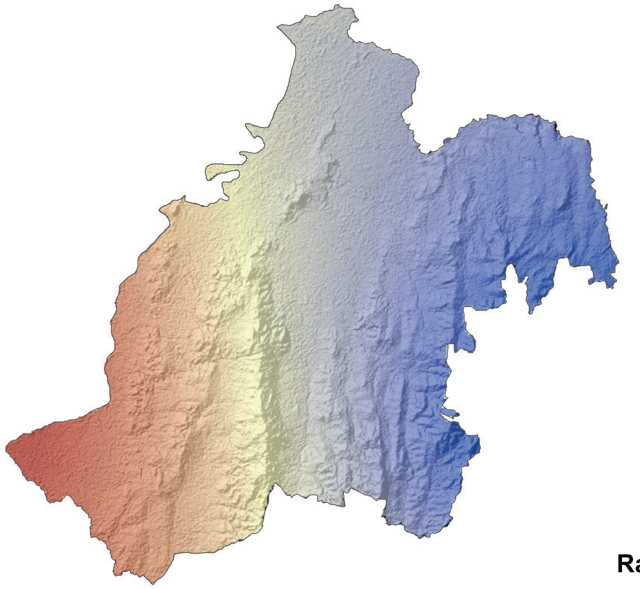
Formations

- In the rift: Alluvio-lacustrine silt,clay, sand and diatomites; In the highlands-vertisol covered, silt, sand and gravels; In the metamorphic belts: metasandstones and metaconglomerates
- Vertisol covered silts, tephra, planosols, calcrete, ash and pyroclastics
- In the rift: vertisol covered planosols, ashes, buffy bedrock and weathered ignimbrite; in the metamorphic belts: friable schists and metasandstones
- Basalt regolith and weathered granites in the metamorphic belts
- Bedrocks

N

0 4 8 16 Kilometers

Rainfall Distribution Pattern



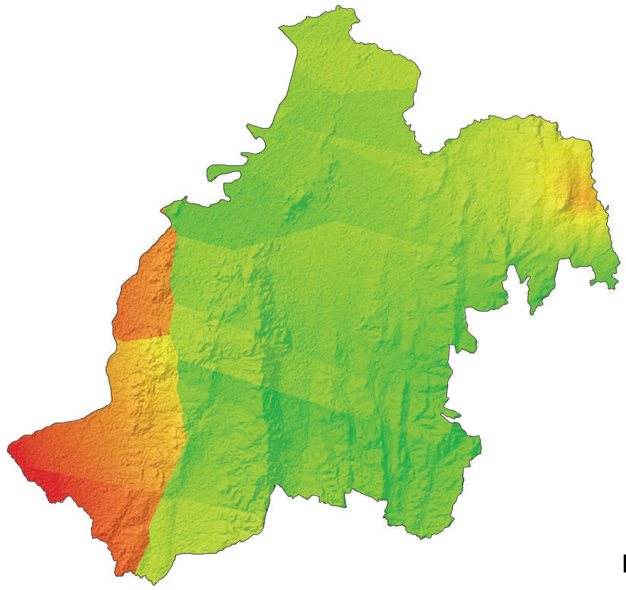
Rainfall (mm/yr)

High : 1460

Low : 887

Character	Amount
Surface Woreda Full	1,189 km^2
Surface Woreda ATA study zone	867 km^2
Annual Renewable Groundwater Recharge	30.79 Mm^3
Irrigation Capacity	976 ha
Potential household numbers to be served	3,905
Potential persons to be served	19,527

Electrical Conductivity

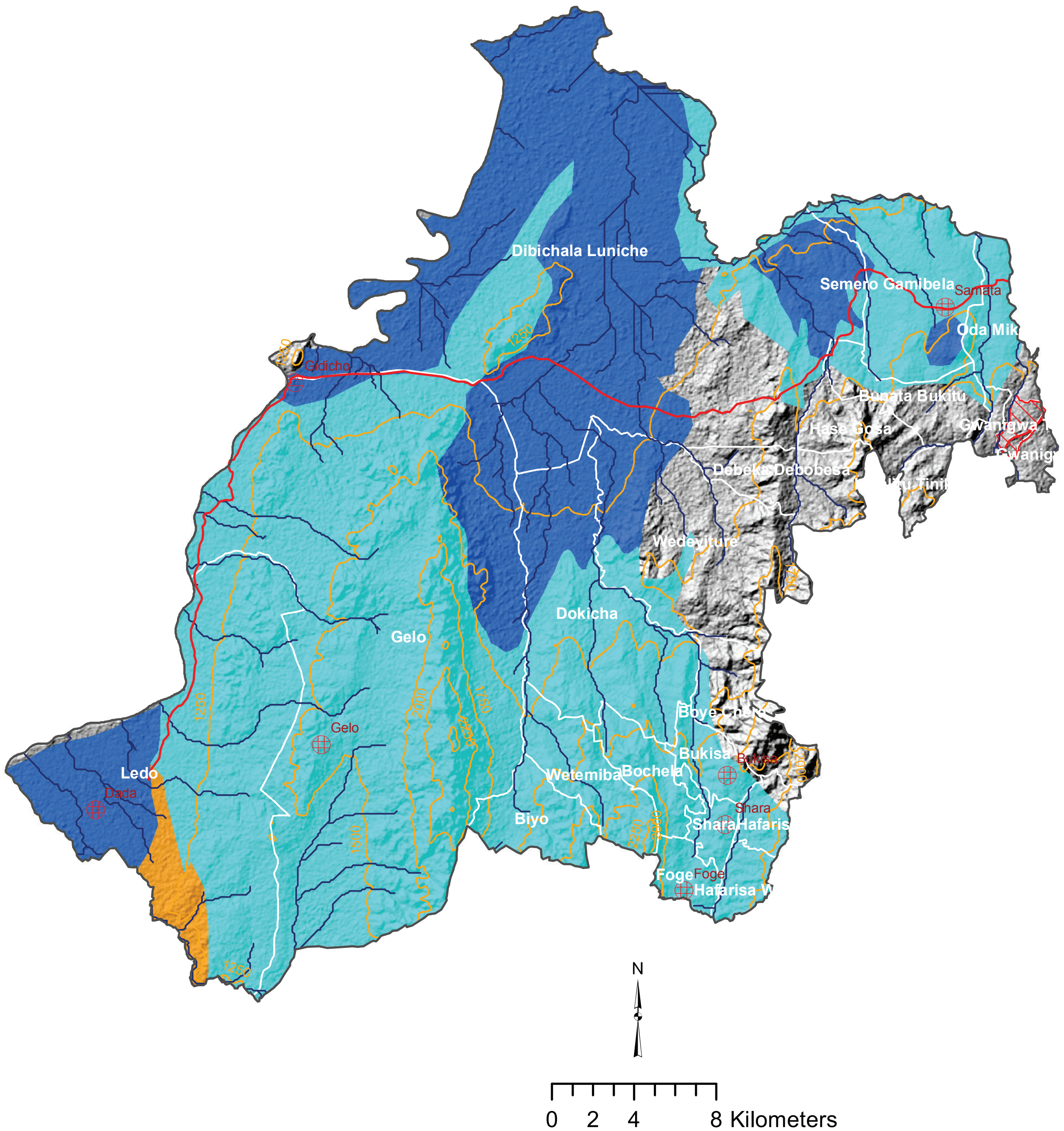


EC Range (µS/cm)

High : 548

Low : 206

Abaya Woreda



Legend

Very Shallow and Shallow Groundwater

Aquifer 1 Extensive and highly productive [Yield = (0.75 – 1) lit/sec] aquifers: Intergranular aquifer with average water level fluctuation (2-4 m). Shallow groundwater level at a depth of less than 30 m. Thickness of superficial sediments varies from 20 to 73m. Excellent water quality for irrigation except locally high TDS may be encountered.

Aquifer 2 & 22 Locally developed and moderately to low productive [Yield = (0.75 – 0.25) lit/sec] aquifers: Intermountainous deposits crossed mostly by perennial rivers with groundwater level fluctuate in the order of 5 to 10 m. Groundwater occur at fissured and/or weathered bedrock and the overlying sediments. At depressions forming plains without perennial rivers, groundwater level has a rapid tendency to decrease because the regional groundwater level is at a greater depth. These aquifers show excellent groundwater quality for irrigation.

Aquifer 4 & 5 Extensive or locally developed and low to very low productive [Yield = (0.75 – 0.25) lit/sec] aquifers: Aquifers developed in the regolith covering volcanic rocks. The shallow groundwater level varies from 10 to 30 m. These aquifers show mainly excellent groundwater quality for irrigation.

No shallow aquifer zone:
Extensive formations consisting of volcanic and basement rocks with minor and limited shallow groundwater resources where groundwater is at different depths and can be developed by deep drilling and spring development.

Access Technology and Diggability

Large diameter hand dug wells with lining of the top 3m, manually drilled tube wells; lining may not be required below 4m; protection against flood required around the well head; periodic dredging is required; easily diggable. Open hand dug wells with concrete or masonry lining of top 3m; no lining required below 3-4m; easily diggable but may require chiseling in places.

Open hand dug wells with full concrete or masonry lining; Manual drilling and casing/lining is recommended because of potential local artesian conditions; top part is easily diggable but may change to hard bedrock after about 10m.

Groundwater can be developed by hand digging (common practice) and manual drilling. Open hand dug wells with concrete or masonry lining of top 3m; no lining required below 3-4m; generally diggable but some chiseling may be required towards the bottom.

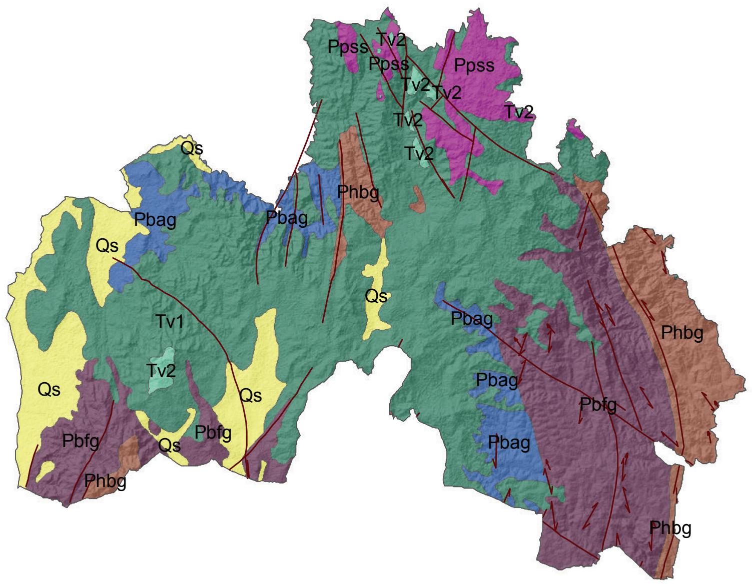
Access only through drilling except locally by hand dug wells.

Kebeles Boundery
Countours (250m Interval)
Rivers
Roads
Rural Towns
Small Rural Towns

Map for very shallow and shallow groundwater resource

Bule Hora Woreda

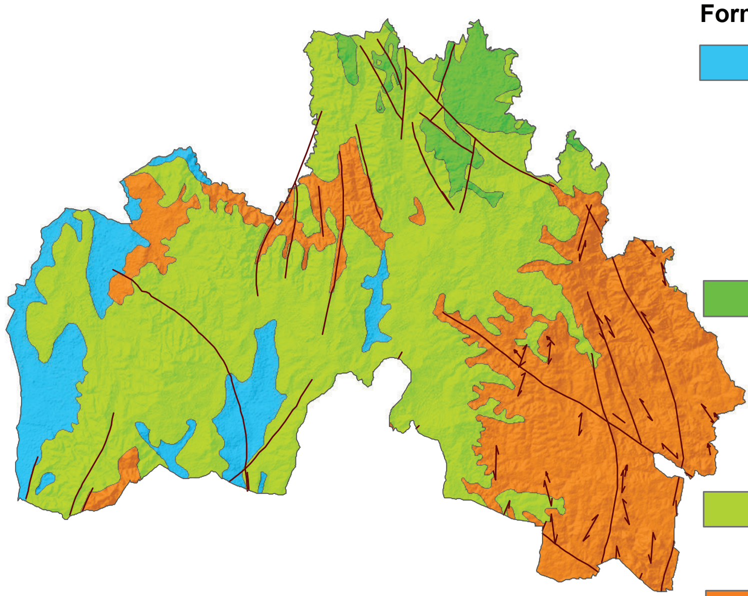
Bed rock Geology



Geological units

- Qs — Alluvium, Elluvium and Illuvium
- Tv2 — Vesicular Basalt and Trachyte
- Tv1 — Basalts and Rhyolites
- Ppss — Adola group: Phylite, Metasiltstone and Metasandstone
- Pgbg — Syntectonic Granite
- Pbfg — Granitized and Migmatized Gneiss
- Pfbg — Schist and Gneiss and Granite
- Pbag — Biotite-hornblend-quartz-feldspar Gneiss
- Phbg — Gneiss and Granite
- Structures

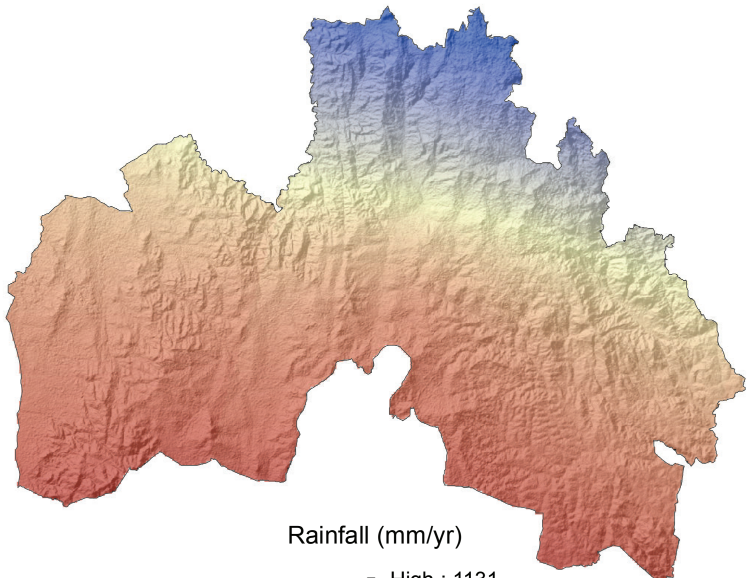
Superficial Deposit



Formations

- In the rift: Alluvio-lacustrine silt,clay, sand and diatomites; In the highlands- vertisol covered, silt, sand and gravels; In the metamorphic belts:metasandstones and metaconglomerates
- In the rift: vertisol covered planosols, ashes, buffy bedrock and weathered ignimbrite; in the metamorphic belts: friable schists and metasandstones
- Basalt regolith and weathered granites in the metamorphic belts
- Thin soil covered gneissose bedrocks
- Structures

Rainfall Distribution Pattern



Rainfall (mm/yr)

High : 1131

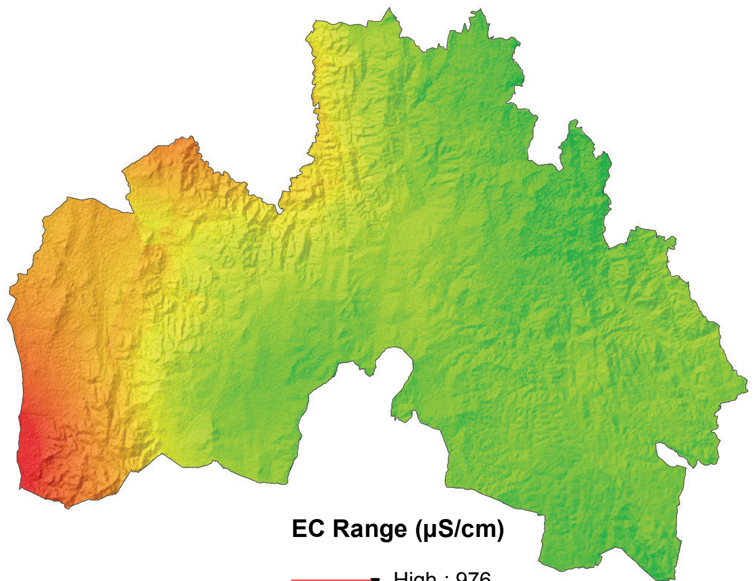
Low : 836

Character	Amount	
Surface Woreda Full	1,694	km^2
Surface Woreda ATA study zone	1,630	km^2
Annual Renewable Groundwater Recharge	15.15	Mm^3
Irrigation Capacity	480	ha
Potential household numbers to be served	1,922	
Potential persons to be served	9,608	

