FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA
MINISTRY OF WATER AND ENERGY

LOT - 2: CONSULTANCY SERVICES FOR HYDROGEOLOGICAL MAPPING USING REMOTE SENSING, GIS, & GEOPHYSICAL SURVEYING

PHASE II– DEVELOPING GROUNDWATER POTENTIAL MAP (FINAL)

January 2022
ADDIS ABABA

Ethiopian Construction Design and Supervision Works Corporation
Water and Energy Design and Supervision Works Sector

P.O. Box 2561, Addis Ababa, Ethiopia
Tel: (+ 251)-11- 661-01-01, (+ 251)-11- 661-65-22
Fax :(+251) -11-661-53-71
E-mail: info@ecdswc.com
Website www.ecdswc.com.
Former Imperial Hotel Avenue,
Addis Ababa,

LOT- 2: HYDROGEOLOGICAL MAPPING USING REMOTE SENSING, GIS, & GEOPHYSICAL SURVEYING

PHASE II– DEVELOPING GROUNDWATER POTENTIAL MAP

January, 2022

Issues and Revision Records

Rev	Date	Originator (s)	Checked by	Approved by	Document Description
	January 2022	Ashebir G. Abenezer M. Seife N. Simegnew T Desta Yoseph Taddese A. Iyasu Ch. Fikirte Abebe Yelekal Yetayew	Ewunetu B.	Ephrem T.	Final Report

This document has been prepared for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority Ministry of Water and Energy (MoWE) once the document gets final acceptance by the client. ECDSWC accepts no responsibility or liability for the consequence of this document being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on the document for such other purpose agrees, and will by such use or reliance be taken to confirm his agreement to indemnify ECDSWC for all loss or damage resulting there from. ECDSWC accepts no responsibility or liability for this document to any party other than the person by whom it was commissioned.

CONSULTANCY SERVICES FOR HYDROGEOLOGICAL MAPPING USING REMOTE SENSING, GIS, & GEOPHYSICAL SURVEYING

PHASE II– DEVELOPING GROUNDWATER POTENTIAL MAP

FINAL REPORT

	STRUCTURE OF THE REPORT
PHASE - I	INCEPTION REPORT
PHASE - II	DEVELOPING GROUNDWATER POTENTIAL MAP
Annex I	BURE MUDAYITU WEREDA GROUNDWATER POTENTIAL MAP
Annex II	ARGOBA LIYU WEREDA GROUNDWATER POTENTIAL MAP
Annex III	DULECHA WEREDA GROUNDWATER POTENTIAL MAP
Annex IV	WUCHALE WEREDA GROUNDWATER POTENTIAL MAP
Annex V	GIRAR JARSO WEREDA GROUNDWATER POTENTIAL MAP
Annex VI	KUYU WEREDA GROUNDWATER POTENTIAL MAP
Annex VII	DERA WEREDA GROUNDWATER POTENTIAL MAP
Annex VIII	ENEBSIE SAR MIDIR WEREDA GROUNDWATER POTENTIAL MAP
Annex IX	SAYINIT WEREDA GROUNDWATER POTENTIAL MAP
Annex X	MEKET WEREDA GROUNDWATER POTENTIAL MAP
Annex XI	BUGNA WEREDA GROUNDWATER POTENTIAL MAP
Annex XII	EBINAT WEREDA GROUNDWATER POTENTIAL MAP
Annex XIII	MISRAK BELESA WEREDA GROUNDWATER POTENTIAL MAP
Annex XV	TSELEMIT WEREDA GROUNDWATER POTENTIAL MAP
PHASE - III	DETAILED SITE SPECIFIC HYDROGEOLOGICAL AND GEOPHYSICAL INVESTIGATION

Executive Summary

The current study aimed at delineating groundwater potential zones of 14 weredas by using integrated remote sensing and GIS-based multi-criteria evaluation in order to identify promising areas for groundwater exploration. The scarcity of water is a major menace in these 14 Weredas spread over 3 regions of Ethiopia.

In the study, RS (Remote Sensing) and GIS (geographic information system) were utilized to generate five thematic layers (Hydrogeological units, Groundwater recharge, Lineament density, Lineament proximity, and TWI) as factors influencing the groundwater potential. All the thematic layers were then assigned weights according to their relative importance in groundwater occurrence and corresponding normalized weights were obtained based on Saaty's Analytical Hierarchy Process (AHP). Based on the rank assigned by a conceptual understanding of the specific weredas and weights aggregating the thematic maps is done using a weighted overlay method to produce a groundwater potential (GWP) map. The GWP maps are verified by overlay analysis with existing boreholes yield. In addition, Single – Parameter sensitivity analyses are also used to examine effective weights.

The spatial distribution of the project weredas GWP zones generally matches with the conceptual understanding of the project weredas and existing boreholes data during model validation. The good agreement of GWP map and existing well data indicate litho–structural control on groundwater recharge and movement process and factors affecting groundwater recharge were carefully analyzed during the development of thematic layers. Based on the result of sensitivity analysis, the effective weights for each thematic layer show some deviation from empirical weights. The GWP maps produced will be used to quickly identify the prospective GWP zones for conducting site-specific investigations.

This study generally demonstrates that GIS and remote sensing techniques coupled with field data can be used for mapping GWP zones, thereby narrowing down the target areas. Then, by conducting a detailed hydrogeological and geophysical survey at phase III, the 14 most appropriate and 14 optional sites will be selected for drilling.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ANNEXES

ABREVIATIONS AND ACRONYMS

ADSWE	-	Amhara Design and Supervision Works Enterprise
a.m.s.l	-	above mean sea level
AOI	-	Area of Interest
ASTER	-	Advanced Spaceborne Thermal Emission and Transmission
BGL	-	Below ground level
CSA	-	Central Statistical Agency
CTI	-	Compound Topographic Index
DD	-	Draw down
DEM	-	Digital elevation model
DFID	-	The UK department for international development fund
E.C.D.S.W.Co	-	Ethiopia Construction Design & Supervision Works Corporation
EC	-	Electrical Conductivity
EGS	-	Ethiopian Geological Survey
EMA	-	Ethiopian Mapping Agency
ENVI	-	Environment for Visualizing Images
ESA	-	European Space Agency
ESRI	-	Environmental Systems Research Institute
ETV	-	Evapotranspiration
FA	-	Flow Accumulation
FD	-	Flow Direction
FDRE	-	Federal Democratic Republic of Ethiopia
GEARS	-	Great East African Rift System
GIS	-	Geographic information system
GPS	-	Global positioning system
GSE	-	Geological Surveys of Ethiopia
GW	-	Groundwater
GWP	-	Groundwater potential
GWPZ	-	Groundwater Potential zone
Hr	-	Hour
IDW	-	Inverse Distance Weighted
km	-	Kilometer
LULC	-	Land use land cover
m	-	Meter
m^3/s	-	cubic meters per second
MCM	-	Million Cubic Meters
MER	-	Main Ethiopian Rift
min	-	Minute
mm	-	Millimeter
MOWE	-	Ministry of Water, and Energy
NDVI	-	Normalized Difference Vegetation Index
NMA	-	National Meteorological Agency
pH	-	Hydrogen - Ion Activity

QGIS	-	Quantum Geographic Information System
RS	-	Remote sensing
SAR	-	Synthetic Aperture Radar
SCP	-	Semi-automatic Classification Plugin
SNAP	-	Sentinel Application Platform
SWL	-	Static water level
TDS	-	Total Dissolved Solids
ToR	-	Terms of References
TRB	-	Tekeze River Basin
TWI	-	Topographic Wetness Index
UTM	-	Universal Transverse Mercator
VES	-	Vertical Electrical Sounding
W.E.D.S.W.S	-	Water & Energy Design and Supervision Works Sector
WetSpass	-	Water & Energy transfer between soil, plants & atmosphere
WWDE	-	Water Well Drilling Enterprise
WWDSE	-	Water Works Design and Supervision Enterprise

1. INTRODUCTION

1.1 General

The consultancy contract agreement was signed between the then Basins Development Authority now Ministry of Water and Energy (Client) and Water & Energy Design and Supervision Works Sector In association with AFX OASIS Water Resources & Hydropower Engineering Construction P.L.C (Consultant) on May 14, 2021, for Hydrogeological Mapping by using an integrated approach of geological mapping, remote sensing, weighted GIS overlay analysis, hydrogeological mapping, and geophysical surveying in order to increase the success rate of drilling and provide resilient water sources to communities in selected 14 Weredas of Ethiopia.

It is the initiation of the client to conduct a groundwater study to make groundwater potential maps and to identify drilling target sites for boreholes and alternatives drilling sites in the 14 Weredas of the project area.

The project covers 14 water-scarce weredas known to have complex hydrogeology. The complexity of the hydrogeology is manifested by low and indirect recharge, high salinity groundwater, rugged topography, low yielding shallow groundwater, and very low past drilling success rates.

The current study aimed at delineating groundwater potential zones of 14 weredas by using integrated remote sensing and GIS-based multi-criteria evaluation to identify promising areas for groundwater exploration. The scarcity of water is a major menace in these 14 Weredas spread over 3 regions of Ethiopia for satisfying human needs.

In the study, RS (Remote Sensing) and GIS (geographic information system) were used to generate five thematic layers such as Hydrogeological units, Groundwater recharge, Lineament density, Lineament proximity, and TWI as factors influencing the groundwater potential. All the thematic layers were then assigned weights according to their relative importance in groundwater occurrence and corresponding normalized weights were obtained based on Saaty’s Analytical Hierarchy Process (AHP). Based on the rank assigned by a conceptual understanding of the specific weredas and weights aggregating the thematic maps is done using a weighted overlay method to obtain a groundwater potential (GWP) map. The GWP maps are verified by overlay analysis with existing boreholes yield data. In addition, Single –Parameter sensitivity analyses are used to examine effective weights.

The Phase – II report has been prepared based upon field inventory data, remotes sensing data, climatological data and GIS weighted overlay and presented in seven chapters as follows.

Chapter-1: Deals with an introduction to the phase II stage report;

Chapter-2: Data and Methodology of the study

Chapter-3: Conceptual Hydrogeological model of the study area

Chapter-4: Result and discussion

Chapter-5: Revised work plan for Phase – III

Chapter-6: Conclusion and Recommendation,

Chapter-7: References

In this report, for simplification and understanding, the overall weredas are categorized into four clusters based on the geographic location as follows:

Table 1: Clustering of Weredas

Name	No. of Weredas included	Weredas under the Cluster
Cluster-1	3	Argoba Liyu wereda , Bure Mudayitu & Dulecha
Cluster-2	4	Dera, Kuyu, Girar Jarso & Wuchale
Cluster-3	2	Sayit & Enebsie Sar Midir
Cluster-4	4	Misrak Belesa, Ebenat, Bugna & Meket
Without cluster name	1	Tselemit

1.2 Location of the project LOT-2

The proposed study areas are located in Amhara, Afar, and Oromia Regional states, which comprises two weredas in north Gondar (Misrak Belesa & Telemet), two weredas in north Wollo (Bugna & Meket), Ebenet wereda in the south Gonder, Sayit wereda in the south Wollo, Enbise Sar midir in the east Gojam, four weredas in north Shewa zone (Dera, Girar Jarso, Kuyu & Wuchale) and three weredas in the Afar zone 3 (Argoba Liyuzone, Bure Mudayitu & Dulecha) the location of the study areas are depicted in figure 1 below.

The project areas are accessible by a network of dry weather roads and the asphalt road that runs from Addis Ababa – Dejen – Debre Markos - Bahirdar-Gonder and Addis Ababa-Awash-Gewane major asphalt roads. In general, all parts of the project areas are accessible from all directions by several all-weather roads, dry season roads, and footpaths.

.

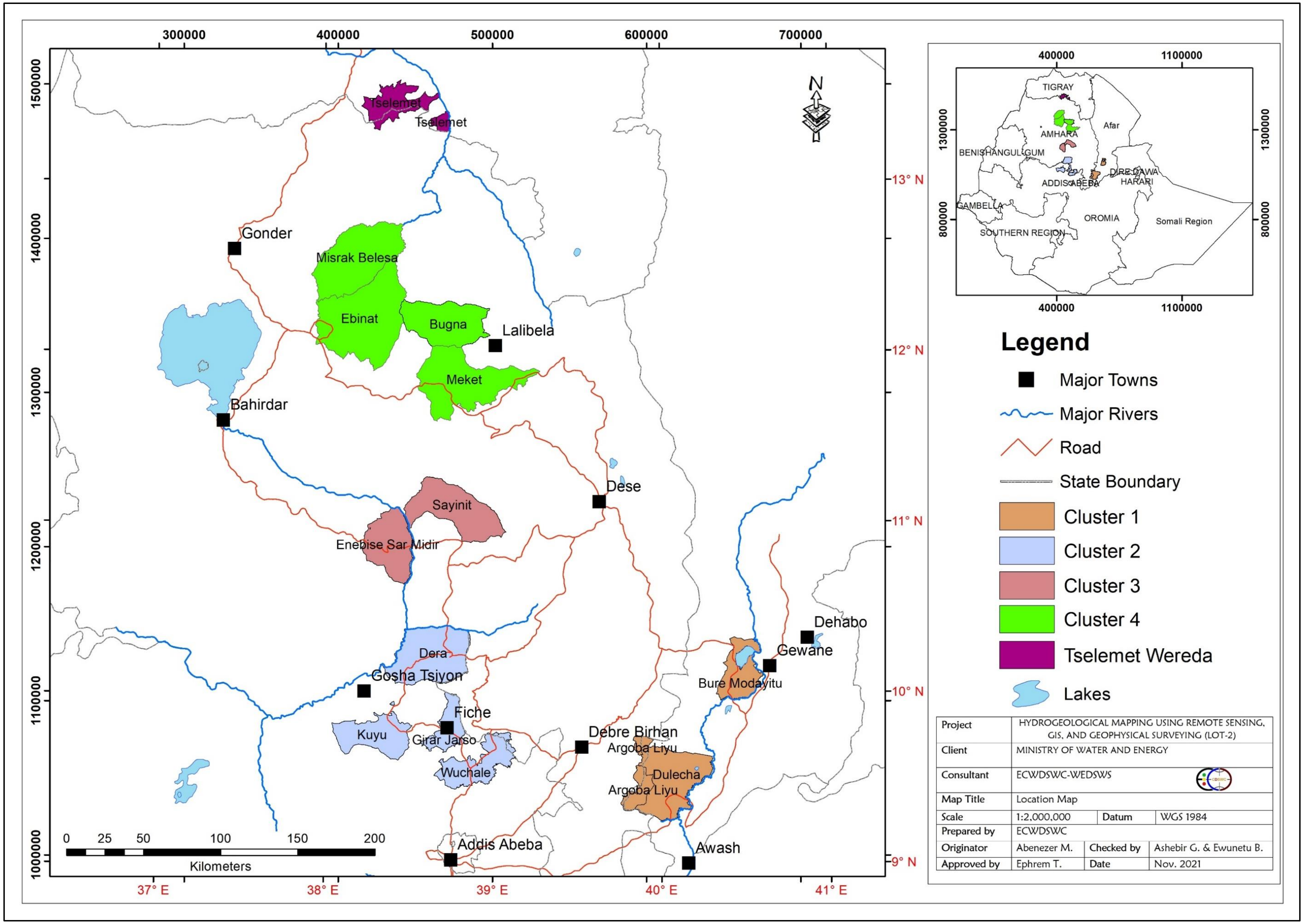


Figure 1: Location of Project areas (LOT-2)

1.3 Objectives of the Study

The main objective of this project is to produce operational hydrogeological maps and recommend drilling sites spread over 3 drought-affected regions of Ethiopia and pinpoint locations with high water demand in combination with high groundwater potential. With the compiled information, associated overlay analyses, and geophysical surveys, 14 most promising drilling sites for groundwater abstraction and 14 alternatives (optional) drilling sites will be selected for each weredas of Lot-2. Generally, the ultimate goal of the climate-resilient WASH project in Ethiopia is to increase access to safe and sustainable water.

The following specific objectives are also associated with the project:

- Carry out National Groundwater Risk Mitigation Strategy and make recommendations.
- Prepare detailed groundwater potential maps for target sites
- Identify one optimal drilling site and one alternative (optional) drilling site per wereda, using these maps and geophysical field investigation, and recommend the type of drilling methodology to be employed.
- Build the capacity of MOWE, Regional governments, and NGOs to use overlay analysis techniques for groundwater potential mapping in Ethiopia.

1.4 Scope of Works

The overall assignment is to carry out the consultancy service for groundwater characterization, Groundwater mapping, and advanced mapping work with internationally known and accepted standards.

The ultimate goal of the project will be to produce operational hydrogeological maps and to identify the most suitable site for drilling. Therefore, this project focused on the preparation of operational hydrogeological maps of 14 weredas of LOT- 2 and identification of target sites for borehole drilling with enhanced drilling success rates and optional drilling sites for each wereda.

1.5 General approach, Deliverables and Planning

The project is designed in three phases to delineate Groundwater potential zones, to prepare operational hydrogeological maps and to select target drilling sites. The technical route is depicted in figure 2 below

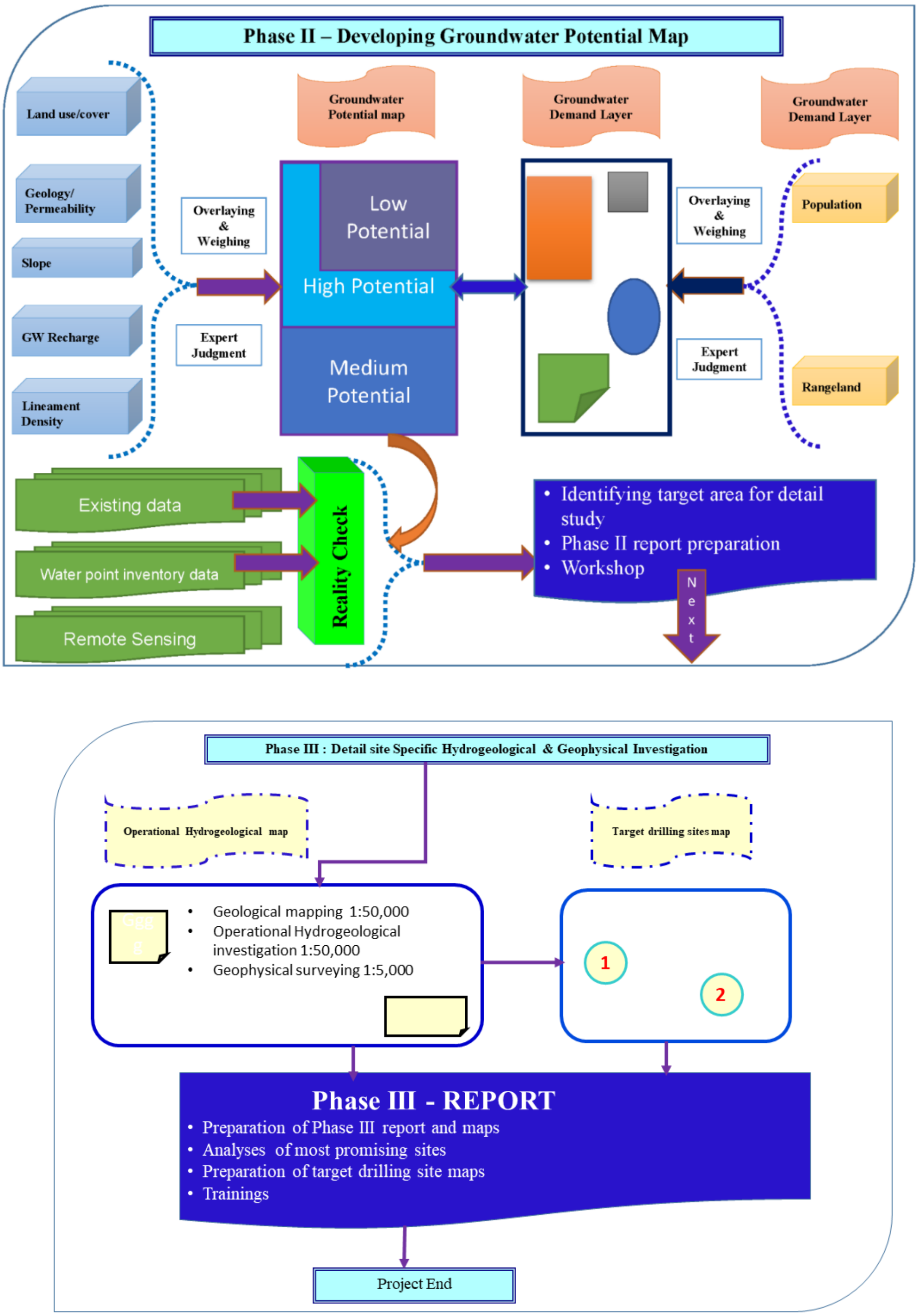


Figure 2: The project phases and the main deliverables

Phase II activities and deliverables

This project was launched on the 24th of May 2021. Since validation and acceptance of Phase I Inception report, the following activities are completed:-

- Field inventory was carried out and basic groundwater data such as SWL, PH, and EC were measured on-site, a water sample was collected for laboratory analysis, available reports were collected from different, government, and private organizations, except Bugna, Meket, and Tselemit weredas due to security problems.
- Climatological datas were collected from NMA and satellite data and also detailed analysis was carried out.
- Hydrological datas were collected from MOWE and detailed analysis was carried out
- Kebeles with Groundwater scarcity were identified by communicating with each weredas water office and target population
- Satellite imagery and maps were acquired and interpreted for land cover mapping, Geological mapping, and lineament extraction of the project weredas.
- Land cover, Soil, Depth to groundwater, Temperature, Rainfall, Wind speed, PET, Elevation maps were prepared.
- Rain days per month, modifying land cover parameter table based on the land cover map was prepared for Groundwater recharge estimation input.
- Groundwater recharge was estimated by using the WetSpass model for the three basins Awash, Abay, and Tekeze basin, and then the Groundwater recharge map was extracted by the respective boundary of each weredas.
- Geological map of 1:100,000 was prepared for each wereda from existing 1:50,000 scale base maps and Satellite images.
- Lineament was extracted from SRTM DEM 30m resolution and Sentinel 1A image radar by using PCI Geomatica software initially, and then the lineament extracted was manually filtered by overlaying road, boundary, and drainage density of project weredas.
- Lineament density and Lineament proximity maps were prepared from extracted lineament
- Topographic Wetness Index was generated for each project weredas
- Hydrogeological sections were constructed for each weredas in order to shows conceptual model.
- Overlay analysis was conducted for the project weredas
- Sensitivity analysis was carried out for the project weredas
- Validation of groundwater potential of each weredas are tested by data of existing boreholes collected.
- Groundwater potential maps were prepared for each weredas
- Phase II report writing and submission

1.6 Risks and mitigation measures

The following anticipated constraints will have an impact on the timely execution of some of the project activities:

- Due to Security issues around the boundary of the Tselemit, Bugna, and Meket Wereda field inventory was not carried out and the model is calibrated by using existing data collected from different organizations.
- Lack and incompleteness of Groundwater data and reports in the Project weredas are observed. The model is validated by using representative data collected during field inventory and existing data collected from different organizations.
- Lack of expert in weredas and Gap in the data handling, storing, and report preparation was observed.

The proposed mitigation measures are depicted as follows: -

- Available Existing data were utilized for validation of the Tselemit, Bugna, and Meket Wereda Groundwater potential maps.
- The data scarcity was filled by collecting existing available hydrogeological information from Wereda and the zone water bureau.
- The capacity building or Knowledge transfer for wereda Hydrogeologist was given and they participated in the groundwater inventory program together with our senior Hydrogeologists.

2. DATA AND METHODOLOGY OF THE STUDY

The study methodology includes various tasks such as preparations for base maps, map updating according to field observations, digitization, and processing of image using software like WetSpass model M1.3, Arc GIS 10.8,Saaty's AHP (K.D.Version 15.09.2018), PCI Geomatrica, ESA-SNAP, ERDAS Imagine and ENVI classic software's and interpretation (See figure 3). In this study, RS (Remote sensing) and GIS (geographic information system) methods were used to generate five thematic layers such as Hydrogeological units, Groundwater recharge, Lineament density, Lineament proximity, and TWI as factors influencing the groundwater potential. All the thematic layers were then assigned weights according to their relative importance in groundwater occurrence and corresponding normalized weights were obtained based on Saaty's Analytical Hierarchy Process (AHP). Based on the rank assigned by the conceptual understanding of the specific weredas and weights aggregating the thematic maps is done using a weighted overlay method to obtain a groundwater potential (GWP) map. The GWP maps are verified by overlay analysis with observed borehole yield data. Single – Parameter sensitivity analyses are used to compute effective weights.

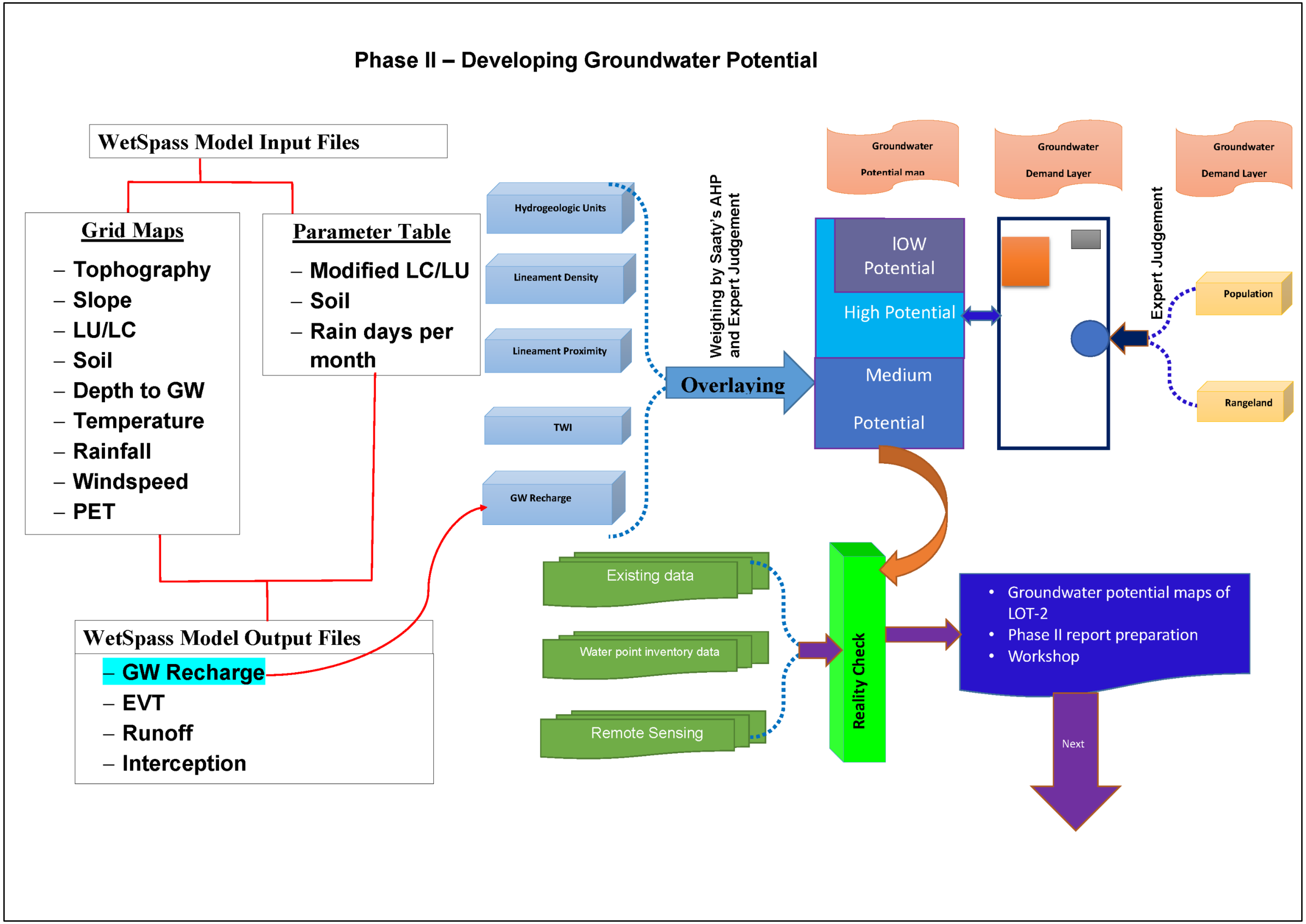


Figure 3: Phase II methods and deliverables

2.1 Remote Sensing data, Field Inventory, and Secondary data

Remote Sensing data

The primary issue in the projects (RS) remote sensing and GIS (Geographic Information System) span is identifying sources and availability of spatial input data and acquiring them. The data source could be primary and secondary. The primary sources are acquiring satellite images and interpreting them, field surveys, and generating out of the surveyed data. The secondary sources are previously conducted projects datasets, national and regionally such as CSA, NMA, EGS, and MoWE archives.

The Geospatial data by nature especially when we are dealing with satellite imagery with multiple band spectrums is a huge file size and hence in this project hundreds of gigabytes of data were collected and integrated. The collected data was further explored for its content, quality, consistency, and extent to use for the study as deemed as a decision support system.

The SRTM DEM with the 30-m resolution is used to extract the slope and drainage network. Topographic maps (Scale 1:50,000) from The Ethiopian Mapping Agency (EMA) are also used to digitize relevant features and drainage networks to enhance the raw DEM. Cloud–free Sentinel 2 imager that has a higher spatial resolution (10m) is used to classify land use /cover, SRTM DEM 30m resolution and Sentinel 1 imager using the interferometry approach and ESA-SNAP environment is used to extract lineament for project weredas, SRTM DEM 30m resolution, Landsat-7 ETM + data 30m spatial resolution and Google Earth image at 5m Spatial resolution, Rainfall data was used from CHIRPS, and then the satellite rainfall data was validated by using data collected from 34 metrological stations from the National Meteorological Agency (NMA) of Ethiopia. The mentioned meteorological data is also suggested to be used in Ethiopian climate by different scholars. One of the advantages of CHIRPS products for groundwater recharge estimation is its characteristics of utilizing the land cover type on its algorithm while developing the product. We considered the following additional datasets: elevation, aspect, and slope derived from 30m SRTM DEM, average January and July temperature acquired from JRA - 55, average January NDVI derived from the MODIS (MOD13Q1) data, average July NDVI derived from the MODIS (MOD13Q1) data. We considered the NDVI as a potential additional dataset because the NDVI shows a fast response to precipitation (greening up), which might be more suitable to represent precipitation patterns related to the Monsoon regime i.e. rainfall patterns are seasonal and directional) compared to elevation. For similar reasons, we included aspect and slope because there might be a certain directional pattern in the rainfall distribution.

Field Inventory and Secondary data

In addition to the remote sensing data, Secondary and primary data such as 30 years of climatological data, river discharge data of 21 Hydrometric stations, Demographic data from CSA 2007, FAO soil data, existing groundwater data, water point inventory data, and available Groundwater data and reports are collected analyzed. The Transmissivity and well discharge data were used for validation of Groundwater potential maps. The summarized inventory and existing data are presented in table 2 and the raw data is annexed (2).

Table 2: Inventoried and existing water points

Wereda	Inventoried water point				Existing water point			
	BH	Shallow wells	HDW	Spring	BH	Shallow wells	HDW	Spring
Argoba Liyu	4							
Bure Mudayitu	7				2			
Dulecha	13							
Wuchale	18	2	22	2	5	113	592	37
Girar Jarso	10	-	13	6	2	28	193	84
Kuyu	10	-	-	4	-	28	402	39
Dera	2	-	67	2	-	-	2	1
Sayit		46	2	4	13			
Enebsie Sarmidir	5	8	1	1	2			
E.Belesa	3	68		1	2	35		
Tselemit					1	16		
Ebenat		54			1	24		
Bugna						3		
Meket					6	22		
Grand Total	**72**	**178**	**105**	**20**	**34**	**269**	**1189**	**161**

Preparation of thematic layers

Preparation of thematic layers involves digitizing existing base maps, digital image processing of remote sensing data, and integration of hydrogeological field data. To produce a GWP maps, the thematic layers of lithological units, Groundwater recharge, lineament density, lineament proximity, and TWI were prepared at a scale of 1:100,000 with a spatial resolution of 100m pixel size. After the preparation of the thematic maps, the rank is assigned to each thematic layers attribute based on the conceptual understanding of each weredas, the maps were converted into raster format, and then weighted overlay analyses were carried out according to assigned suitable weights in the order of their hierarchy process (AHP) (Saaty 1980, 1992) to each thematic layers. Thematic maps for each parameter are prepared as follows.

2.2.1 Geological mapping method of the study area

Geologic map of project weredas are prepared at a scale of 1:100,000 by combining remote sensing and GIS techniques. The methodologies adopted in this work are divided into; (i) Literature review and (ii) Remote sensing and GIS studies.

A literature review was carried out to survey the availability of the geological maps and review of the available geological maps in order to get a general overview of the geology of the area and to identify the gaps and fill these gaps by remote sensing study. The project areas have been mapped by Geological Survey of Ethiopia (GSE) at a scale of 1:50,000 and 1:250,000. These maps gives better information to understand the geological evolution of the project areas. However, these l gaps are identified in GSE maps: -

(i) Lack of exhaustive Imagery interpretation,
(ii) Lack of consistency in lithological naming on geological maps,
(iii) Lack of systematic mapping of litho-stratigraphy, and
(iv) The significance of the lithology and structural data in establishing and understanding the geological process is not discussed in detail.

The data set used and sources for the interpretation of the remote sensing geological map of the area are shown in the table 3. Image interpretation was made both by computer and on printouts in which all pertinent geological data such as lithologic units, delineation of geological contacts, geological structures (linear features, fractures, and faults), and geomorphological elements are mapped. From the different image combinations, layer stack image, decorrelation, stretch image, and IHS-to-RGB- transformation were selected for their valuable information. The IHS to RGB band 1, 2, 3 images are good in picking tonal and textural differences to identify lithologies. Generally, the Decorrelation stretch (band 6, 4, 2) and IHS-RGB transformation (3, 2, 1) image combination identified possible lithologic units on the project area. Moreover, DEM data were used for geomorphological mapping and tracing major lineaments.

Use of GIS and RS softwares (ArcGIS, ERDAS Imagine, ENVI, Global Mapper, GeoMatica) together with the existing geologic maps were used to prepare the geological map of the project Weredas at a scale of 1:100.000. Geological map of the project wereda is presented in annex (3).

Table 3: Existing geological map and Remote sensing data sources

No.	Data used	Data source
1	Topo map @ 1:50,000 and 1:250,000 scale	EMA, 1975
3	Geological Maps of Project Sites @ 1:50,000 and 1:250,000 scale	GSE
4	Shuttle Radar Topography Mission (SRTM), DEM Data @ 30m Spatial Resolution	NASA, & USGS EROS Data Center, 2006 http://glcfapp.glcf.umd.edu:8080/esdi
5	ASTER Global Digital Elevation Model (GDEM), DEM Data @ 30m Spatial Resolution	Japan Space Systems (J-space systems) Japan, cooperation with US, 2009 http://gdem.ersdac.jspacesystems.or.jp/search.jsp
6	LansSAT-7 ETM+ (Enhance Thematic Mapper) Data @ 30m Spatial Resolution	Global Land Cover Facility (GLCF), 2021 http://glcfapp.glcf.umd.edu:8080/esdi/
7	Google Earth Image @ 5m Spatial Resolution	US Dept. of State Geographer, 2021

2.2.2 Lineament Extraction Method

In this study, two Digital Elevation Models (DEM) sources were used to generate lineaments. The first one is SRTM 30m resolution DEM. The second data source used to generate lineament of the study area is Sentinel I imagery using the interferometry approach and ESA-SNAP environment.

As input for the first method, a digital elevation model (DEM) was obtained from SRTM. The study area covers 12 DEM Tiles in total and all the tiles were mosaic in the ArcGIS software environment.

Lineament extraction process from SRTM DEM 30m resolution

The lineament extraction process was carried over the overlayed shaded relief images with multi-illumination directions of (0°, 45°, 90°, and 135° azimuth and sun angle of 30°,). PCI Geomatica software was also used for the automatic lineament extraction. These steps were carried out under the different thresholds, and then lineament extracted was manually filtered by overlaying hill shade, drainage density, and road map of the project weredas.

DEM extraction process from Sentinel - 1 Imagery using Interferometry approach and ESA-SNAP

The second option checked for the lineament extraction is Sentinel 1 using the interferometry approach. We download the Sentinel 1A image and generate DEM, The DEM is used to generate hillsides and extract lineament in PCI GeoMatica. The same parameter, process, and azimuthal angle are applied to the hill shade which is generated from the sentinel 1 image. PCI GeoMatica with different threshold parameters was used to extract the lineaments.

Therefore, the final generated lineament from Sentinel imagery was manually filtered by overlaying hill shade, drainage density, and road map of the project weredas. Generally, the lineament extracted by using SRTM DEM 30m and Lineament extracted from Sentinel 1A image were validated by ground-truthing and by comparing with the existing 1:250,000 geological map of the project wereda.

2.2.3 Groundwater recharge estimation Method

In this study, the Hydrological study was conducted by considering the overall hydrological connectivity of the basin; hence it was important to consider all weredas upstream hydrological characteristics, particularly for all wereda where Main River crosses its boundary by considering the recharging source could be the cumulative effect both the drainage within wereda or rivers crossing each wereda. As the result, all upstream portions of the selected wereda were considered.

Data used for Groundwater Recharge estimation

The water balance quasi-steady-state model (WetSpass) requires a set of input data, that encompasses meteorological data (temperature, precipitation, wind speed, and potential evapotranspiration), distributed groundwater depth, topography (DEM and slope), land use/land cover, and soil types of the four clusters in Awash, Abay and Tekeze River Basins (Ampe et.al. 2012). A list of data that was used as input after resampled into 100m by 100m is presented in table 4. The spatial representation of land use, soil, Rainfall, Temperature, wind speed, PET and Elevation maps, and modified land use, soil, and rain days per months parameter tables used as an input for the model is presented in phase III water balance reports.