N

0 4 8 16 Kilometers

Electrical Conductivity

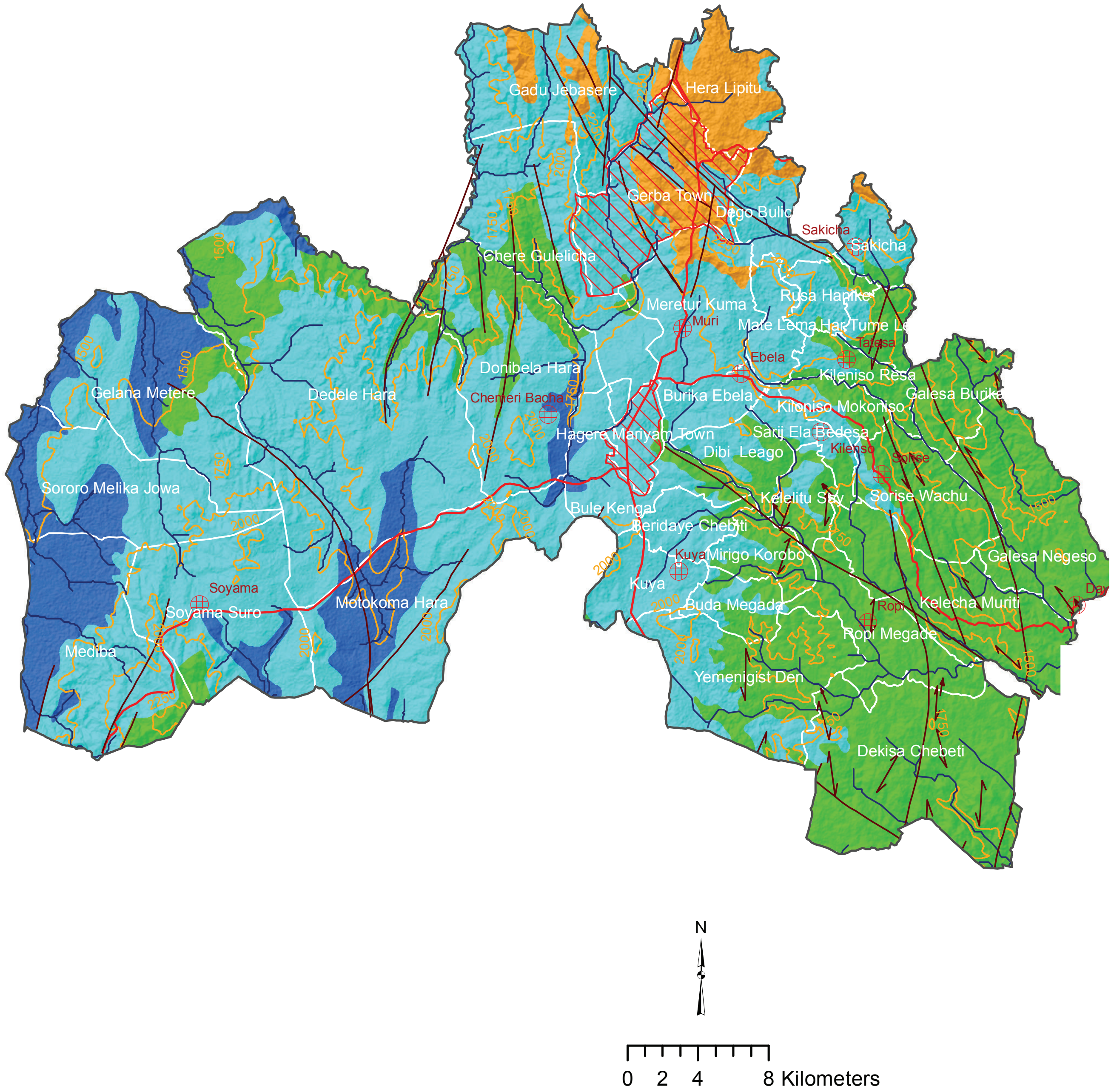


EC Range (µS/cm)

High : 976

Low : 274

Bule Hora Woreda



Legend

Very Shallow and Shallow Groundwater

- Aquifer 1 Extensive and highly productive [Yield = (0.75 – 1) lit/sec] aquifers: Intergranular aquifer with average water level fluctuation (2-4 m). Shallow groundwater level at a depth of less than 30 m. Thickness of superficial sediments varies from 20 to 73m. Excellent water quality for irrigation except locally high TDS may be encountered.
- Aquifer 2 & 22 Locally developed and moderately to low productive [Yield = (0.75 – 0.25) lit/sec] aquifers: Intermountainous deposits crossed mostly by perennial rivers with groundwater level fluctuate in the order of 5 to 10 m. Groundwater occur at fissured and/or weathered bedrock and the overlying sediments. At depressions forming plains without perennial rivers, groundwater level has a rapid tendency to decrease because the regional groundwater level is at a greater depth. These aquifers show excellent groundwater quality for irrigation.
- Aquifer 4 & 5 Extensive or locally developed and low to very low productive [Yield = (0.75 – 0.25) lit/sec] aquifers: Aquifers developed in the regolith covering volcanic rocks. The shallow groundwater level varies from 10 to 30 m. These aquifers show mainly excellent groundwater quality for irrigation.
- Aquifer 3 & 33 Local and moderately productive [Yield = (0.5 – 0.1) lit/sec] minor aquifers: Aquifers developed mainly in basement tectonic zones. Shallow groundwater table depth is less than 30m. The shallow regolith aquifer has minor local importance, however locally good aquifer with moderate productivity (Q> 1 l/s) may be encountered in depressions filled by transported sediments or in cases where regolith thickness exceeds 10 meters. These aquifers show mainly excellent groundwater quality for irrigation.

Access Technology and Diggability

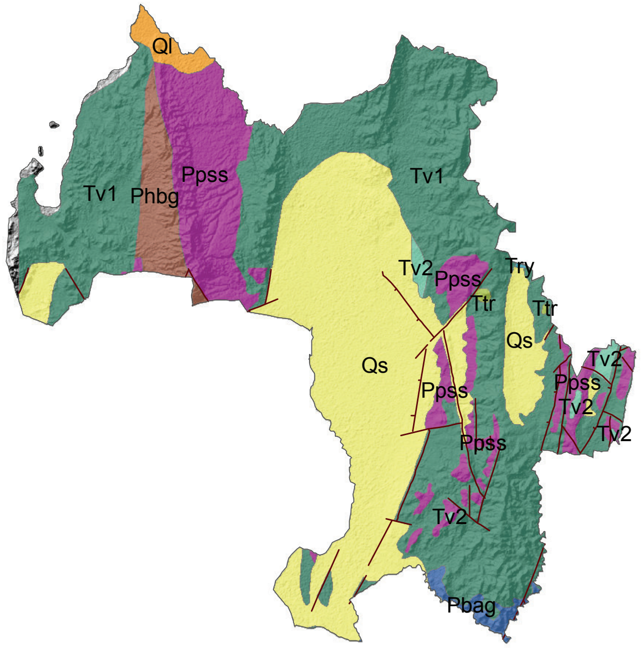
- Large diameter hand dug wells with lining of the top 3m, manually drilled tube wells; lining may not be required below 4m; protection against flood required around the well head; periodic dredging is required; easily diggable. Open hand dug wells with concrete or masonry lining of top 3m; no lining required below 3-4m; easily diggable but may require chiseling in places.
- Open hand dug wells with full concrete or masonry lining; Manual drilling and casing/lining is recommended because of potential local artesian conditions; top part is easily diggable but may change to hard bedrock after about 10m.
- Groundwater can be developed by hand digging (common practice) and manual drilling. Open hand dug wells with concrete or masonry lining of top 3m; no lining required below 3-4m; generally diggable but some chiseling may be required towards the bottom.
- Groundwater can be developed by hand digging and manual drilling. Low diggability with exceptions in places where weathered mantle in local depressions is sufficiently thick.

- Kebeles Boundery
- Major Structures
- Countours (250m Interval)
- Rivers
- Roads
- Rural Towns
- Small Rural Towns

Map for very shallow and shallow groundwater resource

Gelana Woreda

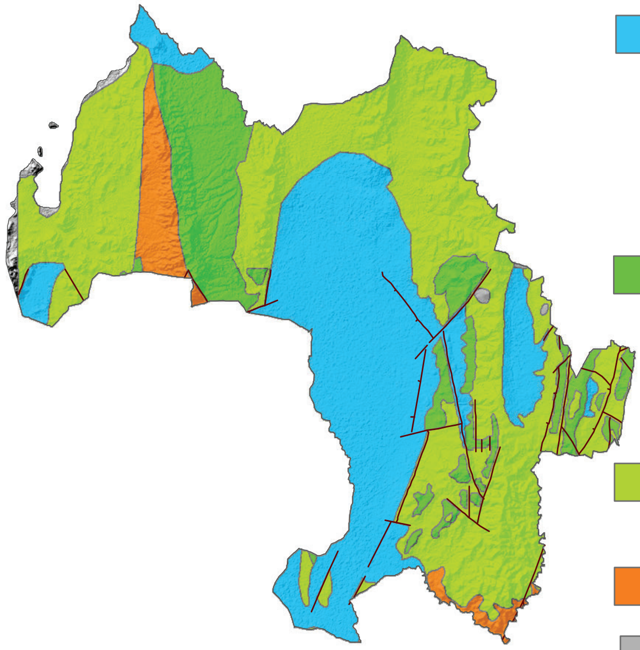
Bed rock Geology



Geological units

- Qs: Alluvium, Elluvium and Illuvium
- Ql: Lacustrine, Volcanoclastic sediments and Tuffs
- Ttr: Trachyte,Tuffs, and Basalt
- Tv2: Vesicular Basalt and Trachyte
- Try: Trachyte, rhyolite and pyroclastics
- Tv1: Basalts and Rhyolites
- Ppss: Adola group: Phylite, Metasiltstone and Metasandstone
- Pbag: Biotite-hornblend-quartz-feldspar Gneiss
- Phbg: Gneiss and Granite
- Structures

Superficial Deposit



Formations

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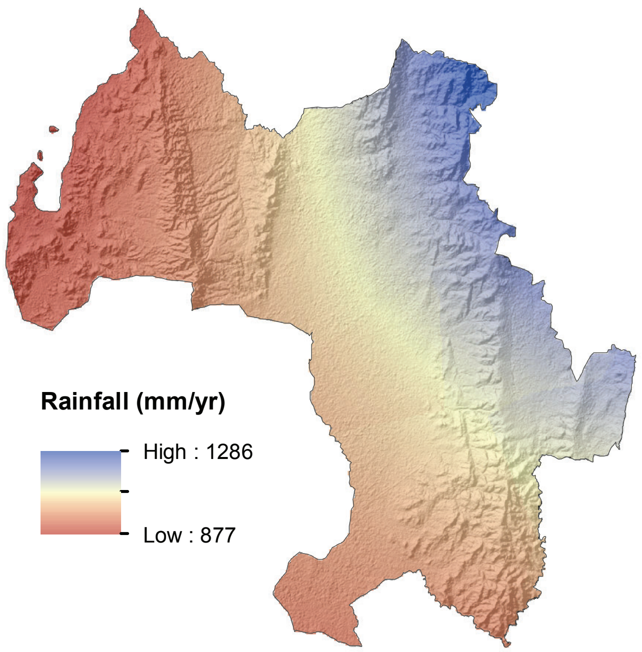
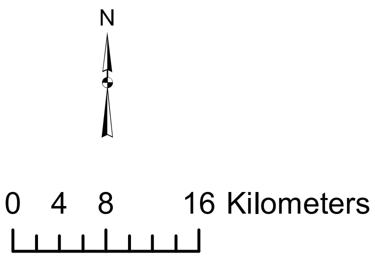
- Bedrocks
- Structures

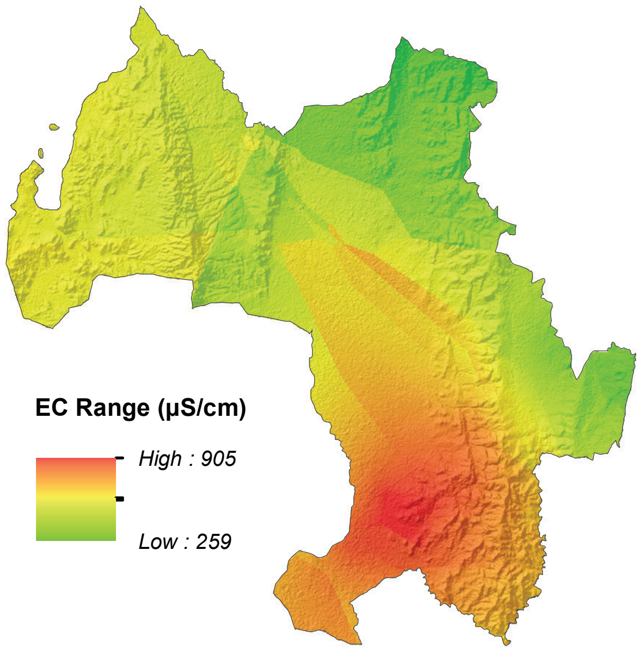
Rainfall Distribution Pattern



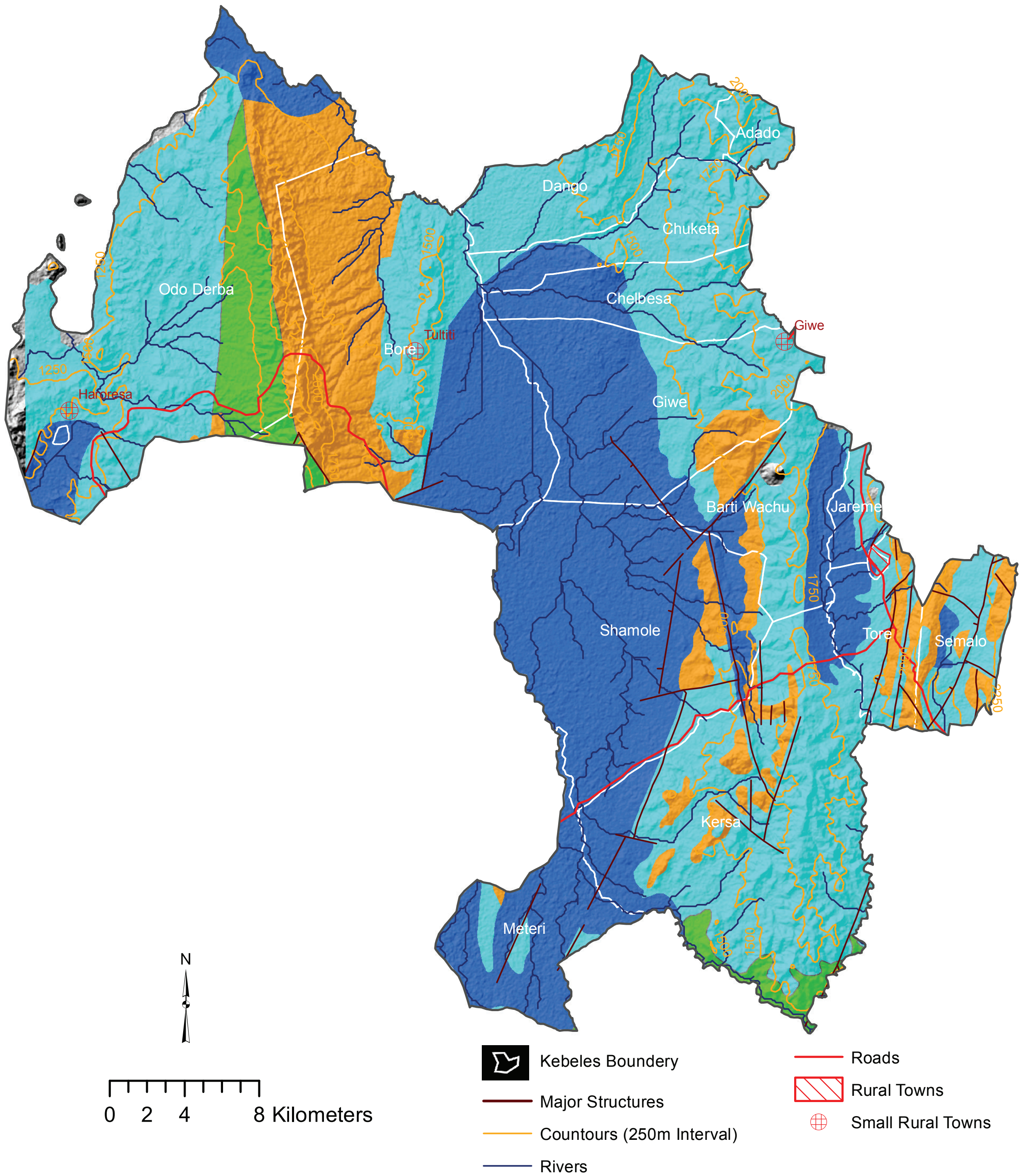
Character	Amount
Surface Woreda Full	1,318 km^2
Surface Woreda ATA study zone	1,097 km^2
Annual Renewable Groundwater Recharge	49.23 Mm^3
Irrigation Capacity	1,561 ha
Potential household numbers to be served	6,244
Potential persons to be served	31,221



Electrical Conductivity



Gelana Woreda



Legend

Very Shallow and Shallow Groundwater

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Aquifer 2 & 22 Locally developed and moderately to low productive [Yield = (0.75 – 0.25) lit/sec] aquifers: Intermountainous deposits crossed mostly by perennial rivers with groundwater level fluctuate in the order of 5 to 10 m. Groundwater occur at fissured and/or weathered bedrock and the overlying sediments. At depressions forming plains without perennial rivers, groundwater level has a rapid tendency to decrease because the regional groundwater level is at a greater depth. These aquifers show excellent groundwater quality for irrigation.

Aquifer 4 & 5 Extensive or locally developed and low to very low productive [Yield = (0.75 – 0.25) lit/sec] aquifers: Aquifers developed in the regolith covering volcanic rocks. The shallow groundwater level varies from 10 to 30 m. These aquifers show mainly excellent groundwater quality for irrigation.

Aquifer 3 & 33 Local and moderately productive [Yield = (0.5 – 0.1) lit/sec] minor aquifers: Aquifers developed mainly in basement tectonic zones. Shallow groundwater table depth is less than 30m. The shallow regolith aquifer has minor local importance, however locally good aquifer with moderate productivity (Q> 1 l/s) may be encountered in depressions filled by transported sediments or in cases where regolith thickness exceeds 10 meters. These aquifers show mainly excellent groundwater quality for irrigation.

No shallow aquifer zone:
Extensive formations consisting of volcanic and basement rocks with minor and limited shallow groundwater resources where groundwater is at different depths and can be developed by deep drilling and spring development.

Access Technology and Diggability

Large diameter hand dug wells with lining of the top 3m, manually drilled tube wells; lining may not be required below 4m; protection against flood required around the well head; periodic dredging is required; easily diggable. Open hand dug wells with concrete or masonry lining of top 3m; no lining required below 3-4m; easily diggable but may require chiseling in places.