Table 4: Dataset used for the evaluation of groundwater recharge

S. N	Input data	Data name	Resolution	Period	Description
1	Rainfall	CHIRIPS	0.25^0x 0.25^0	1980- 2019	Climate Hazards Group Infrared Precipitation with Station data (CHIRPS) designated by incorporating multi-source infrared sourced product. CHIRPS rainfall products and some Spatio-temporal analyses of rainfall using CHIRPS over Ethiopia and other Eastern-Africa regions indicates a potential to be used for various applications (Fenta. A, et. al., 2012; Ayehu, G, et.al. 2018; Maidment. R, et. al., 2013)
2	Temperature	JRA-55	0.56° x 0.56°	1958-2019	Japanese global atmospheric reanalysis project, where The Japan Meteorological Agency (JMA) conducted the second Japanese global atmospheric reanalysis, called the Japanese 55-year Reanalysis or JRA-55. Kobayashi et al. ,2015)
3	Wind speed	ECWF-ERA5		1979-2019	
4	Potential evapotranspiration	Calculated	30 km x 30km		penman-monteith and modified penman-monteith (for open water) used for calculation of PET
5	Groundwater depth	Historic GW data by ECDSWC			
6	Slope	SRTM	30m X 30m	--	SRTM (Shuttle Radar Topography Mission) DEM is a unique product that was produced by NASA and NGA in cooperation with the German and Italian space agencies. The slope of the study area is derived from this high-resolution digital elevation model.
7	Land use/ land cover	Esri	10mx 10m	2020	The recent land use-land cover (2020G.C) was used for the analysis. This layer displays a global map of land use/land cover (LULC). The map is derived from ESA Sentinel-2 imagery at 10m resolution. It is a composite of LULC predictions for 10 classes throughout the year in order to generate a representative snapshot of 2020
8	Soil	FAO			Harmonized World Soil Database v 1.2 and supervised in the Ethiopian context

Groundwater Recharge Estimation Method

Three software or models were used for the study. Spatially distributed water balance quasi-steady-state model (WetSpass), programming language(R) software that is designed for statistical computing and graphics, and geographical information systems (GIS) for analysis and presenting results. The WetSpass stands for water and energy transfer among plants, soil, and atmosphere. A physically-based WetSpass model is usually applied to assess long-term mean spatial pattern and characteristics of recharge, surface runoff, and actual evapotranspiration. In this project, the main target of the WetSpass model is to evaluate the monthly recharge of selected wereda and eventually to understand long term mean annual recharge of the chosen weredas.

As the main task of hydrological analysis is to estimate groundwater recharge in the proposed wereda, the tool commonly recommended for spatial-based groundwater recharge estimation too, WetSpass model were applied. The WetSpass model treats a basin or region as a regular pattern of raster cells. Every raster cell is further sub-divided in a vegetated, bare soil, open water, and impervious surface fraction, for which independent water balance is maintained.

The total water balance per raster cell and hydrological season, calculated as follows: -

$E_{raster} = a_vET_v + a_sE_s + a_oE_o + a_iE_i$ --Eq.1

$S_{raster} = a_vS_v + a_sS_s + a_oS_o + a_iS_i$ --Eq.2

$R_{raster} = a_vR_v + a_sR_s + a_oR_o + a_iR_i$ --Eq.3

Where the index raster refers to raster cell, with ET_{raster}, S_{raster} and R_{raster} respectively, the total evapotranspiration, surface runoff and recharge in a raster cell and av, as,ao and ai respectively the vegetated, bare soil, open water, and impervious area fractions of a raster cell.

The geographic information system (GIS) tool was used for re-sampling and mapping of both input and output parameters. Among four common techniques of re-sampling or adjusting meteorological data resolution, bilinear methods were used to adjust the resolution of precipitation, temperature, and wind speed data towards 100 by 100 meters based on client interest. Overall schematic representation of the applied methodology is presented in figure 4 below:

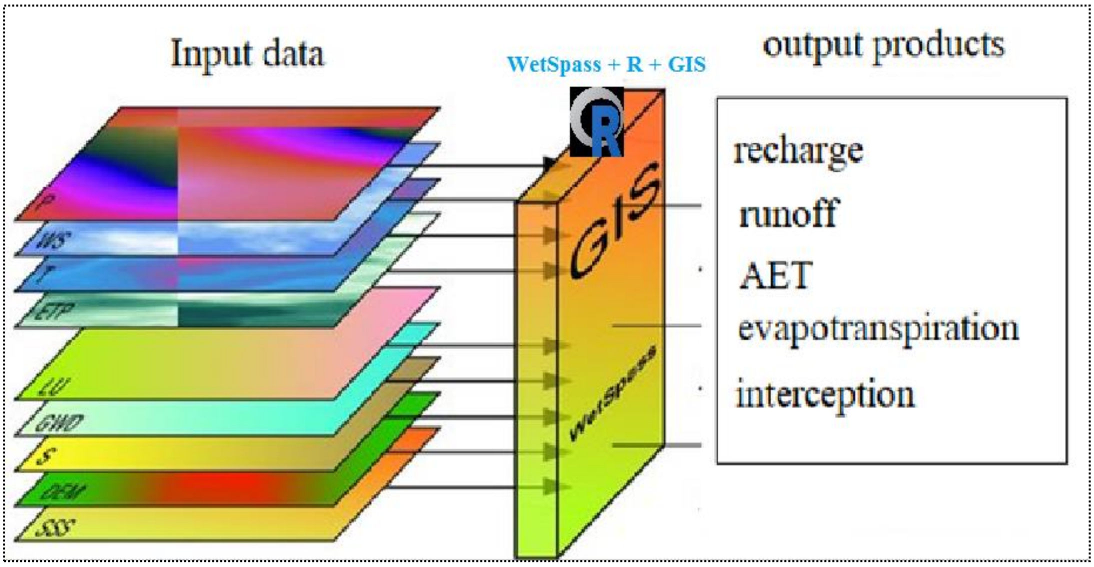


Figure 4: Schematic representation of model used for the study

Land cover data Extraction method

Downloading and processing raster data for land cover classification

Cloud-free Sentinel 2 imagery that has a higher spatial resolution (10 m) is used for LULC image classification. In this stage over 18 sentinels - 2b images were downloaded and pre-processed (geometrically and radio metrically corrected using QGIS software semi-automatic classification (SCP) plugin. In addition, each image was mosaic, enhanced, and resampled using the nearest-neighbor sampling technique in ERDAS IMAGINE Software. All the resampled images were mosaicked for further process (sub setting, LUlC reclassification) using ENVI classic software.

Side by side while capturing fresh primary land cover classification techniques used above, for this project the ESRI land cover of 2020 is used as input. In 2020 ESRI developed a global land cover map from ESA Sentinel-2 10m resolution image and classified it into 10 classes. The originator of the data is suggested to use the dataset for food security, hydrologic modeling, conservation planning, and other related investigations. And hence this dataset will be explored and integrated into our hydrologic modeling with supplements from the land use/cover data generated through the methodologies indicated above.

Therefore, we reclassified the LULC map of ESRI based on our methodology, it was reclassified in 8 classes using Arc GIS reclassification techniques.

Therefore, we reclassified the LULC map of ESRI based on our methodology, it was reclassified in 8 classes using Arc GIS reclassification techniques.

i. Convert raster data into vector
ii. Take an AOI for an additional LULC class, for instance, forest. This class was not included in the ESRI LULC classification
iii. Convert the vector into a raster
iv. Reclassify the raster data with the newly generated LULC classes

Accuracy assessment of supervised classification methods for the re-classified LULC

Accuracy assessment is an important part of any classification project. It compares the classified image to another data source that is considered to be accurate or ground truth data. Thus, high-resolution imagery (Sentinel-2 and Google earth images) was applied for Ground Truth. The accuracy assessment has been done for each wereda over the project area.

The accuracy assessment aims to provide an index of how closely the derived class allocations depicted in the thematic land cover map represent reality. In essence, the summary metrics of accuracy provide a measure of the degree of correctness in the class allocations in the map. Attention is, therefore, focused on thematic accuracy. The confusion matrix is well suited to this task (Table 5). The cases that lie on the main diagonal of the matrix represent those correctly allocated, while those in the off-diagonal elements represent errors. Two types of thematic error, omission, and commission, are possible and both may be readily derived from a confusion matrix (Congalton and Green, 1999). An error of omission occurs when a case belonging to a class is not allocated to that class by the classification. Such a case has been erroneously allocated to another class, which suffers an error of commission.

The most common way to assess the accuracy of a classified map is to create a set of random points from the ground truth data and compare that to the classified data in a confusion matrix. The assessment was done using ArcGIS software.

Checked the error matrix with the formula (Accuracy in % = total true value/total sample value*100) and the total accuracy is 92.22% which is very good.

Table 5: confusion matrix over true values in the project wereda.

OBJECTID	Predicts	Class1	Class2	Class3	Class4	Class5	Class6	Class7	Class8	Total True Value	Total Sample Value	Total Accuracy %
1	1	16	0	0	0	0	0	0	0			
2	2	0	20	0	4	0	0	0	0			
3	3	0	0	37	0	0	0	0	0			
4	4	0	5	0	16	0	0	0	0			
5	5	0	0	0	0	29	1	0	0			
6	6	0	0	0	2	0	24	0	1			
7	7	0	0	0	0	0	0	29	0			
8	8	1	0	0	0	0	1	0	7	178		
		17	25	37	22	29	26	29	8		193	92.22%
										Total Accuracy = Total True Value/Total Sample Value *100		

Land cover/land use map with 92.22 accuracy was prepared and used as an input file for groundwater recharge estimation.

Normalized difference vegetation index (NDVI)

Vegetation indices are a staple remote sensing product and the normalized difference vegetation index (NDVI) is the most widely used vegetation index. The NDVI is a standardized index allowing to generate an image displaying greenness (relative biomass). This index takes advantage of the contrast of the characteristics of two bands from a multispectral raster dataset—the chlorophyll pigment absorption in the red band and the high reflectivity of plant materials in the near-infrared (NIR) band.

NDVI measures the ratio of the reflective difference in the red and near-infrared portions of the spectrum to the sum of red and near-infrared reflectance. Green, healthy vegetation reflects light in the near-infrared portion of the spectrum and absorbs red light, and ranges from values of 1.0 to -1.0 where larger, positive values indicate green vegetation.

One of the input spatial layers for the hydrogeology study is NDVI. To calculate NDVI the inputs are availing appropriate imagery and a program that allows interaction with the image data. QGIS is a great, free option for a GIS program that provides the tools to display, analyze and present remotely sensed data. The following steps below are followed in QGIS and its toolbox environment to calculate NDVI for the project weredas and sample main screenshots were added as pictures for demonstration purposes. As usual, the process started by downloading sentinel 2 images of required bands and used as input for the processing.

i. Open stacked sentinel 2 images in QGIS.
ii. FOR NDVI calculation we are using NIR (band 8) and red (band 4)
iii. Use the raster calculator in QGIS is to calculate NDVI.
iv. NDVI = NIR-RED/NIR +RED

Then the resulting NDVI is classified for visualization purposes and shown in the figure below

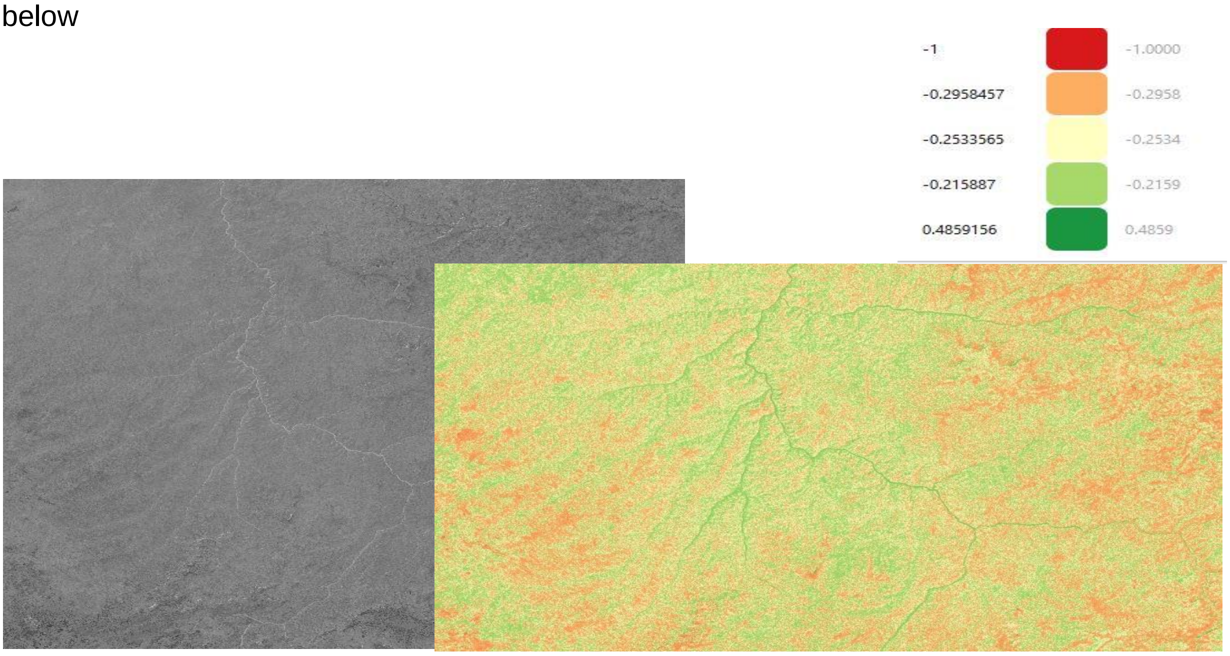


Figure 5: calculated NDVI using QGIS

2.2.4 Topographic Wetness Index (TWI) generation

TWI (also known as the compound topographic index (CTI)) is an indicator that measures the potential on where water tends to accumulate. A high index value indicates a high potential of water accumulated due to a low slope and vice versa.

Typically, the raw TWI indicators range from -3 to 30. The TWI is a unique tool that allows the user to identify areas that could be:

- Identifying the area adversely affected by ponding and flooding caused by rainfall events
- Can provide planners a visual mechanism for site selection of green infrastructure projects
- The identification of areas with increased susceptibility to ponding due to sewer overflow or basement back-ups

The equation given below was used for the estimation of TWI.

$$\mathbf{TWI} = \ln \frac{\alpha}{\tan\beta} \qquad \text{---Eq.4}$$

α = upslope contributing area; β = Topographic gradient (Slope)

2.2.5 Demography data of the project area

According to the report from the Central Statistical Agency Population Projection of Ethiopia for all Regions at wereda Level, July 2021

In order to estimate water demand knowing the population growth rate is very important. Accordingly, the population of Project Weredas is estimated based on to grow at the rate of each region annually in accordance with 2025, 2030 & 2035 CSA estimates of population growth rate for the Oromia region, Afar region, and Amhara region respectively. The projection is based on exponential growth rate model which goes, Pt=PoerΔt

When: Pt = Population at t year, Po= Population at current (initial) year

e=ln10=2.718,Δt= the difference between t year and initial year

Therefore, based on the above exponential population projection formula, the current population size of each project Weredas is projected for the planning period 2035 and the summarized population size is presented in the following tables.

Table 6: Population size of Girar Jarso wereda, July 2021to 2035

Year	Δt	Growth Rate	Girar Jarso Wereda	
			Girar Jarso Rural	Fiche Town
2021	0		41846	50602
2025	4	3.46%	41896	50663
2030	5	2.99%	41934	50708
2035	5	2.65%	41963	50744

Table 7: Population size of Wuchale wereda, July 2021to 2035

Year	Δt	Growth Rate	Wuchale Wereda	
			Wuchale Rural	Muka Turi Town
2021	0		125,128	12,702
2025	4	3.46%	143,699	14,587
2030	5	2.99%	166,869	16,939
2035	5	2.65%	190,508	19,339

Table 8: Population size of Kuyu wereda, July 2021to 2035

Year	Δt	Growth Rate	Kuyu Wereda	
			Kuyu Rural	Gerba Guracha Town
2021	0		138979	39272
2025	4	3.46%	159606	45101
2030	5	2.99%	185340	52373
2035	5	2.65%	211596	59792

Table 9: Population size of Dera wereda, July 2021to 2035

Year	Δt	Growth Rate	Dera Wereda	
			Dera Rural	Gundo Meskel Town
2021	0		237,980.00	15,739.00
2025	4	3.46%	273,300.60	18,074.96
2030	5	2.99%	317,366.35	20,989.28
2035	5	2.65%	362,325.52	23,962.69

Table 10: Number of livestock and poultry (for private holdings), July 2021

Wereda	Cattle	Goats	Sheep	Horses	Mules	Donkey	Poultry
Dera	173551	40568	17350	132	397	27583	60000
Girar Jarso	225086	7888	44478	2382	389	15242	76284
Kuyu	135333	27290	43210	7698	351	25778	122443
Wuchale	182513	4185	88469	27640	2554	31854	60741

Table 11: Population size of Enebise Sar Midir wereda, July 2021 to 2035

Year	Δt	Growth Rate	Argoba Wereda	
			Rural	Gacheni Town
2021	0		24,973	5,048
2025	4	3.10%	25,000	5,053
2030	5	2.70%	25,020	5,057
2035	5	2.50%	25,037	5,061

Table 12: Population size of Sayit Wereda, July 2021 to 2035.

Year	Δt	Growth Rate	Sayit Wereda	
			Rural	Ajibar Town
2021	0		166,304	11,745
2025	4	2.68%	185,120	13,074
2030	5	2.45%	209,242	14,777
2035	5	2.31%	234,858	16,587

Table 13: Number of livestock and Livestock and poultry (for private holdings), July 2021

Wereda	Cattle	Goats	Sheep	Horses	Mules	Donkey	Poultry
Enebise Sar Midir	174565	41868	16950	152	297	25582	56030
Sayit	205086	9888	54578	3372	439	17341	68842

Table 14 Population size of Argoba Liyu wereda, July 2021 to 2035

Year	Δt	Growth Rate	Argoba Wereda
			Rural
2021	0		24,973
2025	4	3.10%	25,000
2030	5	2.70%	25,020
2035	5	2.50%	25,037

Table 15 Population size of Buri Mudaitu wereda, July 2021 to 2035

Year	Δt	Growth Rate	Buri Mudaitu Wereda
			Rural
2021	0		40,361
2025	4	3.10%	46,351
2030	5	2.70%	53,825
2035	5	2.50%	61,450

Table 16 Population size of Dulecha wereda, July 2021 to 2035

Year	∆t	Growth Rate	Dulecha Wereda	
			Rural	Dulecha Town
2021	0		23,717	3,856
2025	4	3.10%	27,237	4,428
2030	5	2.70%	31,629	5,142
2035	5	2.50%	36,109	5,871

Table 17: Number of livestock and poultry (for private holdings), July 2021

Wereda	Cattle	Goats	Sheep	Horses	Mules	Donkey	Poultry	Camel
Dulecha	111014	141690	61186	5669			60000	75206
Argoba	21100	73148	14905	4927	77	1689	28403	
Buri Mudaitu	88811.2	162300.8				4535.2	48000	60164.8

Table 18: Population size of Bugna wereda, July 2021 to 2035

Year	∆t	Growth Rate	Bugna wereda	
			Rular	Town
2021	0		89985	
2025	4	2.68%	90068	
2030	5	2.45%	90134	
2035	5	2.31%	90190	

Table 19: Population size of Misrak Belesa wereda, July 2021 to 2035

Year	∆t	Growth Rate	Misrak Belesa wereda	
			Rular	Town
2021	0		99269	29732
2025	4	2.68%	114002	34145
2030	5	2.45%	132384	39650
2035	5	2.31%	151137	45267

Table 20: Population size of Ebenat wereda, July 2021 to 2035

year	∆t	Growth Rate	Ebenat wereda	
			Rular	Town
2021	0		89985	
2025	4	2.68%	90068	
2030	5	2.45%	90134	
2035	5	2.31%	90190	

Table 21: Population size of Mekiet wereda, July 2021 to 2035Year

			Mekiet wereda	
	∆t	Growth Rate	Rular	Town
2021	0		256158	25168
2025	4	2.68%	294177	28903.39
2030	5	2.45%	341608	33563.65
2035	5	2.31%	390002	38318.38

Table 21: Population size of Dulecha wereda, July 2021 to 2035

			Tselimt wereda	
Year	∆t	Growth Rate	Rular	Town
2021	0		68235	
2025	4	2.68%	68298	
2030	5	2.45%	68348	
2035	5	2.31%	68390	

Table 22: Number of livestock and poultry (for private holdings), July 2021 data collected from Wereda

Woreda	Cattle	Goats	Sheep	Horses	Mules	Donkey	Poultry
Bugna	74524	49018	28715	11	665	12450	117827
Ebenat	238424	196879	45940	92	850	28511	358516
Meket	181990	54000	45000	15400	1500	40000	50000
Misrak Belesa	172470	98476	76463	5	2329	29613	122748
Tselimt	106858	66321	39857		659	12536	78301

3. Conceptual Hydrogeological model of the study area

3.1 Hydrogeological condition of Cluster 1

The study area falls in the middle of the Awash River valley. The hydrogeological conditions of the area depend on the geology, geologic structures, and geomorphology of the area. The study areas are mainly covered by unconsolidated sediment, acidic, intermediate, and basic volcanic rocks covered by thin soil. Alluvial, Ignimbrite, rhyolite, and basalt are the main volcanic rocks of the study area. They are jointed, fractured, and affected by dense weathering.

The geomorphological setup of the study areas are characterized by a series of horst and graben. According to previous studies and hydrogeological set up of the areas, the major sources of recharge for the study areas (Weredas) are:

- Subsurface inflow from western and eastern fractured volcanic rocks,
- precipitation induced within the study areas
- Infiltration from surface rivers and overland flows (river banks infiltration)
- subsurface inflow from the intermountain valley of eastern Amhara region

In addition, geomorphological setup, water level observed, geologic structures, groundwater contour, and conceptual model developed in previous studies (WWDSE, 2011) shows that groundwater recharged at western and eastern highland areas flow toward rift floor (Dulecha and Bure Mudayitu wereda) and mixed up with groundwater recharge from surface rivers and rainfall-induced in the area and heads northward in an almost parallel way with Awash river.

The hydrogeological setup of each wereda is discussed preliminary as follows:

Conceptual Hydrogeological model of Argoba Liyu Wereda

Argoba Liyuwereda is located on the west margin of MER above major faults that separate the rift floor from western highland areas. Topographically, Argoba Liyu wereda is rugged and sloppy and several streams arise from this wereda and flow toward the rift floor. Most of this wereda is covered by Cenozoic volcanic rocks such as rhyolite and basalts. These units are affected by NE and NNE trending faults and lineaments are also observed in these formations.

As depicted on the hydrogeological map and also cross-section constructed along the groundwater flow path to conceptualize groundwater flow and storage in this wereda (Figure 6 and 7) and also stated in previous works (WWDSE, 2011), Argoba Liyuwereda and its vicinities are mainly recharged from direct rainfall-induced within the area and also both the recharged groundwater and overland flow the area flows toward the adjacent low land.

From a hydrogeological point of view, most areas of Argoba Liyuwereda exposures are favorable for groundwater recharge, storage, and movement due to the existence of primary and secondary porosities. However, groundwater recharge in the area flows toward the lowland/rift floor through main fractures due to high head differences.

Conceptual Hydrogeological model of Dulecha Wereda

Dulecha wereda is located partly in Awash graben of MER. It is bounded by the Awash river gorge in the east and Argoba Liyu wereda and major marginal faults in the west direction. Topographically, the eastern part of Dulecha wereda is plain. However, the plain slightly up to an elevation of more than 1500 meters on the western margin (escarpment) of wereda.

Alluvial deposits and volcanic rocks, mainly Ignimbrite and basalts affected by numerous geologic structures are the main formations observed in the area. From a hydrogeological point of view, existences of tectonically impacted hydrogeologic units are deemed crucial for the occurrence and storage of groundwater.

According to previous studies (WWDSE 2011) and also current finding shows that groundwater of Dulecha wereda and its vicinity is recharged from subsurface flow from the western volcanic highland areas, surface rivers, and rainfall-induced within the area and flows toward north direction parallel to Awash river (Figure 6). In addition, surface runoff from the adjacent elevated areas also recharges groundwater of the area as shown on the hydrogeological cross-section constructed along the groundwater flow path (Figure 7). Moreover, two main aquifers named unconsolidated alluvial and fractured volcanic rocks aquifers are identified in Dulecha wereda and adjacent graben located east of Dulecha wereda.

Conceptual Hydrogeological model of Bure Mudayitu Wereda

Bure Mudayitu Wereda is topographically plain in the east and rises slightly up to an elevation of more than 1000 meters on the western escarpment. The plain is dominated by lacustrine deposits. Whereas, areas close to the foot of the escarpment are covered with coarser alluvial deposits.

As observed from superficial deposits and lithological logging of the drilled borehole in Buri kebele of Bure Mudayitu wereda (ECDSWC, 2021), lacustrine deposits and clay that has a thickness of more than 460 meters exists. The thickness of lacustrine deposits decreases close to the foot of the escarpment and fractured volcanic rocks are encountered at shallow depth (32 meters) during drilling of Dengeligita borehole.

Most part of this wereda is swampy and covered by vegetation. According to a previous study conducted for Tendaho irrigation by gauging Awash river flow at Awash and Adaitu stations (WWDSE 2013), 400 MCM to 3076 MCM water losses are observed at Gedebassa swam complex of Bure Mudayitu wereda by evaporation and infiltration towards the ground. However, hydrogeologic units exposed in most parts of this wereda are not good enough in terms of groundwater infiltration, flow, and storage.

According to an inventory conducted, boreholes drilled on plain areas of this wereda are either dry or saline due to the existence of lacustrine deposits. This fact is supported by a number of one-dimensional VES conducted by ECDSWC (2019) for water supply well sittings that show the existence of geo-electric units that exhibit very low apparent resistivity response. According to the developed conceptual model (Figure 9), Bure Mudayitu wereda and its vicinity groundwater is recharged mainly from subsurface flow from west highland including subsurface inflow from the intermountain valley of eastern Amhara region area through Jewaha outlet, subsurface inflow from southern areas, and surface rivers (mainly Awash River) and flow towards the northeast direction (Figure 8).

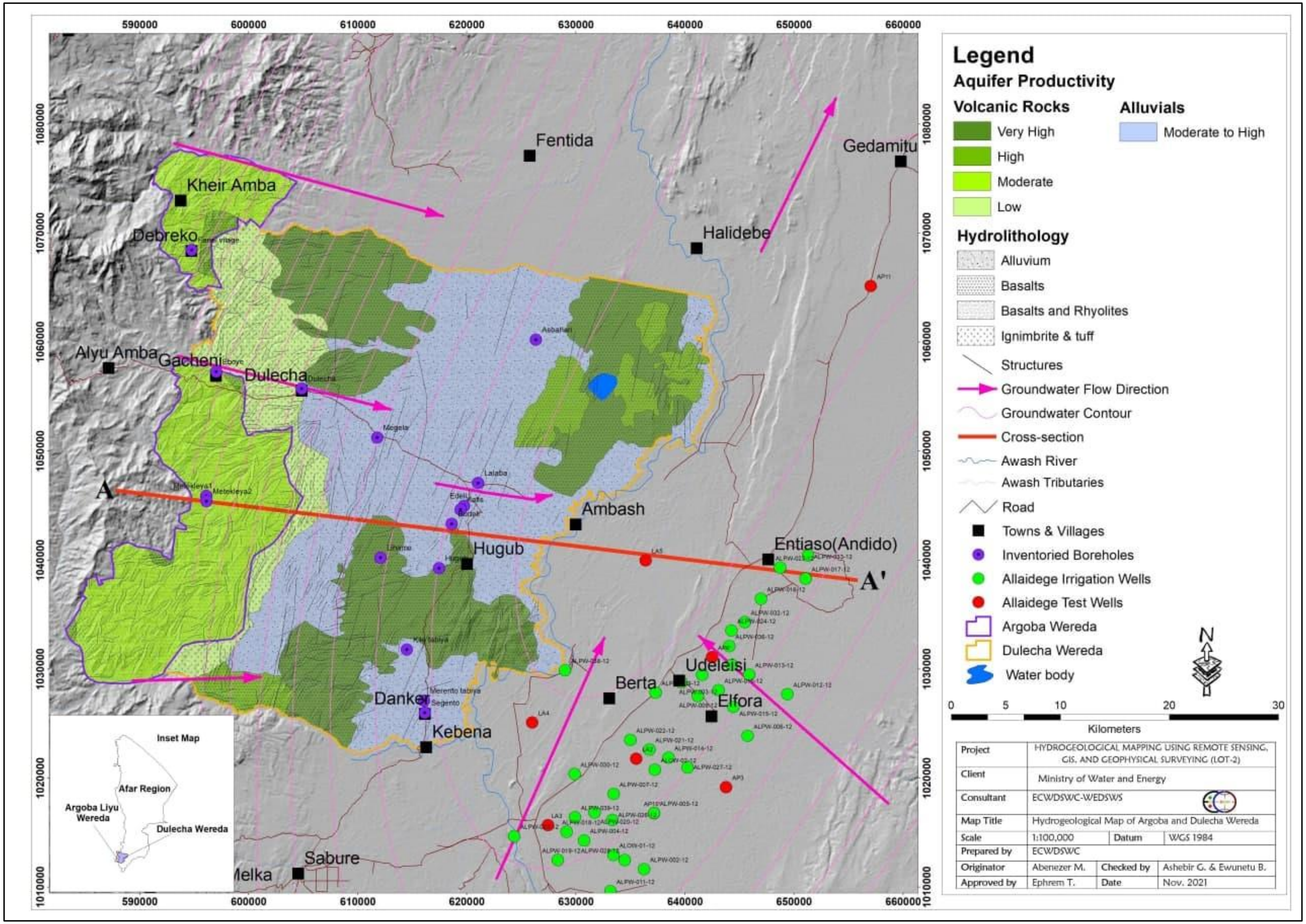


Figure 6 : Hydrogeological map of Argoba Liyu and Dulecha weredas

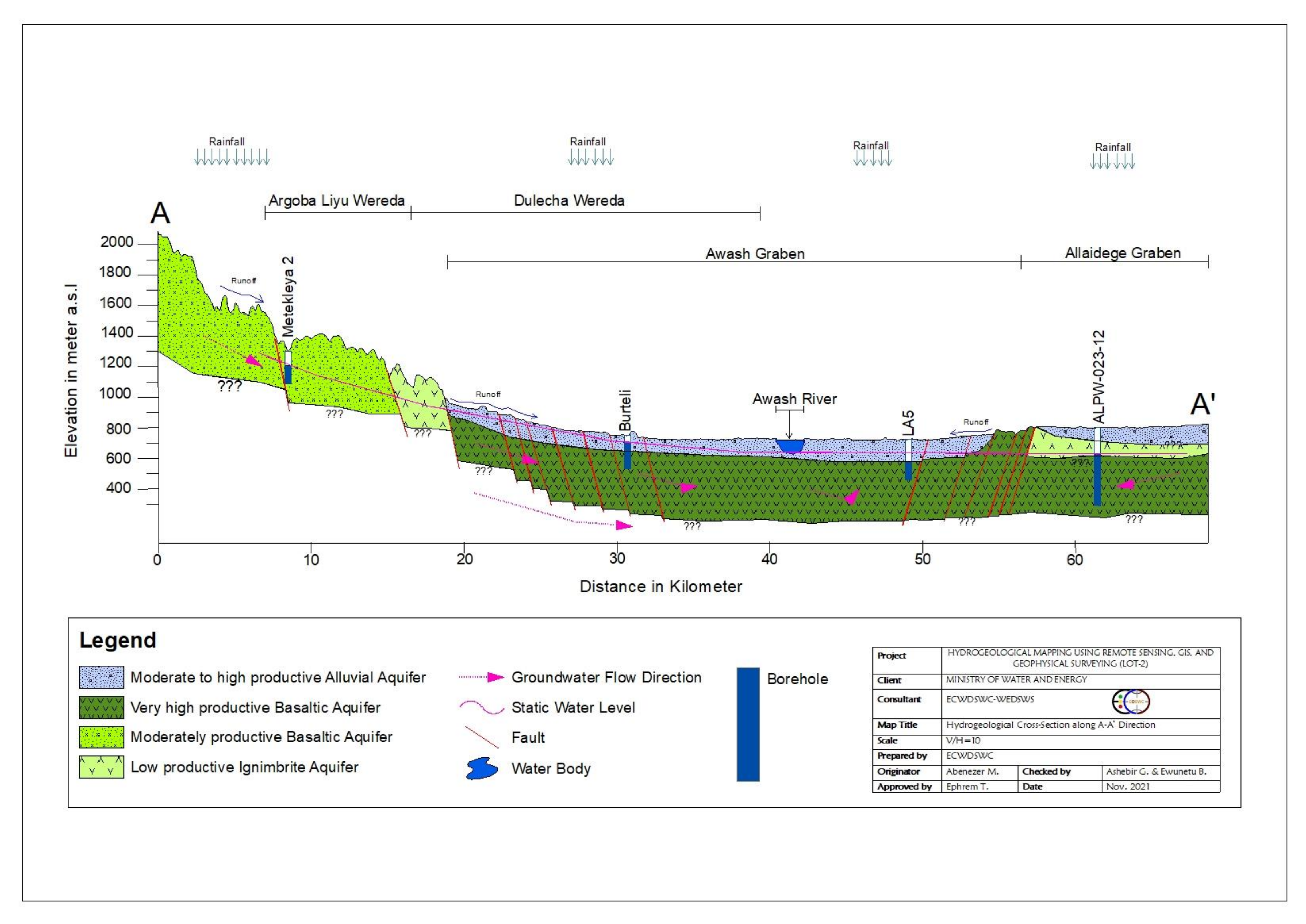


Figure 7 : Hydrogeological cross – section along A-A' Direction

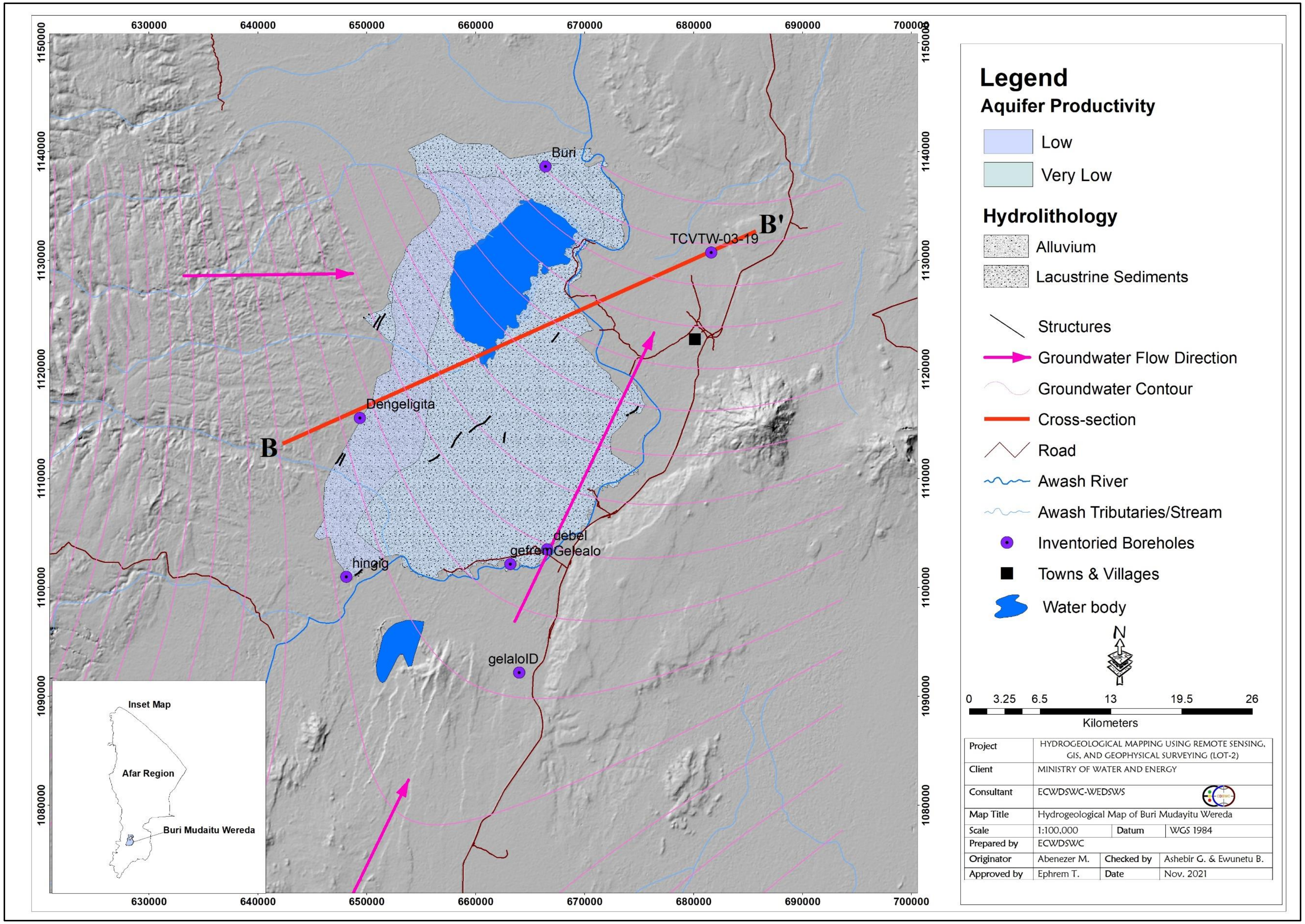


Figure 8 : Hydrogeological map of Buri Mudayitu Wereda

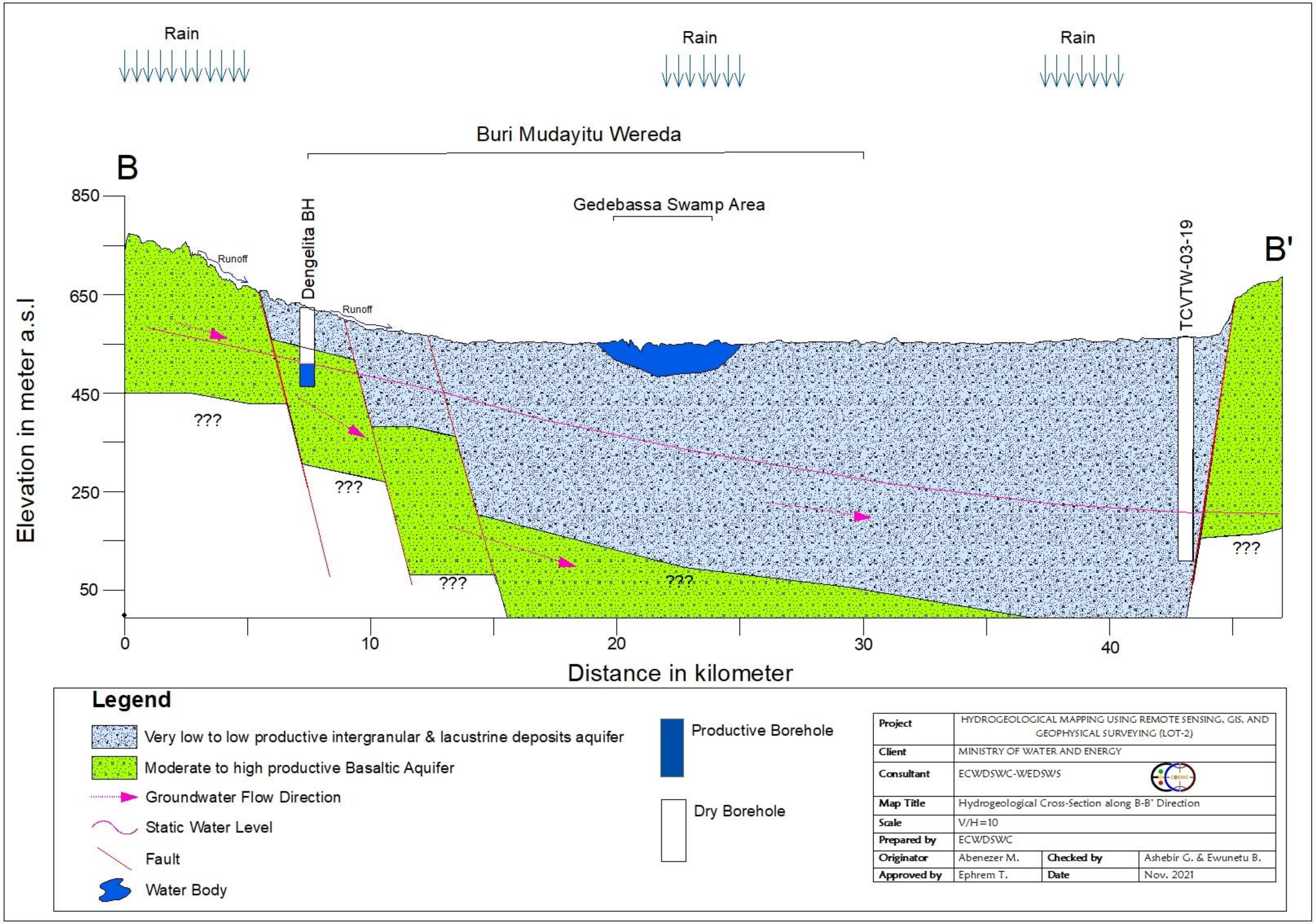


Figure 9: Hydrogeological cross – section along B-B' Direction

3.2 Hydrogeological condition of Cluster 2

Based on hydraulic characteristics of rock units, spring discharge, depth to the groundwater, mode of recharge, and groundwater intake to their system, the Hydrogeological condition of Wuchale, Girar Jarso, Kuyu, and Dera weredas are conceptualized and discussed as follows:

Conceptual Hydrogeological model of Wuchale wereda

Wuchale wereda is located partly in the Jema sub-basin and partly in the mugger sub-basin. Topographically, Wuchale wereda is plain land. Most part of the wereda is covered by alluvial deposits and volcanic rocks, mainly Aiba and Tarmaber basalts. The yield and transmissivity of boreholes drilled in this wereda revealed that the intergranular alluvial aquifer and the basaltic aquifer have moderate to very high groundwater potential due to primary and secondary permeability of the lithological units exposed in the area.

As depicted on the hydrogeological map and also cross-section constructed along the groundwater flow path to conceptualize groundwater flow and storage in this wereda (Figure 10 and 11), the local geomorphic setup and subsurface configuration of permeable and impermeable rock units control the depth and pattern of groundwater circulation in the area. The E-W oriented horst of the impermeable mudstone underlying the Tertiary volcanics control aquifer distribution into Muger and Upper Awash groundwater sub-basin where surface water and groundwater divides do not coincide.

The elevation of depth to groundwater level in hand-dug wells and deep boreholes shows that groundwater tapped by hand-dug wells and deep boreholes is in different flow systems. The elevation of depth to water levels in hand-dug wells is very near the surface and represents the local groundwater sub-system in the upper water-table aquifer that discharges to the nearest surface water bodies or infiltrates downward and recharges the basaltic aquifer underneath.

Conceptual Hydrogeological model of Girar Jarso wereda

Girar Jarso wereda is located partly in the Jema sub-basin and partly in the mugger sub-basin. Topographically, the southern part of Girar Jarso wereda is plain land and the northern part is a rugged and sloppy topographic setup. Most part of the wereda is covered by volcanic rocks, mainly Ashangi basalt, Alaje formation, Aiba and Tarmaber basalts, and sedimentary rocks such as Upper sandstone, Muger mudstone, Limestone, and Lower sandstone.

The yield and transmissivity of boreholes drilled in this wereda revealed that the Aiba and Tarmaber basaltic aquifer has moderate to high groundwater potential due to secondary permeability of the lithological units exposed in the area. Besides in the northern part of the wereda at the contact between Ashangi basalt and Muger mudstone spring with the low discharge of 1.6l/s.

As depicted on the hydrogeological map and also cross-section constructed along the groundwater flow path to conceptualize groundwater flow and storage in this wereda (Figure 12 and 13), the local geomorphic setup and subsurface configuration of permeable and impermeable rock units control the depth and pattern of groundwater circulation in the area. The E-W oriented horst of the impermeable mudstone underlying the Tertiary volcanic control aquifer distribution into Jema and Upper Awash groundwater sub-basin where surface water and groundwater divides do not coincide.

The elevation of depth to groundwater level in hand-dug wells and deep boreholes shows that groundwater tapped by hand-dug wells and deep boreholes is in different flow systems. The elevation of depth to water levels in hand-dug wells is very near the surface and represents the local groundwater sub-system in the upper water-table aquifer that discharges to the nearest surface water bodies or infiltrates downward and recharges the basaltic aquifer underneath.

Conceptual Hydrogeological model of Kuyu wereda

Kuyu wereda is located in the Mugger sub-basin. Topographically, the Northern part of Kuyu wereda is plain land and the southern part is a rugged and sloppy topographic setup. Most part of the wereda is covered by volcanic rocks, mainly Aiba and Tarmaber basalts and sedimentary rocks such as Upper sandstone, Mugger mudstone, Limestone, and Lower sandstone.

The yield and transmissivity of boreholes drilled in this wereda revealed that the intergranular alluvial aquifer and the basaltic aquifer have moderate to high groundwater potential due to primary and secondary permeability of the lithological units exposed in the area. Besides in the southern part of the wereda at the contact between Antalo limestone and Muger mudstone springs with the moderate discharge of 2 and 4 l/s.

As depicted on the hydrogeological map and also cross-section constructed along the groundwater flow path to conceptualize groundwater flow and storage in this wereda (Figure 14 and 15), the local geomorphic setup and subsurface configuration of permeable and impermeable rock units control the depth and pattern of groundwater circulation in the area. The E-W oriented horst of the impermeable mudstone underlying the Tertiary volcanic control aquifer distribution into Mugger and Upper Awash groundwater sub-basin where surface water and groundwater divides do not coincide.

Conceptual Hydrogeological model of Dera wereda

Dera wereda is located in the Jema sub-basin and the western part surrounded by the Abay River. Topographically, the central and southern central part of Dera wereda is plain land, and surrounding the central and southern central part is rugged, gorge and sloppy topographic setup. The central and southern central part of the wereda is covered by volcanic rocks, mainly Aiba and Tarmaber basalts, and the surrounding central part in Abay and Jema river gorge sedimentary rocks such as Upper sandstone, Muger mudstone, Limestone, and Lower sandstone exposed.

The yield and transmissivity of boreholes drilled in this wereda revealed that the basaltic aquifer has moderate groundwater potential due to the secondary permeability of the lithological units exposed in the area. Surrounding the central and southern central part of Dera wereda there is no spring, BH, and their no sub-surface information in limestone, Gypsum, upper and lower sandstone formations.

As depicted on the hydrogeological map and also cross-section constructed along the groundwater flow path to conceptualize groundwater flow and storage in this wereda (Figure 16 and 17), the local geomorphic setup and subsurface configuration of permeable and impermeable rock units control the depth and pattern of groundwater circulation in the area.

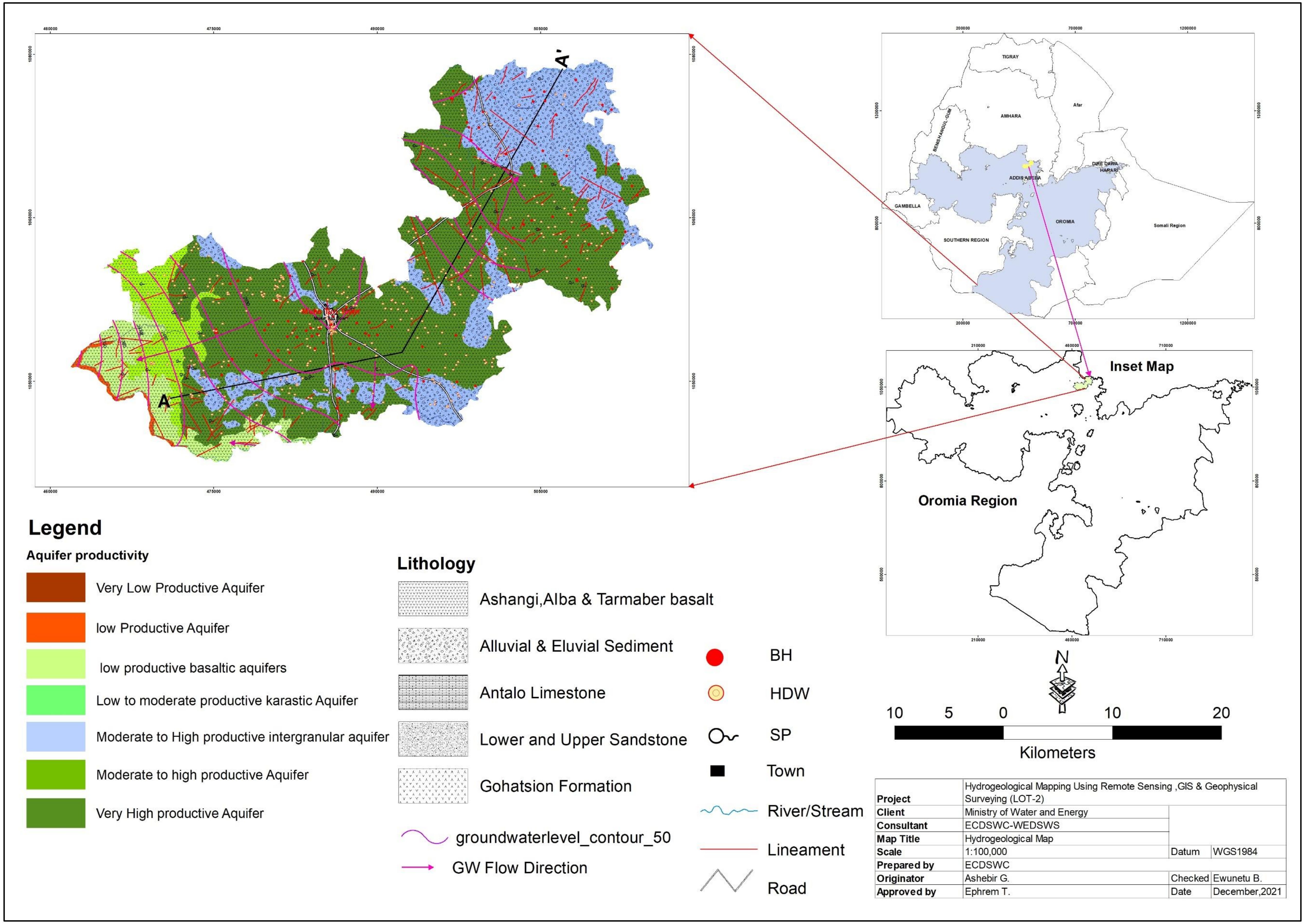


Figure 10: Hydrogeological map of Wuchale wereda

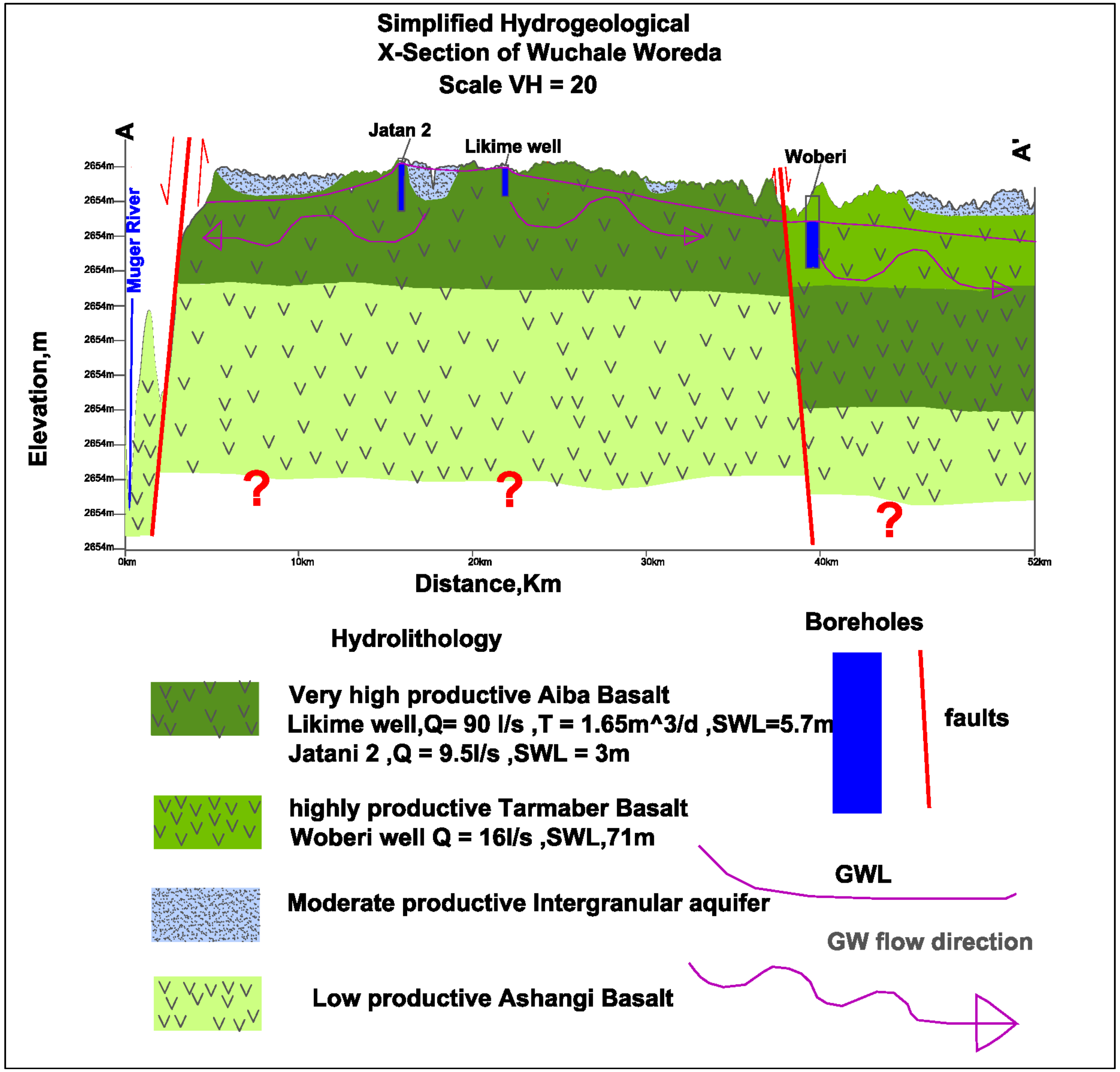


Figure 11 : Hydrogeological section of Wuchale wereda

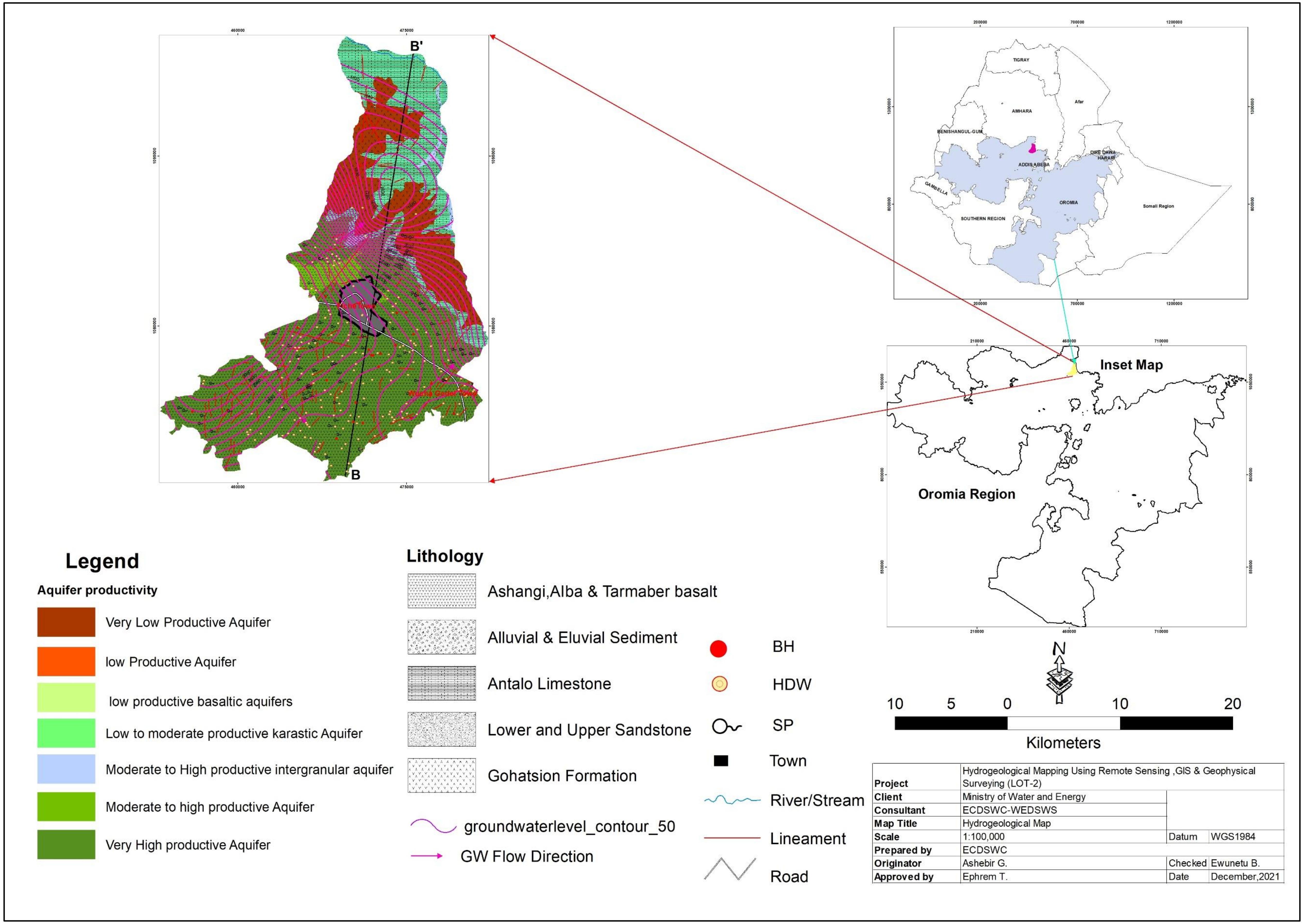


Figure 12 : Hydrogeological map of Wuchale wereda

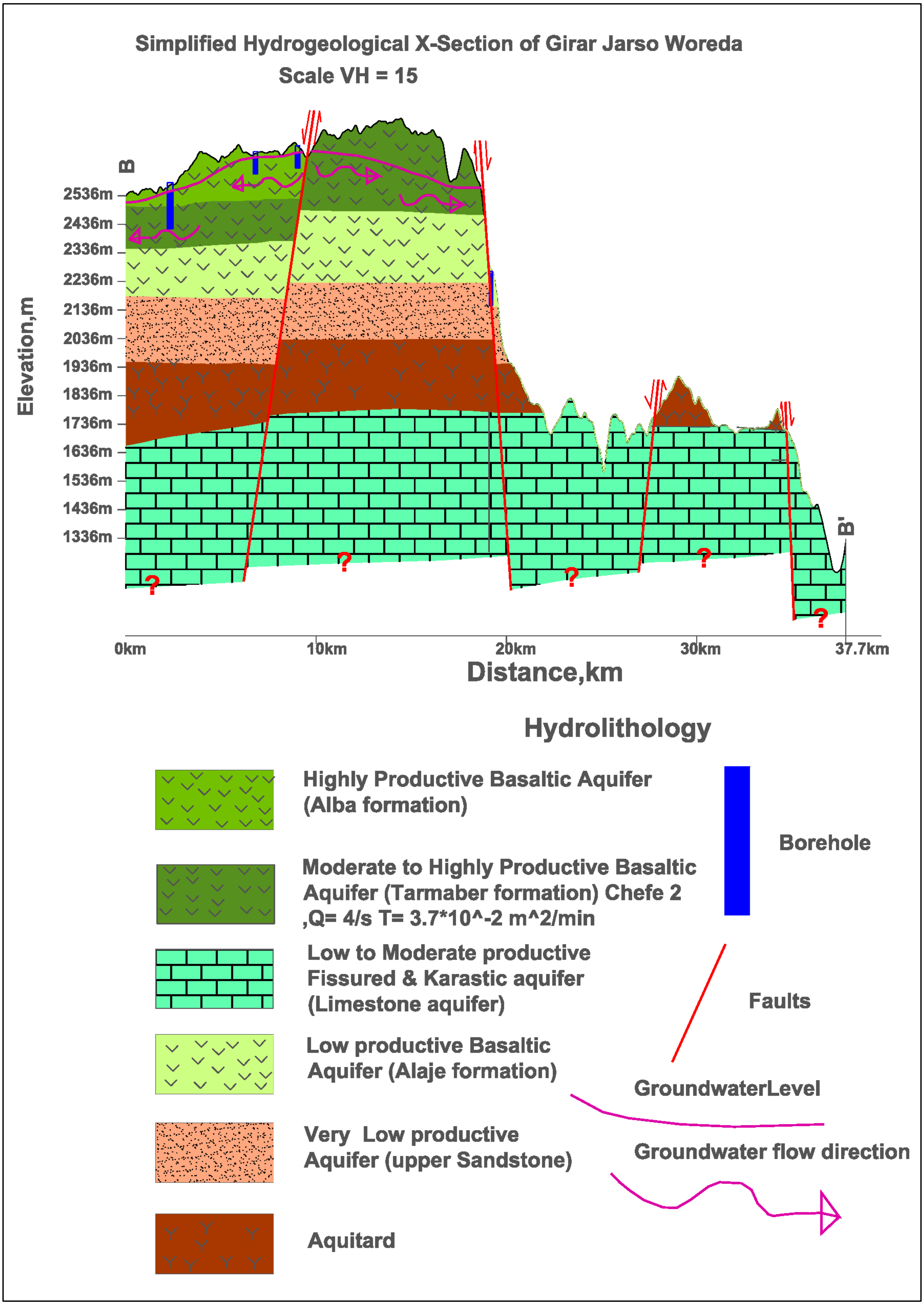


Figure 13: Hydrogeological section of Girar Jarso wereda

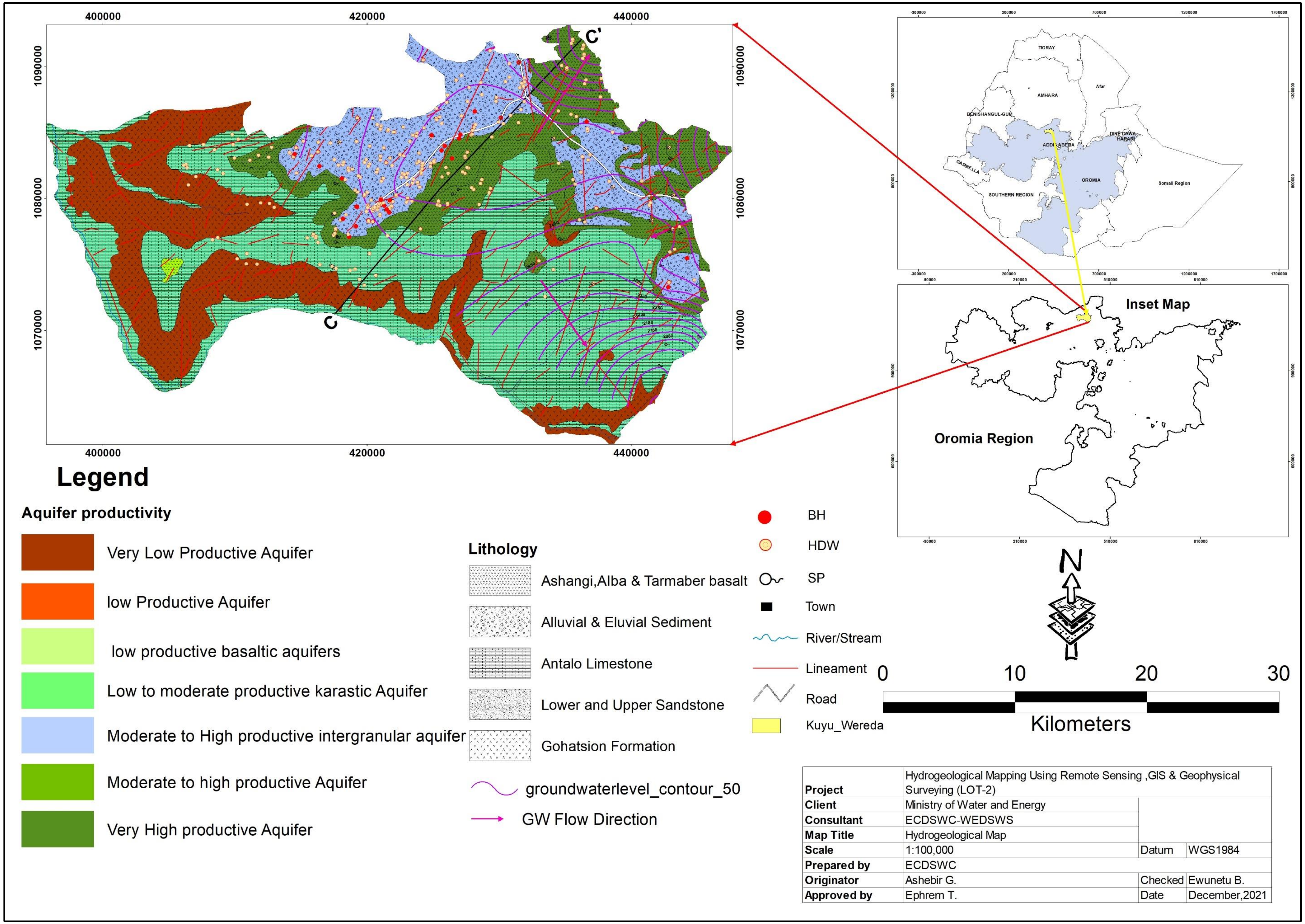


Figure 14 : Hydrogeological map of Kuyu wereda

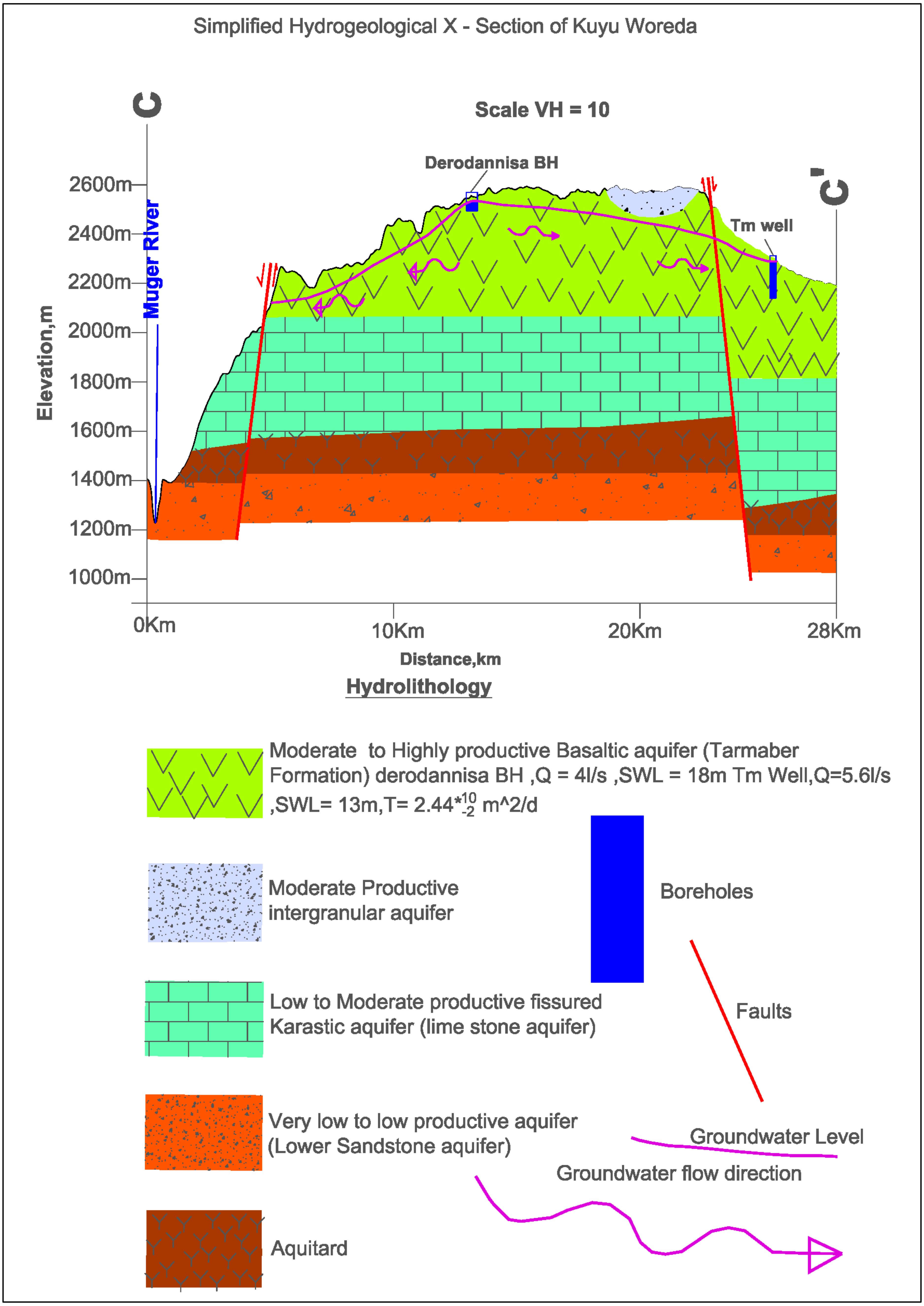


Figure 15:Hydrogeological Section of Kuyu Wereda

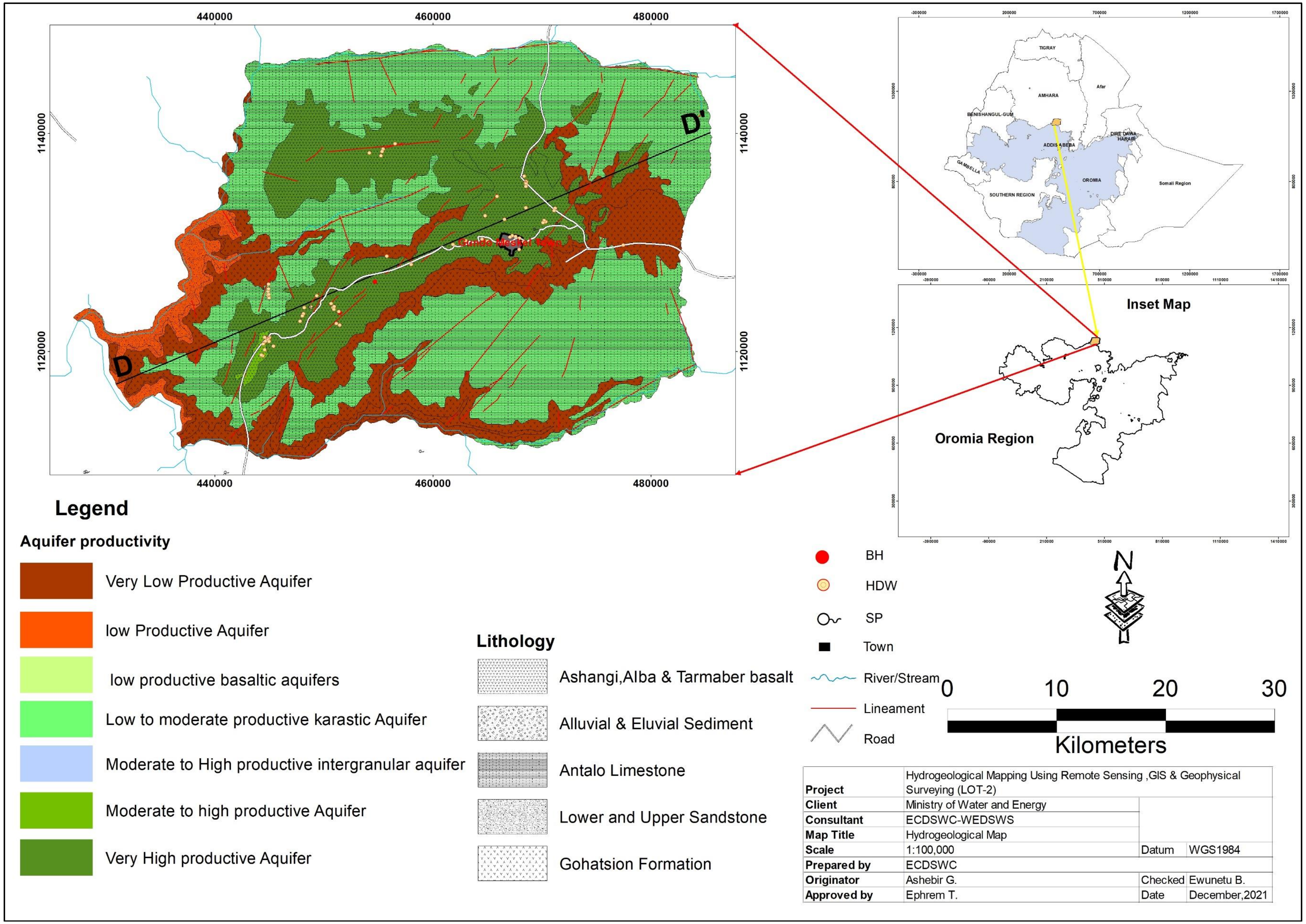


Figure 16: Hydrogeological map of Dera wereda

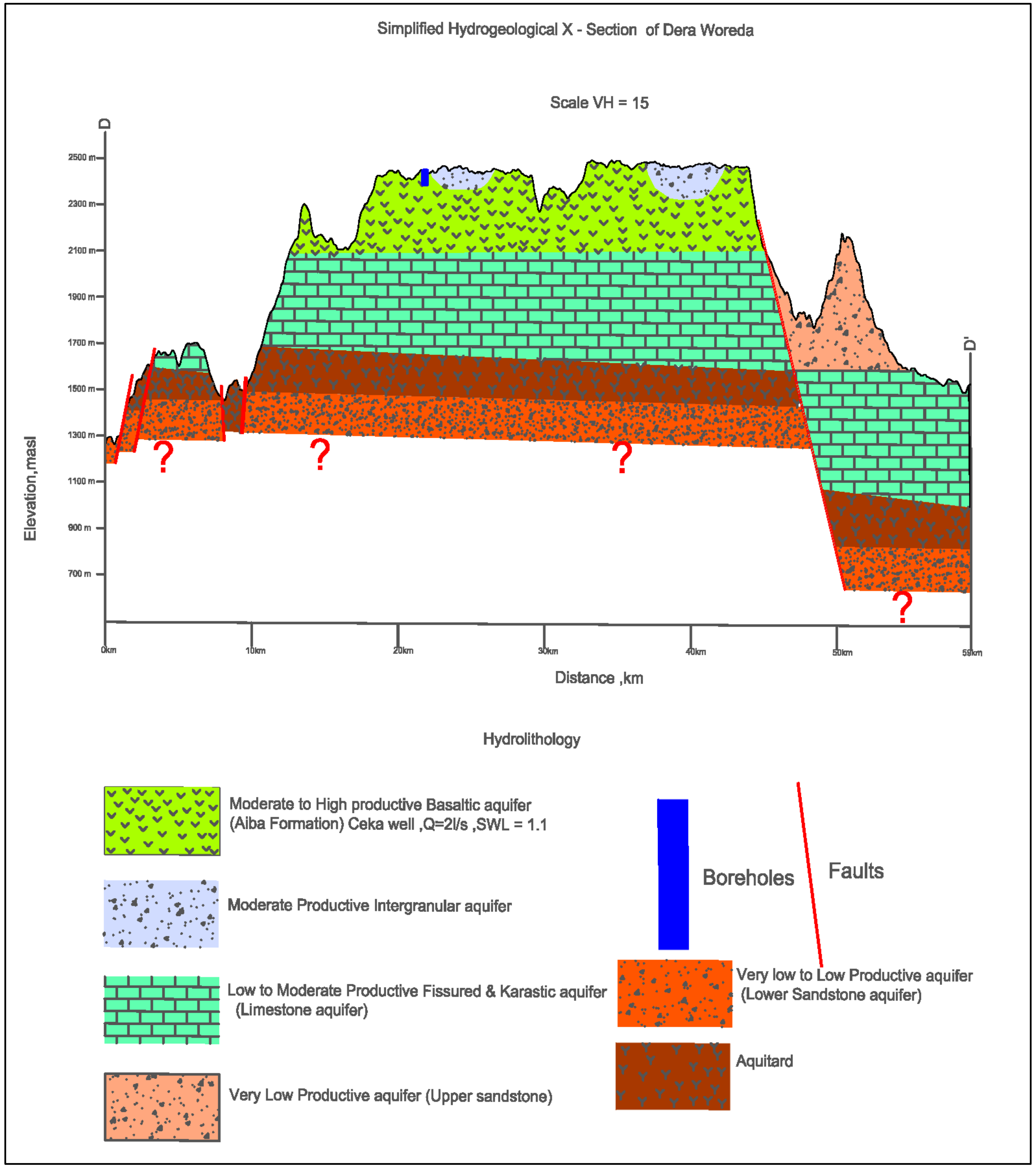


Figure 17 : Hydrogeological Section of Dera Wereda

3.3 Hydrogeological setup & Conceptual model of cluster 3

Conceptual model of Enebise Sar Midir and Sayit Weredas

After integration of existing data analysis was carried out and conceptual setup was made to verify the groundwater system of the study areas.