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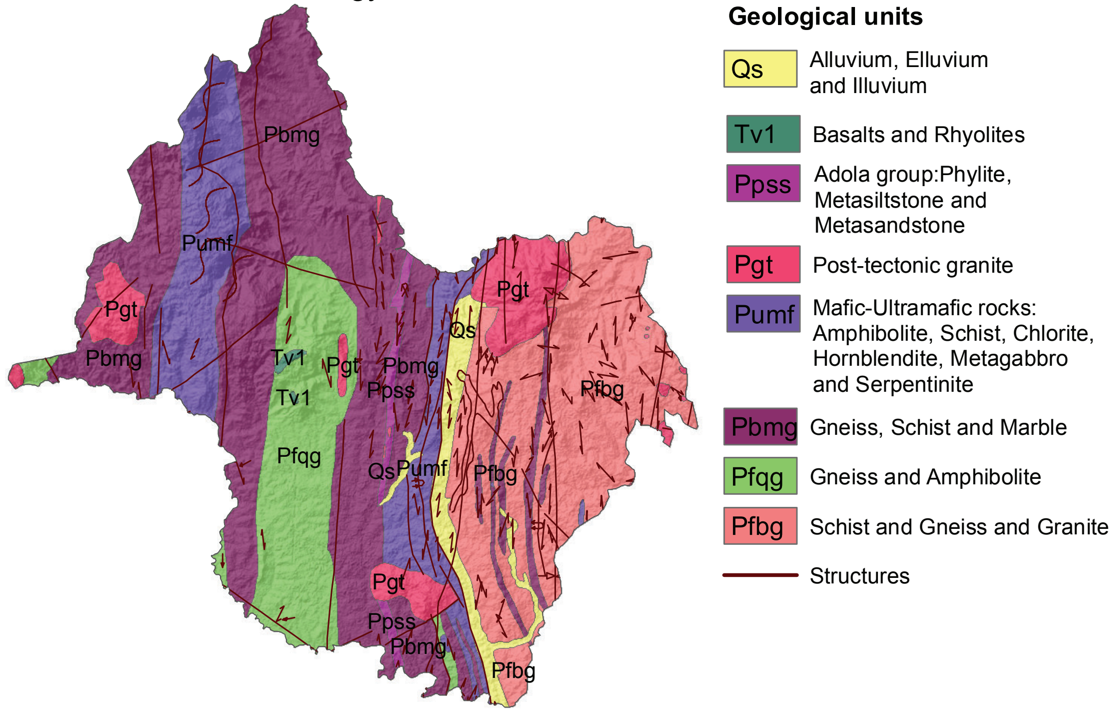
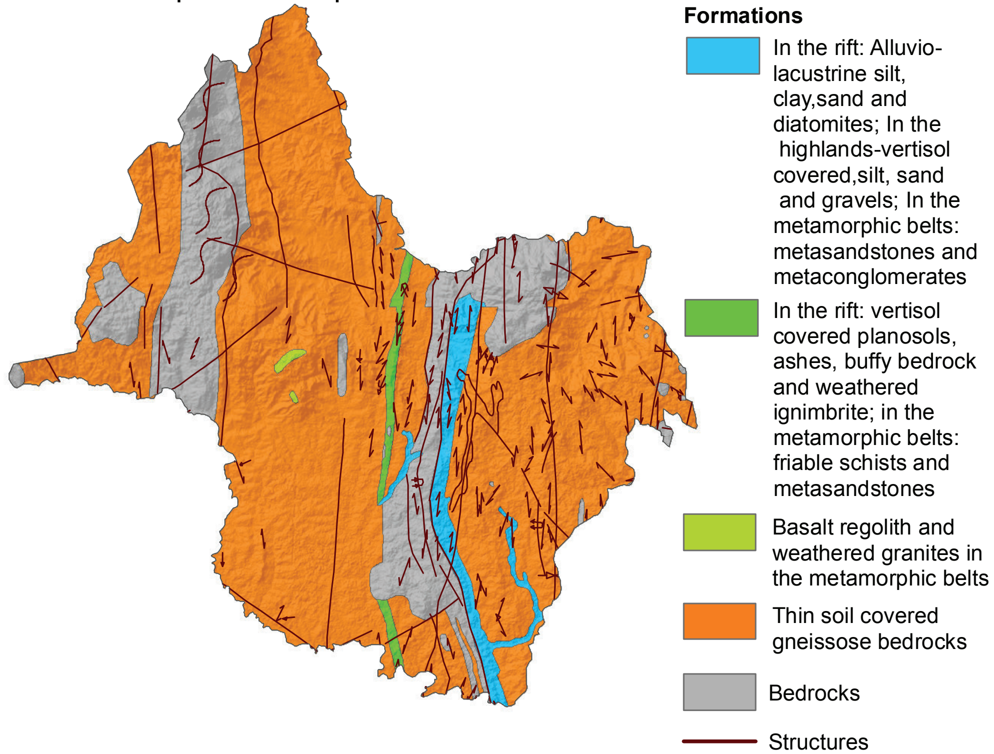
Map for very shallow and shallow groundwater resource

Adola Woreda

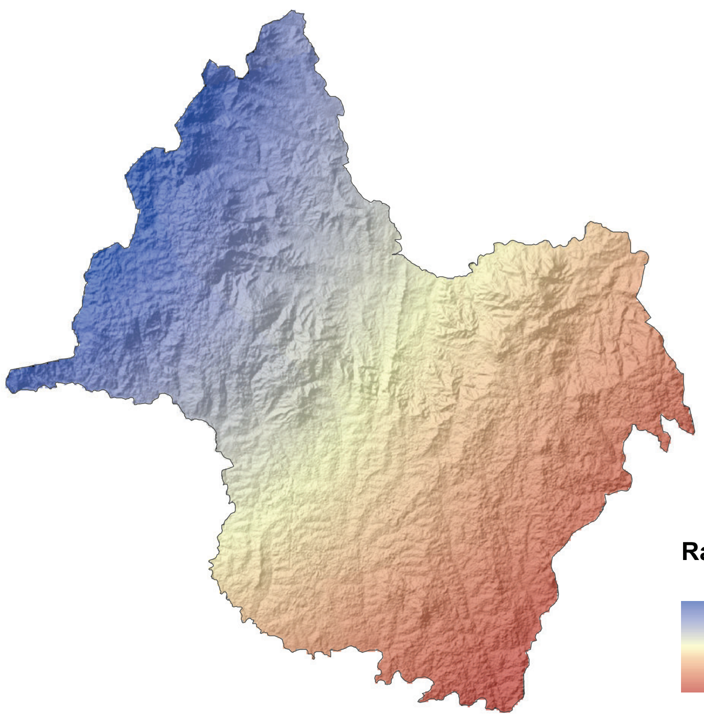
Bed rock Geology



Superficial Deposit

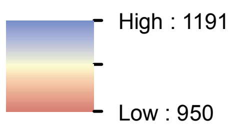


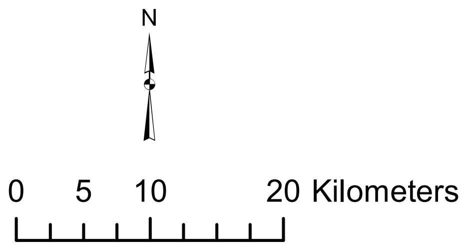
Rainfall Distribution Pattern



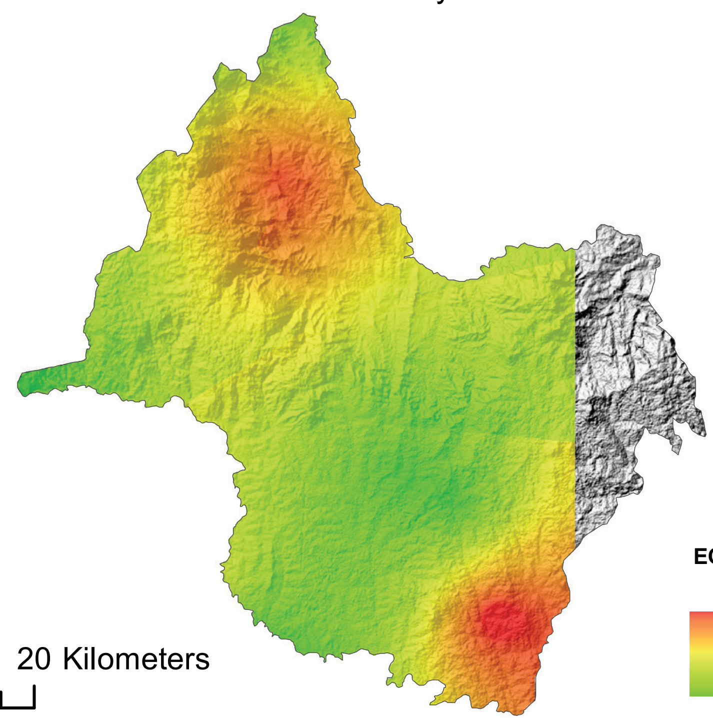
Character	Amount
Surface Woreda Full	1,262 km ^{2}
Surface Woreda ATA study zone	963 km ^{2}
Annual Renewable Groundwater Recharge	20.88 Mm^3
Irrigation Capacity	662 ha
Potential household numbers to be served	2,648
Potential persons to be served	13,242

Rainfall (mm/yr)



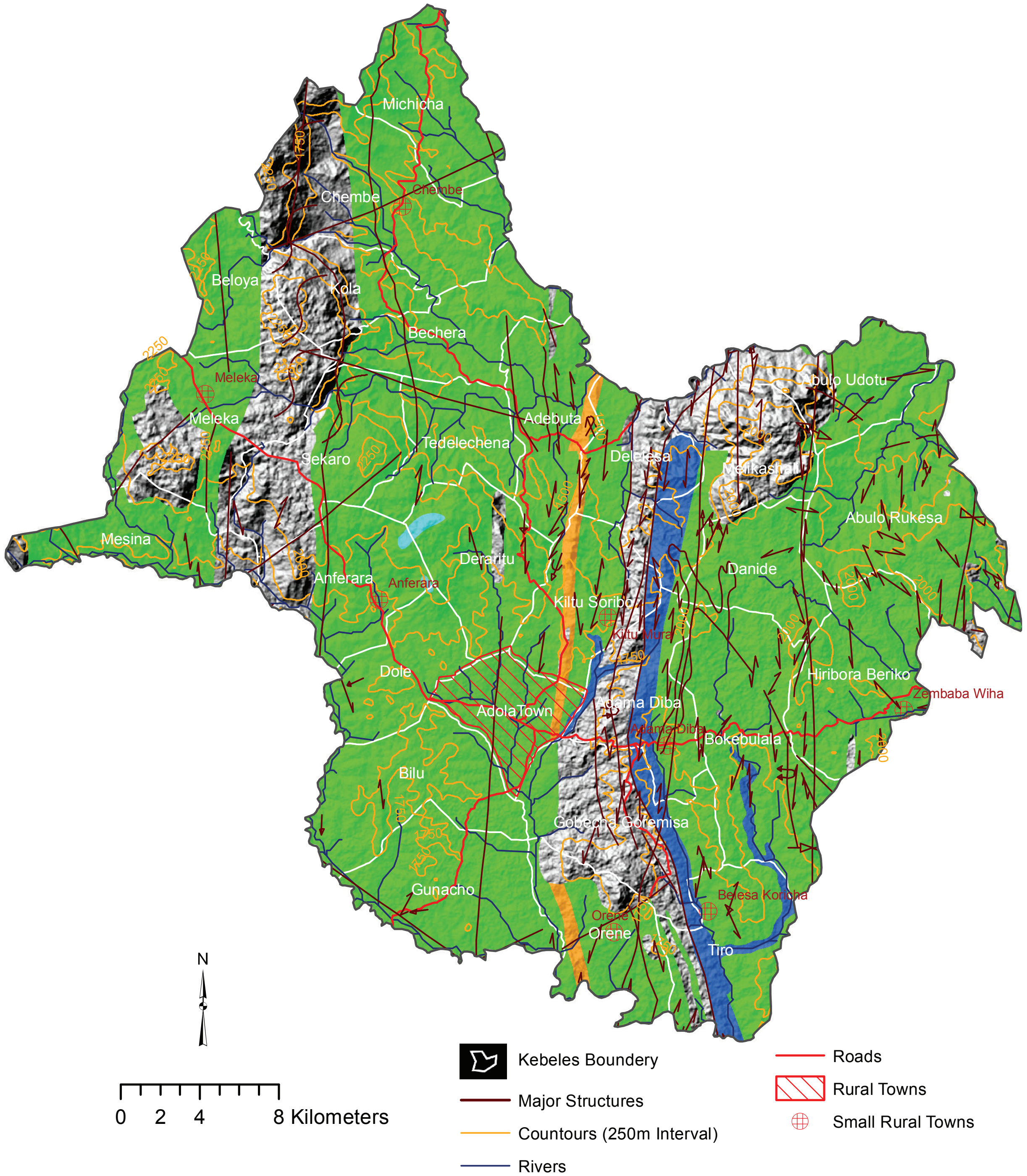


Electrical Conductivity



EC Range (µS/cm)

Adola Woreda



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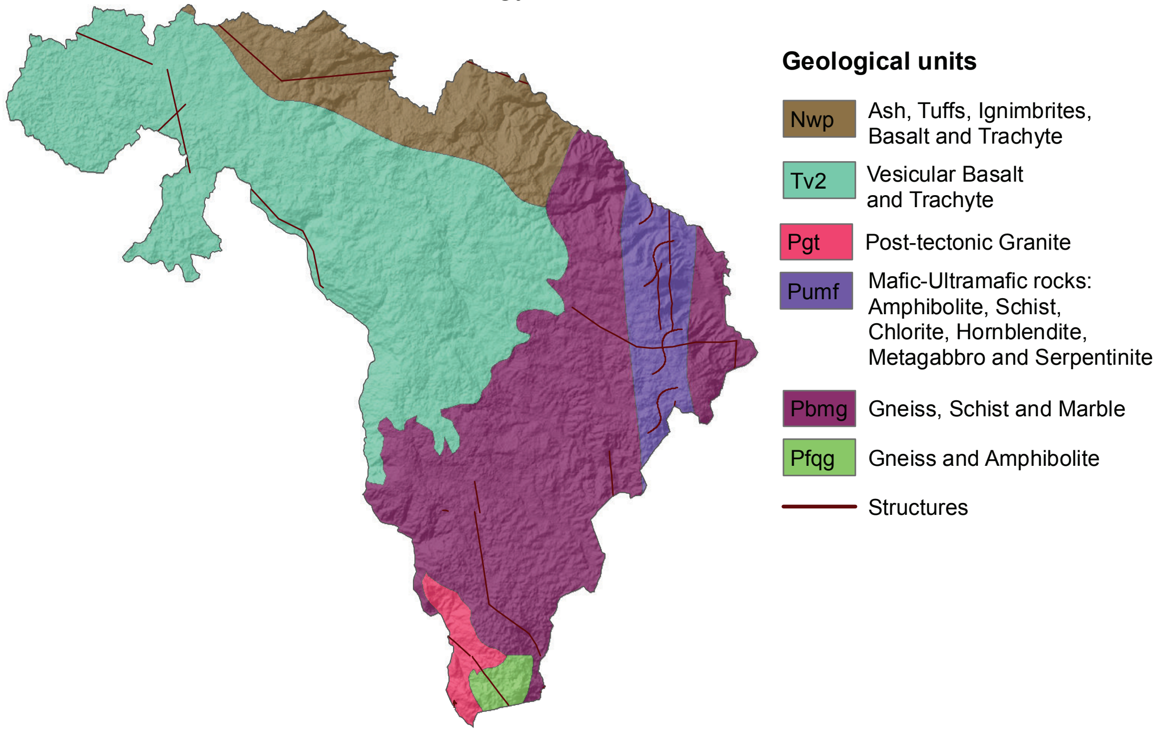
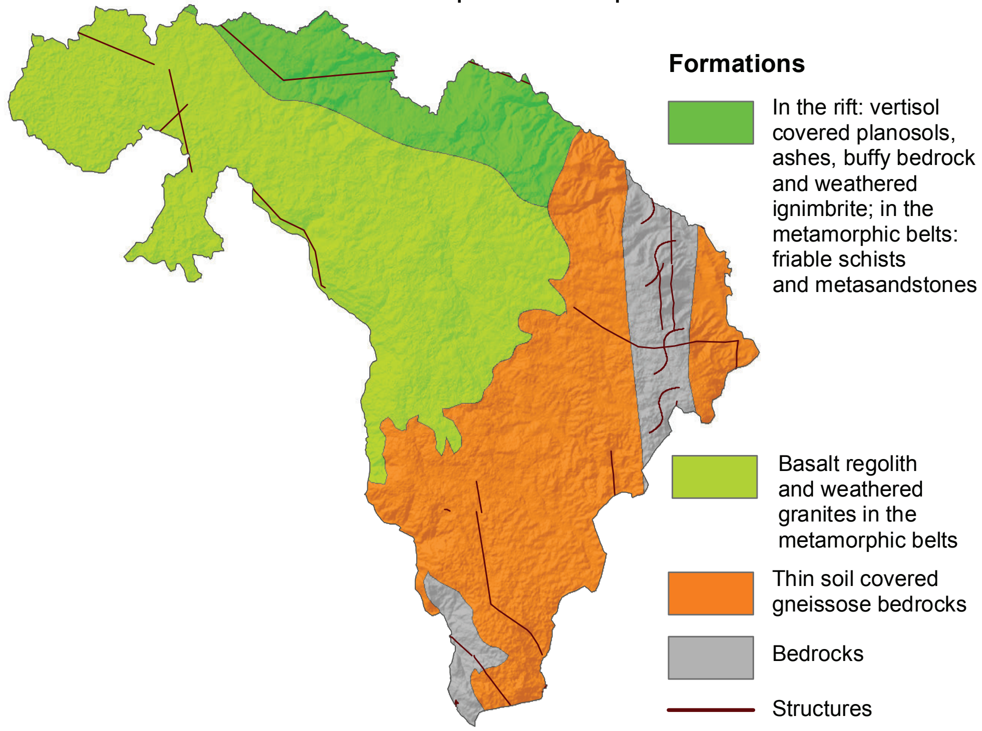
Map for very shallow and shallow groundwater resource