In Enebise Sar Midir wereda the collected data shows that the wells discharge are ranging from 0.2 to 10 l/s with a maximum depth of 181m. Depth to water level decreases (comes up) from north-west to south-east direction. The lithological log of these boreholes of the area generally shows that on the top part (0 - 20) meters depth soft formations, in the middle part up to 74m acidic formations and > 74m massive and fractured basalt, which is may be described as the upper aquifer. In this area, the northwestern part is acts as a recharge area and the southeastern part as a discharge area. As can be seen from the hydrogeological cross-section, the groundwater flow system is from the northwest to southeast direction.

In Sayit wereda, the collected data shows that the wells discharge are ranging from 0.1 to 8 l/s with a maximum depth of 77m. Generally, depth to water level decreases (comes up) from east to west direction. The lithological log of these boreholes of the area generally shows that, on the top part (0 - 5) meters depth soft formations and > 5m weathered and fractured basalt, which is may be described as the upper aquifer. In general, in this area, the eastern part is acts as a recharge area and the western part as a discharge area. As can be seen from the hydrogeological x-sections, the groundwater flow system in this area is from east to west, west to east, and north to south directions.

Geology and hydrogeology of the study areas have been used to construct a conceptual model for groundwater recharge, occurrence, and flow. Therefore, the conceptual model of these areas is presented in Figures 18, 19, 20, and 21 below

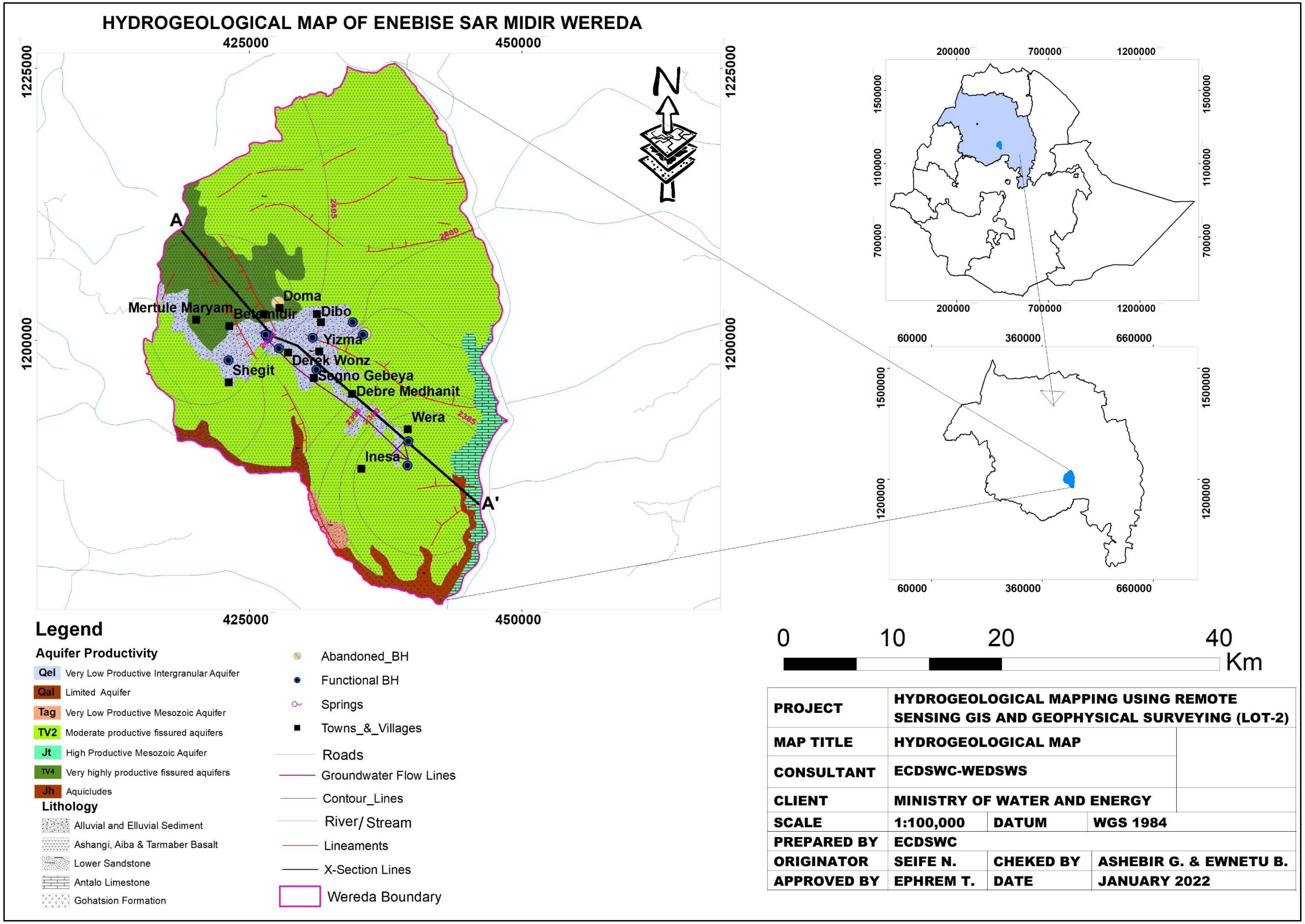


Figure 18: Hydrogeological map of Enebise Sar Midir Wereda

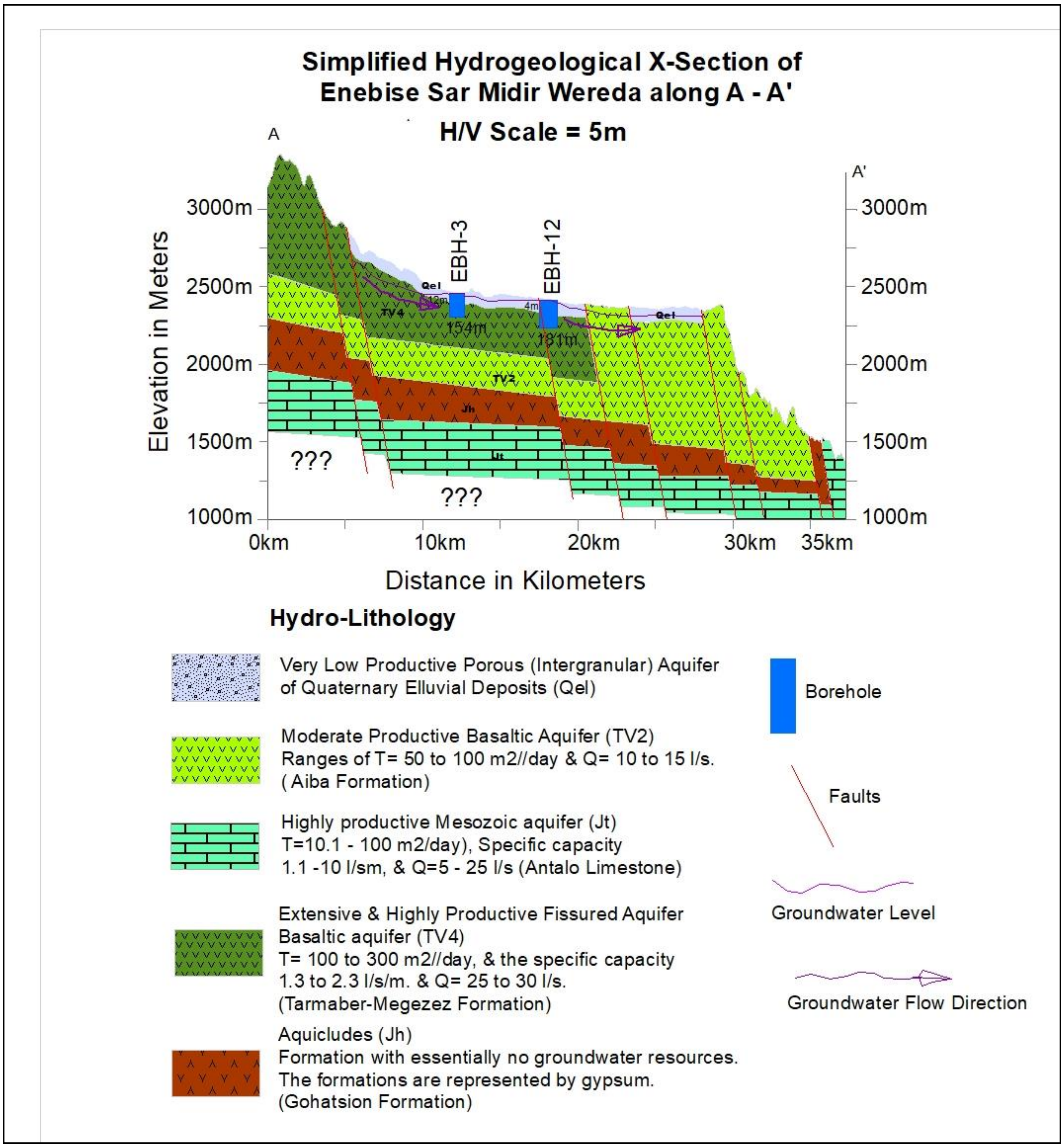


Figure 19: Hydrogeological section of Enebise Sar Midir wereda

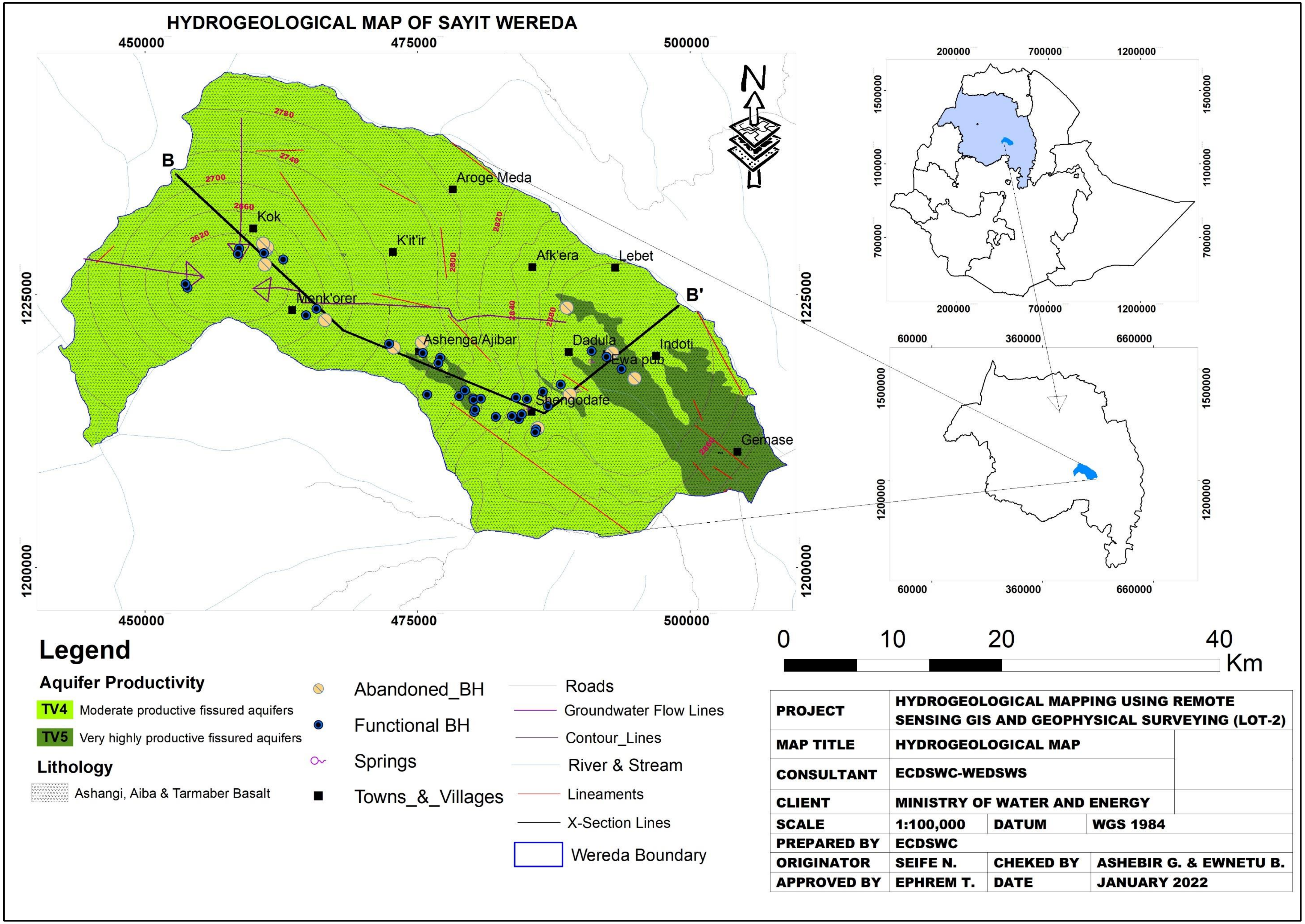


Figure 20: Hydrogeological map of Sayit Wereda

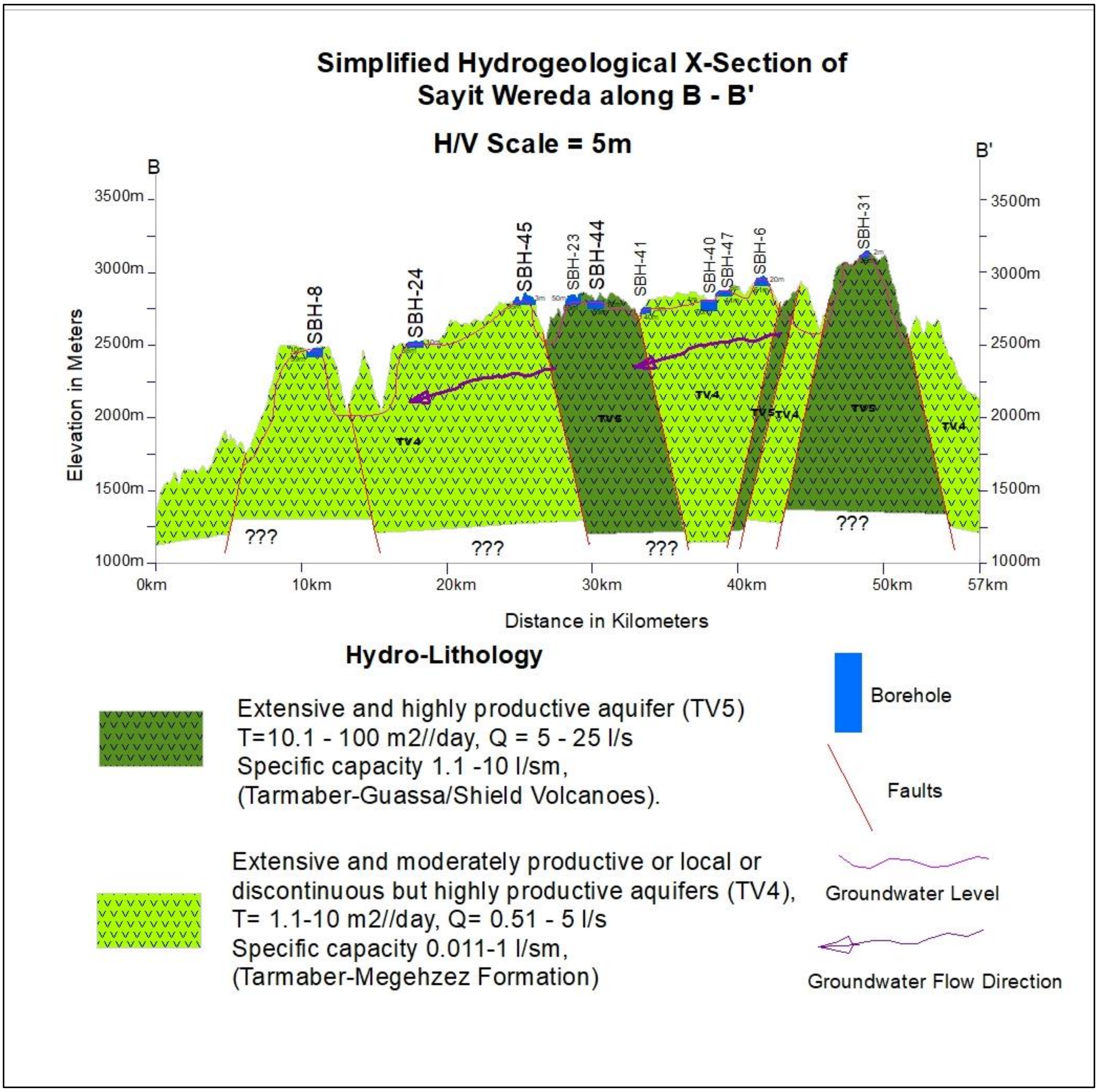


Figure 21: Hydrogeological Section of Sayit wereda

3.14 Hydrogeological condition of Cluster 4

The study areas fall in the upper Tekeze basin. The hydrogeological conditions of the area depend on the geology, geologic structures, and geomorphology of the area. The geology of the study areas is mainly Consolidated and unconsolidated sediment and basic volcanic rocks covered by thin soil, pyroclastic, trachyte, and basalt are the main volcanic rocks of the study area. They are jointed, fractured, and affected by dense weathering.

Geomorphologicaly the study areas are rugged. According to previous studies and hydrogeological set up of the study areas, the major sources of recharge for the study areas (Weredas) are:

- precipitation induced within the study areas
- Infiltration from surface rivers and overland flows

In addition, geomorphological setup, water level observed, geologic structures, groundwater contour, and conceptual model developed in previous studies shows that groundwater recharged at central and northern highland areas flow toward Tekeze gorge and mixed up with groundwater recharge from surface rivers and rainfall-induced in the area and heads northward.

The hydrogeological setup of each areas (Weredas) is discussed as follows:

Misrak Belesa and Ebenat

The Tertiary volcanic rocks in the study area are fractured and jointed. Numerous good discharge springs emerge along with the fractures and contacts. This is due to that the plateaus have high precipitation, infiltration, storage, and low evapotranspiration. Few water points at Mesozoic sandstone and sediments are inventoried having lower yields and quality that drain highland volcanic rocks. Structurally affected Tana graben and lacustrine sediments of the Tana graben area are highly productive for groundwater resource development. On the other hand, valleys along the extended fractures of the river channels that have a thick succession of alluvial deposits have also good groundwater resource regions. They have recharge from rainfall, groundwater base flow, and direct runoff.

The groundwater flow direction is determined using water level data available for existing boreholes, dug wells, and springs. Groundwater flow is discussed here on the basis of topography, geology, and structures.

Topographically, much like the flow of water in a river, the flow of groundwater is subjected to gravity and is almost always in motion, flowing from areas of higher elevation to areas of lower elevation. Groundwater appears at the surface in the form of springs under the plateaus and as dug wells at the stream valleys. The boreholes are shallow. Generally, groundwater flow in the area can be indicated from the northern and southern highlands to the central Tekeze gorge.

Most of the study area rivers are oriented in the direction of the E-W extended fractures and flow towards Tekeze gorge, and the groundwater follows these paths. These fractures control the movements of groundwater in the alluvial deposits.

Lithologically, groundwater flow in the hard rock is through fractured zones and the weathered mantle called overburden or regolith. Groundwater flow in the Tertiary volcanic rock and in the sedimentary sandstone can be horizontal along with the bedding and/or can be vertical along with the vertical fractures. The outlet springs can indicate the general groundwater flow direction in the Tertiary volcanic rock.

As depicted on the hydrogeological map and also cross-section constructed along the groundwater flow path to conceptualize groundwater flow and storage in this wereda (Figure 22, 23, 24 & 25) and also stated in previous works, the Tertiary volcanic units are recharged directly from precipitation, perennial rivers, and runoff and groundwater flow. However, the Tekeze river gorge and lithological units along with the gorges, Mesozoic sediments of lower sandstone have low rainfall and increased potential evapotranspiration with low recharge from rainfall infiltration. The low drainage density, low precipitation, and productivity of the wells in the metamorphic formations indicate that considerable recharge occurs from groundwater flow and perennial rivers. High precipitation and an increase in spring discharge during the rainy season in the volcanic rocks indicate recharge occurs from rainfall infiltration. On the other hand, the lacustrine sediments obtain recharge from rainfall, groundwater base flow, and direct runoff.

From a hydrogeological point of view, most areas of these weredas exposures are favorable for groundwater recharge, storage, and movement due to the existence of primary and secondary porosities..

Bugna and Meket

From a geomorphological point of view, the groundwater may follow the surface drainage system. The topography of the area generally slopes towards the west and northwest. Topographically, much like the flow of water in a river, the flow of groundwater is subjected to gravity, flowing from areas of higher elevation to areas of lower elevation. Groundwater appears at the surface in the form of springs under the plateaus and as dug wells at the stream valleys at some part of Meket wereda and the boreholes are shallow. Generally, groundwater flow in the area can be indicated from the Eastern and southern highlands to the central Tekeze gorge.

In shallow groundwater, the movement and flow direction are dependent on the inclination, steepness, or slope of the topography in the area. The direction of flow of springs controlled by topographic breaks is an indicator of the possible groundwater flow. As shown on the hydrogeological map and on cross-section constructed along the groundwater flow path to conceptualize groundwater flow and storage in these weredas (Figure 26, 27, 28 and 29) and also stated in previous works, the Tertiary volcanic units are recharged directly from precipitation, perennial rivers, and runoff. The groundwater flows from the southern mountain chain to the north and northwest. Existing data generally show groundwater flow to the northwest.

Tselemit Wereda

The geology of the area is mainly tertiary trap volcanics consisting of black olivine alkali basalt flows. It is coarse, intergranular texture has well-developed columnar jointing, and has concentrations of white zeolite and inter-flow fossil soils. Inter bedded lacustrine deposits of white silicified limestone and diatomite with gastropods occur at several levels.

The hydrogeological setup of the area shows that, the major sources of recharge for the study area (Tselemit Wereda) is deemed to be from Ras-Dashen Mountain composed of mainly tertiary trap volcanic to the northeastern direction toward Tekeze gorge through fractured, dissected intermountain valleys of erosional effects and jointed tertiary basalts.

In addition, geomorphological setup, geologic structures, NE river orientations in the Tselemit wereda shows that the groundwater recharged on the highland areas of Ras-Dashen Mountain is anticipated to get the highest annual rainfall and flows toward the Tekeze river gorge. According to the preliminary hydrogeological map of the area depicted below the study, wereda is found mainly within the extensive and moderately productive fissured aquifers of the tertiary trap basalts (Figure 30 and 31).

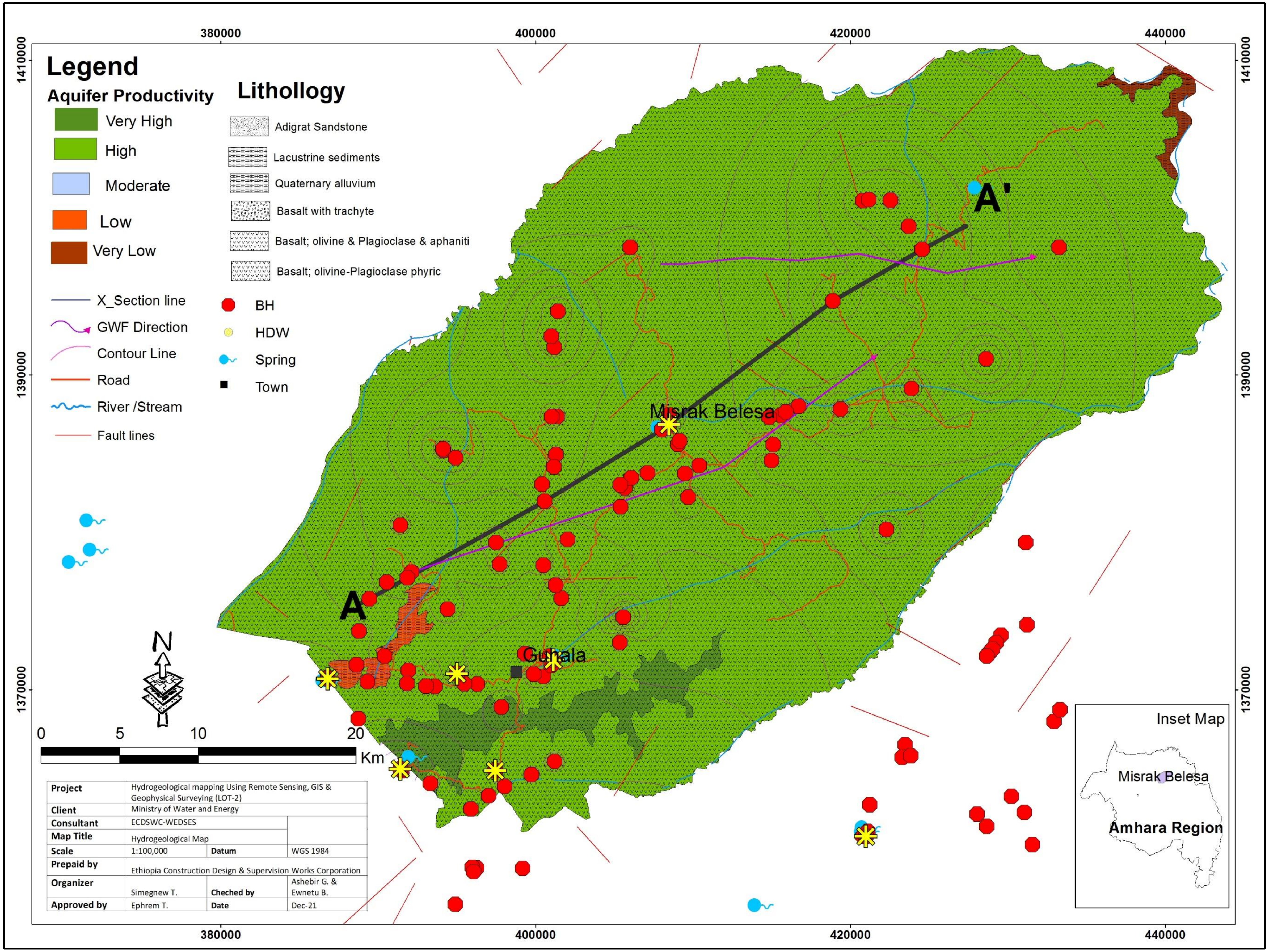


Figure 22: Hydrogeological map of Misrak Belesa wereda

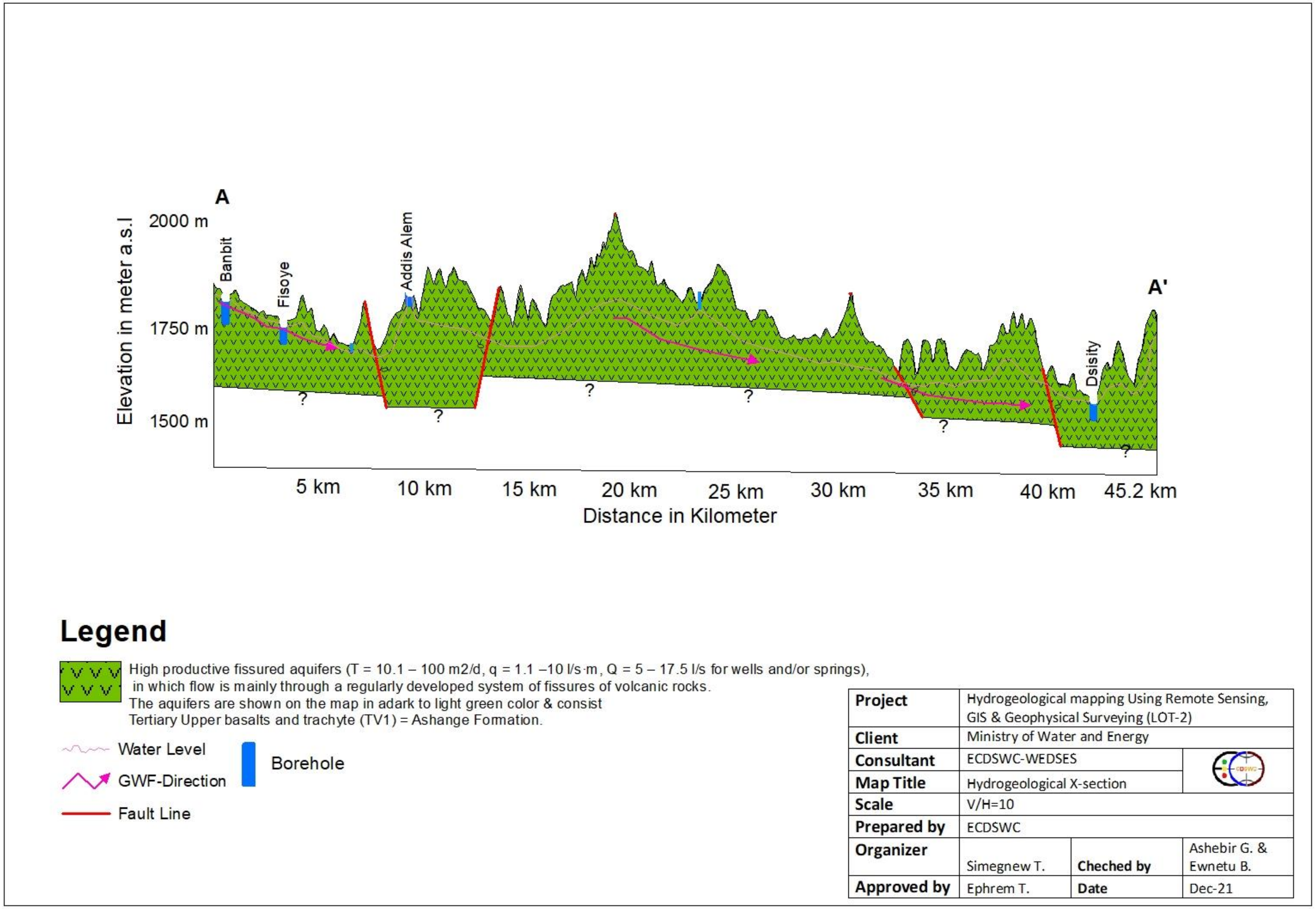
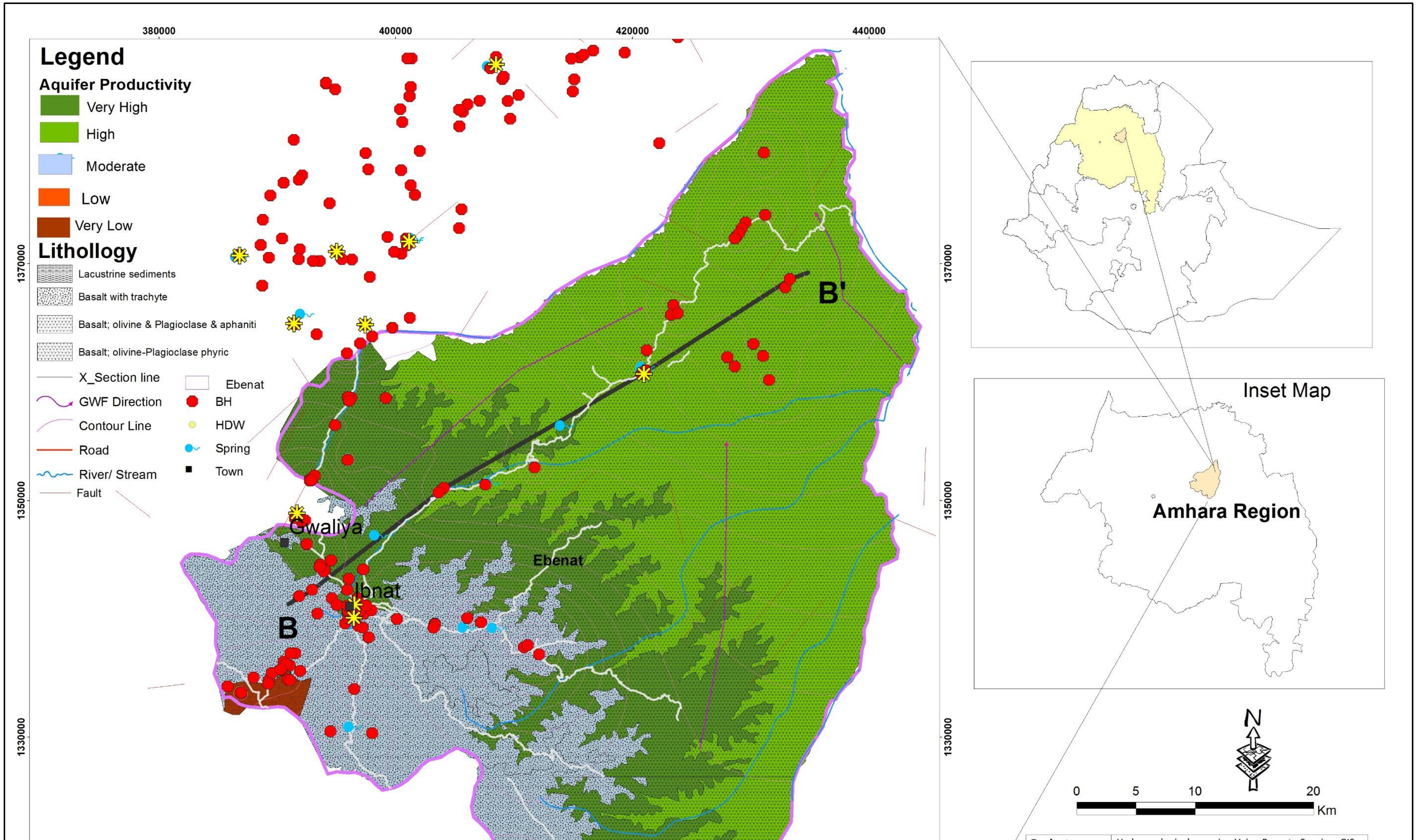


Figure 23: Hydrogeological Section Misrak Belesa wereda



Project	Hydrogeological mapping Using Remote Sensing, GIS & Geophysical Surveying (LOT-2)		
Client	Ministry of Water and Energy		
Consultant	ECDSWC-WEDSES		
Map Title	Hydrogeological Map		
Scale	1:100,000	Datum	WGS 1984
Organizer	Simegnew T.	Cheched by	Ashebir G. & Ewnetu B.
Approved by	Ephrem T.	Date	Dec-21

Figure 24: Hydrogeological map of Ebenat Wereda

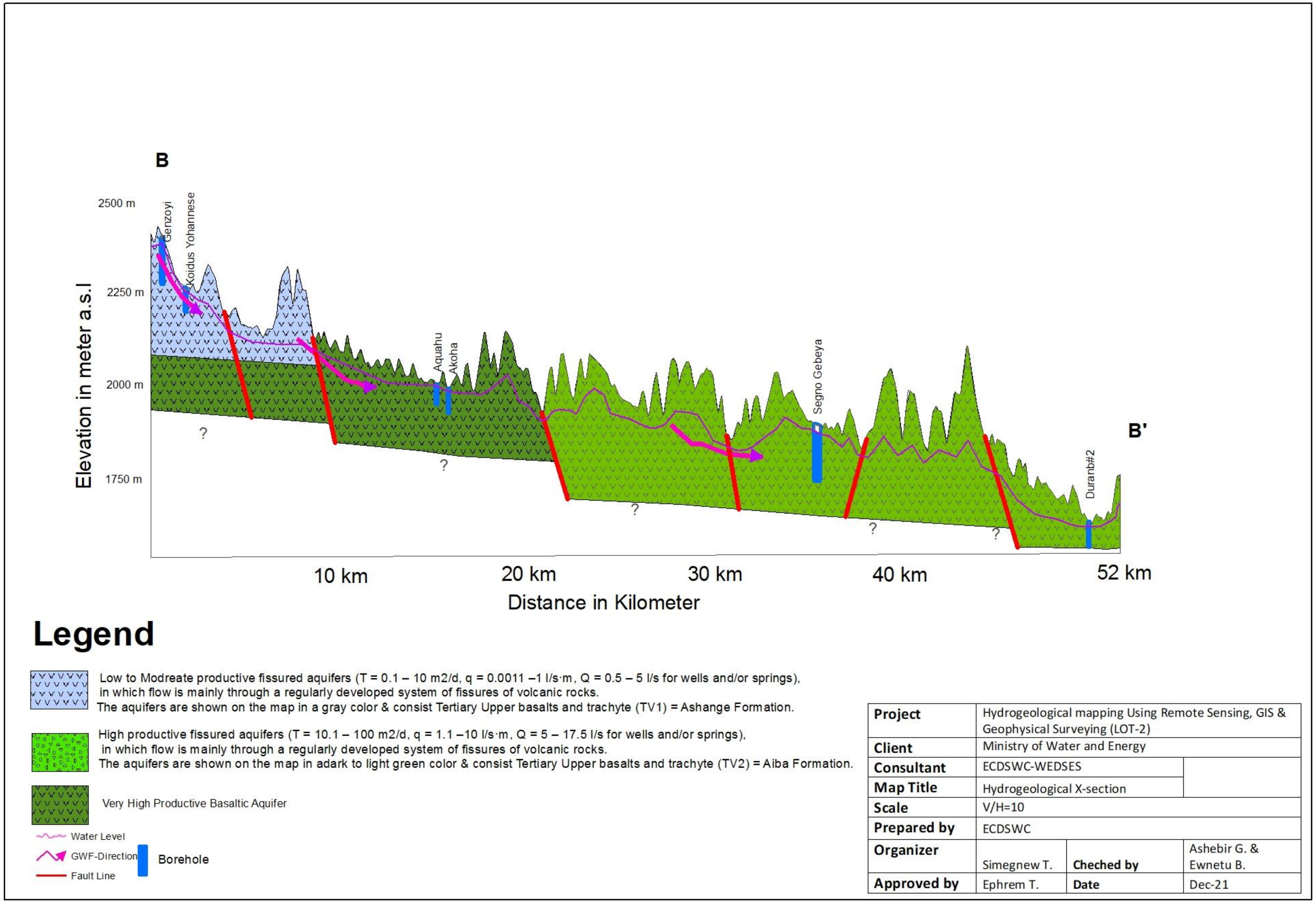


Figure 25: Hydrogeological Section of Ebenat wereda

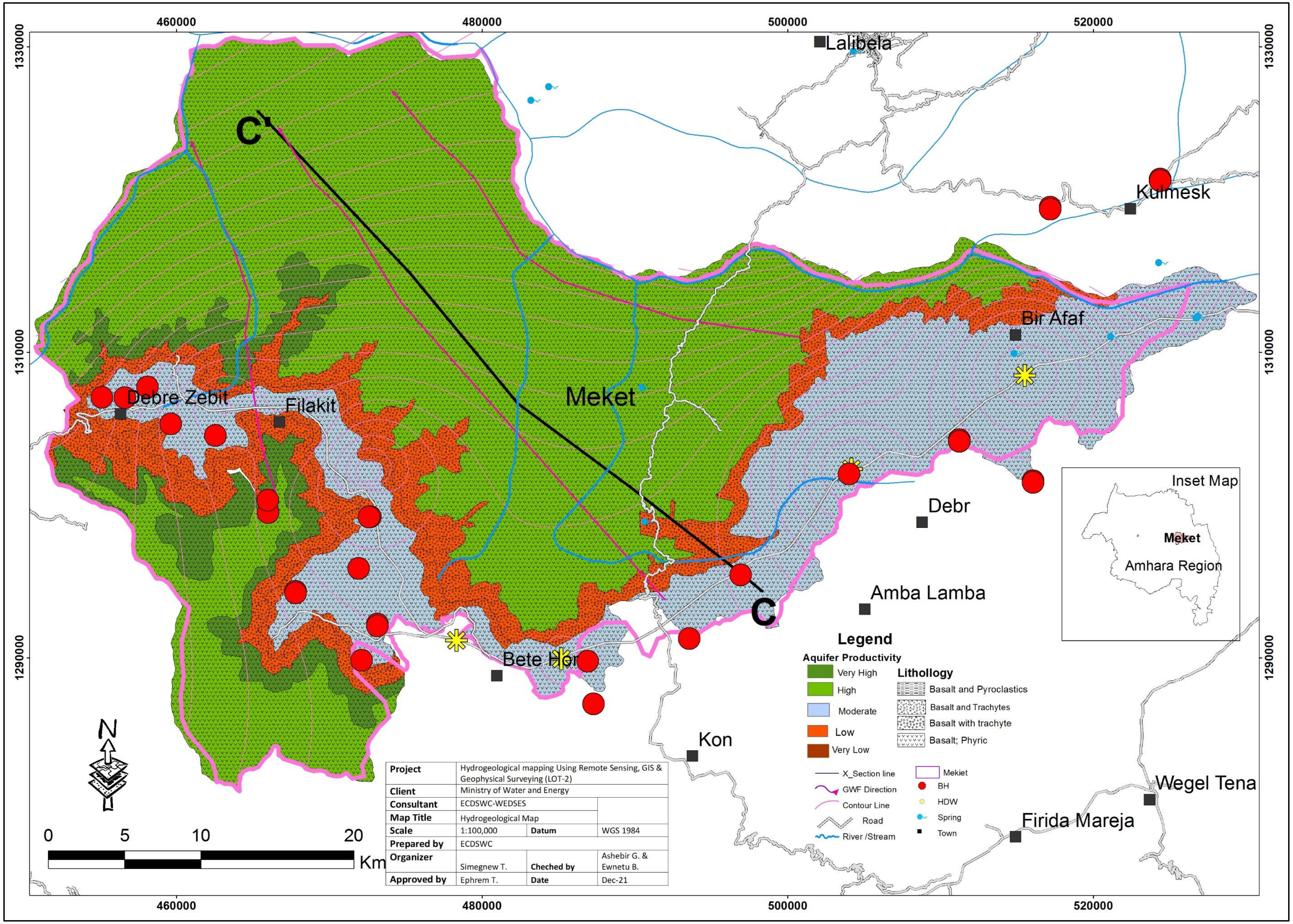
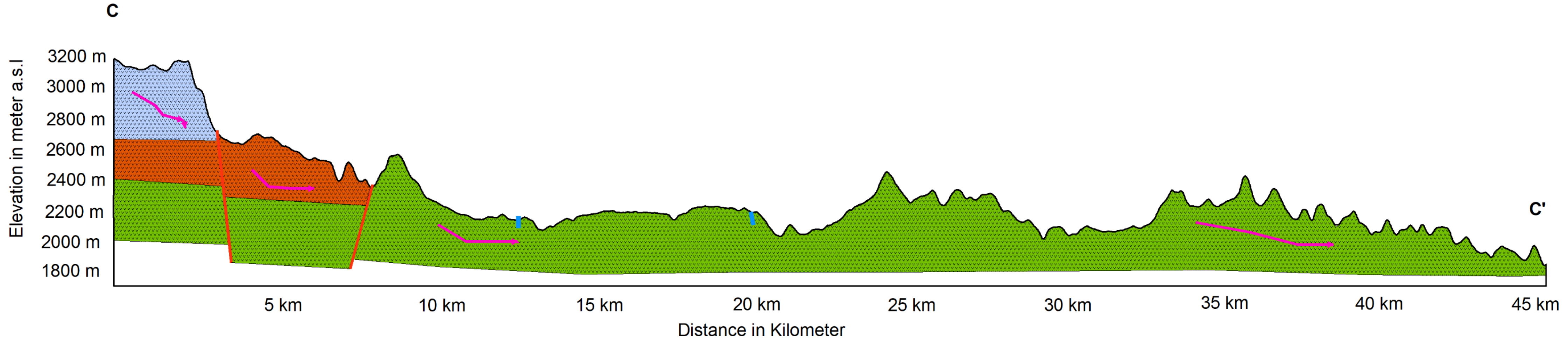


Figure 26: **Hydrogeological map of Meket wereda**



Legend

Low to Modreate productive fissured aquifers (T = 0.1 – 10 m2/d, q = 0.0011 –1 l/s·m, Q = 0.5 – 5 l/s for wells and/or springs), in which flow is mainly through a regularly developed system of fissures of volcanic rocks. The aquifers are shown on the map in a gray color & consist Tertiary Upper basalts and trachyte (TV1) = Ashange Formation.

Low to Modreate productive fissured aquifers (T = 0.11 – 1 m2/d, q = 0.0011 –0.01 l/s·m, Q = 0.05 – 0.5 l/s for wells and/or springs), in which flow is mainly through a regularly developed system of fissures of volcanic rocks. The aquifers are shown on the map in a red color & consist Tertiary Upper basalts and trachyte (TV2) = Aiba Formation.

High productive fissured aquifers (T = 10.1 – 100 m2/d, q = 1.1 –10 l/s·m, Q = 5 – 17.5 l/s for wells and/or springs), in which flow is mainly through a regularly developed system of fissures of volcanic rocks. The aquifers are shown on the map in adark to light green color & consist Tertiary Upper basalts and trachyte (TV5) = Tarma berr-Guassa formation

River

GWF-Direction

Fault Line

Project	Hydrogeological mapping Using Remote Sensing, GIS & Geophysical Surveying (LOT-2)		
Client	Ministry of Water & Energy		
Consultant	ECDSWC-WEDSES		
Map Title	Hydrogeological X-section		
Scale	V/H=5		
Prepared by	ECDSWC		
Organizer	Simegnew T.	**Cheched by**	Ashebir G. & Ewnetu B.
Approved by	Ephrem T.	**Date**	Dec-21

Figure 27: Hydrogeological section Meket wereda

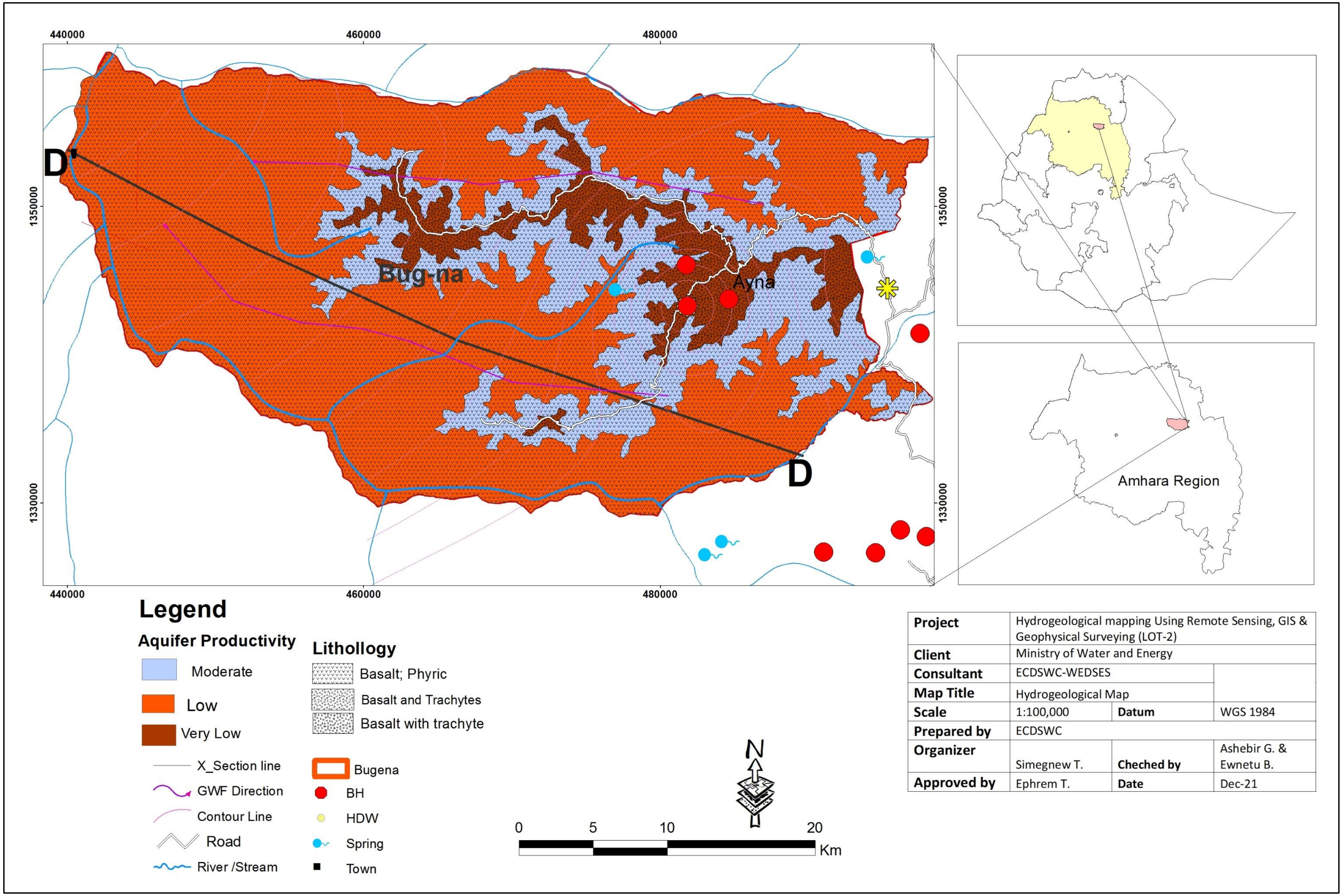


Figure 28: Hydrogeological map of Bugna Wereda

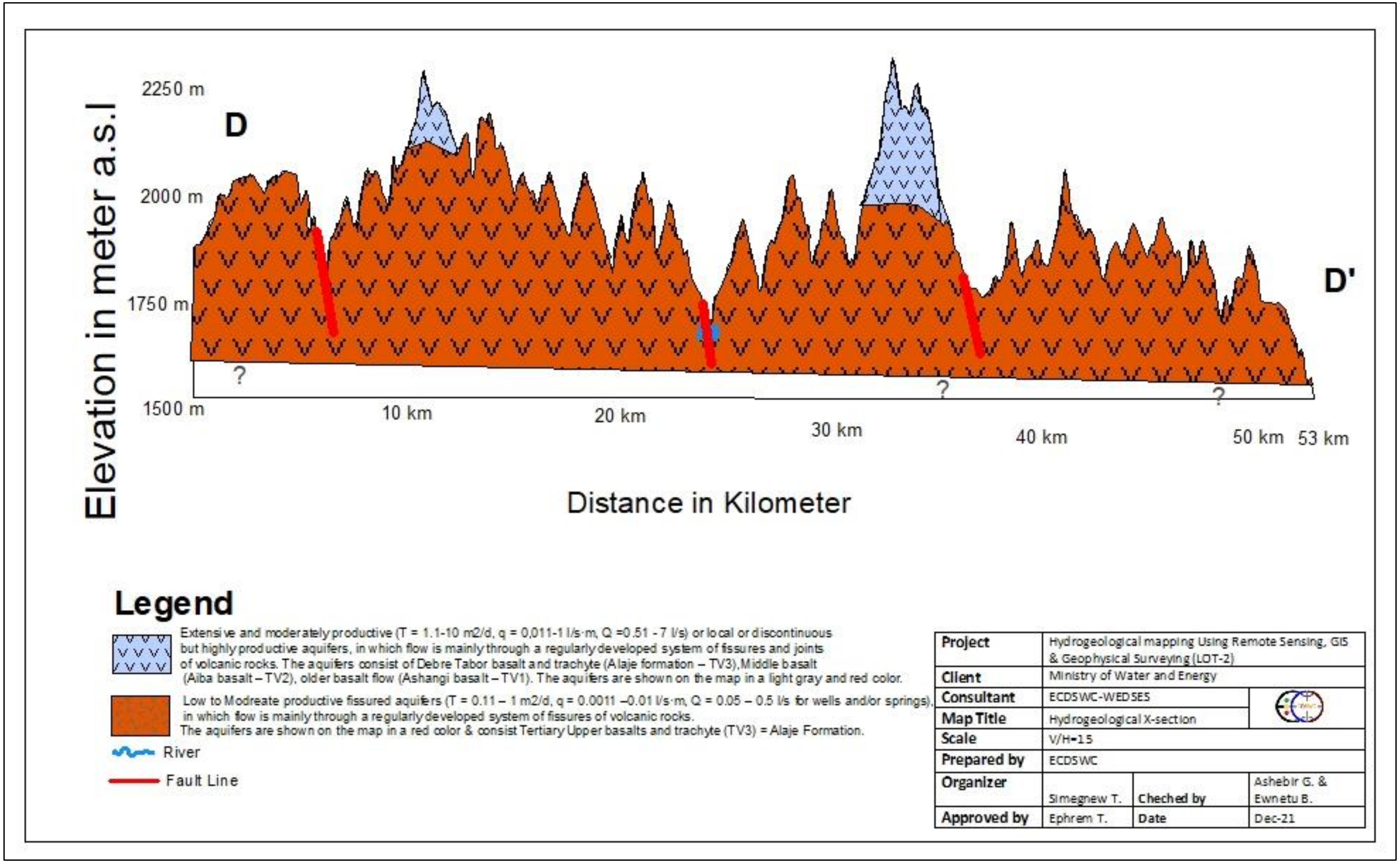


Figure 29: Hydrogeological Section along D – D'

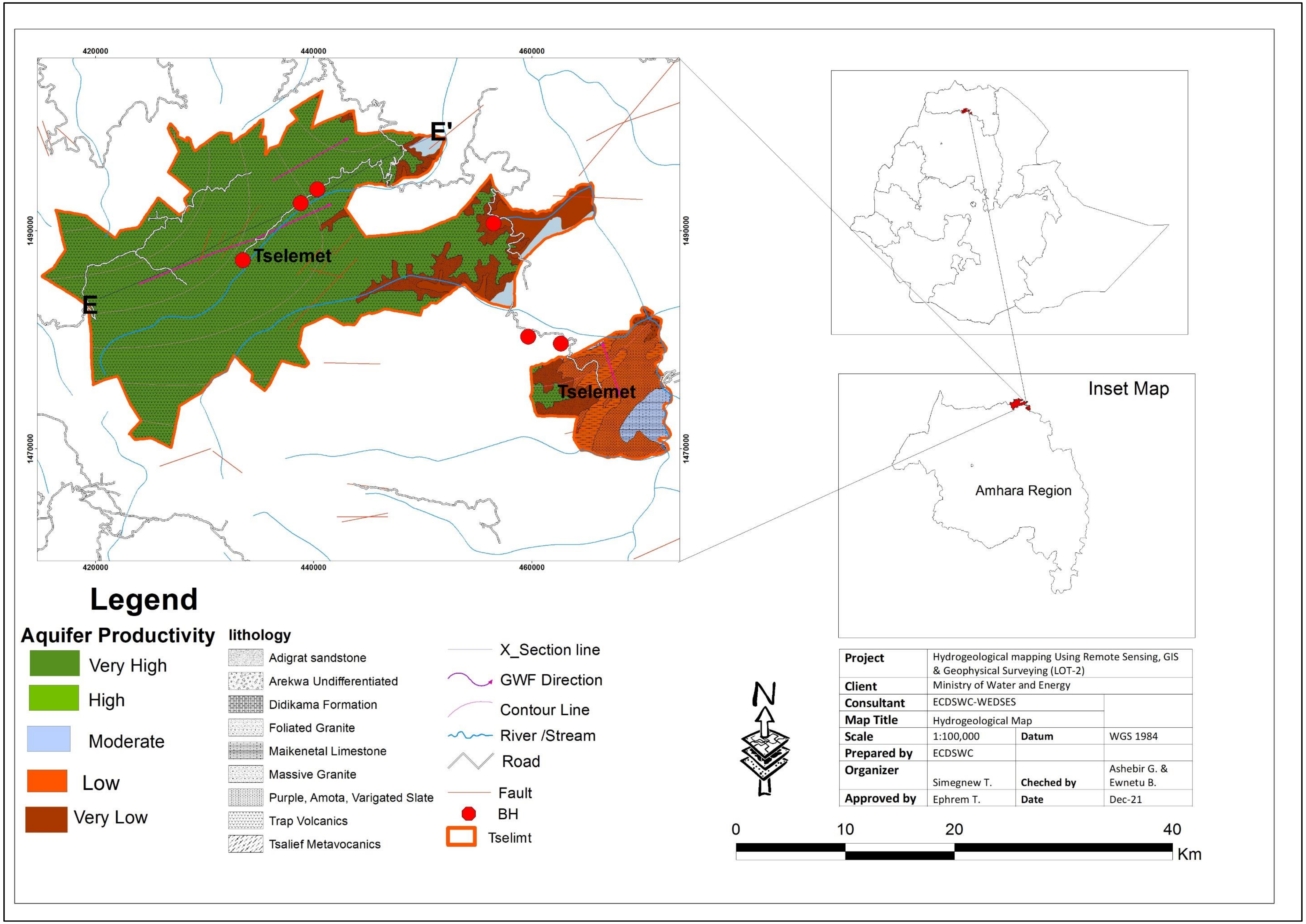


Figure 30: Hydrogeological map of Tselemit wereda

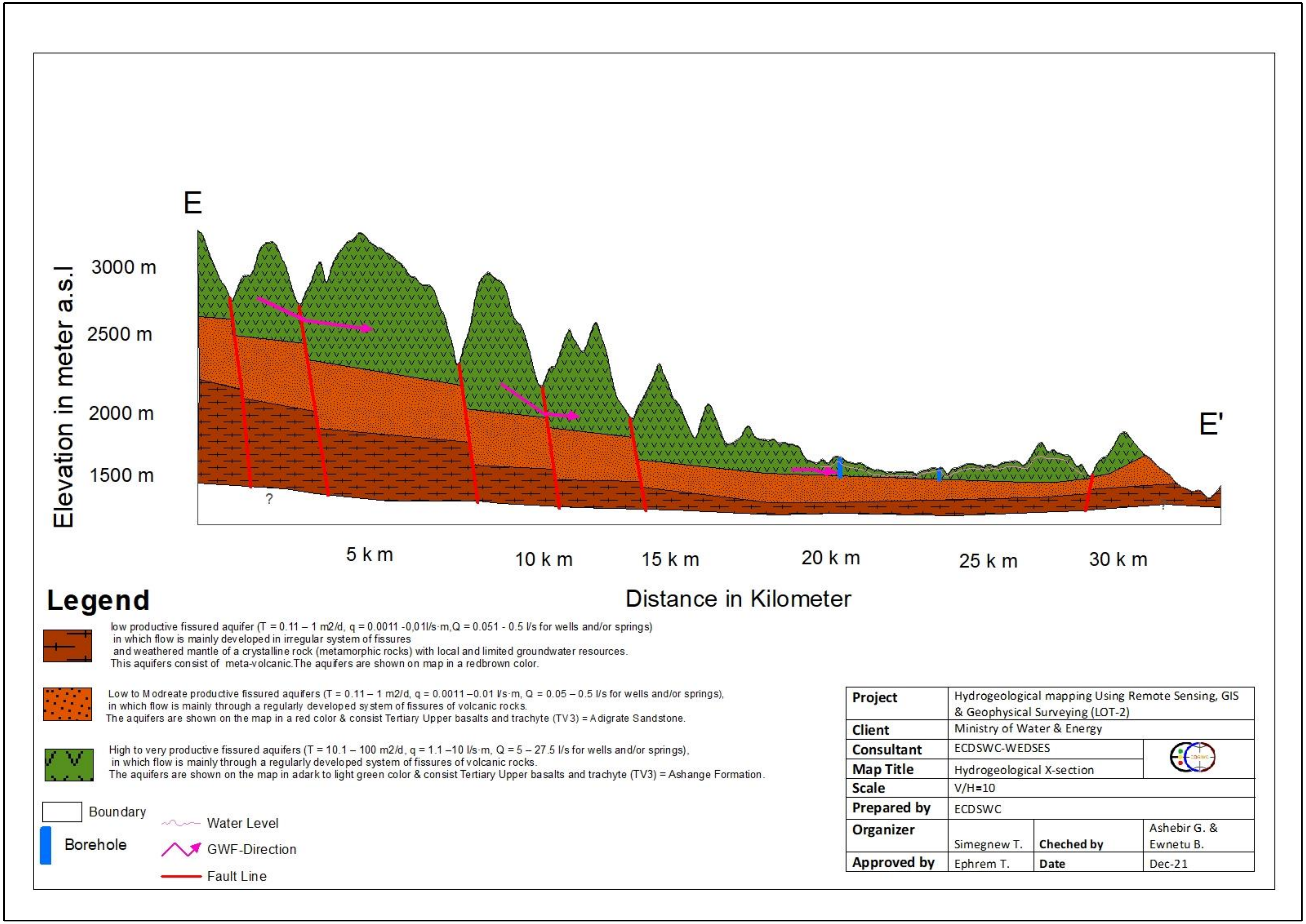


Figure 31 : Hydrogeological Section along E – E'

4. RESULT AND DISCUSSION

4.1 Multi-criteria decision analysis (MCDA) Weight assignment using AHP of each wereda

Five information layers (Lithology, Recharge, TWI, Lineament density, and Lineament proximity) that determine the groundwater potential are selected for all weredas, and weights are determined based on conceptual groundwater system for each weredas separately.

The weighting criterias are prepared by AHP (Analytic Hierarch process) (EVM multiple inputs) (K.D. Version 15.09.2018) based on the conceptual model and thematic layers proposed to use. As the hydrogeological conditions vary greatly across the projects, weights were determined for each Wereda separately (See Table 25 to 43). The minimum and maximum values are included as well, which will be taken as the basis for sensitivity analyses on the mapped groundwater potential zones.

Analytic Hierarchy Process

The first step of the AHP method is to assign the level of importance of each factor based on Saaty's (2008) scale values. Consequently, all factors are compared in a pairwise comparison matrix. The weight which was assigned to different thematic layers was normalized using Saaty's AHP techniques. To control and test the Consistency Ratio (CR) is calculated. The first step to calculate CR is to compute the maximum eigenvalue (ʎmax). Then, calculate the consistency Index (CI) using equation 5, where n is a number of factors.CR is resulted by dividing CI by RI (ratio Index). The value of RI is given based on Saaty's 1 – 9. If the value is less than 0.1, the judgment of weights is acceptable and consistent. If CR is greater than 10%, we need to revise the subjective judgment.

$$CI = \frac{\lambda max - n}{n - 1} \text{ --- Eq.5}$$

Consistency Ratio = Consistency Index /Random Index

$$CR \quad \frac{CI}{RI} \text{ --- E.q.6}$$

Table 23: Random Index

Attribute	3	4	5	6	7	8	9	10
RI	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

Table 24 : Pair-wise Comparison Matrix by using AHP for Dera and Kuyu weredas

Matrix		Lithology	Recharge	TWI	Lineament density	Lineament Proximity	normalized principal Eigenvector
		1	2	3	4	5	
Lithology	1	1	2	5	5	7	48.29%
Recharge	2	1/2	1	3	3	3	25.35%
TWI	3	1/5	1/3	1	2	2	11.66%
Lineament density	4	1/5	1/3	1/2	1	1	7.62%
Lineament Proximity	5	1/7	1/3	1/2	1	1	7.07%

	Criterion	Comment	Weights	+/-
1	Lithology		48.3%	7.1%
2	Recharge		25.4%	5.3%
3	TWI		11.7%	2.8%
4	Lineament density		7.6%	1.4%
5	Lineament Proximity		7.1%	0.9%

Eigenvalue				Lambda:	5.071		MRE:	18.9 %	
Consistency Ratio	0.37	GCI:	0.06	Psi:	0.0%	CR:	1.6 %		

Table 25: Pair-wise Comparison Matrix by using AHP for Girar Jarso, and Wuchale weredas.

Matrix		Lithology	Recharge	TWI	Lineament density	lineament Proximity	normalized principal Eigenvector
		1	2	3	4	5	
Lithology	1	1	2	3	6	7	43.02%
Recharge	2	1/2	1	3	6	7	32.41%
TWI	3	1/3	1/3	1	3	3	13.97%
Lineament density	4	1/6	1/6	1/3	1	1	5.48%
Lineament Proximity	5	1/7	1/7	1/3	1	1	5.13%

	Criterion	Comment	Weights	+/-
1	Lithology		43.0%	12.3 %
2	Recharge		32.4%	7.3%
3	TWI		14.0%	2.1%
4	lineament density		5.5%	0.9%
5	lineament Proximity		5.1%	0.6%

Eigenvalue				Lambda:	5.079	MRE:	20.0 %
Consistency Ratio	0.37	GCI:	0.07	Psi:	0.0%	CR:	1.8%

Table 26: Assigned rank for various classes of all thematic layers of Dera and Kuyu wereda

Factors	Weight	Class	Groundwater Storage potential	Assigned Rank
Lithology	48.29	Aiba Basalt	Very high productive	5
		Tarmaber Basalt	High productive	4
		Antalo Limestone	Moderate	3
		Ashangi formation/Adigrat Sandstone	low Productive	2
		Upper Sandstone/Gohatsion Formation	Very low Productive	1
Recharge	25.35	523.38 - 292.22	Very high	5
		292.21 - 230.86	High	4
		230.85 - 160.74	Medium	3
		160.73 - 95.87	low	2
		95.86 - 11.71	Very Low	1
TWI	11.66	19.73 - 12.92	Very high	5
		12.91 - 10.29	High	4
		10.28 - 8.37	Medium	3
		8.36 - 7	low	2
		6.99 - 4.48	Very Low	1
Lineament Density	7.62	2.15 – 1.73	Very high	5
		1.72 – 1.3	High	4
		1.29 – 0.87	Medium	3
		0.86 – 0.44	low	2
		0.43 – 0	Very Low	1
Lineament Proximity	7.07	0 - 250	Very high	5
		250 - 750	High	4
		750 - 1250	Medium	3
		1250 - 2000	low	2
		2000 - 7500	Very Low	1

Table 27: Assigned rank for various classes of all thematic layers of Girar Jarso and Wuchale wereda

Factors	Weight	Class	Groundwater Storage potential	Assigned Rank
Lithology	43.02	Aiba Basalt	Very high productive	5
		Alluvium / Quaternary Basalt/Tarmaber	High productive	4
		/limestone	Moderate	3
		Adigrat Sandstone	low Productive	2
		Debre Libanos Sandstone/Muger Mudstone	Very low Productive	1
Recharge	32.41	459.67 - 280.01	Very high	5
		292.21 - 230.86	High	4
		230.85 - 160.74	Medium	3
		160.73 - 95.87	low	2
		95.86 - 11.71	Very Low	1
TWI	13.97	19.73 - 12.92	Very high	5
		12.91 - 10.29	High	4
		10.28 - 8.37	Medium	3
		8.36 - 7	low	2
		6.99 - 4.48	Very Low	1
Lineament Density	5.48	2.25 - 1.2	Very high	5
		1.19 - 0.81	High	4
		0.8 - 0.49	Medium	3
		0.48 - 0.18	low	2
		0.17 - 0	Very Low	1
Lineament Proximity	5.13	0 - 250	Very high	5
		250 - 750	High	4
		750 - 1250	Medium	3
		1250 - 2000	low	2
		2000 - 5000	Very Low	1

Table 28:Pair-wise Comparison Matrix by using AHP for Bure Mudayitu wereda

Matrix		Lithology	Recharge	Lineament density	Lineament proximity	TWI	normalized principal Eigenvector
		1	2	3	4	5	
Lithology	1	1	7	7	9	9	66.10%
Recharge	2	1/7	1	1	1	2	9.99%
Lineament density	3	1/7	1	1	1	1	8.58%
Lineament proximity	4	1/9	1	1	1	1	8.16%
TWI	5	1/9	1/2	1	1	1	7.17%

	Criterion	Comment	Weights	+/-
1	Lithology		66.1%	5.1%
2	Recharge		10.0%	2.5%
3	Lineament density		8.6%	1.1%
4	Lineament proximity		8.2%	1.1%
5	TWI		7.2%	1.4%

Eigenvalue					Lambda:	5.054		MRE:	16.6%
Consistency Ratio	0.37	GCI:	0.05	Psi:	0.0%	CR:	1.2%		

Table 29: Pair-wise Comparison Matrix by using AHP for Dulecha Wereda

Matrix		lithology	Recharge	Lineament density	Lineament proximity	TWI	normalized principal Eigenvector
		1	2	3	4	5	
lithology	1	1	1	2	7	7	35.65%
Recharge	2	1	1	1	5	7	28.52%
Lineament density	3	1/2	1	1	7	7	26.84%
Lineament proximity	4	1/7	1/5	1/7	1	1	4.66%
TWI	5	1/7	1/7	1/7	1	1	4.34%

	Criterion	Comment	Weights	+/-
1	lithology		35.6%	10.0%
2	Recharge		28.5%	4.5%
3	Lineament density		26.8%	5.6%
4	Lineament proximity		4.7%	0.7%
5	TWI		4.3%	0.5%

Eigenvalue			Lambda:	5.072		MRE:	19.1%	
Consistency Ratio	0.37	GCI:	0.06	Psi:	0.0%	CR:	1.6%	

Table 30:Pair-wise Comparison Matrix by using AHP for Argoba Liyu wereda

Matrix		Lithology	Recharge	Lineament density	Lineament proximity	TWI	normalized principal Eigenvector
		1	2	3	4	5	
Lithology	1	1	2	7	9	9	51.63%
Recharge	2	1/2	1	3	7	7	29.06%
Lineament density	3	1/7	1/3	1	3	3	10.59%
Lineament proximity	4	1/9	1/7	1/3	1	1	4.36%
TWI	5	1/9	1/7	1/3	1	1	4.36%

	Criterion	Comment	Weights	+/-
1	Lithology		51.6%	14.4%
2	Recharge		29.1%	2.2%
3	Lineament density		10.6%	2.4%
4	Lineament proximity		4.4%	0.8%
5	TWI		4.4%	0.8%

Eigenvalue			Lambda:	5.080		MRE:	20.0%	
Consistency Ratio	0.37	GCI:	0.07	Psi:	0.0%	CR:	1.8%	

Table 31: Assigned rank for various classes of all thematic layers of Buri Mudayitu wereda

Factors	Weight	Class	Groundwater Storage potential	Assigned Rank
Lithology	66.1	Alluvium	Low Productive	2
		Lacustrine Sediment	Very low Productive	1
		Neogene Lacustrine Sediment	Very low Productive	1
Recharge	10.0	200.13 – 250.15	Very high	5
		161.86 - 200.13	High	4
		110.85 - 161.86	Medium	3
		59.84 - 110.85	low	2
		0 - 59.84	Very Low	1
TWI	7.2	12.54 – 17.48	Very high	5
		11.02 – 12.54	High	4
		9.8 – 11.02	Medium	3
		8.78 – 9.8	low	2
		6.72 – 8.78	Very Low	1
Lineament Density	8.6	0.642 – 0.957	Very high	5
		0.413 – 0.642	High	4
		0.244 – 0.413	Medium	3
		0.082 – 0.244	low	2
		0 – 0.082	Very Low	1
Lineament Proximity	8.2	0 - 250	Very high	5
		250 - 500	High	4
		500 - 750	Medium	3
		750 - 1000	low	2
		> 1000	Very Low	1

Table 32: Assigned rank for various classes of all thematic layers of Argoba Liyu Wereda

Factors	Weight	Class	Groundwater Storage potential	Assigned Rank
Lithology	51.6	Basalt and Rhyolite	Moderate Productive	3
		Tarmaber Basalt	High Productive	4
Recharge	29.1	212.92 – 301.61	Very high	5
		182.18 – 212.92	High	4
		154.08 – 182.18	Medium	3
		130.37 – 154.08	low	2
		77.68 – 130.37	Very Low	1
TWI	4.4	12.54 – 18.35	Very high	5
		10.47 – 12.54	High	4
		9.01 – 10.47	Medium	3
		7.7 – 9.01	low	2
		4.5 – 7.7	Very Low	1
Lineament Density	10.6	2.52 – 4.18	Very high	5
		1.95 – 2.52	High	4
		1.41 – 1.95	Medium	3
		0.82 – 1.41	low	2
		0 – 0.82	Very Low	1
Lineament Proximity	4.4	0 - 250	Very high	5
		250 - 500	High	4
		500 - 750	Medium	3
		750 - 1000	low	2
		> 1000	Very Low	1

Table 33 : Assigned rank for various classes of all thematic layers of Dulecha Wereda

Factors	Weight	Class	Groundwater Storage potential	Assigned Rank
Lithology	35.6	Alluvium	Very high Productive	5
		Dofan Basalt	Very high Productive	5
		Kesem Basalt	High Productive	4
		Pleistocene Basalt	High Productive	4
		Sela Dingay-Debre Birhan-Goro Ignimbrite, tuff	Low Productive	2
Recharge	28.5	192.19 – 280.05	Very high	5
		153.75 – 192.19	High	4
		118.61 – 153.75	Medium	3
		79.07 – 118.61	low	2
		0 – 79.07	Very Low	1
TWI	4.3	11.98 – 17.48	Very high	5
		9.69 – 11.98	High	4
		8.03 – 9.69	Medium	3
		6.82 – 8.03	low	2
		4.97 – 6.82	Very Low	1
Lineament Density	26.8	1.66 – 2.83	Very high	5
		1.12 – 1.66	High	4
		0.67 – 1.12	Medium	3
		0.27 – 0.67	low	2
		0 – 0.27	Very Low	1
Lineament Proximity	4.7	0 - 250	Very high	5
		250 - 500	High	4
		500 - 750	Medium	3
		750 - 1000	low	2
		> 1000	Very Low	1

Table 34: Pair-wise Comparison Matrix by using AHP for Misrak Belesa & Ebenat weredas

Criterion		Comment	Weights	+/-
1	Lithology		41.3%	3.8%
2	Recharge		21.5%	0.6%
3	Lineament Density		21.5%	0.6%
4	Lineament proximity		11.2%	1.1%
5	TWI		4.4%	0.5%

Eigenvalue			Lambda:	5.013			MRE:	8.2%
Consistency Ratio	0.37	GCI:	0.01	Psi:	0.0%	CR:	0.3%	

Matrix		Lithology	Recharge	Lineament Density	Lineament Proximity	TWI	**normalized principal Eigenvector**
		1	2	3	4	5	
Lithology	1	1	2	2	4	8	41.34%
Recharge	2	1/2	1	1	2	5	21.54%
Lineament Density	3	1/2	1	1	2	5	21.54%
Lineament Proximity	4	1/4	1/2	1/2	1	3	11.21%
TWI	5	1/8	1/5	1/5	1/3	1	4.37%

Table 35: Pair-wise Comparison Matrix by using AHP for Bugna and Meket weredas

Criterion		Comment	Weights	+/-
1	Lithology		35.5%	4.1%
2	Recharge		31.4%	3.9%
3	Lineament Density		17.3%	2.4%
4	Lineament Proximity		10.7%	2.6%
5	TWI		5.1%	1.0%

Eigenvalue						Lambda:	5.036		MRE:	17.2%
Consistency Ratio	0.37	GCI:	0.05	Psi:	3.3%	CR:	1.3%			

Matrix		Lithology	Recharge	Lineament Density	Lineament Proximity	TWI	normalized principal Eigenvector
		1	2	3	4	5	
Lithology	1	1	1	2	4	7	35.55%
Recharge	2	1	1	2	3	5	31.43%
Lineament Density	3	1/2	1/2	1	2	3	17.27%
Lineament Proximity	4	1/4	1/3	1/2	1	3	10.66%
TWI	5	1/7	1/5	1/3	1/3	1	5.09%

Table 36: Pair-wise Comparison Matrix by using AHP for Tselemit wereda

Matrix		Lithology	GW Recharge	TWI	Lineament density	Lineament proximity	normalized principal Eigenvector
		1	2	3	4	5	
Lithology	1	1	2	2	9	9	41.67%
GW Recharge	2	1/2	1	2	7	7	28.88%
TWI	3	1/2	1/2	1	7	7	21.77%
Lineament density	4	1/9	1/7	1/7	1	1	3.84%
Lineament proximity	5	1/9	1/7	1/7	1	1	3.84%

Criterion		Comment	Weights	+/-
1	Lithology		41.7%	9.3%
2	Recharge		28.9%	8.3%
3	TWI		21.8%	5.1%
4	Lineament density		3.8%	0.5%
5	Lineament proximity		3.8%	0.5%

Eigenvalue						Lambda:	5.090		MRE:	21.3%
Consistency Ratio	0.37	GCI:	0.07	Psi:	0.0%	CR:	2.0%			

Table 37: Pair-wise Comparison Matrix by using AHP for Misrak Belesa & Ebenat weredas.