Bore Woreda

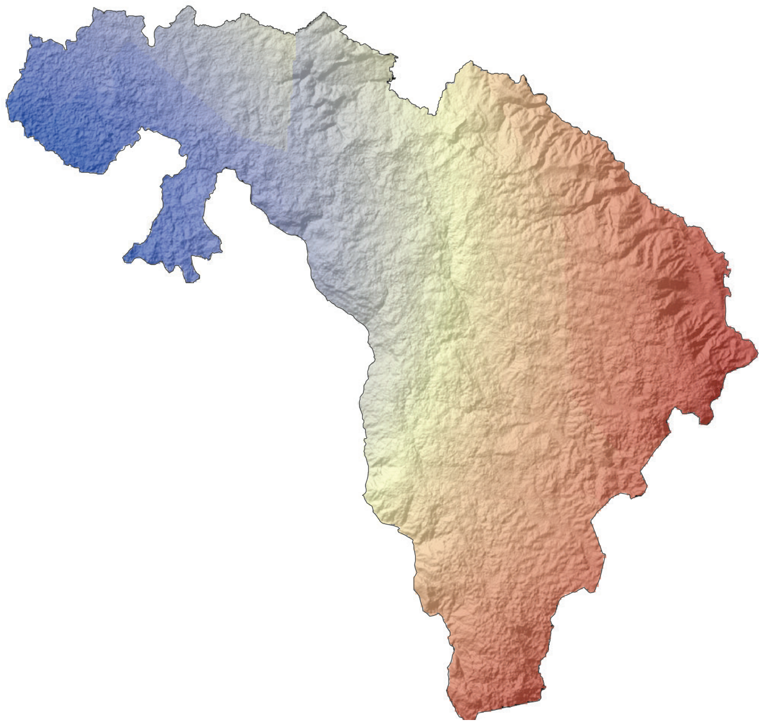
Bed rock Geology



Superficial Deposit



Rainfall Distribution Pattern

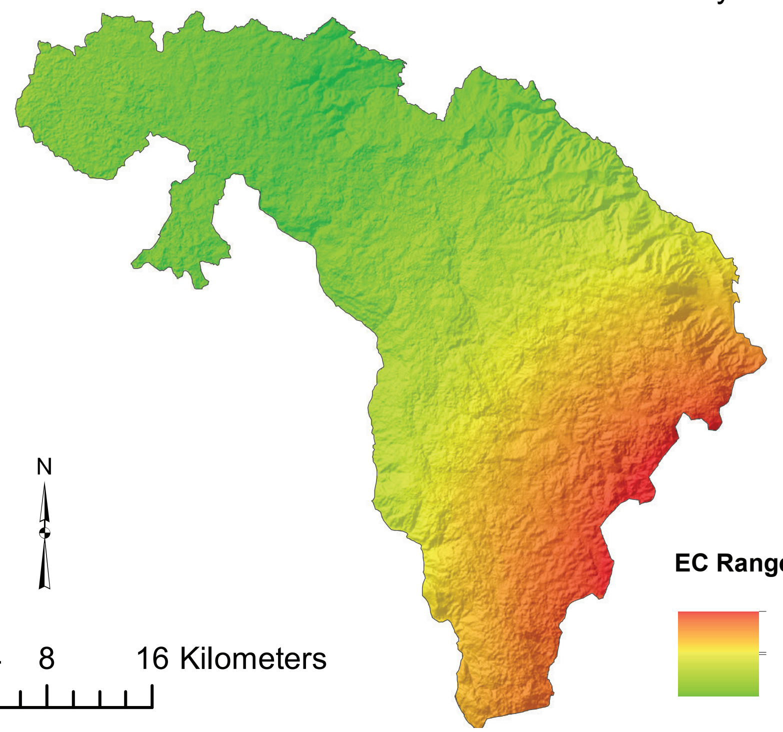


Character	Amount
Surface Woreda Full	1,269 km^2
Surface Woreda ATA study zone	1,269 km^2
Annual Renewable Groundwater Recharge	52.82 Mm^3
Irrigation Capacity	1,675 ha
Potential household numbers to be served	6,699
Potential persons to be served	33,497

N

0 4 8 16 Kilometers

Electrical Conductivity



Map for very shallow and shallow groundwater resource

Bore Woreda

Legend

Very Shallow and Shallow Groundwater

Aquifer 2 & 22 Locally developed and moderately to low productive [Yield = (0.75 – 0.25) lit/sec] aquifers: Intermountainous deposits crossed mostly by perennial rivers with groundwater level fluctuate in the order of 5 to 10 m. Groundwater occur at fissured and/or weathered bedrock and the overlying sediments. At depressions forming plains without perennial rivers, groundwater level has a rapid tendency to decrease because the regional groundwater level is at a greater depth. These aquifers show excellent groundwater quality for irrigation.

Aquifer 4 & 5 Extensive or locally developed and low to very low productive [Yield = (0.75 – 0.25) lit/sec] aquifers: Aquifers developed in the regolith covering volcanic rocks. The shallow groundwater level varies from 10 to 30 m. These aquifers show mainly excellent groundwater quality for irrigation.

Aquifer 3 & 33 Local and moderately productive [Yield = (0.5 – 0.1) lit/sec] minor aquifers: Aquifers developed mainly in basement tectonic zones. Shallow groundwater table depth is less than 30m. The shallow regolith aquifer has minor local importance, however locally good aquifer with moderate productivity (Q> 1 l/s) may be encountered in depressions filled by transported sediments or in cases where regolith thickness exceeds 10 meters. These aquifers show mainly excellent groundwater quality for irrigation.

No shallow aquifer zone:
Extensive formations consisting of volcanic and basement rocks with minor and limited shallow groundwater resources where groundwater is at different depths and can be developed by deep drilling and spring development.

Access Technology and Diggability

Open hand dug wells with full concrete or masonry lining; Manual drilling and casing/lining is recommended because of potential local artesian conditions; top part is easily diggable but may change to hard bedrock after about 10m.

Groundwater can be developed by hand digging (common practice) and manual drilling. Open hand dug wells with concrete or masonry lining of top 3m; no lining required below 3-4m; generally diggable but some chiseling may be required towards the bottom.

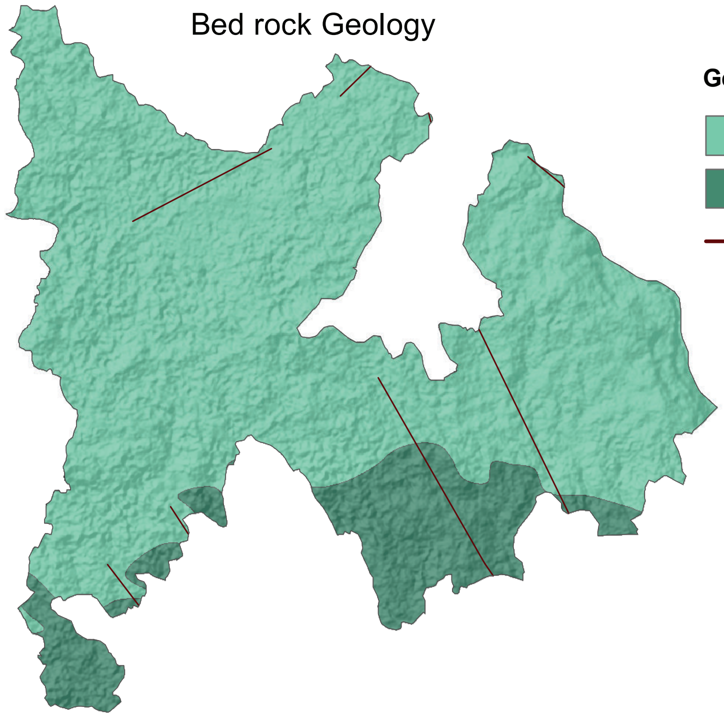
Groundwater can be developed by hand digging and manual drilling. Low diggability with exceptions in places where weathered mantle in local depressions is sufficiently thick.

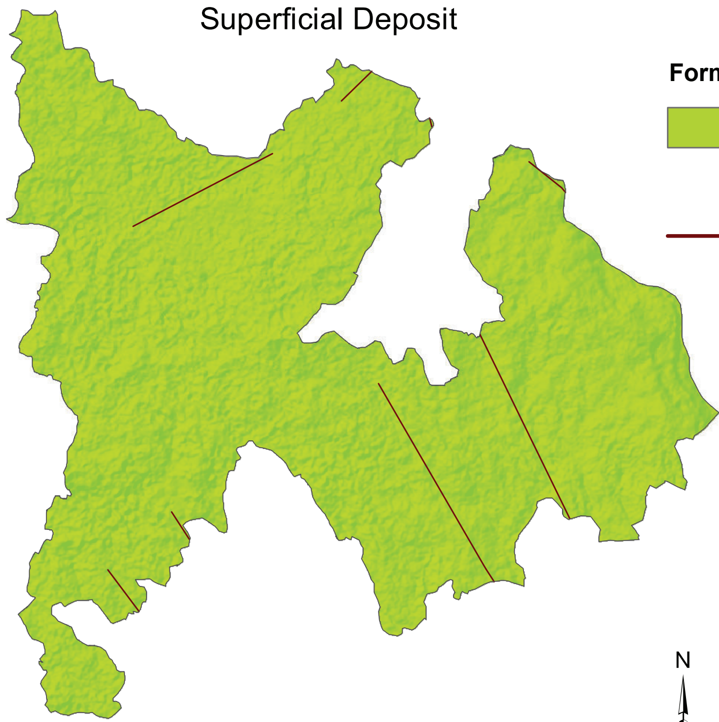
Access only through drilling except locally by hand dug wells.

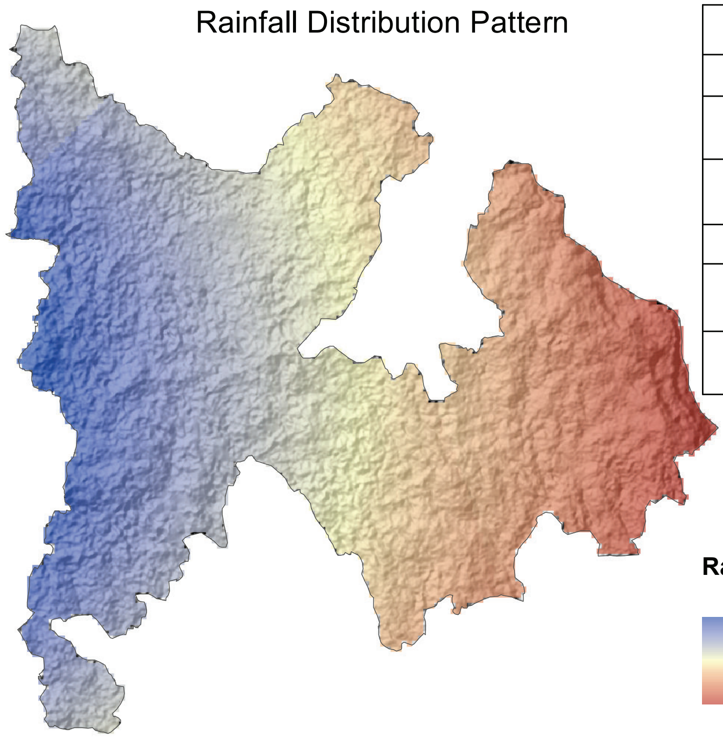
Kebeles Boundery
Major Structures
Countours (250m Interval)
Rivers
Roads
Rural Towns
Small Rural Towns

Map for very shallow and shallow groundwater resource

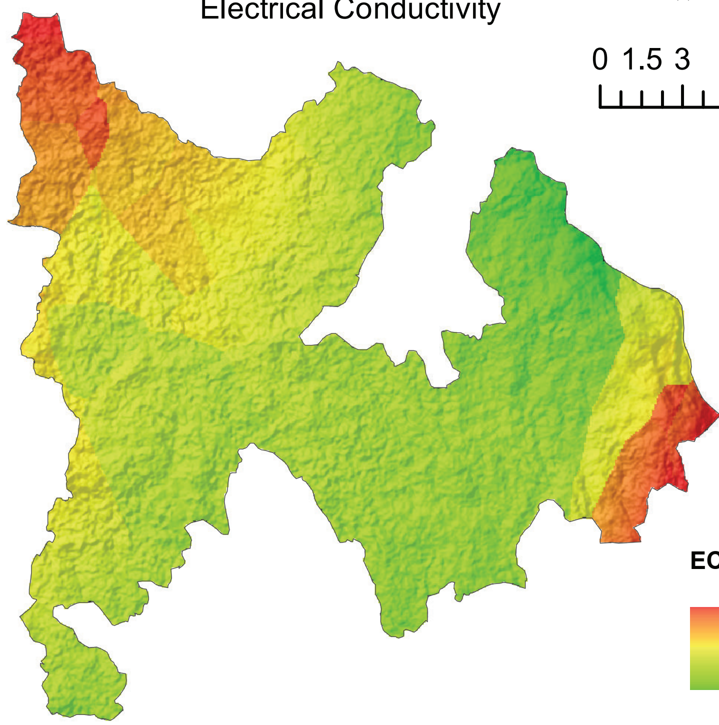
Dima (Afele Kola) Woreda





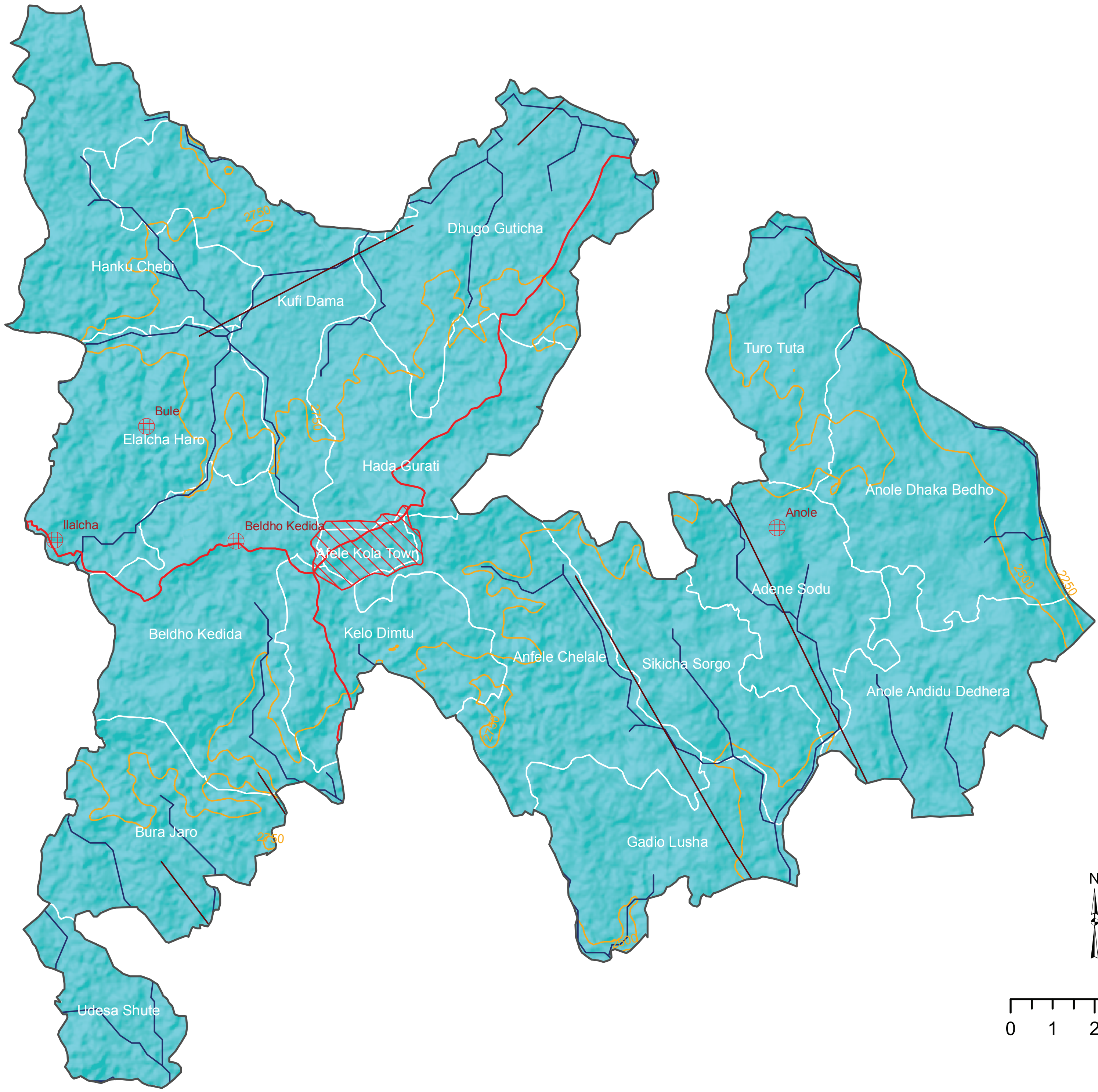


Character	Amount	
Surface Woreda Full	324	km^2
Surface Woreda ATA study zone	324	km^2
Annual Renewable Groundwater Recharge	2.40	Mm^3
Irrigation Capacity	76	ha
Potential household numbers to be served	304	
Potential persons to be served	1,522	



Map for very shallow and shallow groundwater resource

Dima (Afele Kola) Woreda



Legend

Very Shallow and Shallow Groundwater

Aquifer 2 & 22 Locally developed and moderately to low productive [Yield = (0.75 – 0.25) lit/sec] aquifers: Intermountainous deposits crossed mostly by perennial rivers with groundwater level fluctuate in the order of 5 to 10 m. Groundwater occur at fissured and/or weathered bedrock and the overlying sediments. At depressions forming plains without perennial rivers, groundwater level has a rapid tendency to decrease because the regional groundwater level is at a greater depth. These aquifers show excellent groundwater quality for irrigation.