Factors	Weight	Class	Groundwater Storage potential	Assigned Rank
Lithology	41.3	Basalt, olivine plagioclase, phyric	Very high productive	5
		Basalt, olivine plagioclase, aphanitic	High productive	4
		Basalt with trachyte	Moderate	3
		Quaternary Alluvium	low Productive	2
		Adigrat Sandstone	Very low Productive	1
Recharge	21.5	456 - 303	Very high	5
		222 – 303	High	4
		164 - 222	Medium	3
		122 - 164	low	2
		0 - 122	Very Low	1
Lineament Density	21.5	0.9 – 1.13	Very high	5
		0.7 – 0.9	High	4
		0.4 – 0.7	Medium	3
		0.2 – 0.4	low	2
		0 – 0.2	Very Low	1
Lineament Proximity	11.2	250 - 750	Very high	5
		750 - 1250	High	4
		1250 - 2000	Medium	3
		2000 - 5000	low	2
		>5000	Very Low	1
TWI	4.4	14 - 22	Very high	5
		10 - 14	High	4
		8.1 - 10	Medium	3
		6.8 – 8.1	low	2
		4.6 – 6.8	Very Low	1

Table 38: Assigned rank for various classes of all thematic layers of Bugna and Mekiet wereda

Factors	Weight	Class	Groundwater Storage potential	Assigned Rank
Lithology	35.5	Basalt, olivine plagioclase, phyric	Very high productive	5
		Basalt, olivine plagioclase, aphanitic	High productive	4
		Basalt & Pyroclastic	Moderate	3
		Basalt &Trachyte	low Productive	2
		Basalt with Trachyte	Very low Productive	1
Recharge	31.4	243 -- 435	Very high	5
		194 -- 243	High	4
		150 -- 194	Medium	3
		108 -- 150	low	2
		0 -- 108	Very Low	1
Lineament Density	17.3	1.4 – 1.7	Very high	5
		1.0 – 1.4	High	4
		0.6 – 1.0	Medium	3
		0.3 – 0.6	low	2
		0.0 – 0.3	Very Low	1
Lineament Proximity	10.7	0 - 250	Very high	5
		250 - 750	High	4
		750 - 1250	Medium	3
		1250 - 2000	low	2
		>2000	Very Low	1
TWI	5.1	14 -- 21	Very high	5
		10 -- 14	High	4
		8 -- 10	Medium	3
		6.6 -- 8	low	2
		6.6 – 4.3	Very Low	1

Table 39: Assigned rank for various classes of all thematic layers of Tselemit wereda

Factors	Weight	Class	Groundwater Storage potential	Assigned Rank
Lithology	41.67	Trap Volcanics	Very high productive	5
		Un differentiated formation	High productive	4
		Limestone	Moderate	3
		Adigrat Sandstone	low Productive	2
		Massive Granite	Very low Productive	1
Recharge	28.88	394 -- 202	Very high	5
		202 -- 152	High	4
		152 -- 108	Medium	3
		108 -- 77	low	2
		77 -- 0	Very Low	1
TWI	21.77	13 – 19	Very high	5
		9 – 13	High	4
		7.5 – 9	Medium	3
		6.1 – 7.5	low	2
		6.1 – 3.8	Very Low	1
Lineament Density	3.84	1.15 – 1.44	Very high	5
		0.8 – 1.15	High	4
		0.5 – 0.8	Medium	3
		0.3 – 0.5	low	2
		0.3 – 0.0	Very Low	1
Lineament Proximity	3.84	0 - 250	Very high	5
		250 - 750	High	4
		750 - 1250	Medium	3
		1250 - 2000	low	2
		>2000	Very Low	1

Table 40: Pair-wise Comparison Matrix by using AHP for Sanit & Enebise Sar Midir Weredas

Matrix		Lithology	Recharge	TWI	Lineament density	Lineament proximity	normalized principal Eigenvector
		1	2	3	4	5	
Lithology	1	1	2	3	5	6	42.92%
Recharge	2	1/2	1	3	4	5	30.01%
TWI	3	1/3	1/3	1	2	2	12.89%
Lineament density	4	1/5	1/4	1/2	1	2	8.36%
Lineament proximity	5	1/6	1/5	1/2	1/2	1	5.82%

	Criterion	Comment	Weights	+/-
1	Lithology	Lithology	42.9%	9.5%
2	Recharge	Groundwater recharge	30.0%	6.2%
3	TWI	Topographic wetness index	12.9%	2.5%
4	Lineament density	Lineament density	8.4%	1.9%
5	Lineament proximity	Lineament proximity	5.8%	1.1%

Eigenvalue				Lambda:	5.087		MRE:	20.8%
Consistency Ratio	0.37	GCI:	0.07	Psi:	0.0%	CR:	1.9%	

Table 41: Assigned rank for various classes of all thematic layers of Sayit wereda

Factors	Weight (%)	Class	Groundwater Storage potential	Assigned Rank
Lithology	42.92	Tarmaber-Megezez formation	High productive	4
		Tarmaber-Gugssa formation	Moderate	3
Recharge	30.01	530.50 – 315.16	Very high	5
		315.15 – 261.81	High	4
		261.80 – 188.71	Medium	3
		188.70 – 105.73	low	2
		105.72 – 26.69	Very Low	1
TWI	12.89	21 - 14	Very high	5
		13 – 9.9	High	4
		9.8 - 8	Medium	3
		7.9 – 6.5	low	2
		6.4 – 4.5	Very Low	1
Lineament Density	8.36	1.10 - 0.61	Very high	5
		0.60 - 0.41	High	4
		0.40 - 0.25	Medium	3
		0.24 – 0.088	low	2
		0.087 - 0	Very Low	1
Lineament Proximity	5.82	0 - 350	Very high	5
		350 - 650	High	4
		650 – 1,500	Medium	3
		1,500 – 2,500	low	2
		2,500 – 7,500	Very Low	1

Table 42: Assigned rank for various classes of all thematic layers of Enebise Sar Midir wereda

Factors	Weight (%)	Class	Groundwater Storage potential	Assigned Rank
Lithology	42.92	Tarmaber-Megezez formation	Very high productive	5
		Antalo Limestone	High productive	4
		Ashangi formation	Moderate	3
		Elluvial sediment	low Productive	2
		Gohatsion formation	Very low Productive	1
Recharge	30.01	473.88 – 379.12	Very high	5
		379.11 – 284.34	High	4
		284.33 – 189.56	Medium	3
		189.55 – 94.78	low	2
		94.77 - 0	Very Low	1
TWI	12.89	21 - 14	Very high	5
		13 – 9.9	High	4
		9.8 - 8	Medium	3
		7.9 – 6.5	low	2
		6.4 - 4.5	Very Low	1
Lineament Density	8.36	1.20 – 0.96	Very high	5
		0.95 - 0.72	High	4
		0.71 - 0.49	Medium	3
		0.48 - 0.25	low	2
		0.24 - 0	Very Low	1
Lineament Proximity	5.82	0 - 350	Very high	5
		350 - 550	High	4
		550 - 850	Medium	3
		850 – 1,500	low	2
		1,500 – 5,500	Very Low	1

4.2 Reclassification of Thematic layers

4.2.1 Hydro - lithologic units

Hydrogeological units play a fundamental role in governing the spatial distribution and occurrence of groundwater. The porosity, size of pore space, and the ease at which the pore spaces are interconnected control storage and permeability of geologic medium that in turn affect the availability of groundwater in the area of interest. The main lithologic units found in the study area consist of Elluvium& alluvial sediments, Aiba basalt, Tarmaber-Megezez basalt, Ignimbrite, Adigrat sandstone, Gohatsion formation, and Antalo limestone. These lithologic units have been given weights (rates) based on hydraulic properties (hydraulic conductivity, transmissivity, Storativity and yields observed from pumping test, lithologic log (well completion reports) of the area. Based on the conceptual understanding of the project weredas, the Hydrogeological units of the project weredas were classified as very high, high, moderate, low, and very low potential. The reclassified hydrogeological units are presented in figures 32 to 45 below.

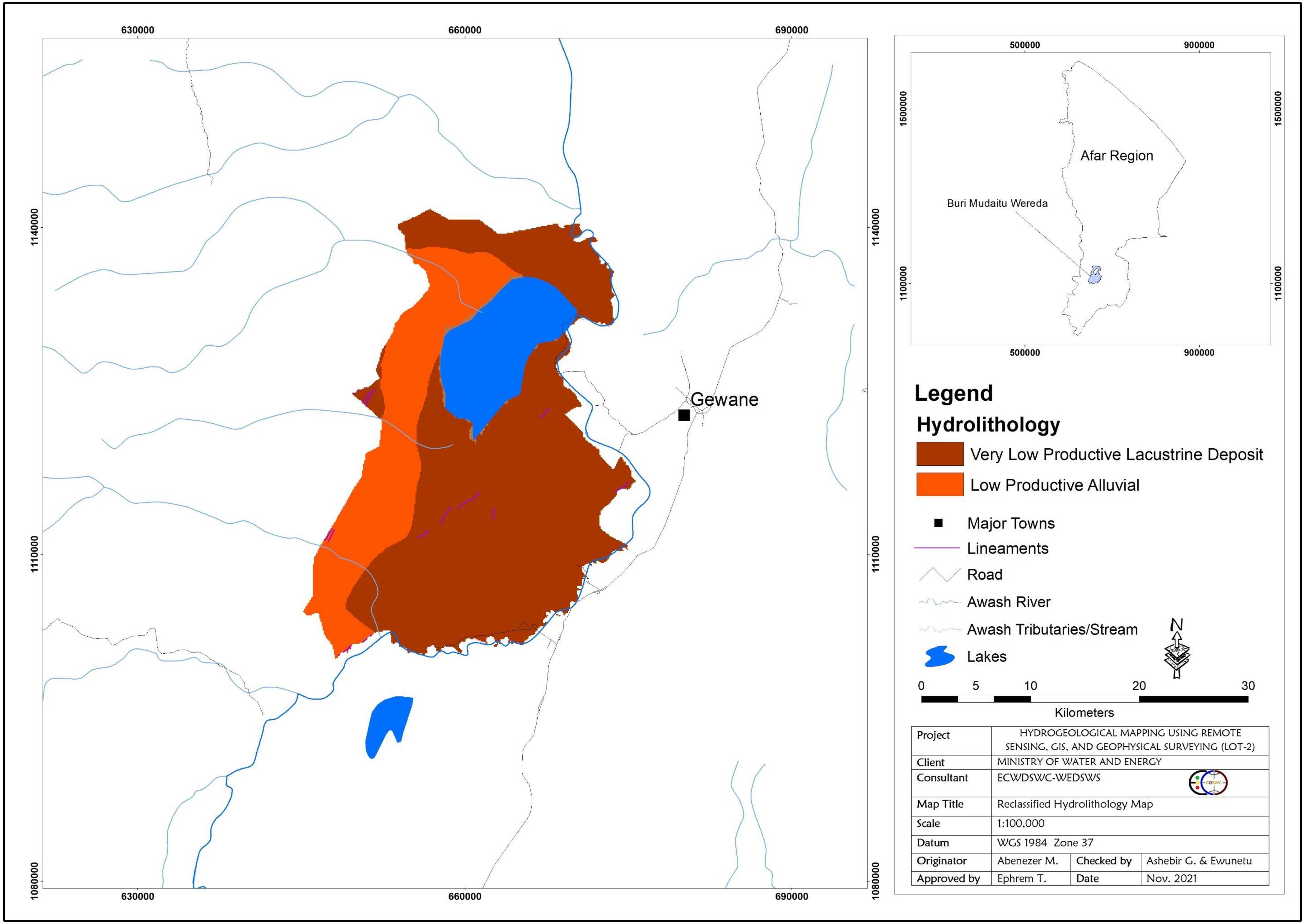
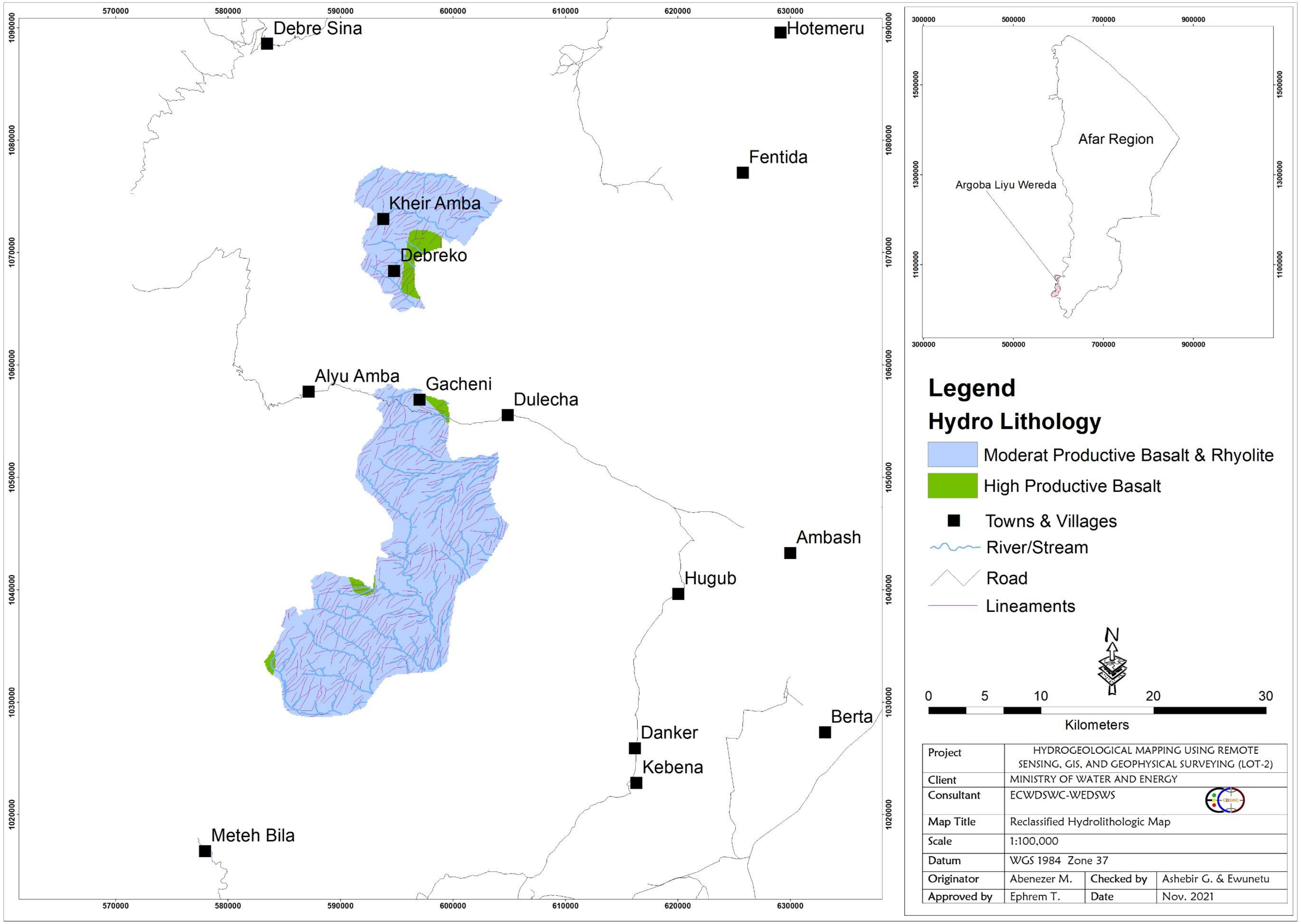


Figure 32: Hydro – Lithologic unit of Buri Mudaitu Wereda



Project	HYDROGEOLOGICAL MAPPING USING REMOTE SENSING, GIS, AND GEOPHYSICAL SURVEYING (LOT-2)
Client	MINISTRY OF WATER AND ENERGY
Consultant	ECWDSWC-WEDSWS
Map Title	Reclassified Hydrolithologic Map
Scale	1:100,000
Datum	WGS 1984 Zone 37
Originator	Abenezer M. Checked by Ashebir G. & Ewunetu
Approved by	Ephrem T. Date Nov. 2021

Figure 33 Hydro – Lithologic unit of Argoba Liyu Wereda

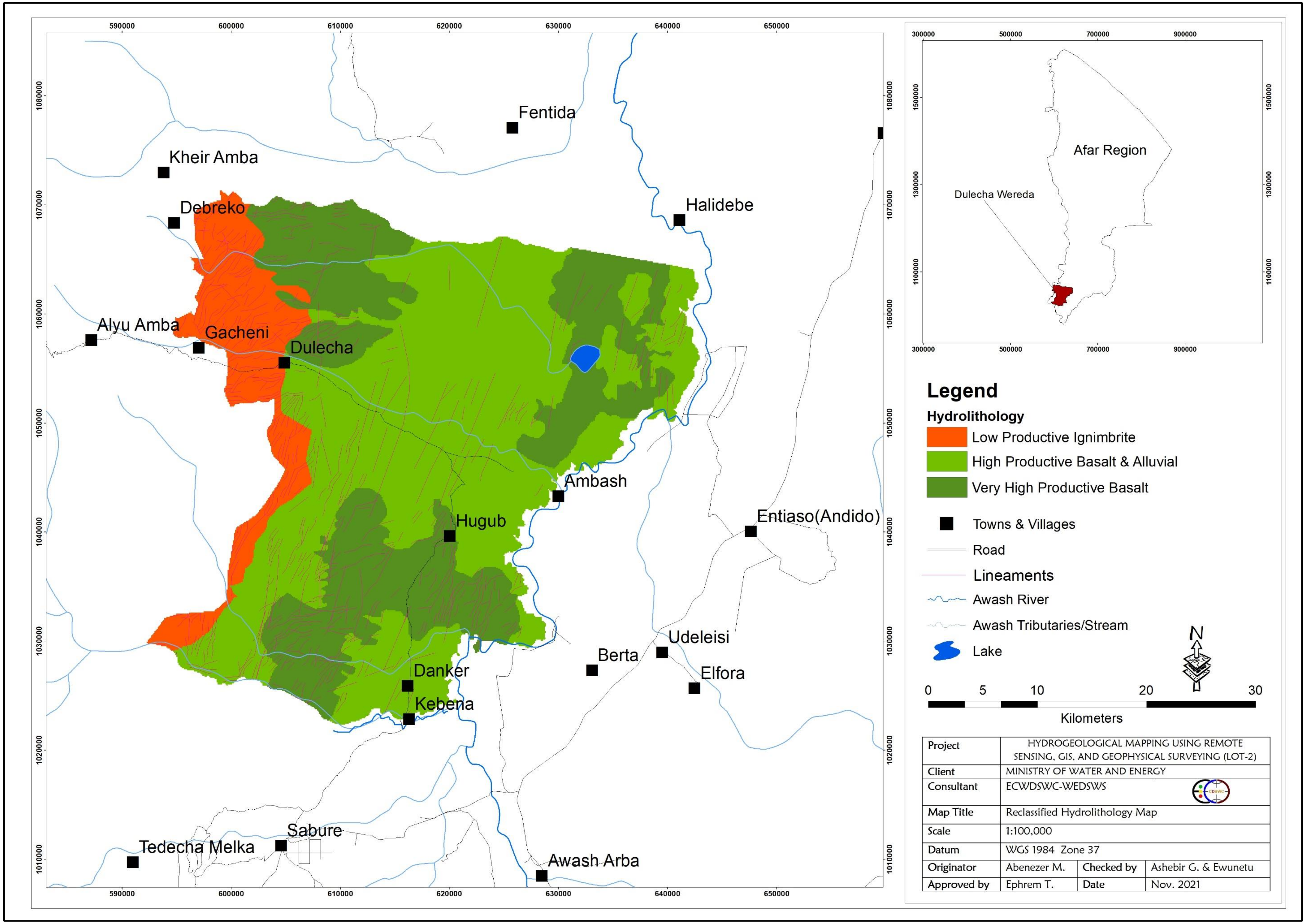


Figure 34: Hydro – Lithologic unit of Dulecha Wereda

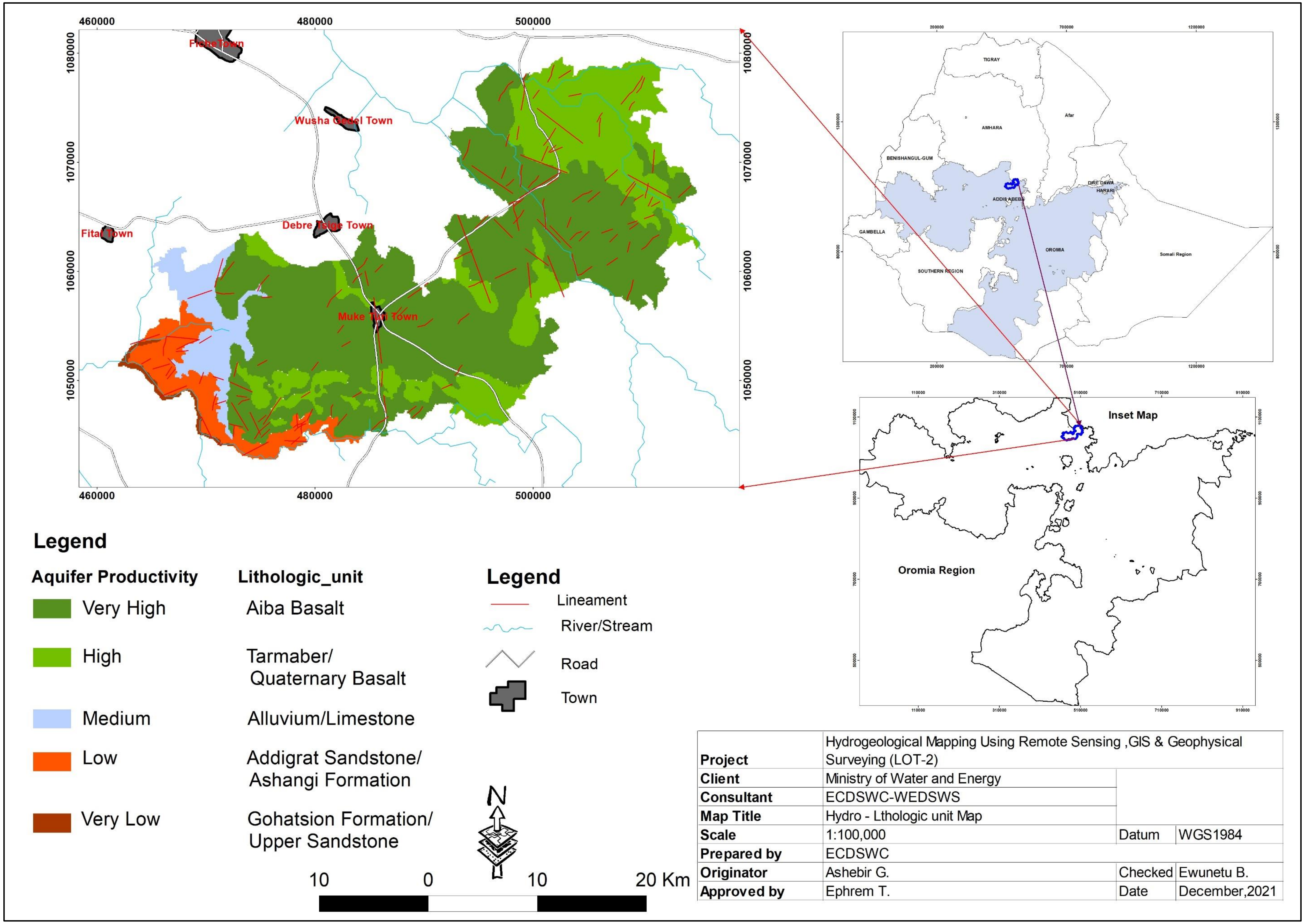


Figure 35: Hydro – Lithologic Unit of Wuchale Wereda

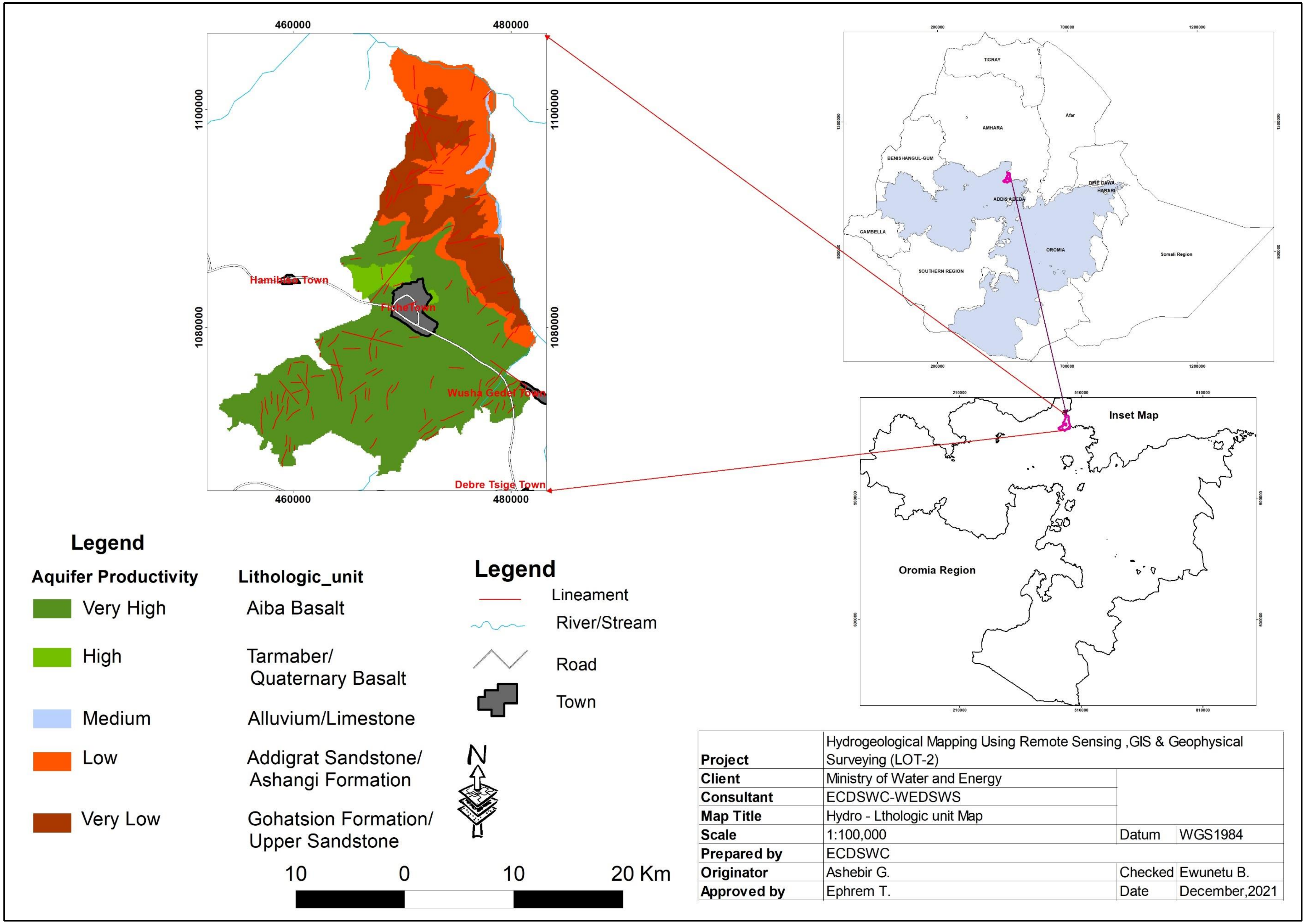
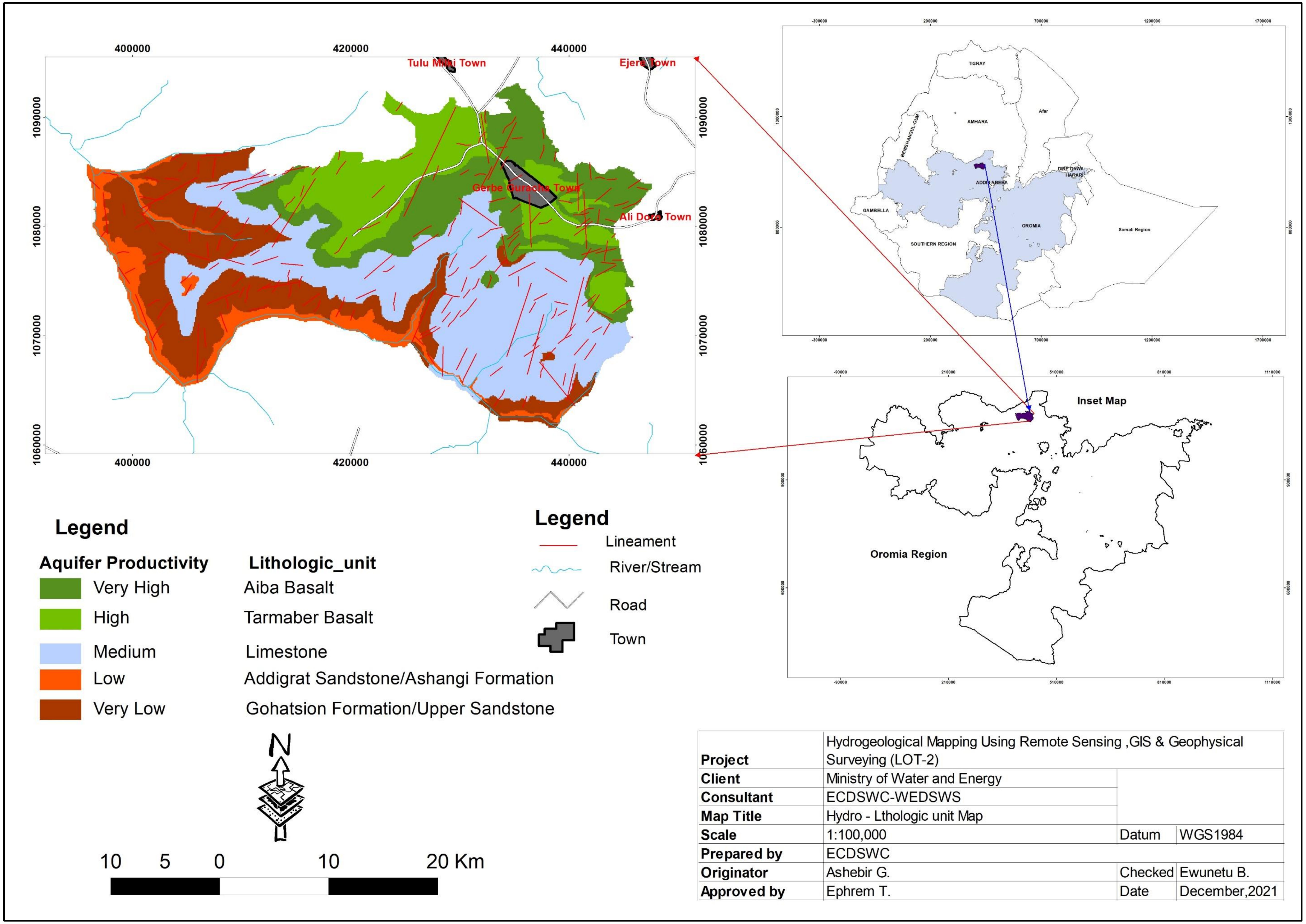


Figure 36: Hydro – Lithologic Unit of Girar Jarso Wereda



Project	Hydrogeological Mapping Using Remote Sensing ,GIS & Geophysical Surveying (LOT-2)		
Client	Ministry of Water and Energy		
Consultant	ECDSWC-WEDSWS		
Map Title	Hydro - Lthologic unit Map		
Scale	1:100,000	Datum	WGS1984
Prepared by	ECDSWC		
Originator	Ashebir G.	Checked	Ewunetu B.
Approved by	Ephrem T.	Date	December,2021

Figure 37: Hydro – Lithologic Unit of Kuyu Wereda

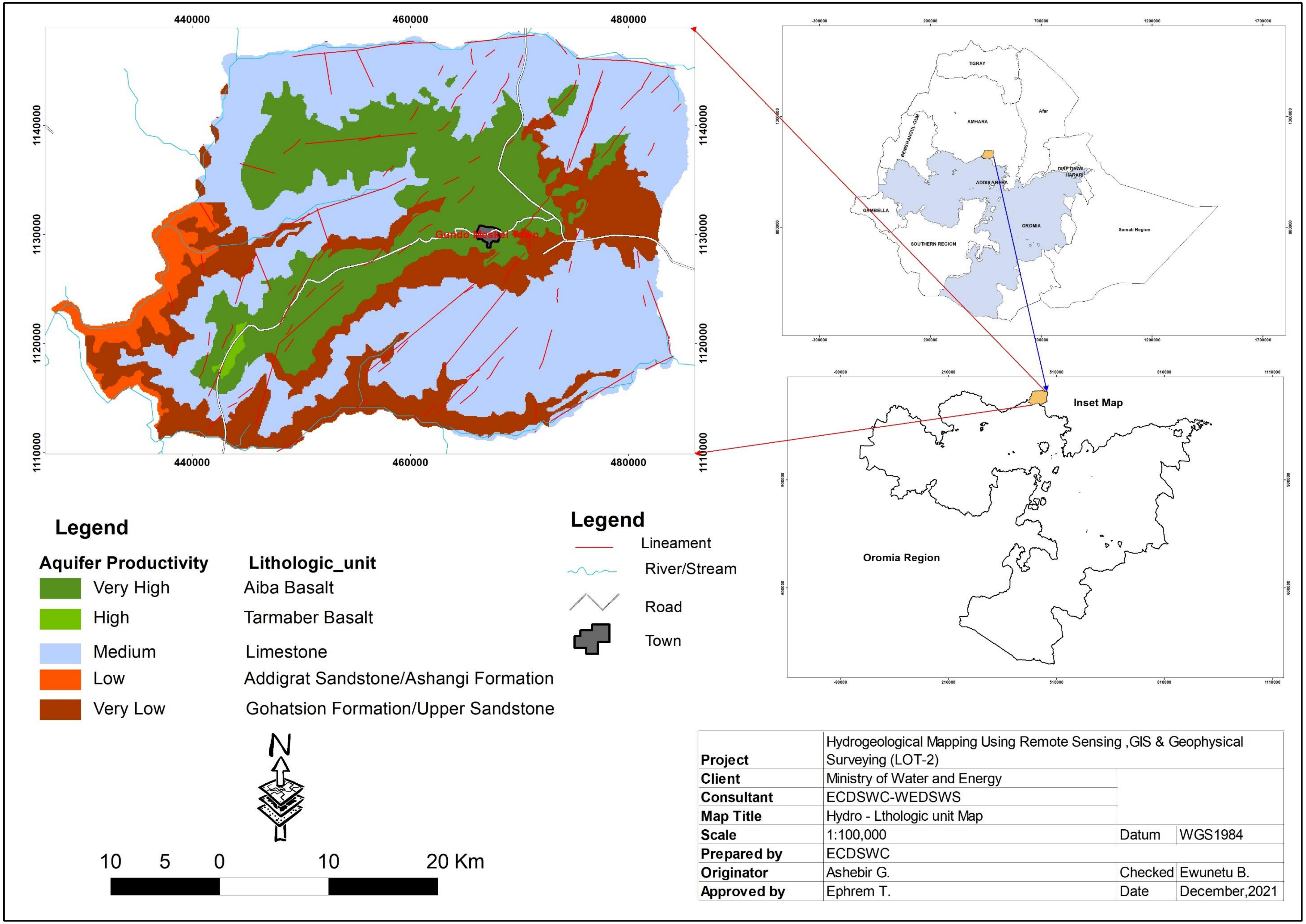
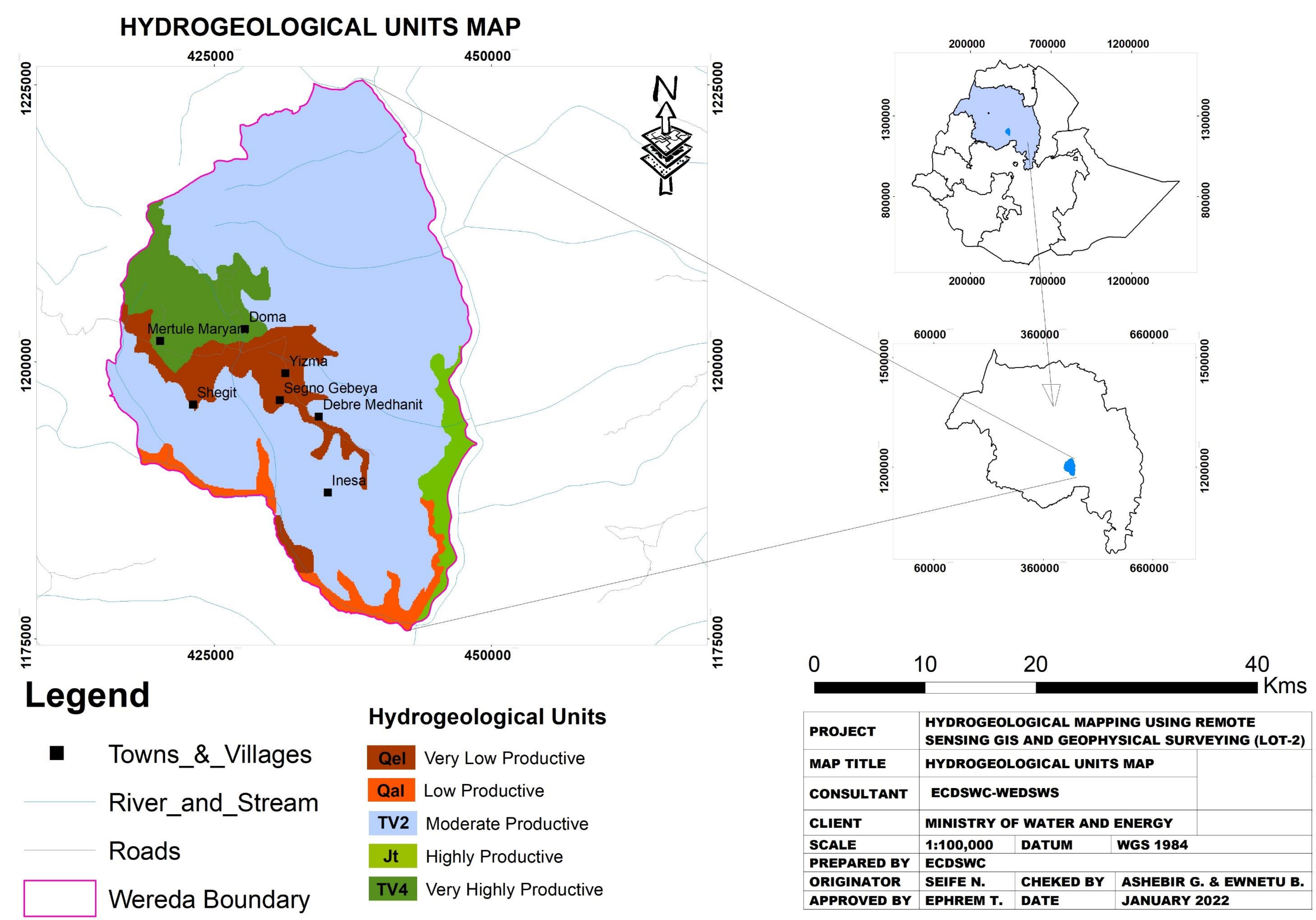


Figure 38 : Hydro – Lithologic Unit of Dera Wereda



PROJECT	HYDROGEOLOGICAL MAPPING USING REMOTE SENSING GIS AND GEOPHYSICAL SURVEYING (LOT-2)		
MAP TITLE	HYDROGEOLOGICAL UNITS MAP		
CONSULTANT	ECDSWC-WEDSWS		
CLIENT	MINISTRY OF WATER AND ENERGY		
SCALE	1:100,000	DATUM	WGS 1984
PREPARED BY	ECDSWC		
ORIGINATOR	SEIFE N.	CHEKED BY	ASHEBIR G. & EWNETU B.
APPROVED BY	EPHREM T.	DATE	JANUARY 2022

Figure 39: Hydro – Lithologic Unit of Enebise Sar Midir Wereda

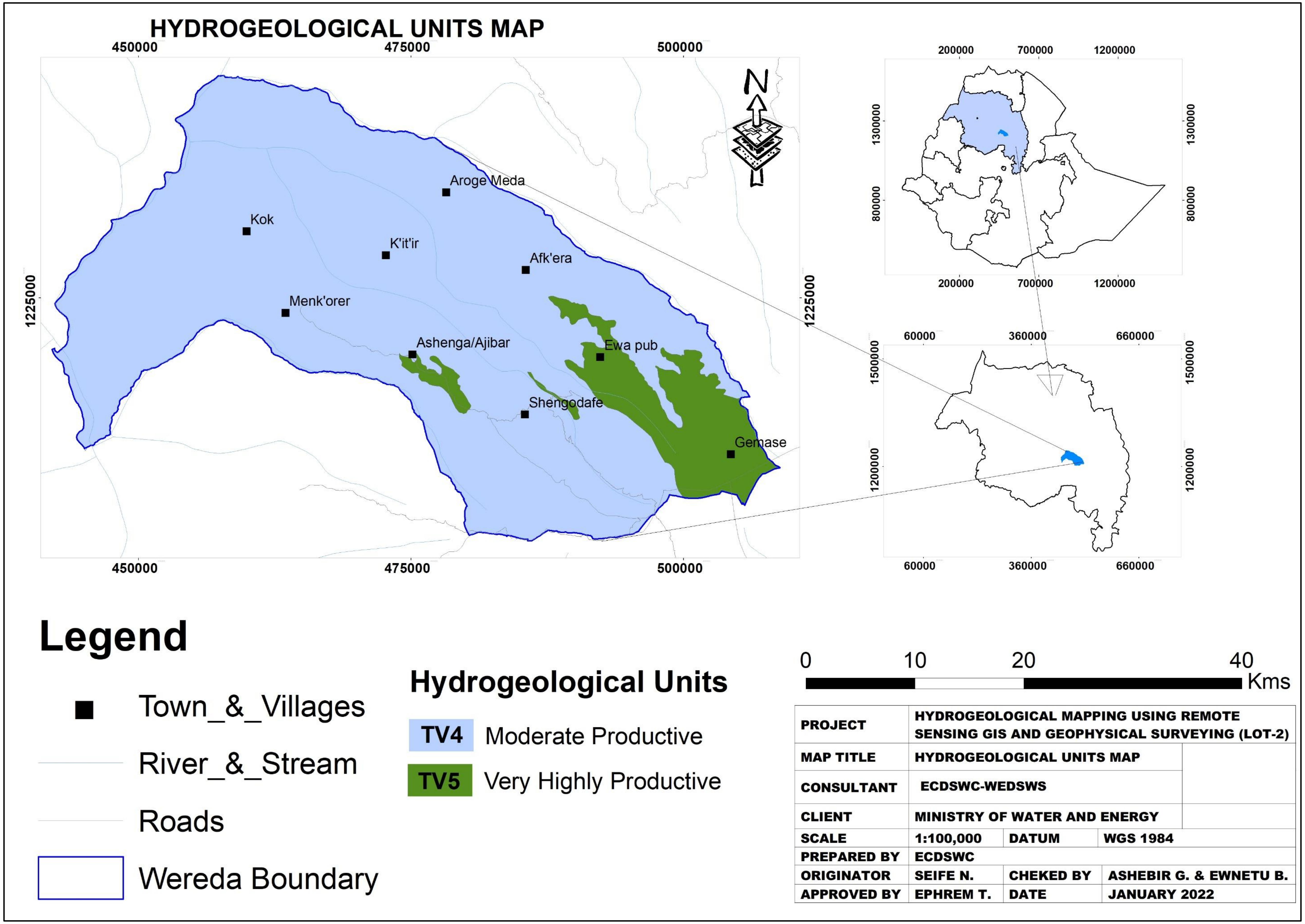


Figure 40: Hydro – Lithologic Unit of Sayit Wereda

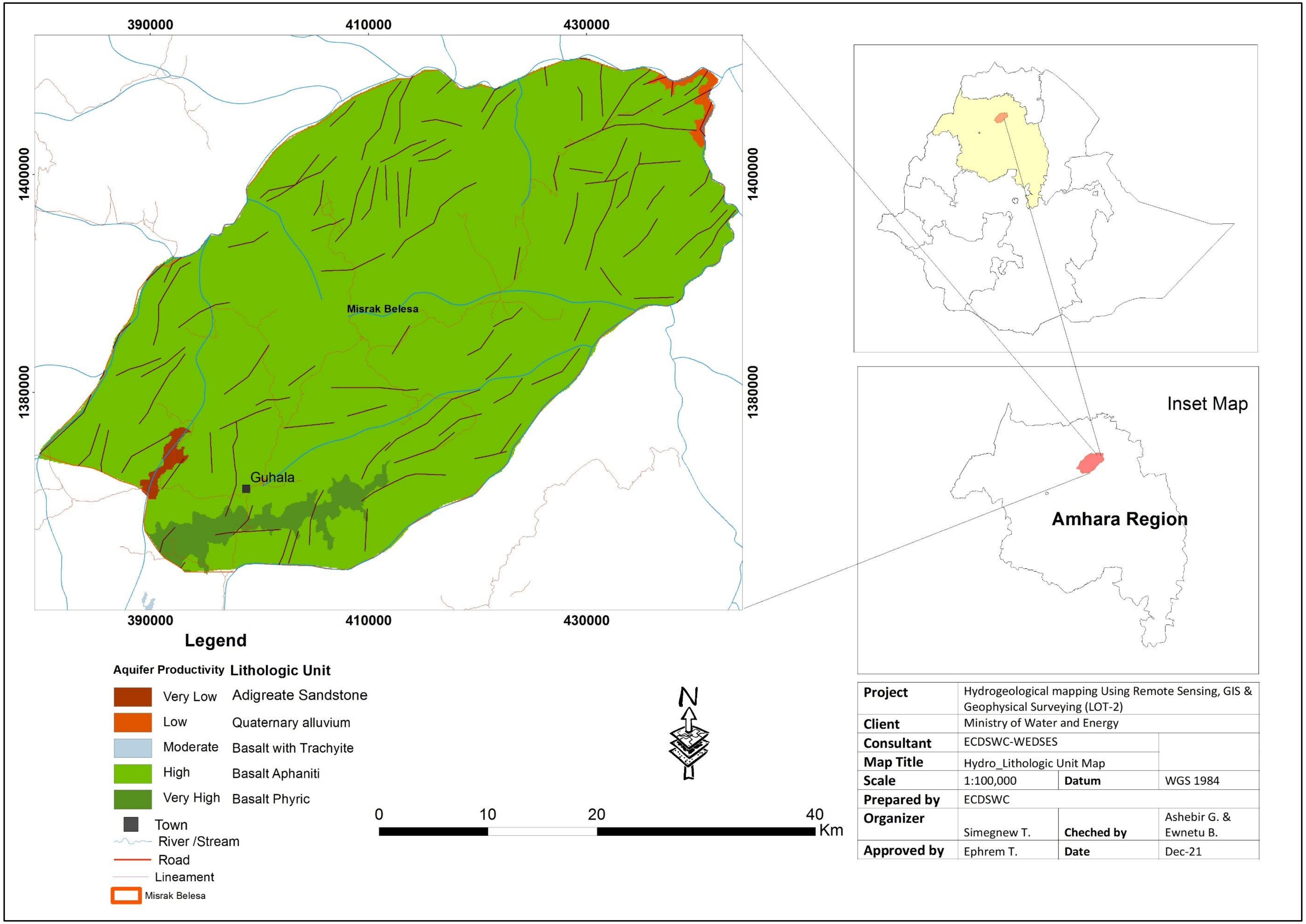
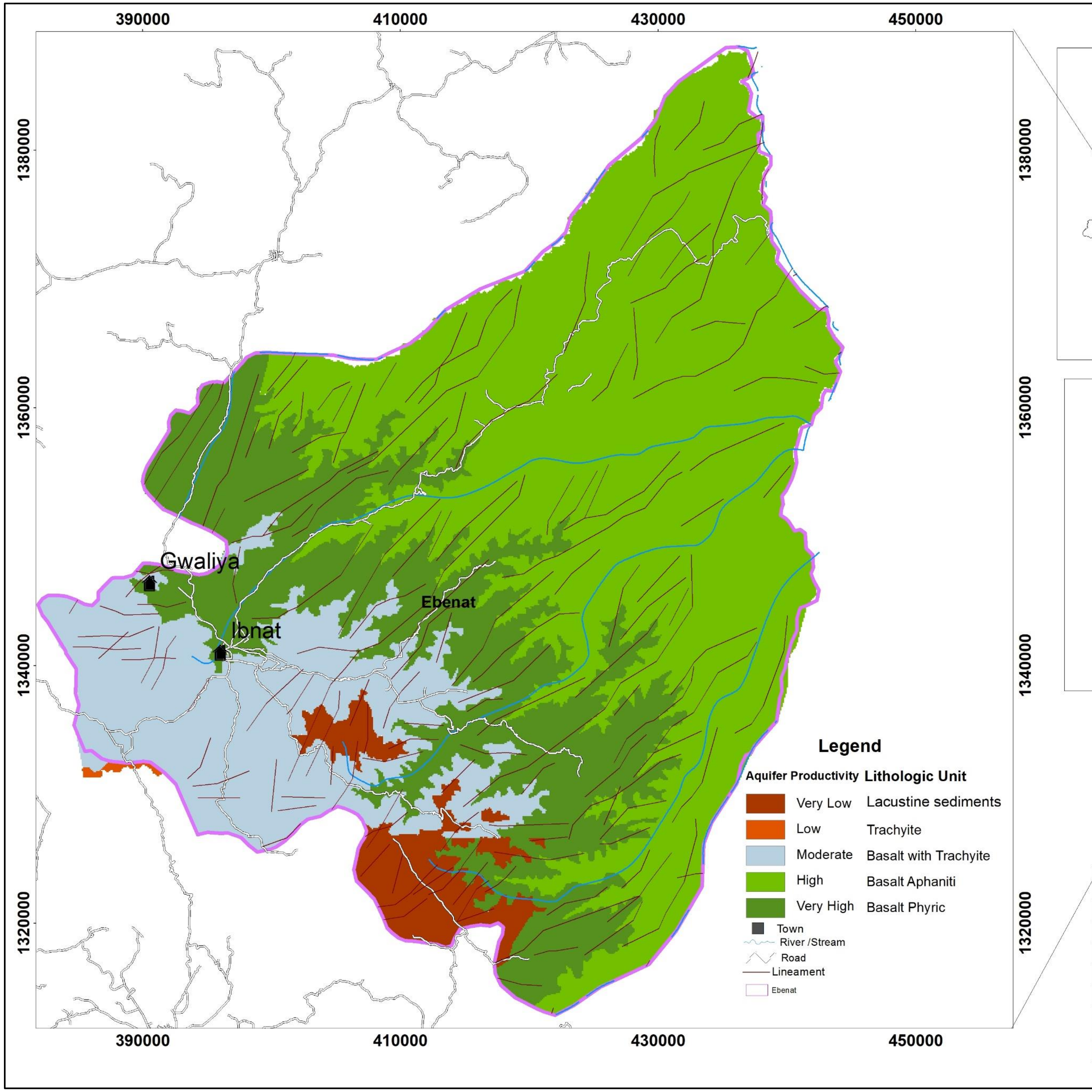


Figure 41: Hydro – Lithologic Unit of Misrak Belesa Wereda



Project	Hydrogeological mapping Using Remote Sensing, GIS & Geophysical Surveying (LOT-2)		
Client	Ministry of Water & Energy		
Consultant	ECDSWC-WEDSES		
Map Title	Hydro_Lithologic Unit Map		
Scale	1:100,000	Datum	WGS 1984
Prepared by	ECDSWC		
Organizer	Simegnew T.	Cheched by	Ashebir G. & Ewnetu B.
Approved by	Ephrem T.	Date	Dec21

Figure 42: Hydro – Lithologic Unit of Ebenat Wereda

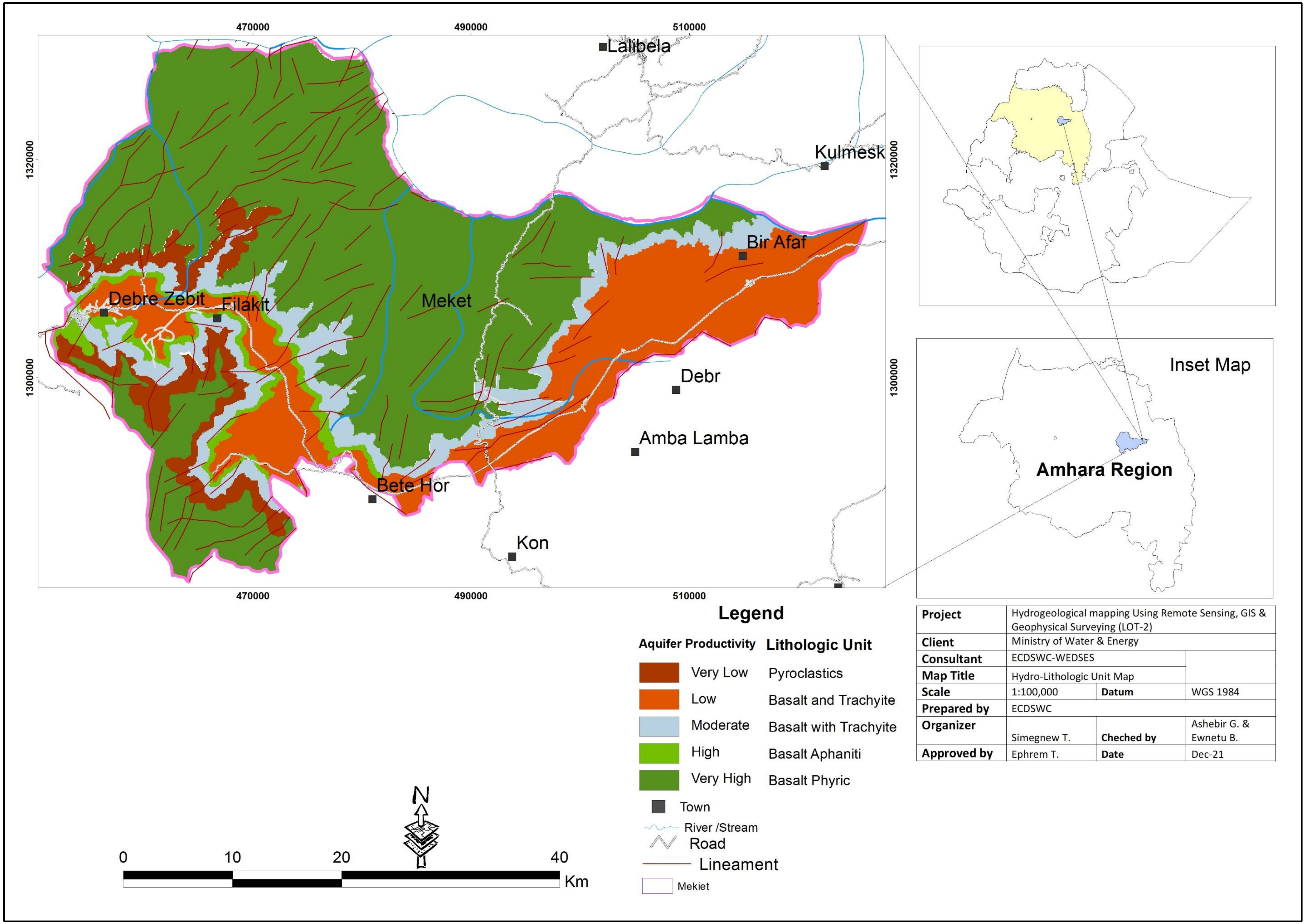


Figure 43: Hydro – Lithologic Unit of Mekiet Wereda

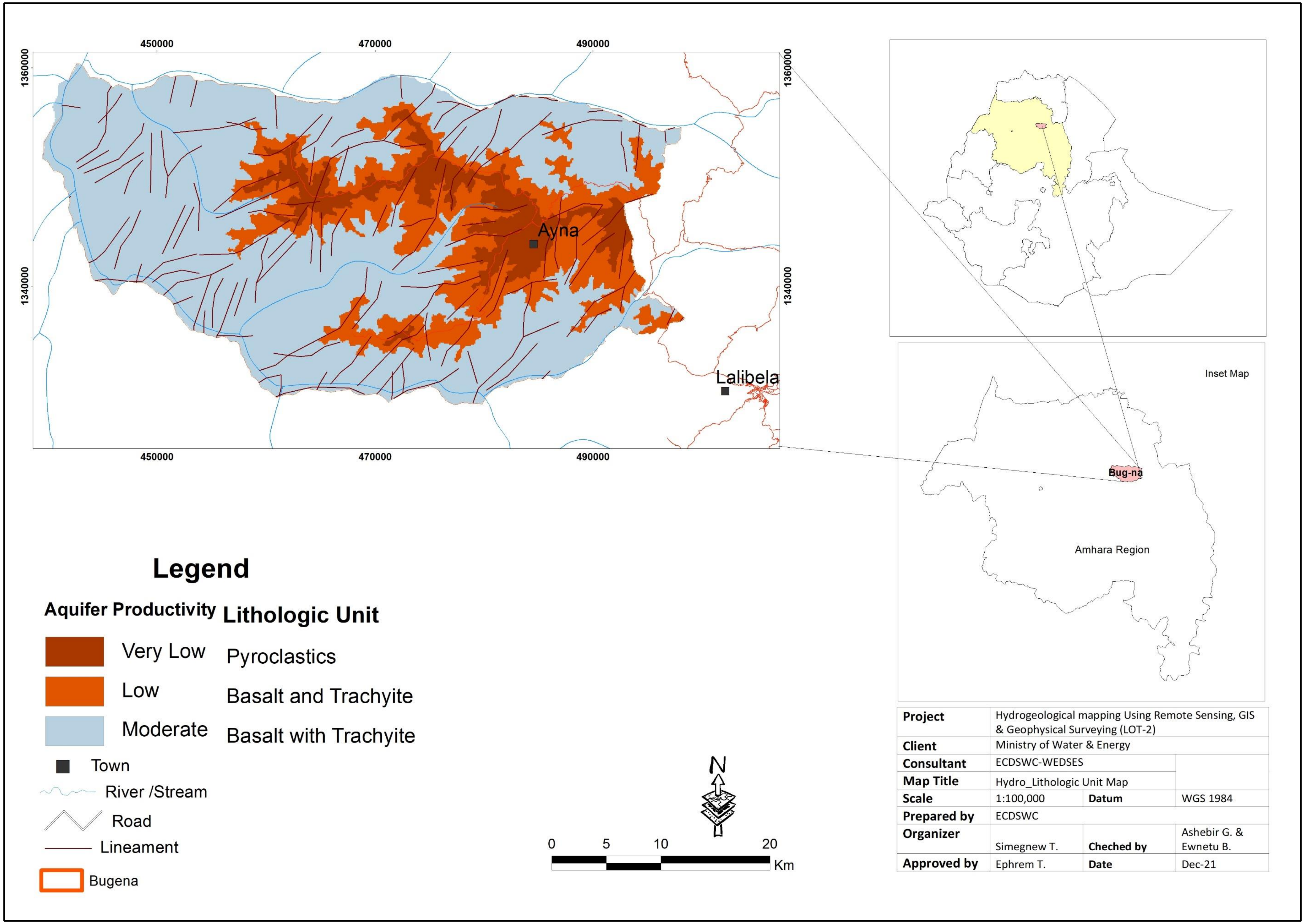


Figure 44: Hydro – Lithologic Unit of Bugna Wereda

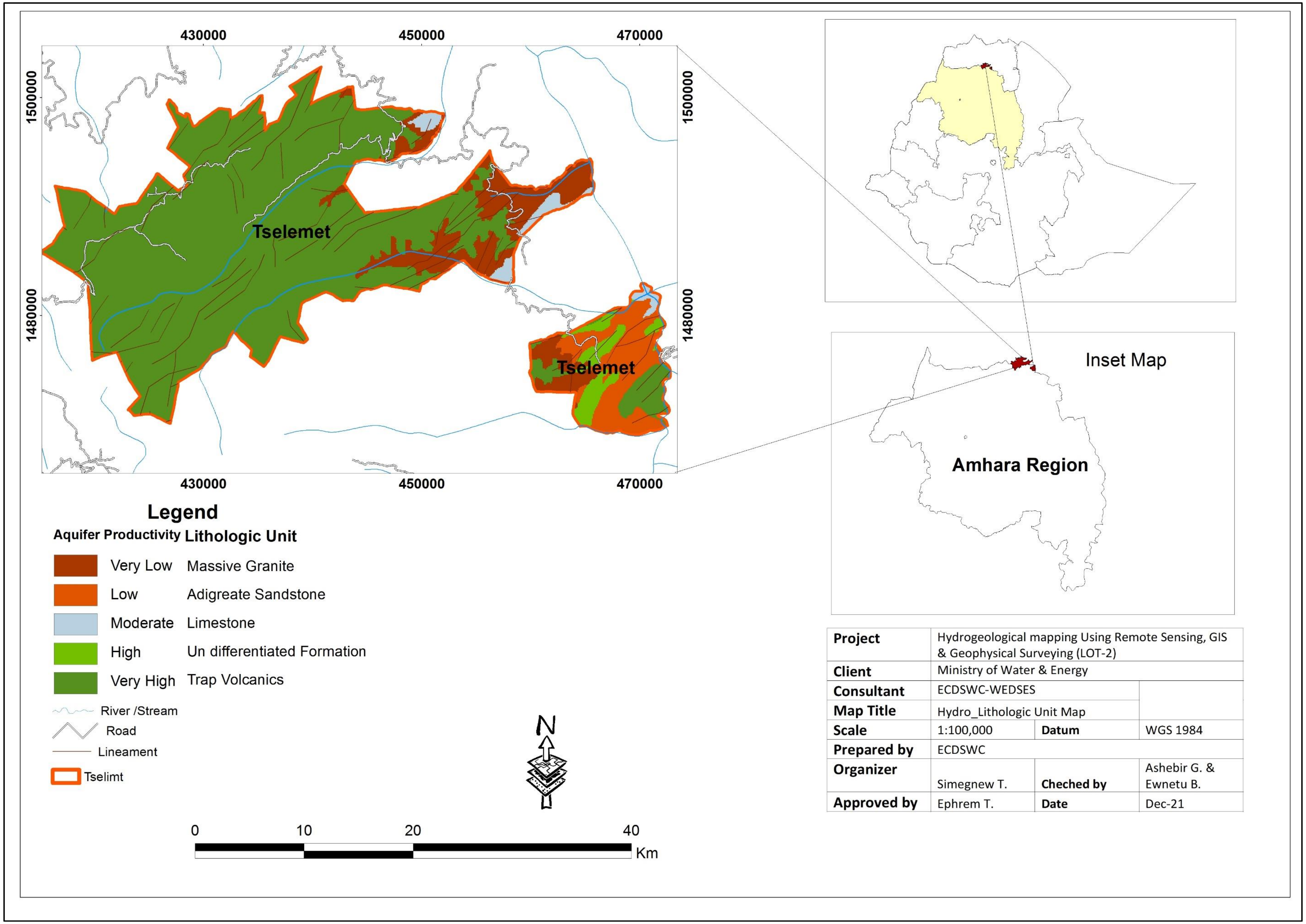


Figure 45: Hydro – Lithologic unit of Tselemit wereda

4.2.2 Groundwater Recharge

Groundwater recharge of Awash basin (upstream Cluster 1 weredas), Abay basin (upstream of cluster 2 & 3 Weredas), and Tekeze basin (upstream of cluster 4 & Tselemit wereda) were estimated by using the WetSpass model, and then groundwater recharge of the study areas were extracted by respective weredas boundary.

The WetSpass model produces monthly hydrological parameters like grid maps of groundwater recharge, actual evapotranspiration, surface runoff, interception loss, evaporation, etc. In this study, the annual groundwater recharge, annual actual evapotranspiration, and annual surface runoff are calculated from monthly recharge, actual evapotranspiration, and surface runoff by using a raster calculator of ARC GIS 10.8 respectively. A brief description of this output will be presented as a separate document in the phase III water balance study report.

There are different models to estimate recharge in a given area depending on actual areal conditions. In this case, the WetSpass model estimates monthly long-term spatial distribution amounts of groundwater recharge of Awash, Abay, and Tekeze basins by subtracting the monthly surface runoff, Interception, and evapotranspiration from the monthly precipitation.

Usually, the recharge areas are in topographic high places; discharge areas are located in topographic low. Using only a topographic setup of the area could not be enough to classify the area as recharge and discharge zones. Land use/land cover, soil types, and morphology of land are equally important in the classification of the area into recharge and discharge zones.

Since recharge is a result of evapotranspiration and surface runoff processes it incorporates all influences and spatial patterns of these processes.

Figures 46 to 59 show the yearly groundwater recharge estimated with the WetSpass model of each project weredas. The recharge estimated was used as one thematic layer for groundwater potential mapping of the project weredas. The values were reclassified into five categories or classes such as very low, low, moderate, high, and very high by using the natural break classification method. The high weights have been assigned for high groundwater recharge areas and vice versa.

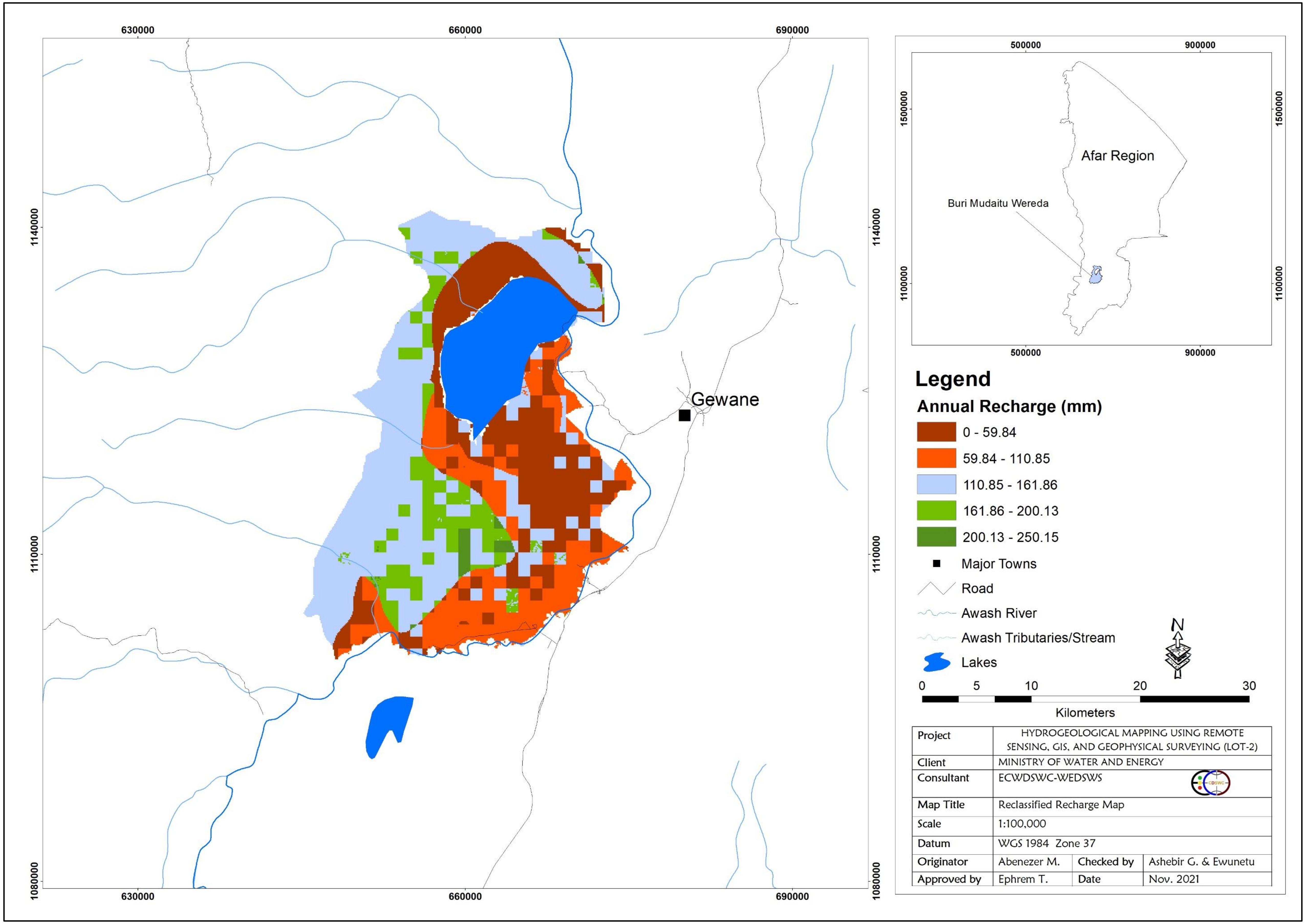
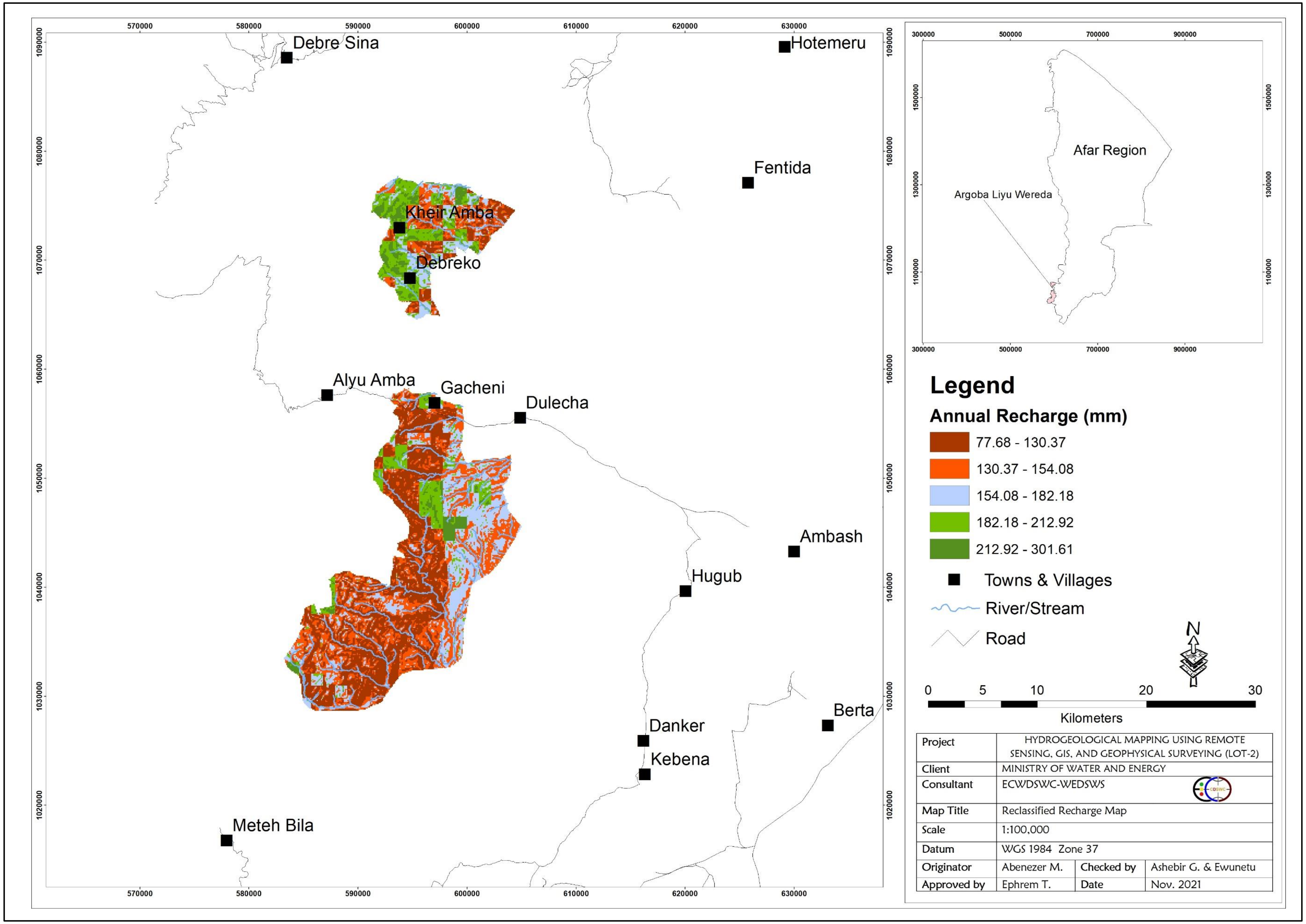


Figure 46: Groundwater recharge of Buri Mudaitu Wereda



Project	HYDROGEOLOGICAL MAPPING USING REMOTE SENSING, GIS, AND GEOPHYSICAL SURVEYING (LOT-2)		
Client	MINISTRY OF WATER AND ENERGY		
Consultant	ECWDSWC-WEDSWS		
Map Title	Reclassified Recharge Map		
Scale	1:100,000		
Datum	WGS 1984 Zone 37		
Originator	Abenezer M.	Checked by	Ashebir G. & Ewunetu
Approved by	Ephrem T.	Date	Nov. 2021