Access Technology and Diggability

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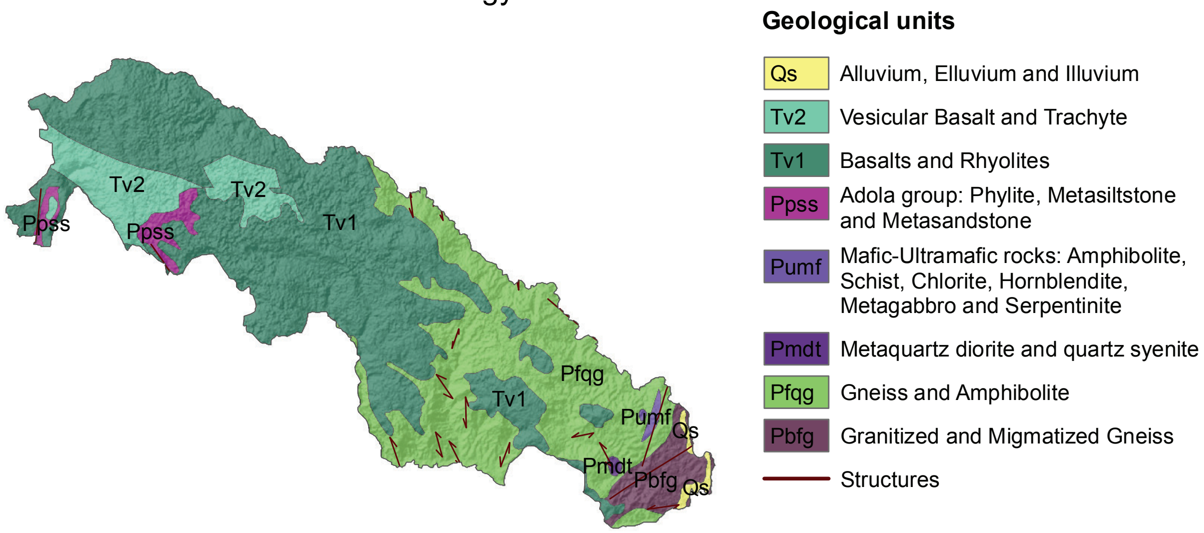
- Kebeles Boundery
- Major Structures
- Countours (250m Interval)
- Rivers
- Roads
- Rural Towns
- Small Rural Towns

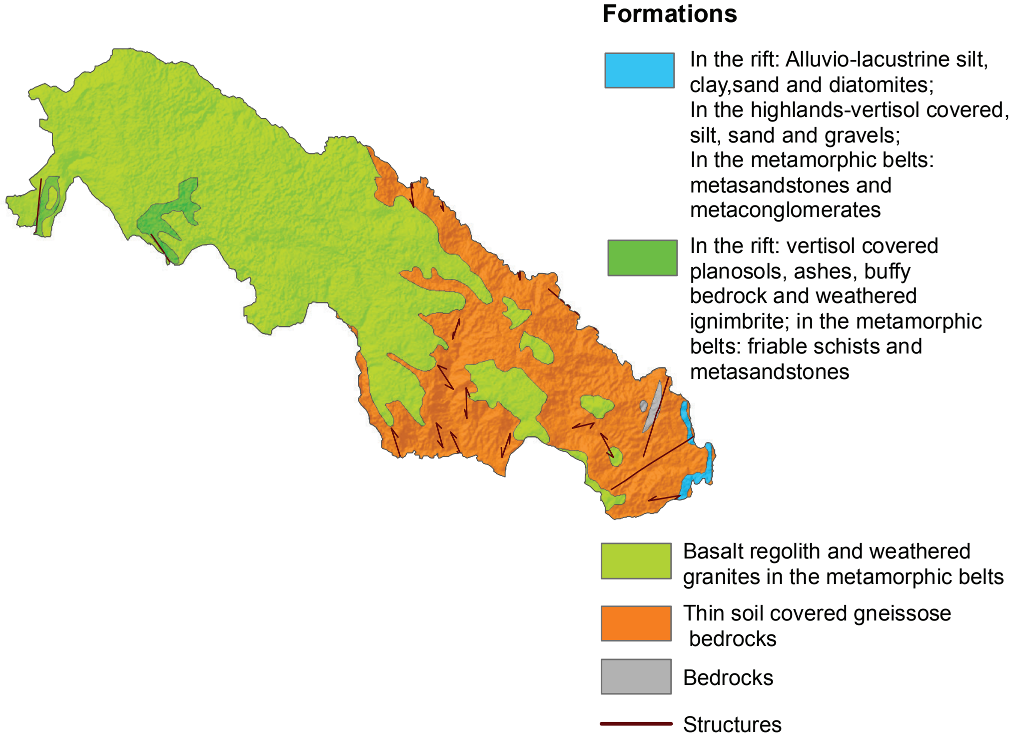
Map for very shallow and shallow groundwater resource

Hambela Wamena Woreda

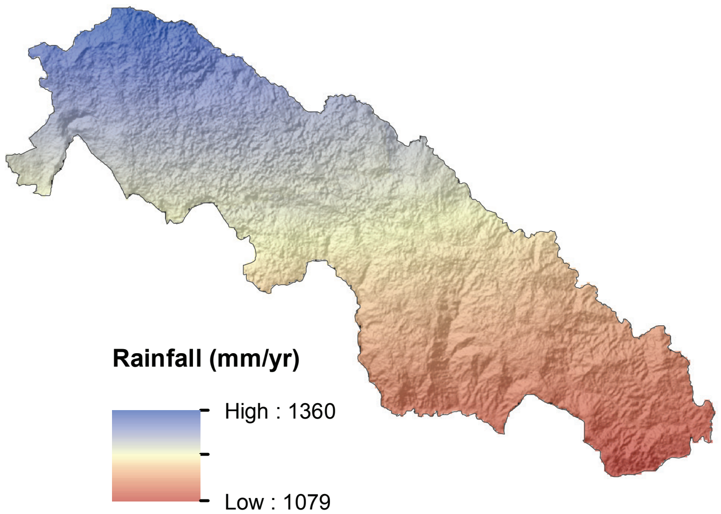
Bed rock Geology



Superficial Deposit

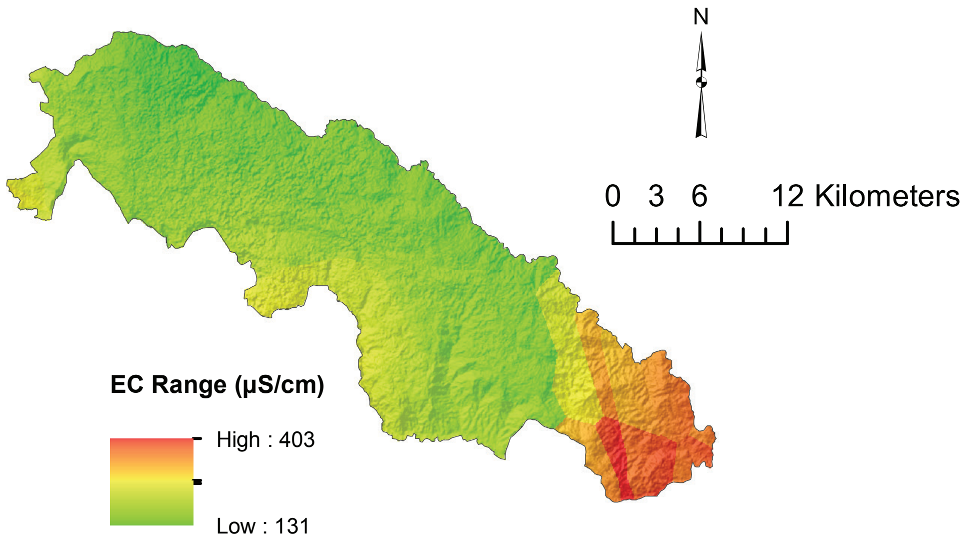


Rainfall Distribution Pattern

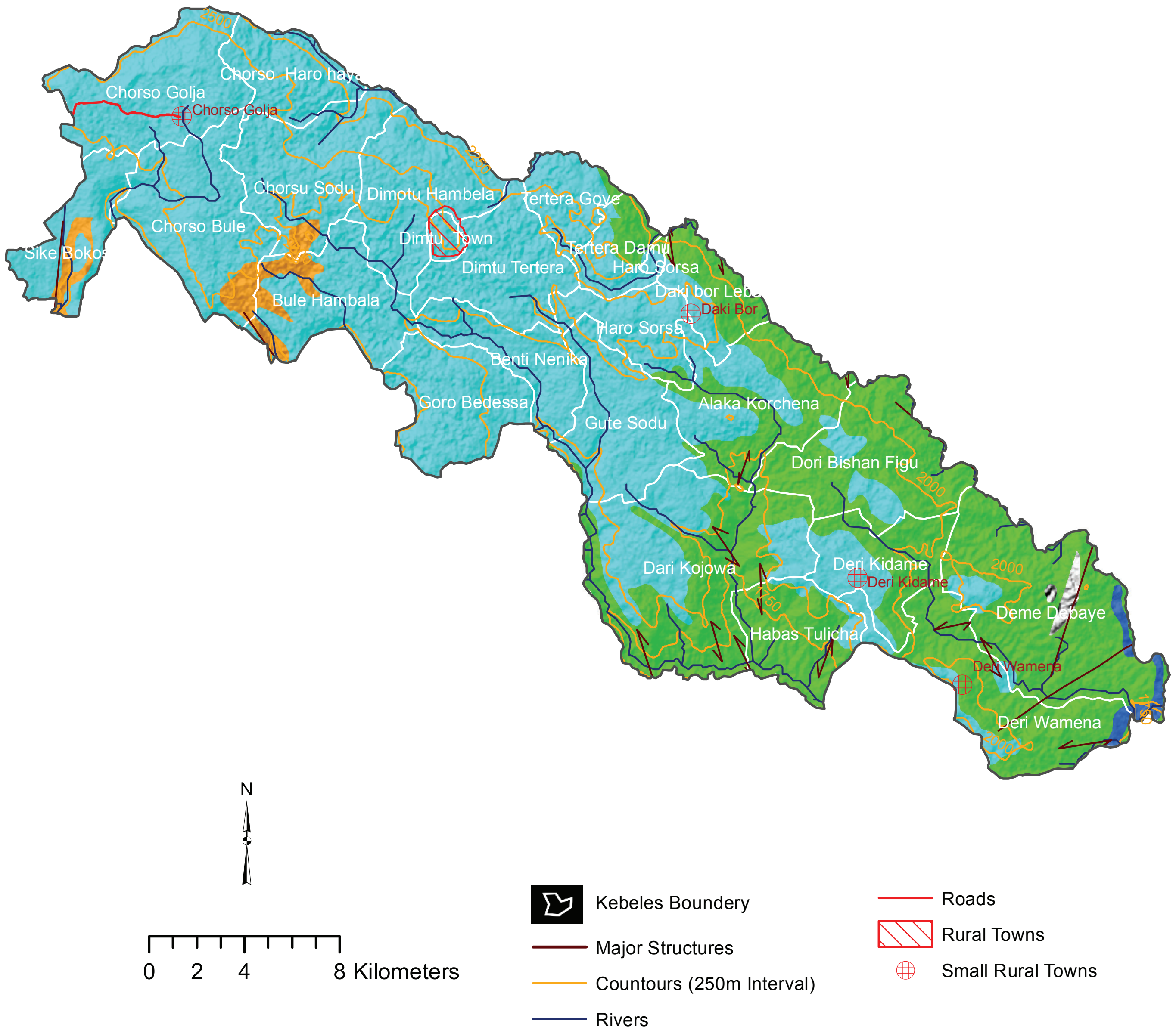


Character	Amount
Surface Woreda Full	572 km^2
Surface Woreda ATA study zone	572 km^2
Annual Renewable Groundwater Recharge	15.57 Mm^3
Irrigation Capacity	494 ha
Potential household numbers to be served	1,975
Potential persons to be served	9,875

Electrical Conductivity



Hambela Wamena Woreda



Map for very shallow and shallow groundwater resource

Legend

Very Shallow and Shallow Groundwater

Aquifer 1 Extensive and highly productive [Yield = (0.75 – 1) lit/sec] aquifers: Intergranular aquifer with average water level fluctuation (2-4 m). Shallow groundwater level at a depth of less than 30 m. Thickness of superficial sediments varies from 20 to 73m. Excellent water quality for irrigation except locally high TDS may be encountered.

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Aquifer 3 & 33 Local and moderately productive [Yield = (0.5 – 0.1) lit/sec] minor aquifers: Aquifers developed mainly in basement tectonic zones. Shallow groundwater table depth is less than 30m. The shallow regolith aquifer has minor local importance, however locally good aquifer with moderate productivity (Q> 1 l/s) may be encountered in depressions filled by transported sediments or in cases where regolith thickness exceeds 10 meters. These aquifers show mainly excellent groundwater quality for irrigation.

No shallow aquifer zone:
Extensive formations consisting of volcanic and basement rocks with minor and limited shallow groundwater resources where groundwater is at different depths and can be developed by deep drilling and spring development.

Access Technology and Diggability

Large diameter hand dug wells with lining of the top 3m, manually drilled tube wells; lining may not be required below 4m; protection against flood required around the well head; periodic dredging is required; easily diggable. Open hand dug wells with concrete or masonry lining of top 3m; no lining required below 3-4m; easily diggable but may require chiseling in places.

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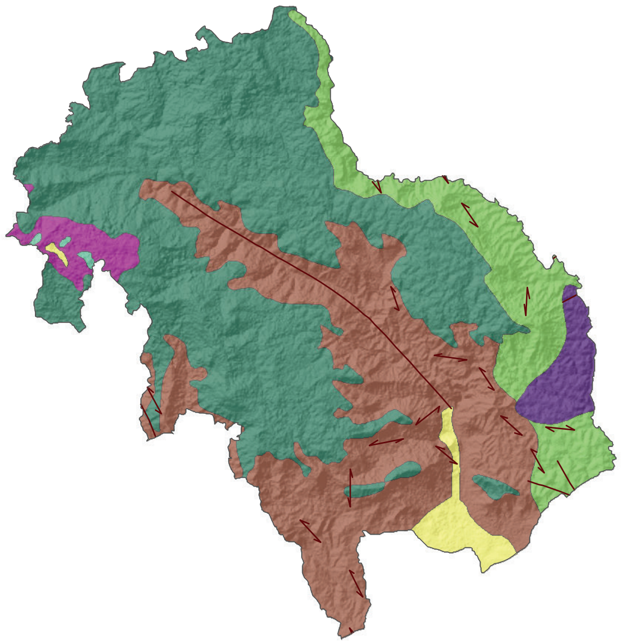
Groundwater can be developed by hand digging and manual drilling. Low diggability with exceptions in places where weathered mantle in local depressions is sufficiently thick.

Access only through drilling except locally by hand dug wells.

Qercha Woreda

Bed rock Geology



Geological units

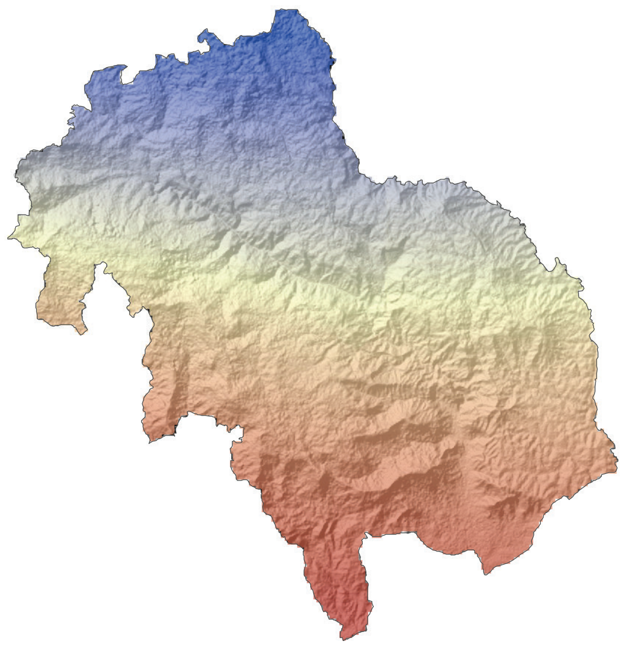
- Qs — Alluvium, Elluvium and Illuvium
- Tv2 — Vesicular Basalt and Trachyte
- Tv1 — Basalts and Rhyolites
- Ppss — Adola : GroupPhylite, Metasiltstone and Metasandstone
- Pmdt — Metaquartz diorite and quartz syenite
- Pfqg — Gneiss and Amphibolite
- Phbg — Gneiss and Granite
- Structures

Superficial Deposit

Formations

- In the rift: Alluvio-lacustrine silt,clay, sand and diatomites; In the highlands-vertisol covered, silt, sand and gravels; In the metamorphic belts: metasandstones and metaconglomerates
- In the rift: vertisol covered planosols, ashes, buffy bedrock and weathered ignimbrite; in the metamorphic belts: friable schists and metasandstones
- Basalt regolith and weathered granites in the metamorphic belts
- Thin soil covered gneissose bedrocks
- Structures

Rainfall Distribution Pattern



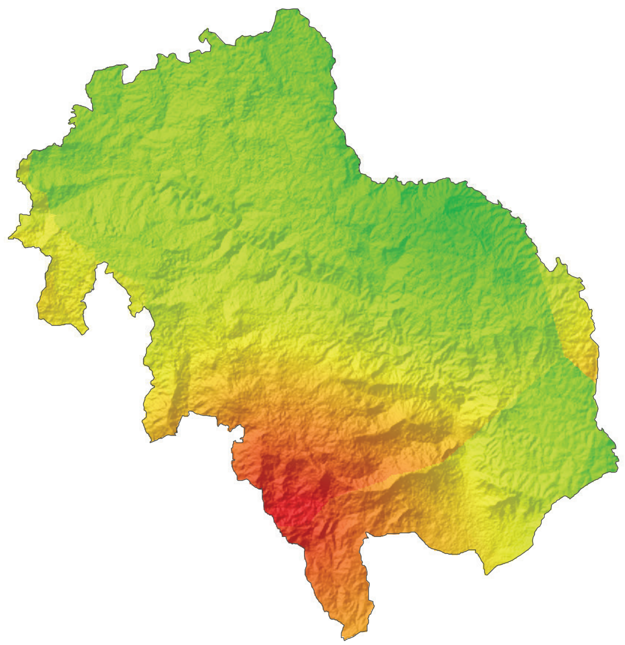
Character	Amount	
Surface Woreda Full	739	km^2
Surface Woreda ATA study zone	739	km^2
Annual Renewable Groundwater Recharge	30.51	Mm^3
Irrigation Capacity	967	ha
Potential household numbers to be served	3,870	
Potential persons to be served	19,348	

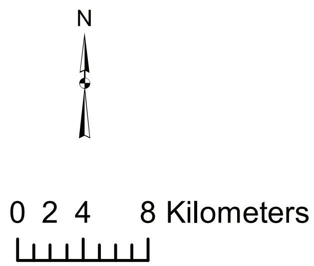
Rainfall (mm/yr)

High : 1205

Low : 926

Electrical Conductivity





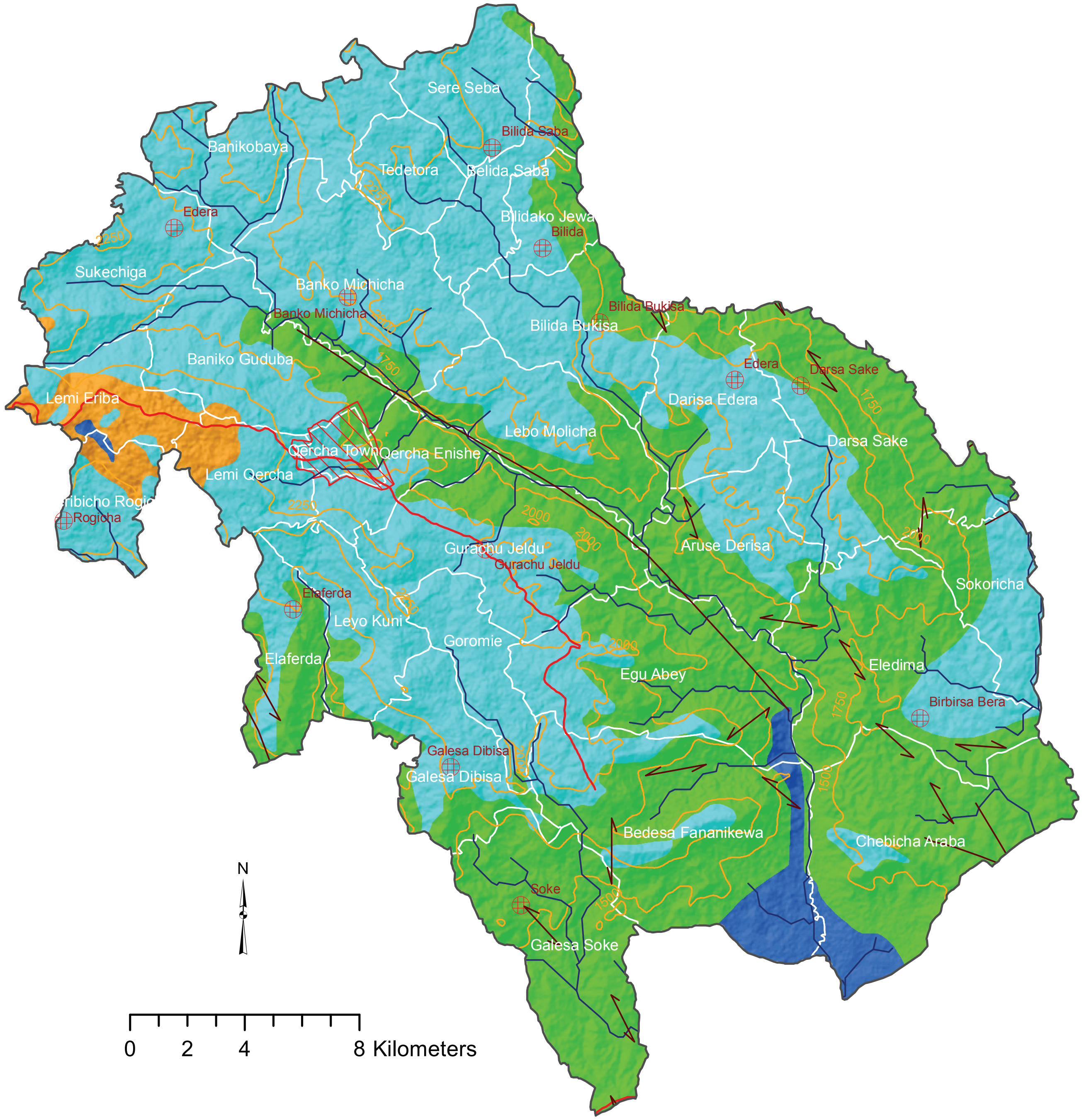
EC Range (µS/cm)

High : 488

Low : 202

Map for very shallow and shallow groundwater resource

Qercha Woreda



Legend

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- Aquifer 1 Extensive and highly productive [Yield = (0.75 – 1) lit/sec] aquifers: Intergranular aquifer with average water level fluctuation (2-4 m). Shallow groundwater level at a depth of less than 30 m. Thickness of superficial sediments varies from 20 to 73m. Excellent water quality for irrigation except locally high TDS may be encountered.
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Access Technology and Diggability

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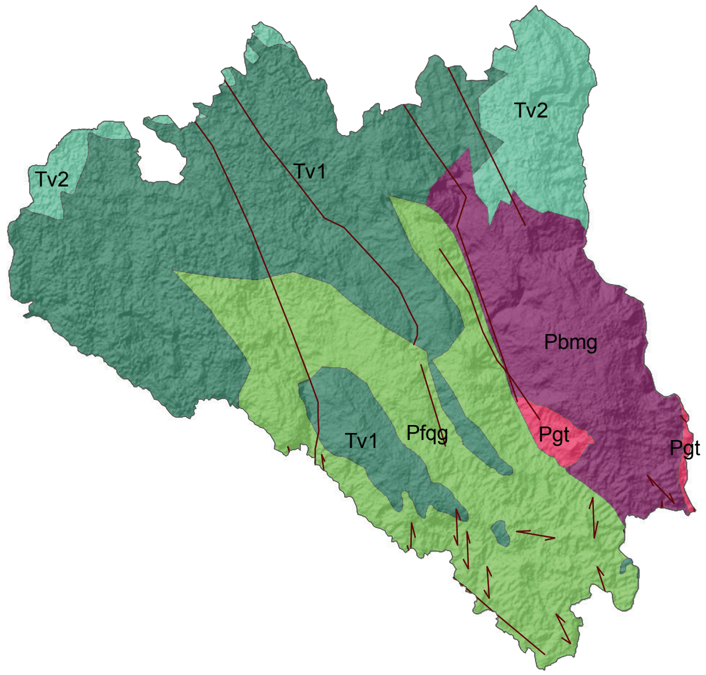
- Kebeles Boundery
- Major Structures
- Countours (250m Interval)
- Rivers
- Roads
- Rural Towns
- Small Rural Towns

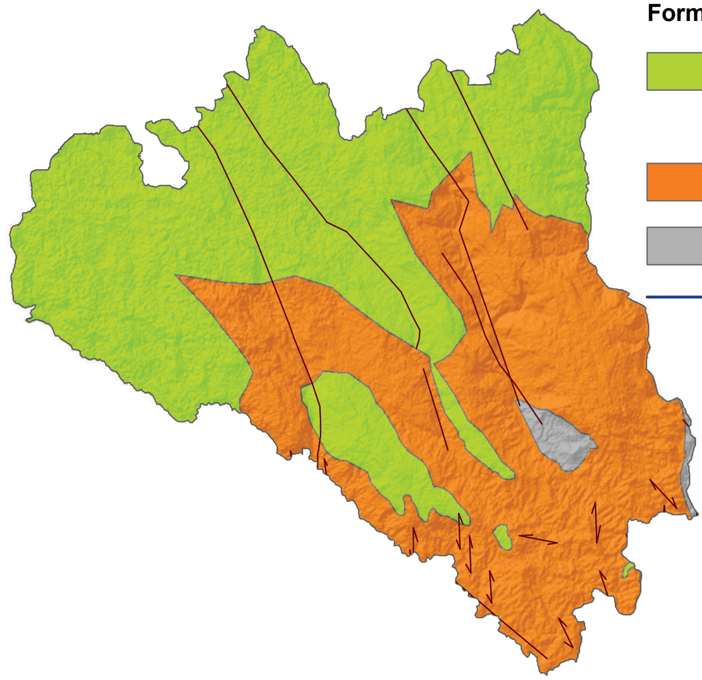
Map for very shallow and shallow groundwater resource

Uraga Woreda

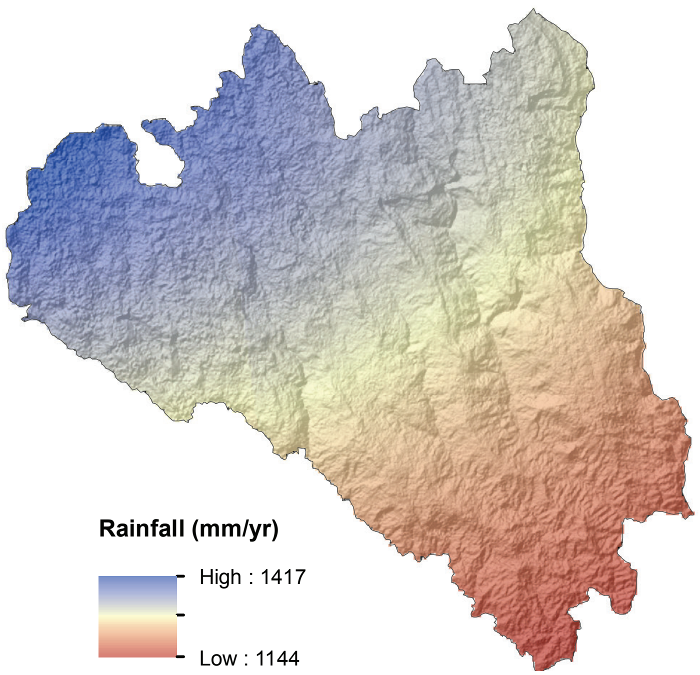
Bed rock Geology



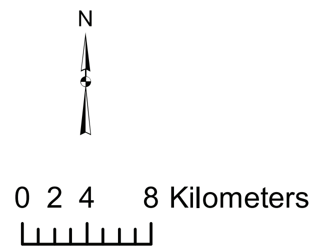
Superficial Deposit



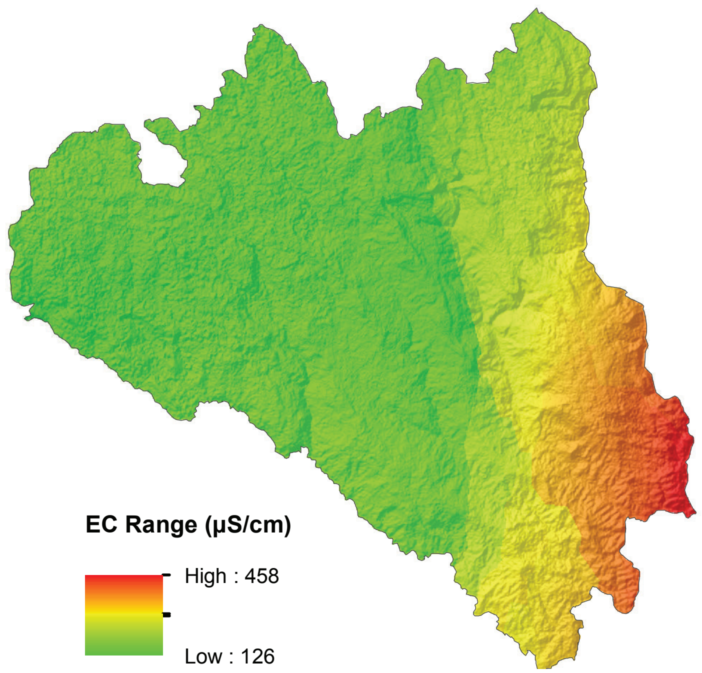
Rainfall Distribution Pattern



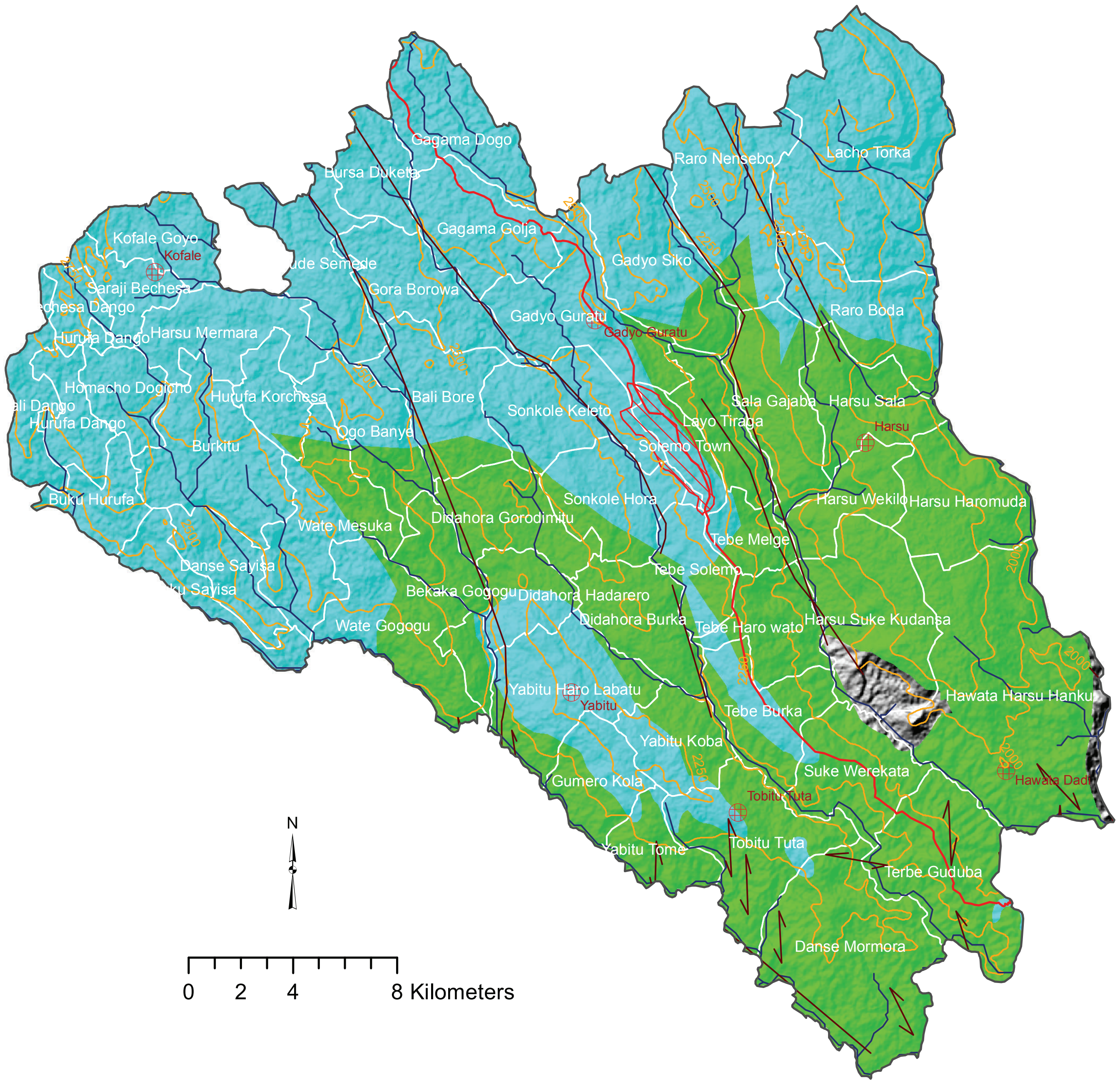
Character	Amount
Surface Woreda Full	928 km ^{2}
Surface Woreda ATA study zone	928 km ^{2}
Annual Renewable Groundwater Recharge	15.22 Mm ^{3}
Irrigation Capacity	483 ha
Potential household numbers to be served	1,930
Potential persons to be served	9,652



Electrical Conductivity



Uraga Woreda



Legend

Very Shallow and Shallow Groundwater

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- No shallow aquifer zone: Extensive formations consisting of volcanic and basement rocks with minor and limited shallow groundwater resources where groundwater is at different depths and can be developed by deep drilling and spring development.

Access Technology and Diggability

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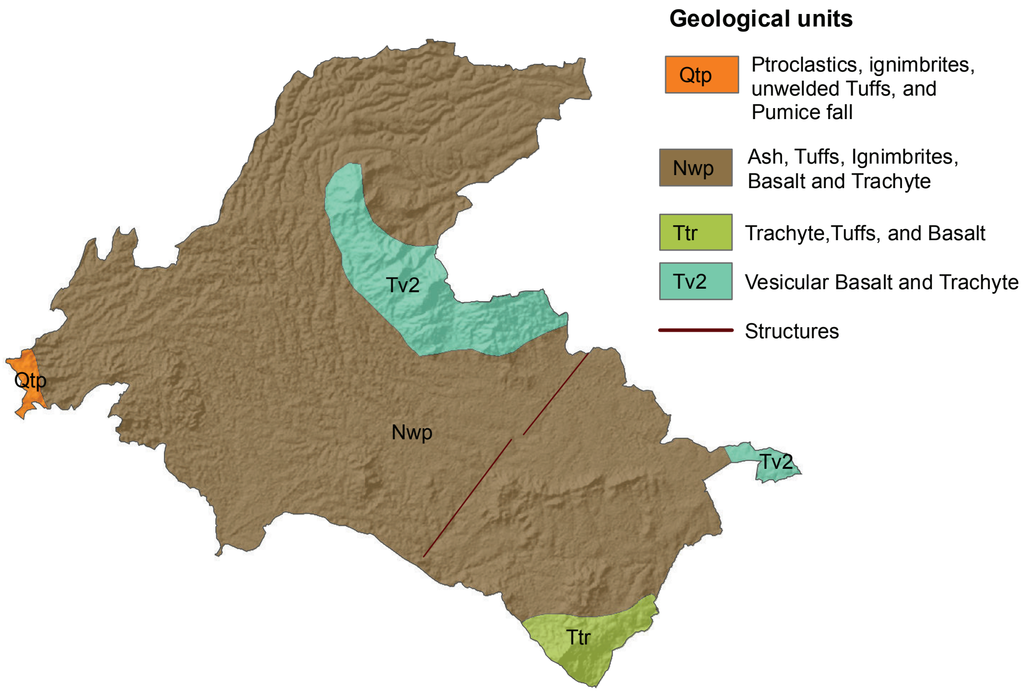
- Groundwater can be developed by hand digging and manual drilling. Low diggability with exceptions in places where weathered mantle in local depressions is sufficiently thick.
- Access only through drilling except locally by hand dug wells.

- Kebeles Boundery
- Major Structures
- Countours (250m Interval)
- Rivers
- Roads
- Rural Towns
- Small Rural Towns

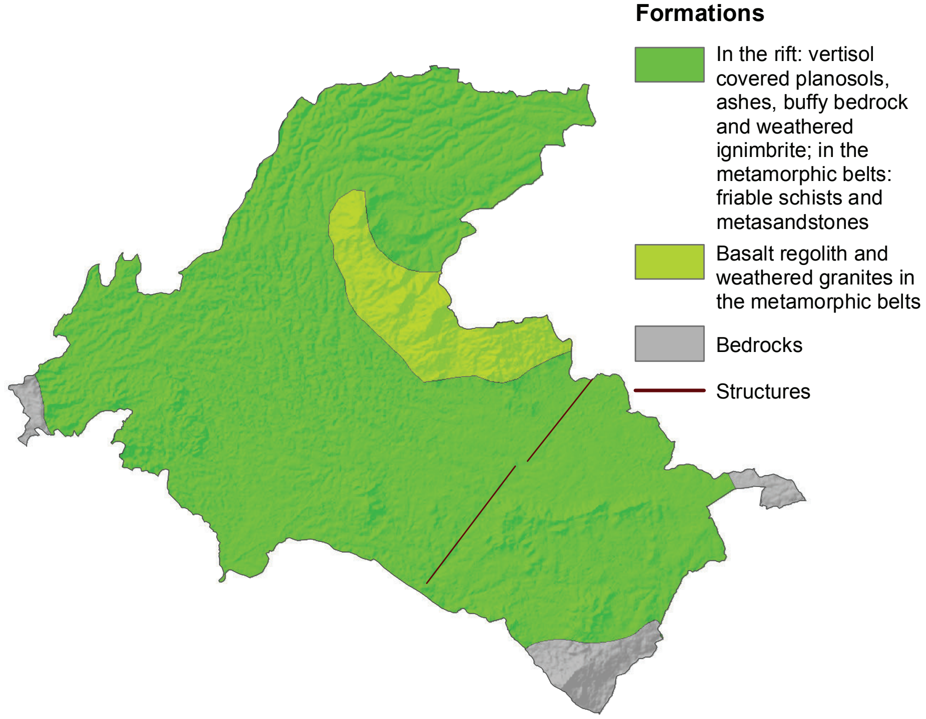
Map for very shallow and shallow groundwater resource

Kokosa Woreda

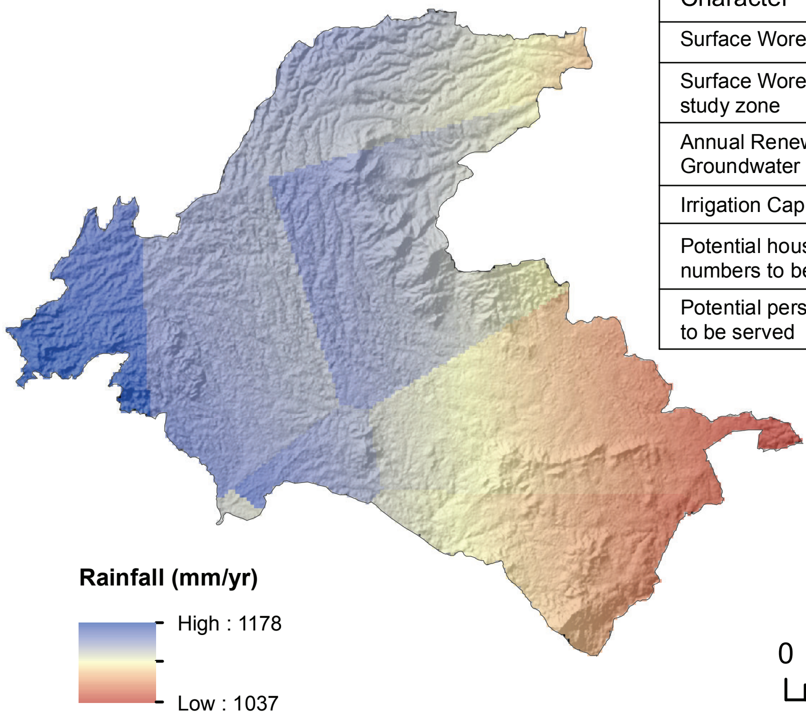
Bed rock Geology



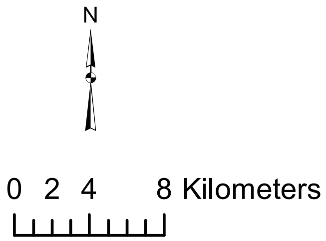
Superficial Deposit



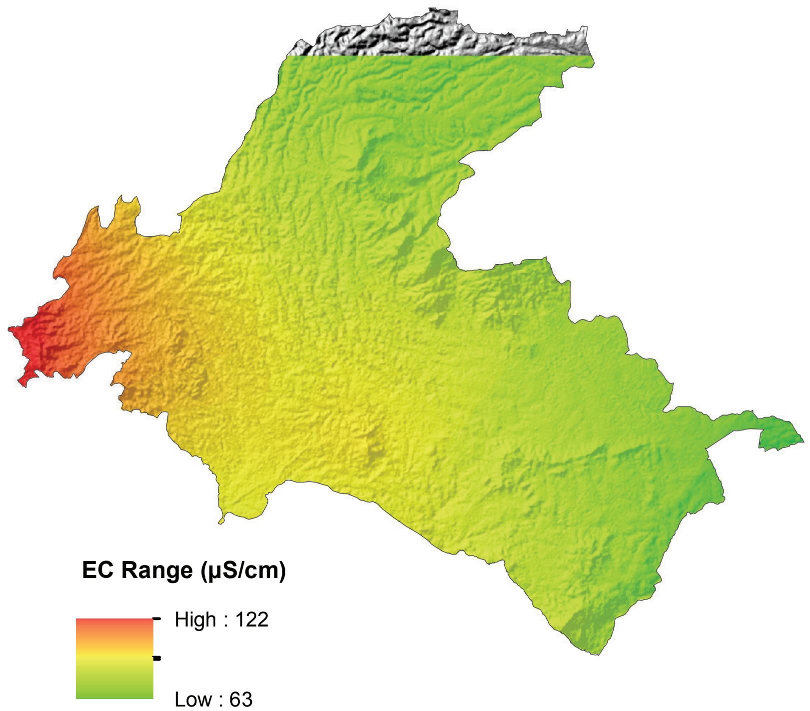
Rainfall Distribution Pattern



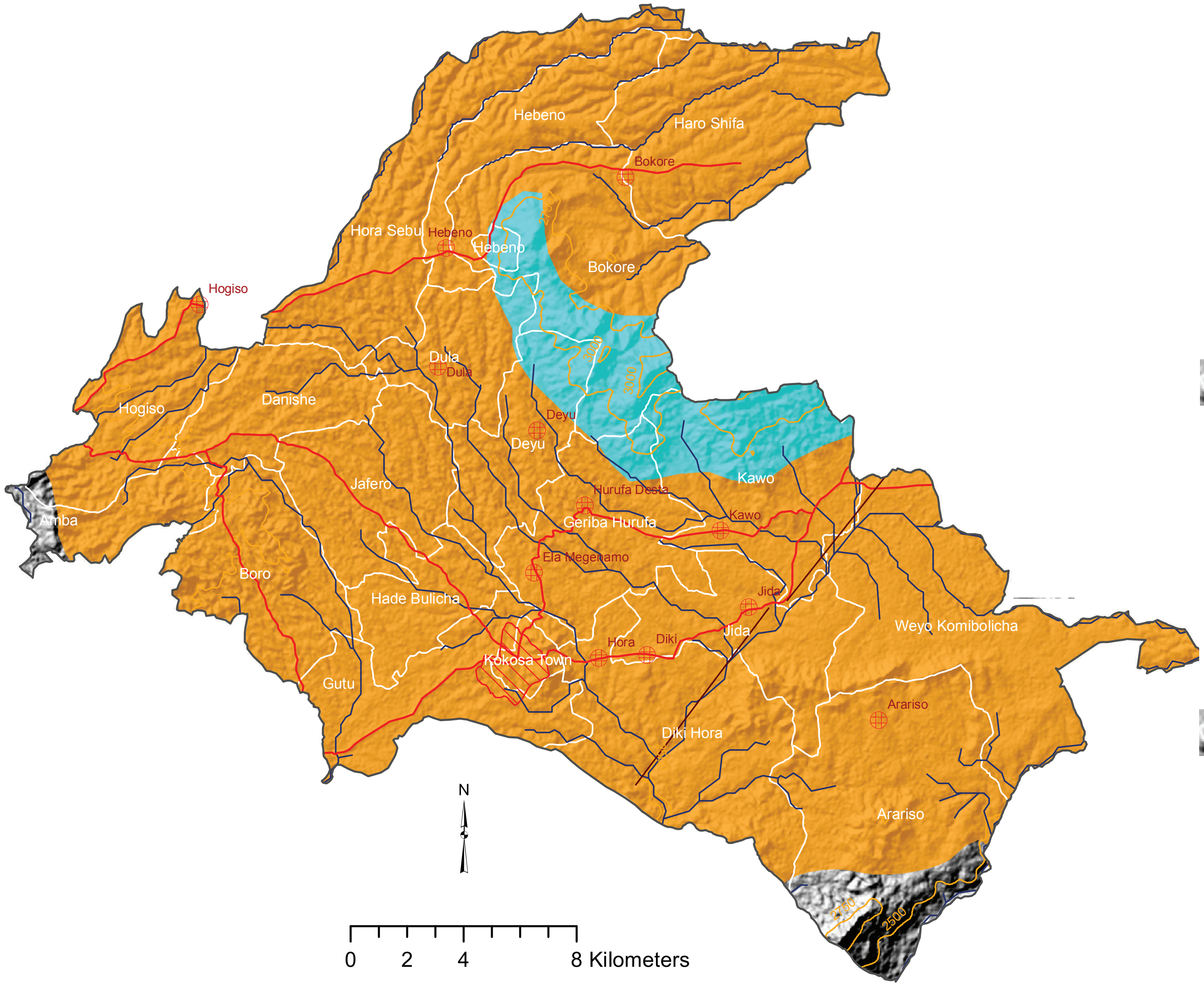
Character	Amount
Surface Woreda Full	632 km^2
Surface Woreda ATA study zone	509 km^2
Annual Renewable Groundwater Recharge	12.78 Mm^3
Irrigation Capacity	405 ha
Potential household numbers to be served	1,621
Potential persons to be served	8,105



Electrical Conductivity



Kokosa Woreda



Legend

Very Shallow and Shallow Groundwater

Aquifer 2 & 22 Locally developed and moderately to low productive [Yield = (0.75 – 0.25) lit/sec] aquifers: Intermountainous deposits crossed mostly by perennial rivers with groundwater level fluctuate in the order of 5 to 10 m. Groundwater occur at fissured and/or weathered bedrock and the overlying sediments. At depressions forming plains without perennial rivers, groundwater level has a rapid tendency to decrease because the regional groundwater level is at a greater depth. These aquifers show excellent groundwater quality for irrigation.

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Extensive formations consisting of volcanic and basement rocks with minor and limited shallow groundwater resources where groundwater is at different depths and can be developed by deep drilling and spring development.

Access Technology and Diggability

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Kebeles Boundery
Major Structures
Countours (250m Interval)
Rivers
Roads
Rural Towns
Small Rural Towns

Map for very shallow and shallow groundwater resource

Appendix A. Tables and Graphs

1. Baseflow assessment using hydrograph separation

Basin	River – sub-basin	Station	Hydrograph separation [m3/s]	Specific baseflow [l/s.km2]	Main aquifers
Dawa	Dawa	Digati	2.21	0.93	Basement
Dawa	Mormora	Megado	8.75	6.3	Basement
Dawa	Awata	Shakiso	2.84	1.76	Basement
Gelana	Gelena	Tore	2.34	1.54	Basalt, alluvium
Gelana	Upper Gelana	Yirga Chefe	0.23	0.81	Basalt
Genale	Logita	Bensa	6.25	8.6	Basalt
Genale	Borona	Daye	4.12	12.01	Basalt
Genale	Gelana	Bona Kike	3,98	10.6	Basalt
Genale	Ererte	Bona Kike	1.66	16.8	Basalt
Genale	Morodo	Bona Kike	1.05	12.2	Basalt
Genale	Konkona	Daye	1.15	22.1	Basalt
Genale	Gambetu	Aroresa	1.62	6.0	Basalt
Genale	Upper Genale	Girja	39.34	12.4	Basalt
Gidabo	Gidabo	Aposto	4.2	6.5	Basalt
Gidabo	Kolla	Aleta Wondo	1.5	7.3	Basalt
Gidabo	Sala	Dila College	1.81	26.8	Escarpment
Gidabo	Dimtu	Bore	3.0	104.9	Escarpment

2. Base flow assessment using the Kille method

Basin	River – sub-basin	Station	Kille method [m³/s]	Specific baseflow [l/s.km²]	Main aquifers
Dawa	Dawa	Digati	1.86	0.78	Basement
Dawa	Mormora	Megado	5.5	4.0	Basement
Dawa	Awata	Shakiso	3.5	2.17	Basemen
Gelana	Gelena	Tore	1.63	1.9	Basalt, alluvium
Gelana	Upper Gelana	Yirga Chefe	0.22	0.77	Basalt
Genale	Logita	Bensa	4.28	5.9	Basalt
Genale	Borona	Daye	2.95	8.6	Basalt
Genale	Gelana	Bona Kike	2.62	7.0	Basalt
Genale	Ererte	Bona Kike	0.97	9.8	Basalt

Genale	Morodo	Bona Kike	0.29	3.4	Basalt
Genale	Konkona	Daye	0.26	5.0	Basalt
Genale	Gambetu	Aroresa	1.25	4.6	Basalt
Genale	Upper Genale	Girja	24.64	7.7	Basalt
Gidabo	Gidabo	Aposto	2.65	4.1	Basalt
Gidabo	Kolla	Aleta Wondo	1.0	4.9	Basalt
Gidabo	Sala	Dila College	1.74	25.8	Escarpment
Gidabo	Dimtu	Bore	1.29	44.5	Escarpment

3. Baseflow calculation using modified Darcy's Law

River	S	H	T	Qb l/s/km2
Genale	202	1586	0.000029	9.27
Gidabo	149	1591	0.000027	6.30
Awata	196	1495	0.000028	8.33
Gelana	163	1644	0.000012	3.10
Mormora	200	1457	0.000028	8.27
Dawa	181	1449	0.000028	7.44

4. Summary of baseflow data

Basin	Area [km2]	Specific runoff [l/s.km2]	Specific baseflow [l/s.km2]	Main aquifers
Dawa	2369.0	1.0	0.9	Basement
Mormora	1321.0	9.5	5.1	Basement
Awata	1617.1	10.3	2.0	Basement
Gelena	3446.2	2.9	1.7	Volcanic, sedimentary
Gidabo	3317.1	3.5	5.0	Volcanic, sedimentary
Genale	3179.3	16.0	10.1	Volcanic

5. Surface inflow into the selected lakes

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

6. Evaporation from selected lakes

Lake	Area km2	Pan [mm]	E [Mm3]
Abaya	1,084.8	1850	2,013.1
Chamo	315.3	1847	582.4
Chew Bahir	762.8	1395	1,064.1

7. Groundwater recharge into selected lakes

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

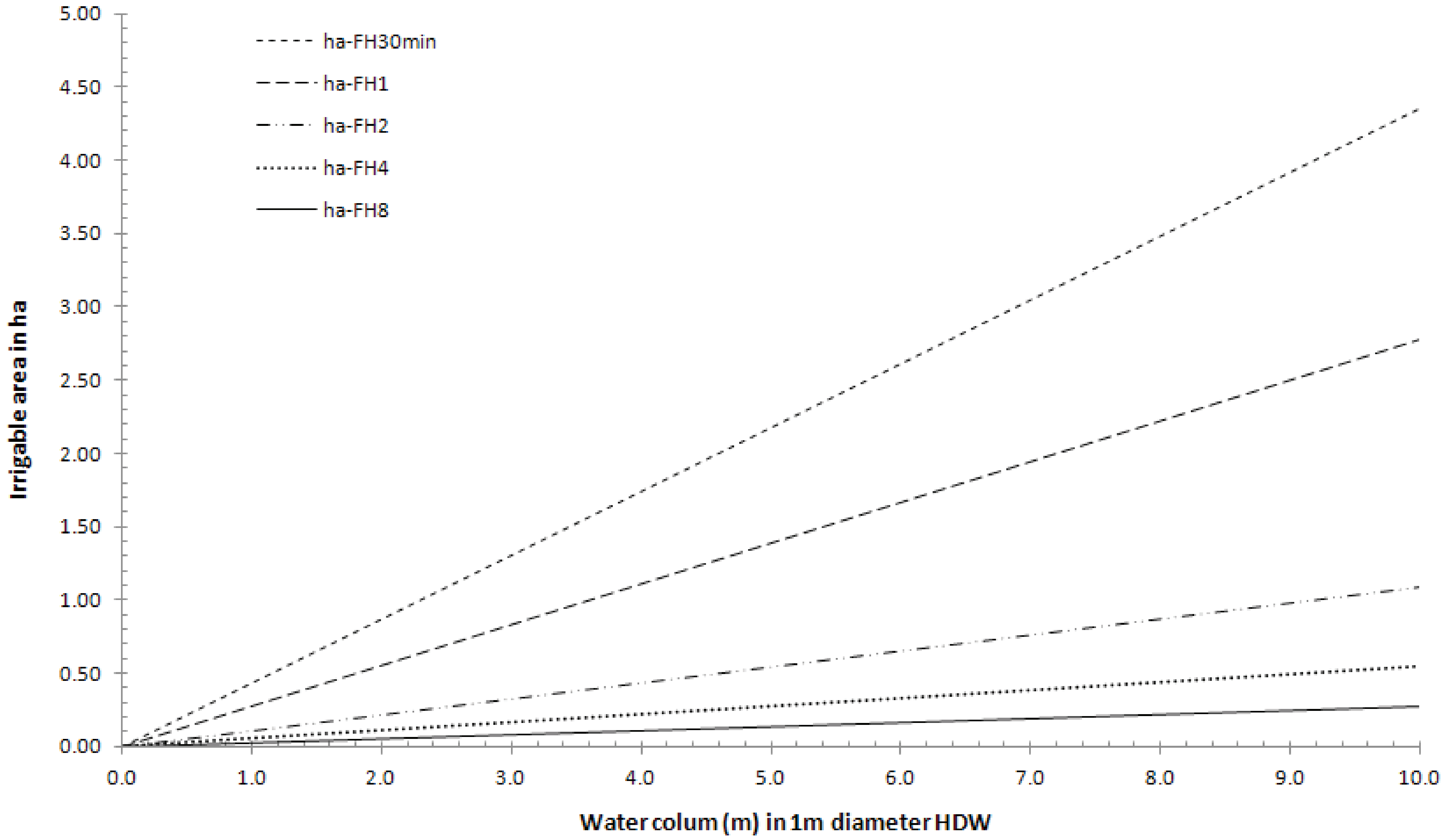
8. Summary of adopted baseflow and recharge in the project area

Sub - basin	Area km^2	Specific baseflow (l/s/km2)	Recharge (mm)
Gelana	3,856	2.0	80
Gidabo	3,491	4.0	100 - 250
Genale	3,177	5.0	250
Mormora	1,321	4.0	150
Awata	1,617	2.17	100
Dawa	2,375	0.74	30

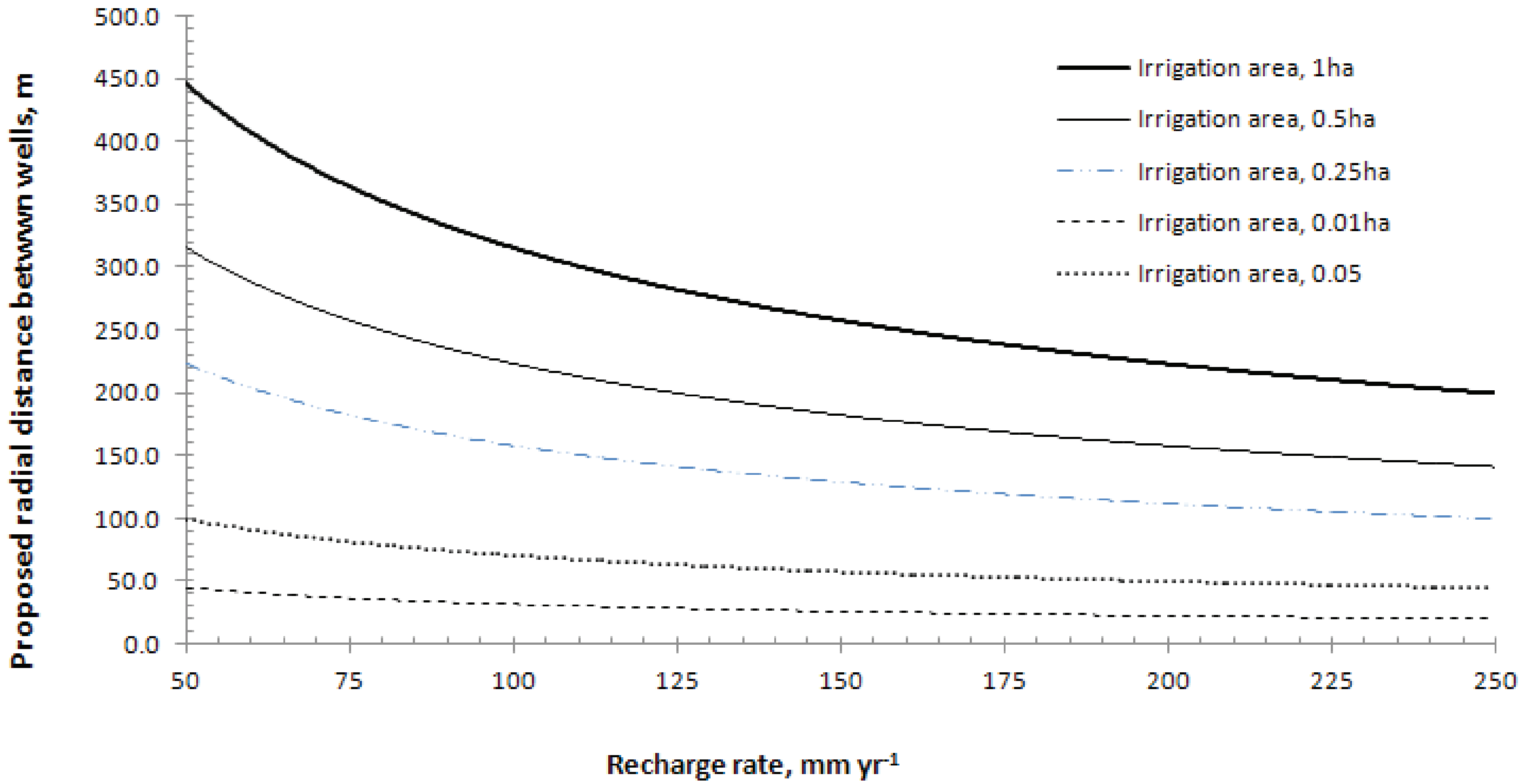
9. Proposed productivity classification of the five aquifers based on newly suggested productivity range and their comparison against conventional aquifer classification

Conventional aquifer productivity classification			Proposed aquifer productivity classification of shallow and very shallow aquifers for HH irrigation	
Aquifer Productivity	Transmissivity (m^2/day)	Yield (L/S)	Aquifer Productivity	Yield (L/S)
Very high productivity	>500	>25	Very high productivity	> 1
High Productivity	100-500	5-25	High Productivity	0.75-1
Moderate Productivity	50-100	2-5	Moderate Productivity	0.5-0.75
Low Productivity	10-50	0.5-2	Low Productivity	0.25-0.5
Very Low Productivity	1-10	0.01-0.5	Very Low Productivity	0.1-0.25
Aquitard	< 1	< 0.01	Aquitard	< 0.1

10. Monogram (tool) to design and decide water column and potential irrigable area from a dug well



11. Proposed well spacing corresponding to recharge zones and acreage of land each scheme is intended to irrigate

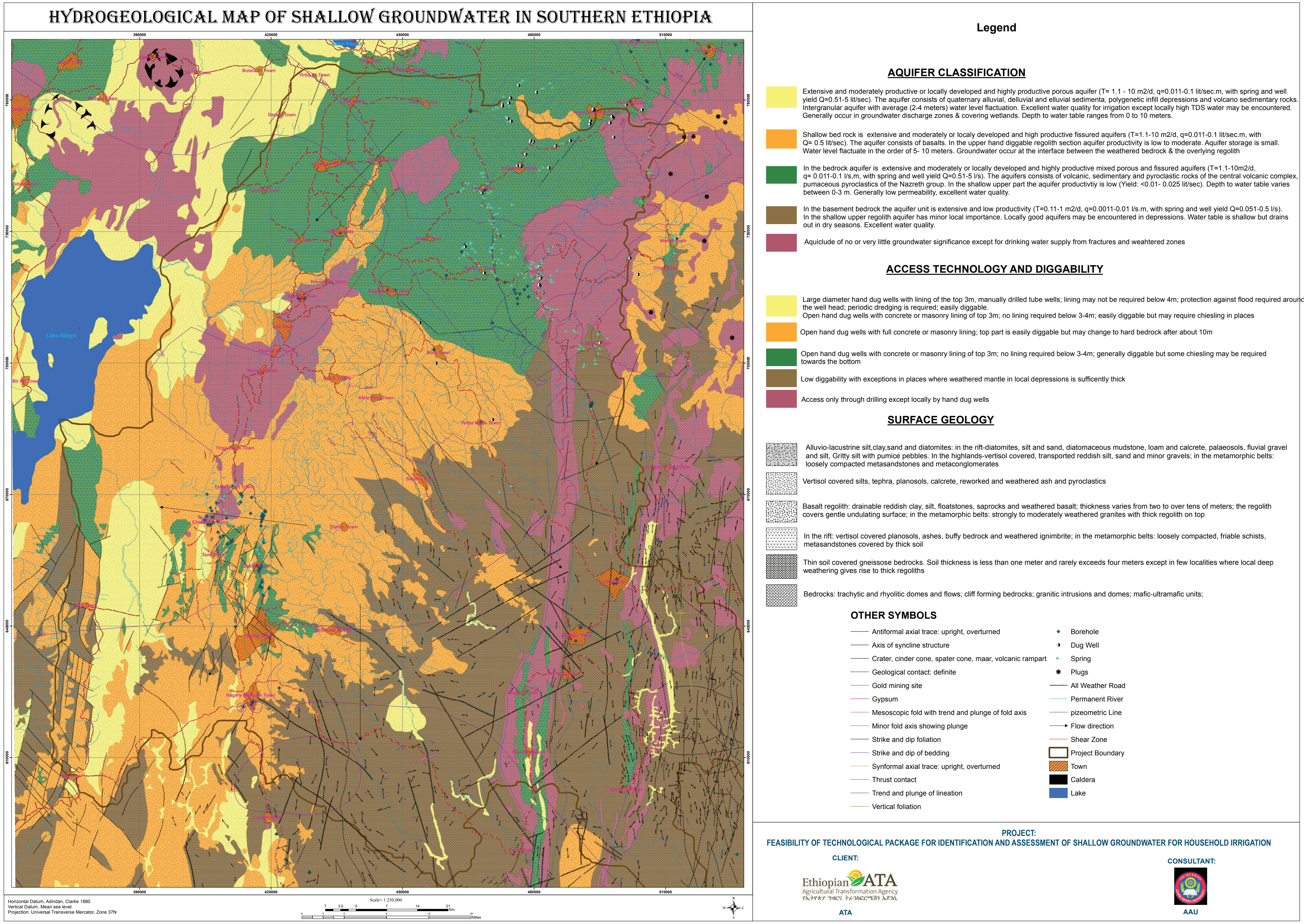


12. Summary of shallow Aquifer characteristics and Access technology and Diggability

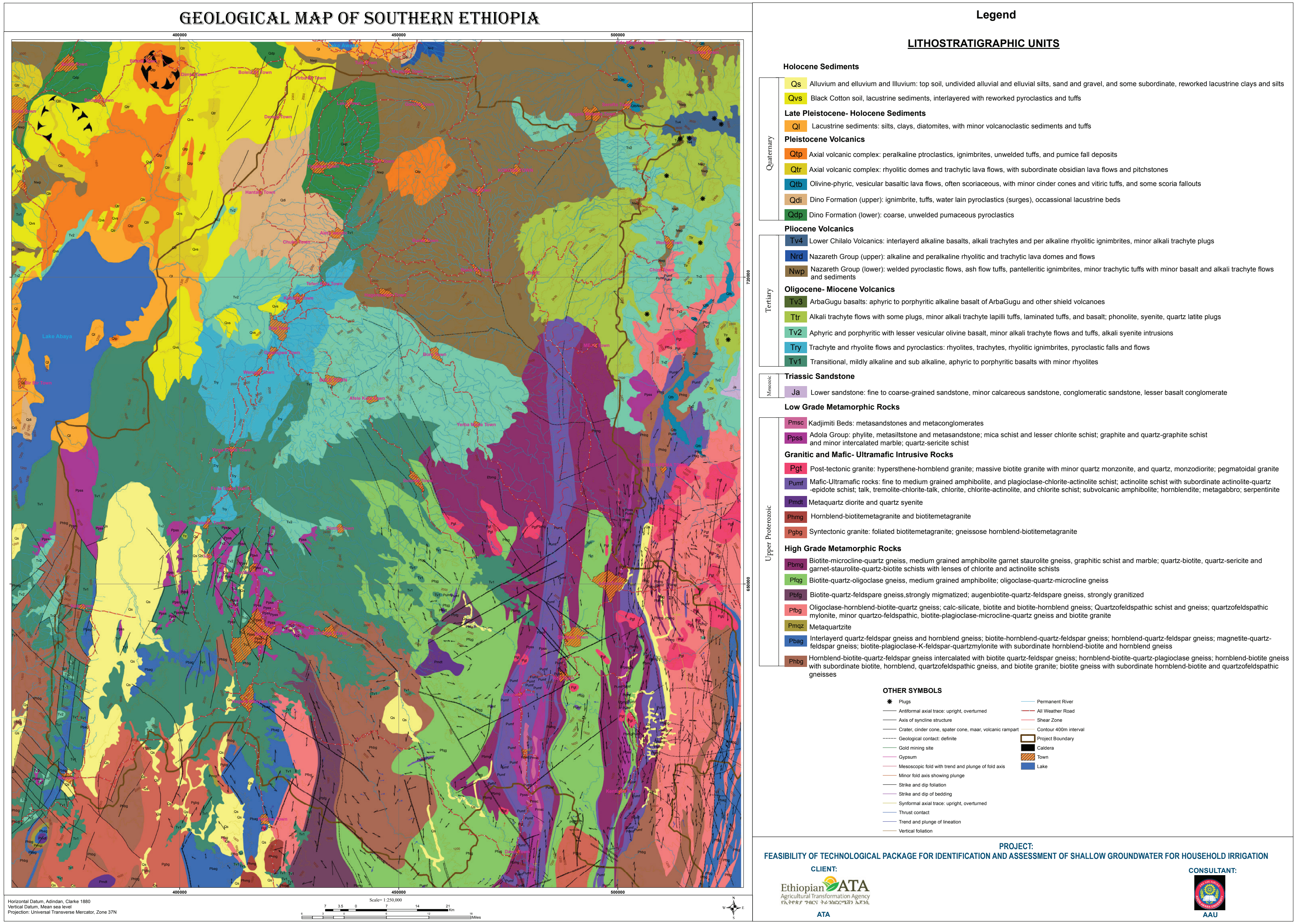
Aquifer type	Aquifer characteristics	Access technology and Diggability
Aquifer 1	Aquifer 1 Extensive and highly productive [Yield = (0.75 – 1) lit/sec] aquifers: Intergranular aquifer with average water level fluctuation (2-4 m). Shallow groundwater level at a depth of less than 30 m. Thickness of superficial sediments varies from 20 to 73m. Excellent water quality for irrigation except locally high TDS may be encountered	Large diameter hand dug wells with lining of the top 3m, manually drilled tube wells; lining may not be required below 4m; protection against flood required around the well head; periodic dredging is required; easily diggable. Open hand dug wells with concrete or masonry lining of top 3m; no lining required below 3-4m; easily diggable but may require chiseling in places.
Aquifer 2 & 22	Locally developed and moderately to low productive [Yield = (0.75 – 0.25) lit/sec] aquifers: Intermountainous deposits crossed mostly by perennial rivers with groundwater level fluctuate in the order of 5 to 10 m. Groundwater occur at fissured and/or weathered bedrock and the overlying sediments. At depressions forming plains without perennial rivers, groundwater level has a rapid tendency to decrease because the regional groundwater level is at a greater depth. These aquifers show excellent groundwater quality for irrigation.	Open hand dug wells with full concrete or masonry lining ; Manual drilling and casing / lining is recommended because of potential local artesian conditions; top part is easily diggable but may change to hard bedrock after about 10m .
Aquifer 3 & 33	Local and moderately productive [Yield = (0.5 – 0.1) lit/sec] minor aquifers: Aquifers developed mainly in basement tectonic zones. Shallow groundwater table depth is less than 30m. The shallow regolith aquifer has minor local importance, however locally good aquifer with moderate productivity (Q> 1 l/s) may be encountered in depressions filled by transported sediments or in cases where regolith thickness exceeds 10 meters. These aquifers show mainly excellent groundwater quality for irrigation.	Groundwater can be developed by hand digging and manual drilling. Low diggability with exceptions in places where weathered mantle in local depressions is sufficiently thick.
Aquifer 4 & 5	Extensive or locally developed and low to very low productive [Yield = (0.75 – 0.25) lit/sec] aquifers: Aquifers developed in the regolith covering volcanic rocks. The shallow groundwater level varies from 10 to 30 m. These aquifers show mainly excellent groundwater quality for irrigation.	Groundwater can be developed by hand digging (common practice) and manual drilling. Open hand dug wells with concrete or masonry lining of top 3m; no lining required below 3-4m; generally diggable but some chiseling may be required to wards the bottom.
No Shallow Aquifer Zone	Extensive formations consisting of volcanic and basement rocks with minor and limited shallow groundwater resources where groundwater is at different depths and can be developed by deep drilling and spring development.	Access only through drilling except locally by hand dug wells.

Appendix B. Maps

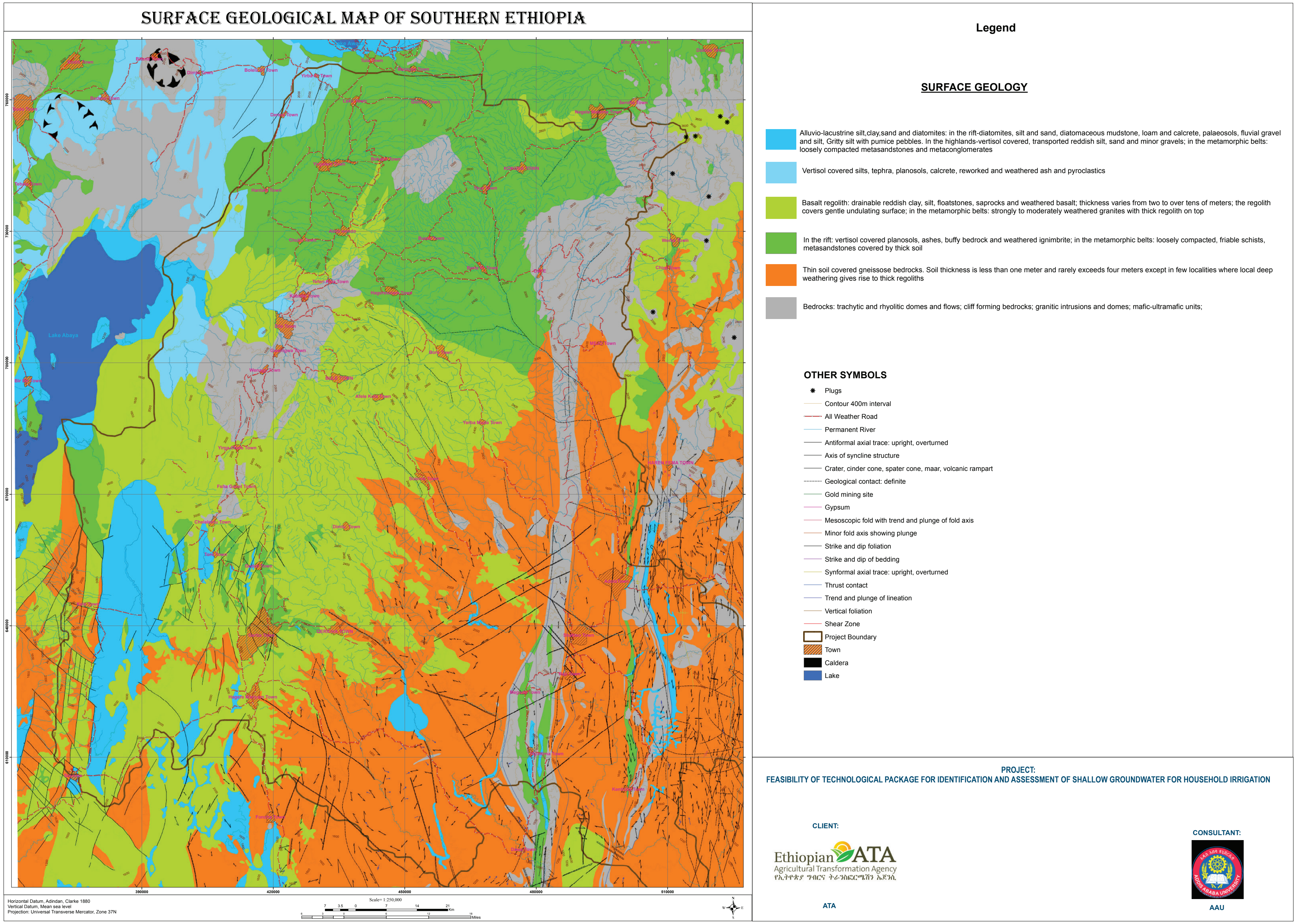
1. Very Shallow and Shallow Groundwater Map



2. Bed Rock Geological Map



3. Surface Geological (Superficial Deposit) Map



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