Figure 47: Groundwater recharge of Argoba Liyu Wereda

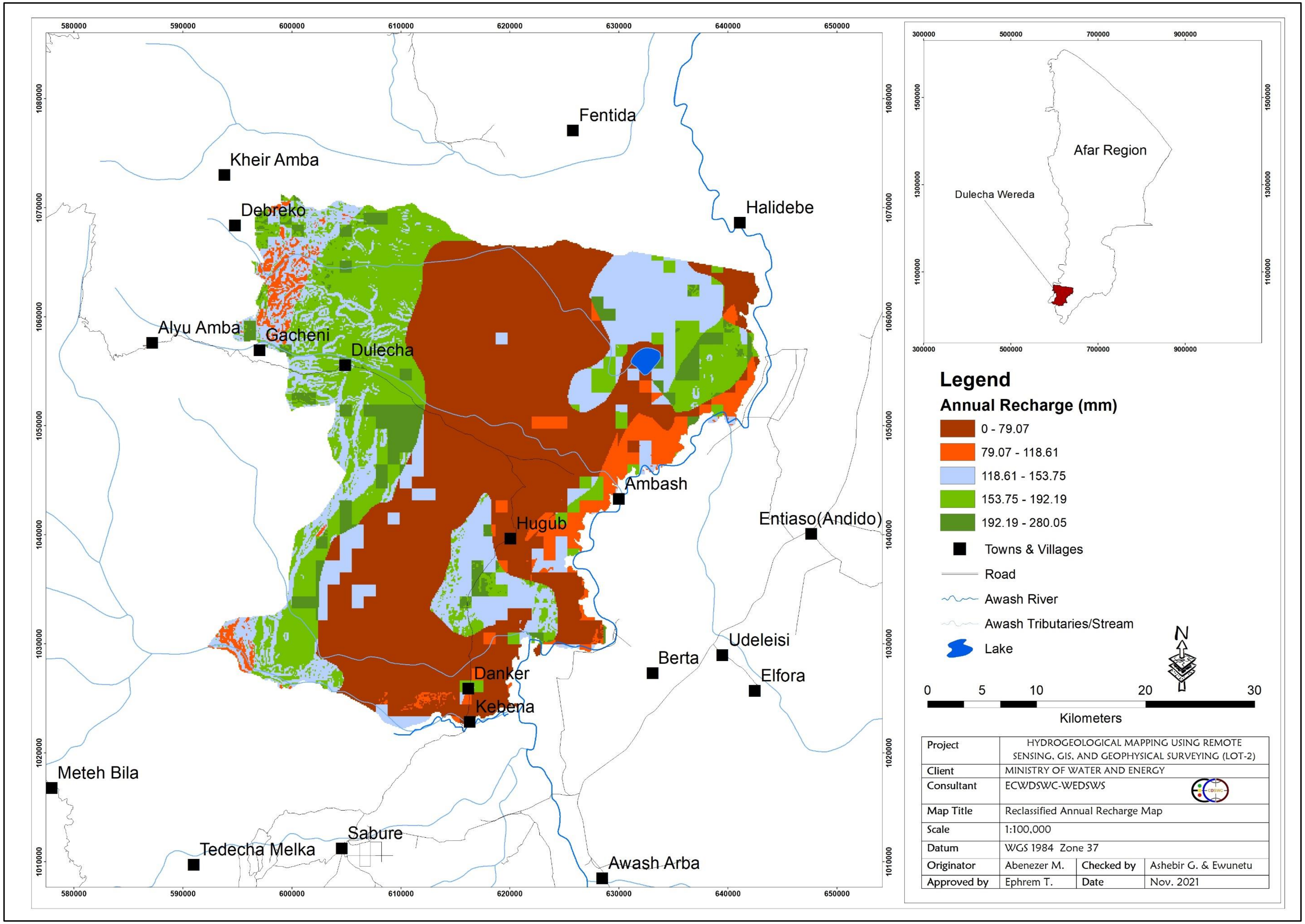


Figure 48: Groundwater recharge of Dulecha Wereda

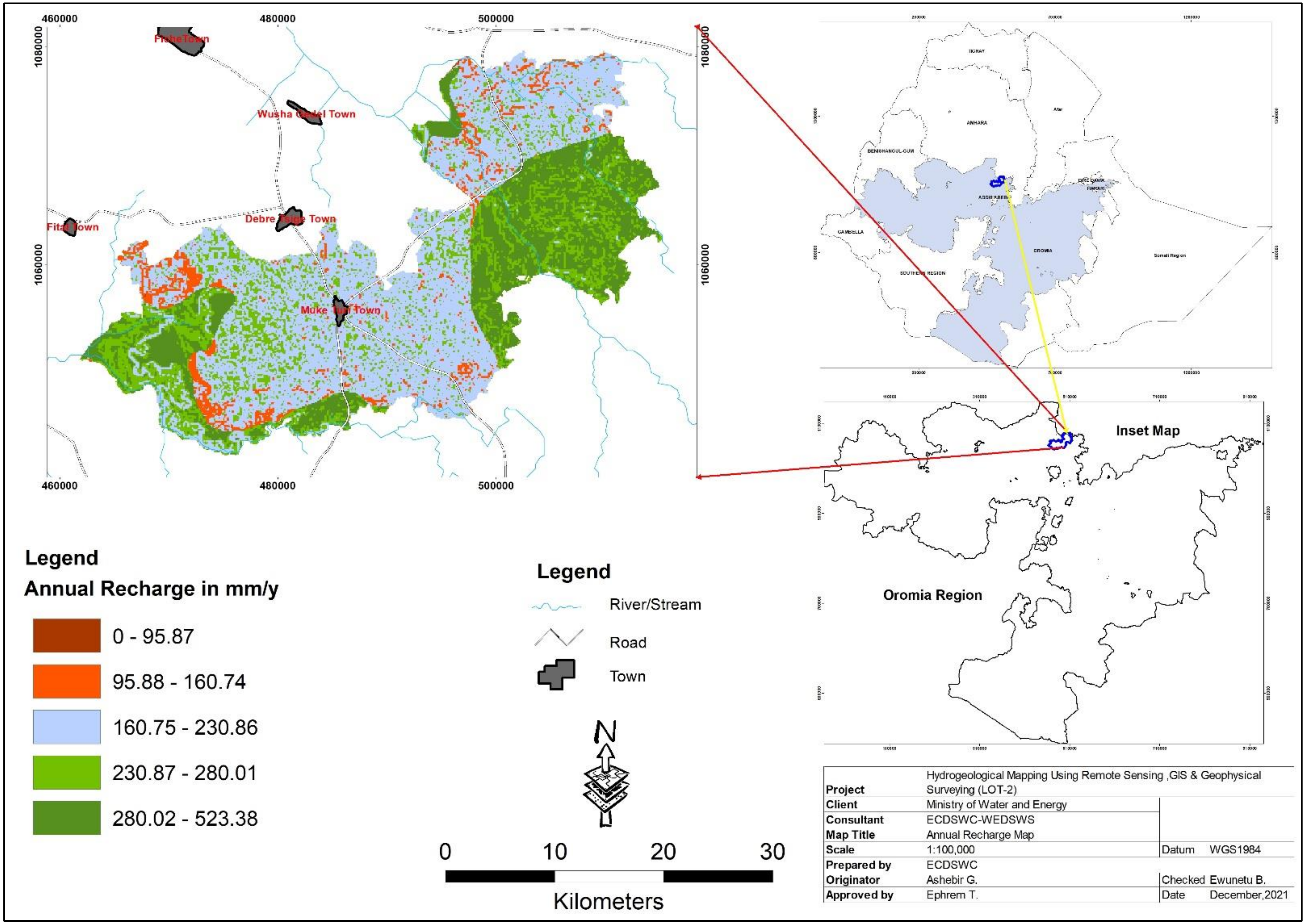


Figure 49: Groundwater recharge of Wuchale Wereda

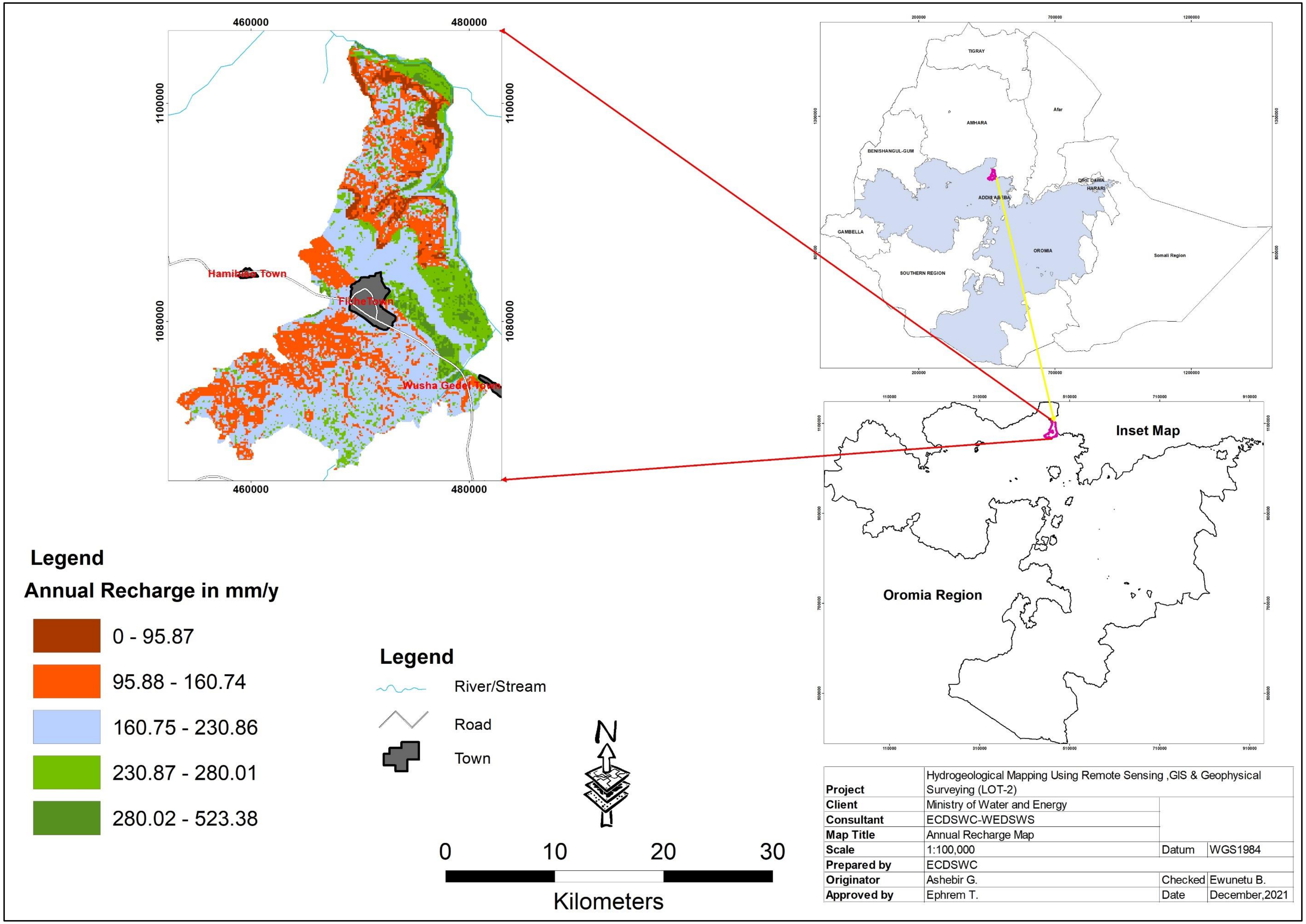


Figure 50: Groundwater recharge of Girar Jarso Wereda

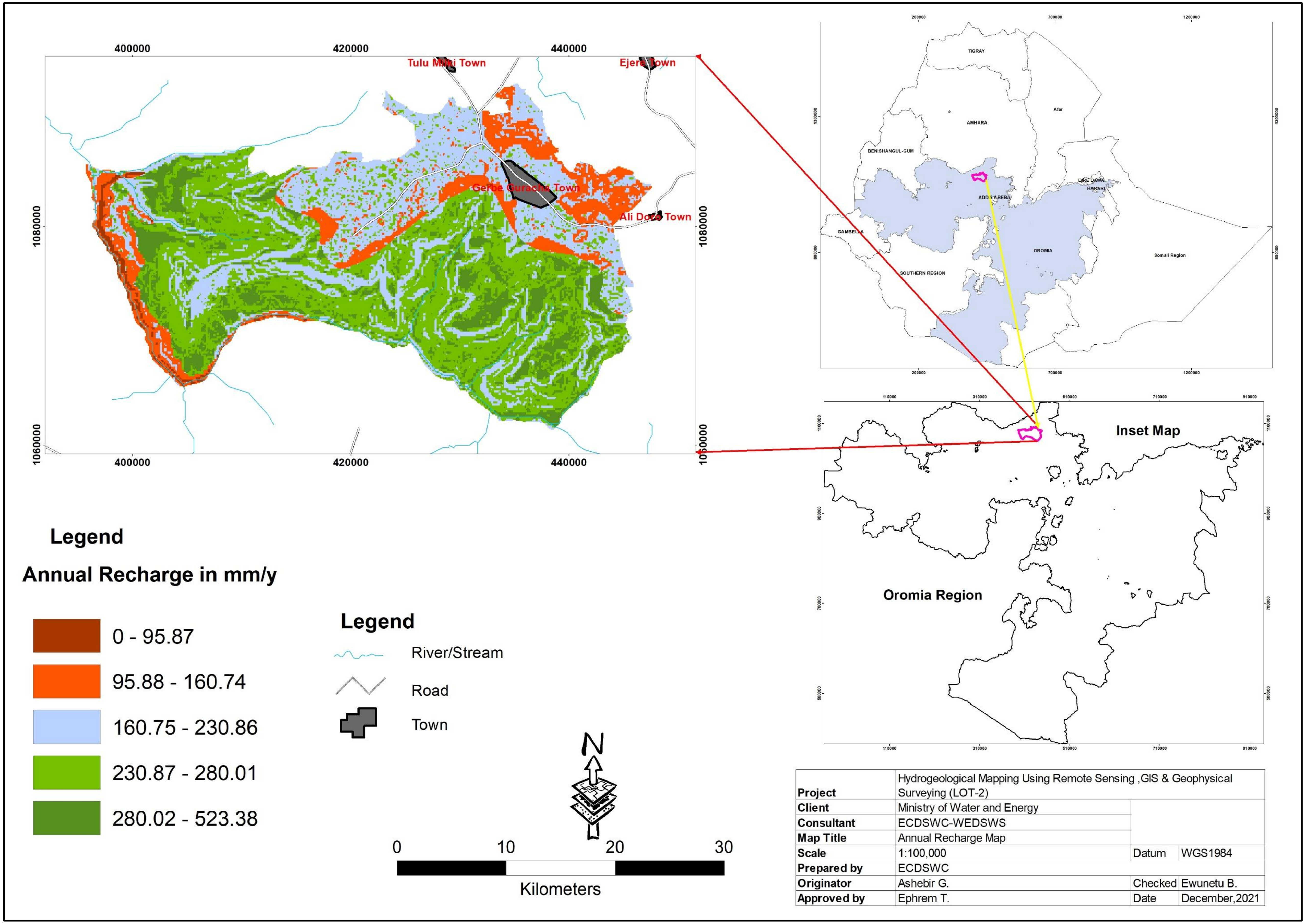


Figure 51: Groundwater recharge of Kuyu Wereda

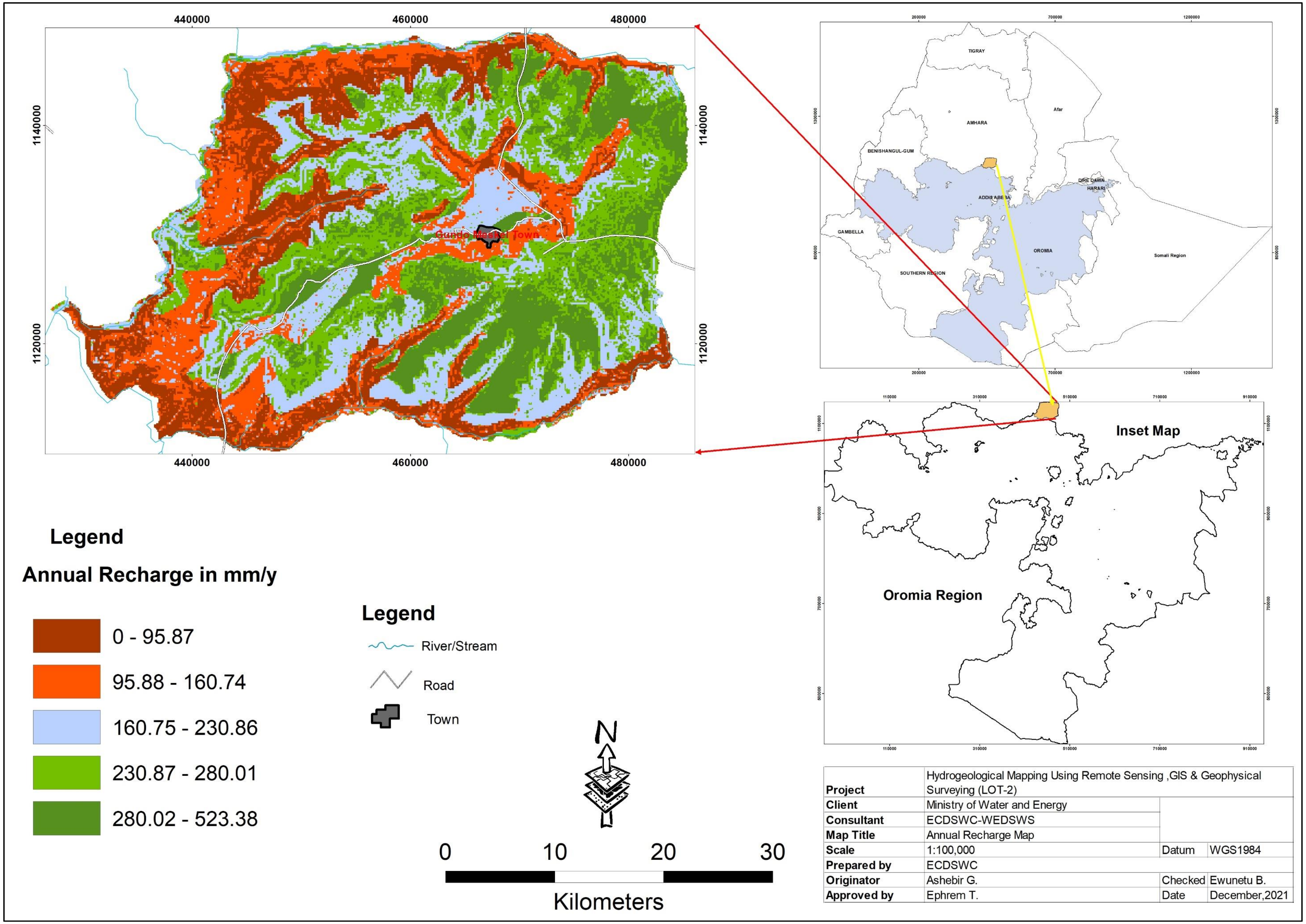


Figure 52: Groundwater recharge of Dera Wereda

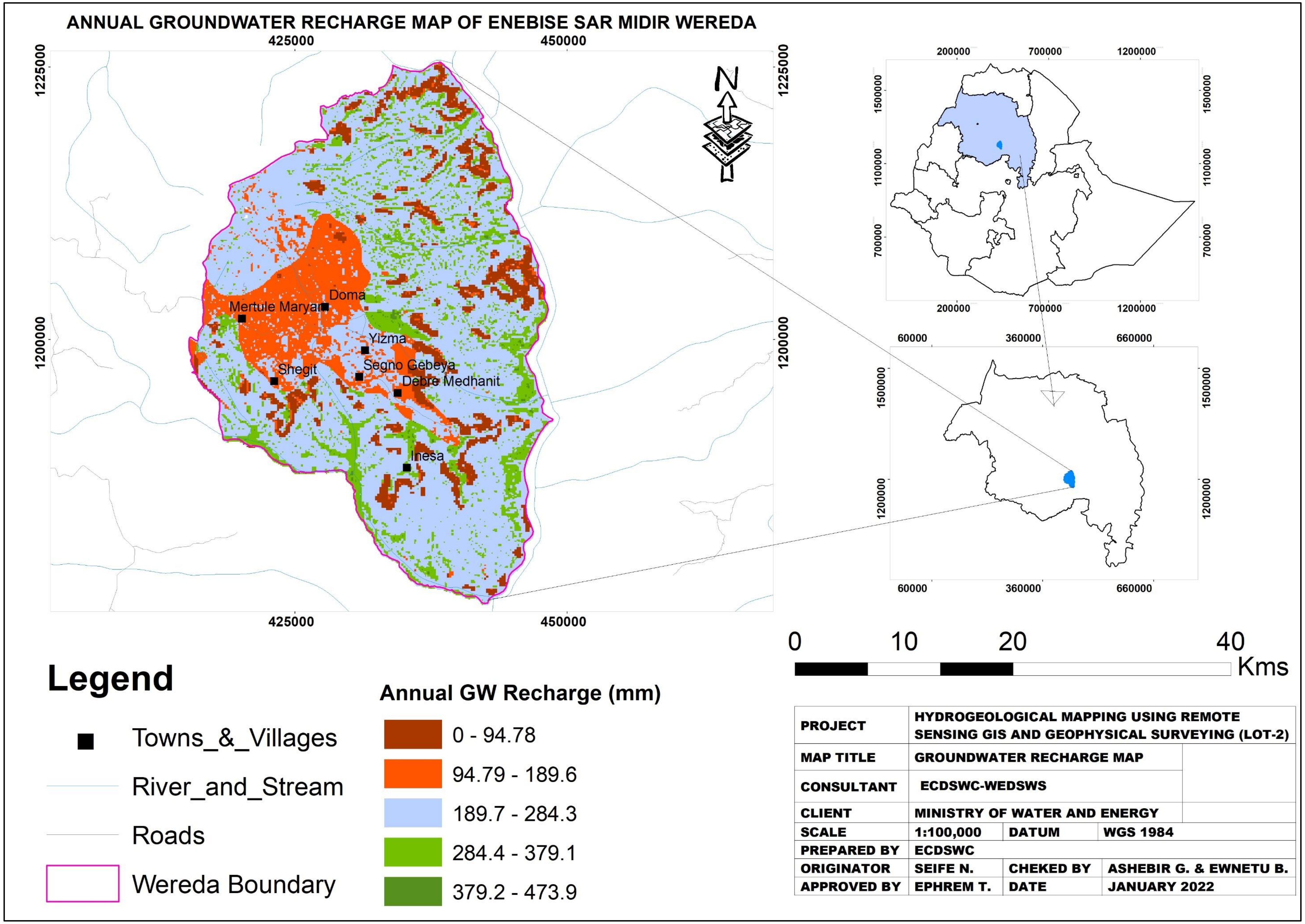


Figure 53: Groundwater recharge of Enebise Sar Midir Wereda

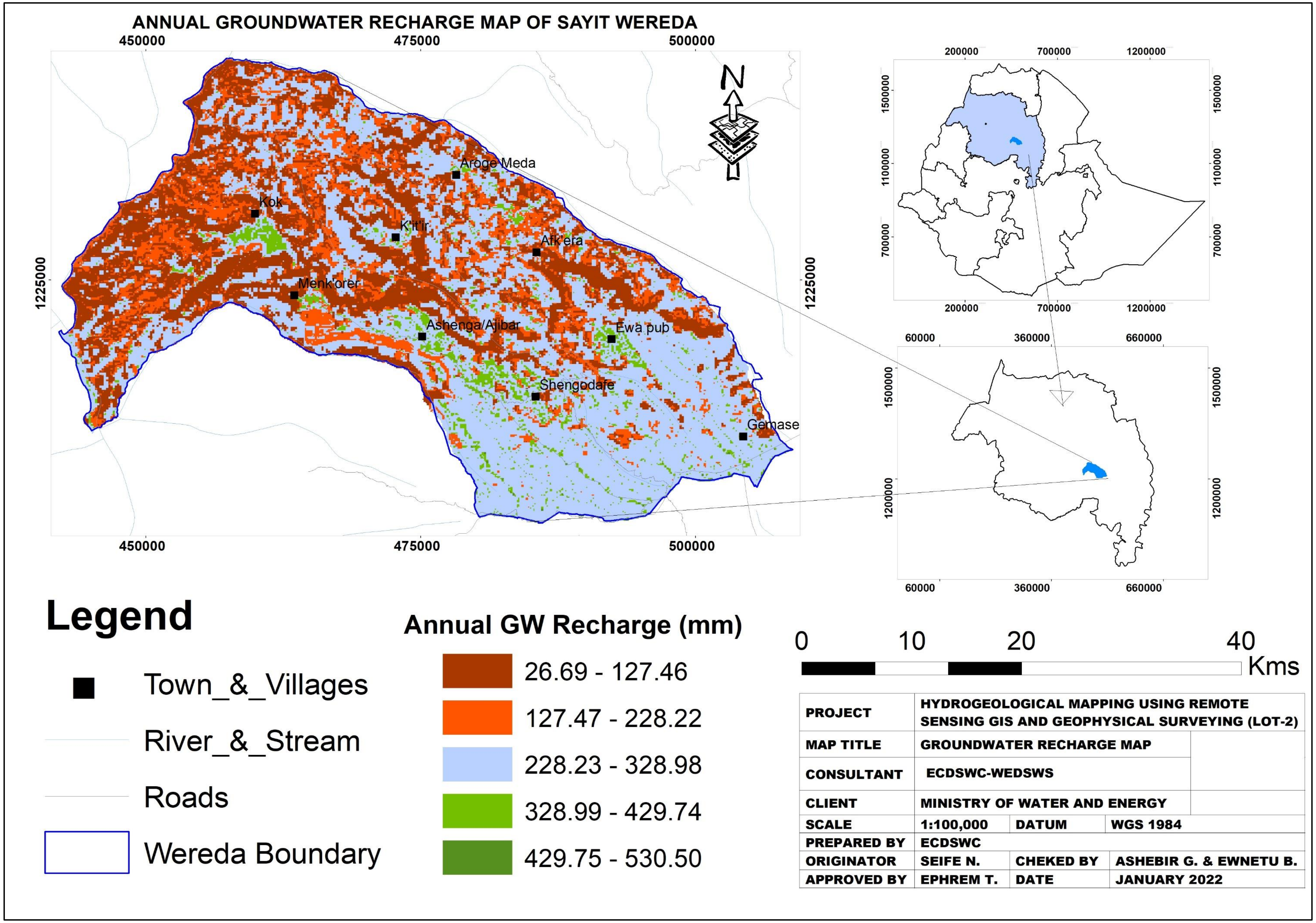


Figure 54 Groundwater recharge of Sayit Wereda

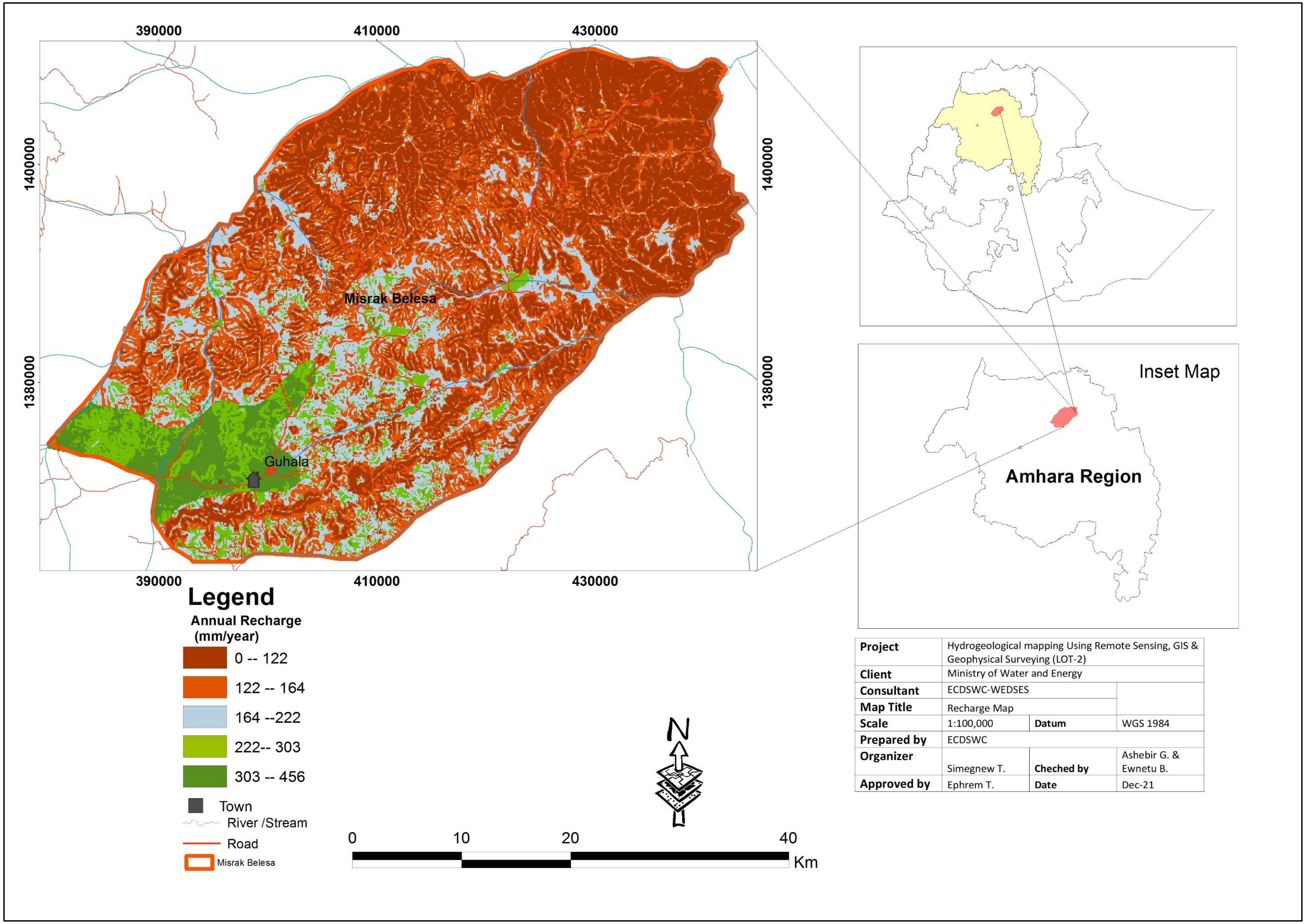


Figure 55 Groundwater recharge of Misrak Belesa

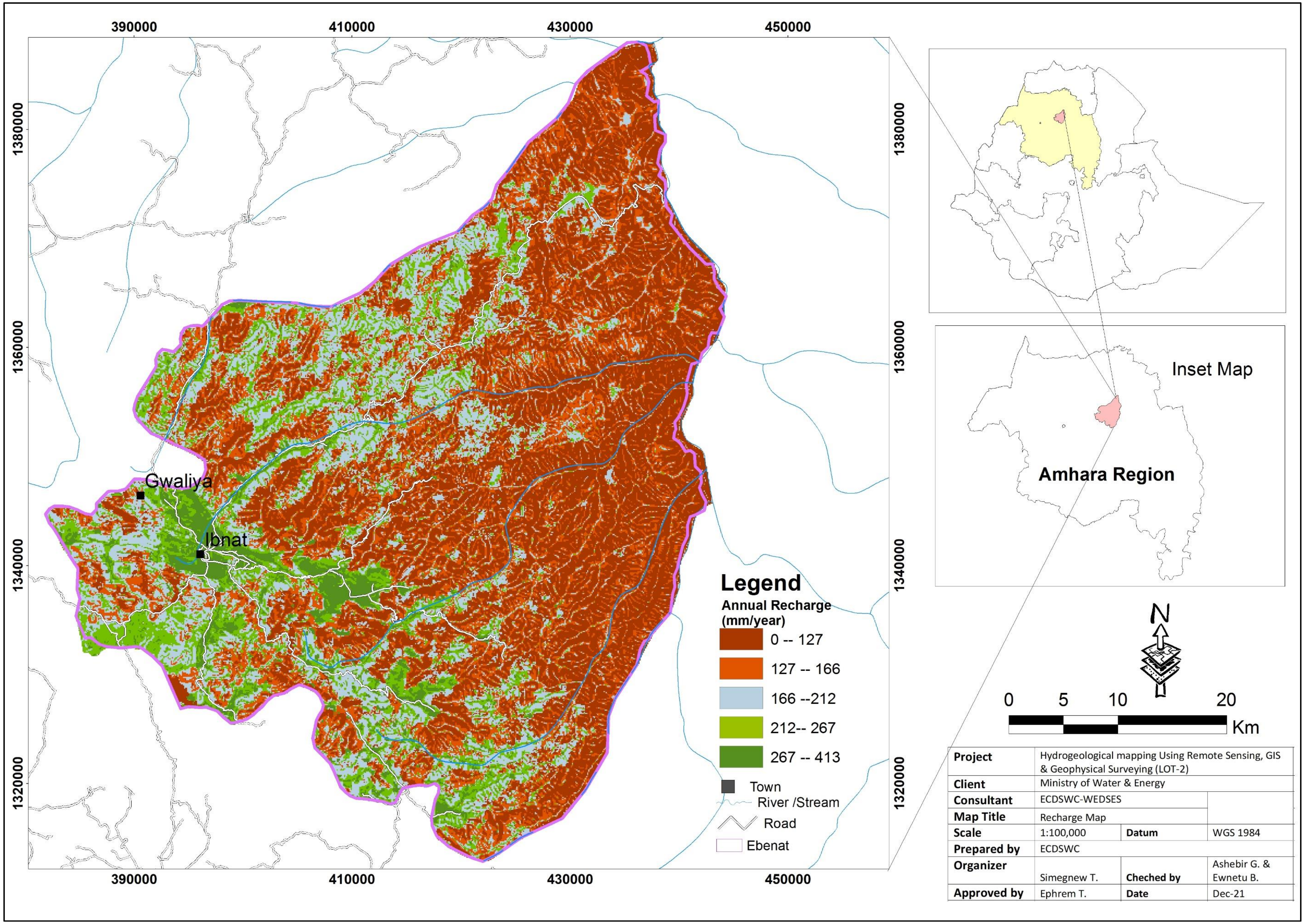


Figure 56 Groundwater recharge of Ebenat Wereda

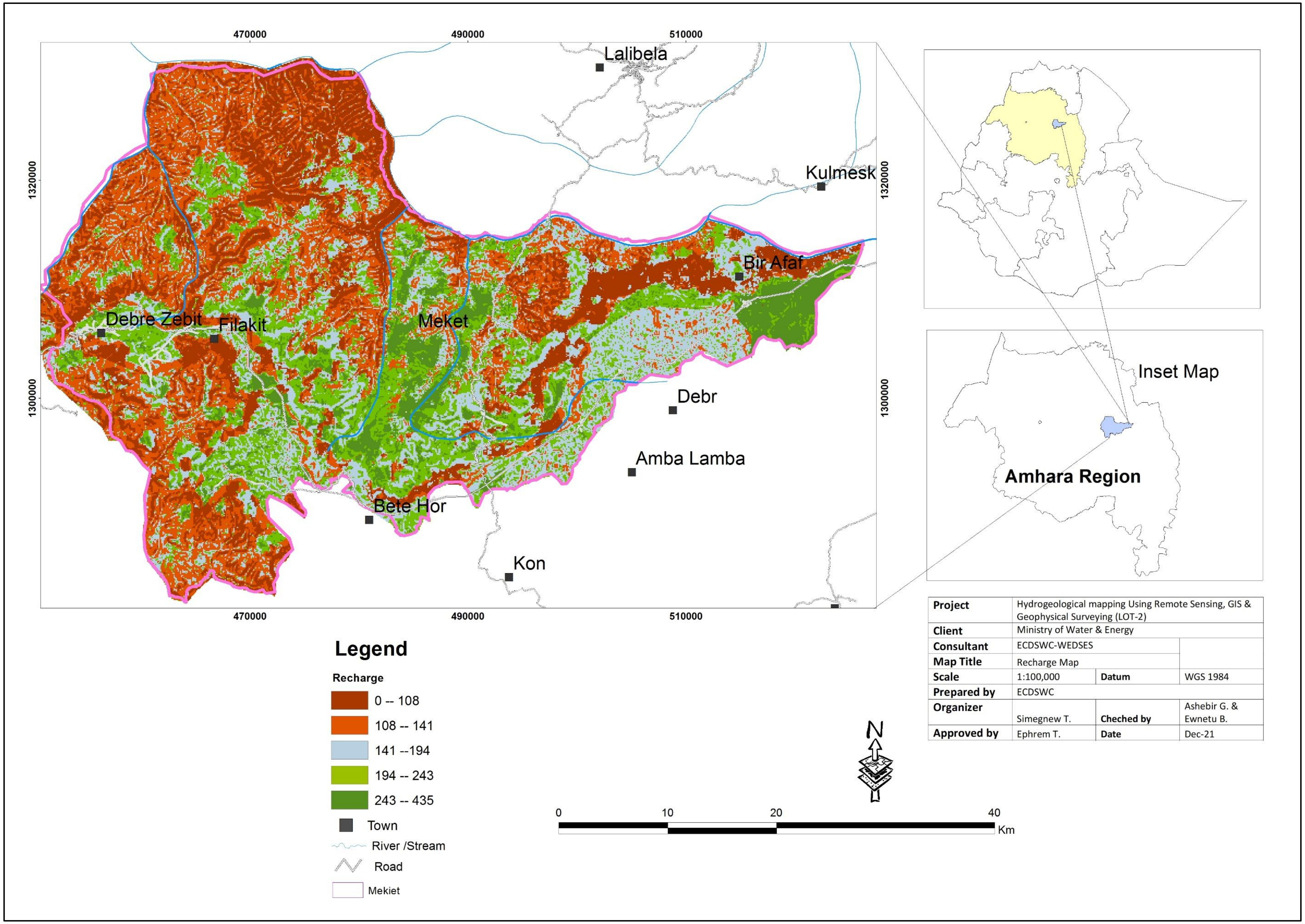


Figure 57 Groundwater recharge of Mekiet Wereda

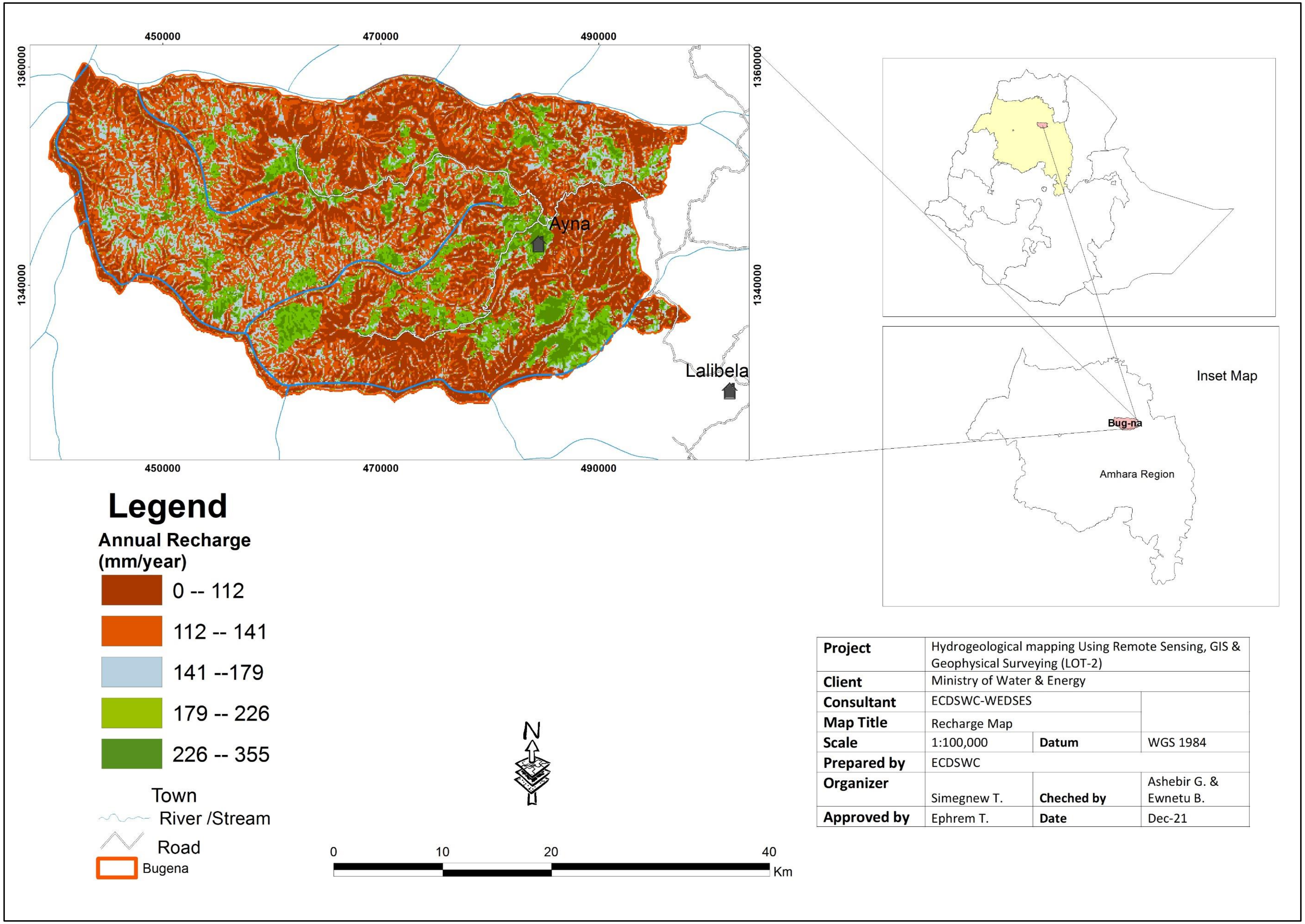


Figure 58 Groundwater recharge of Bugna Wereda

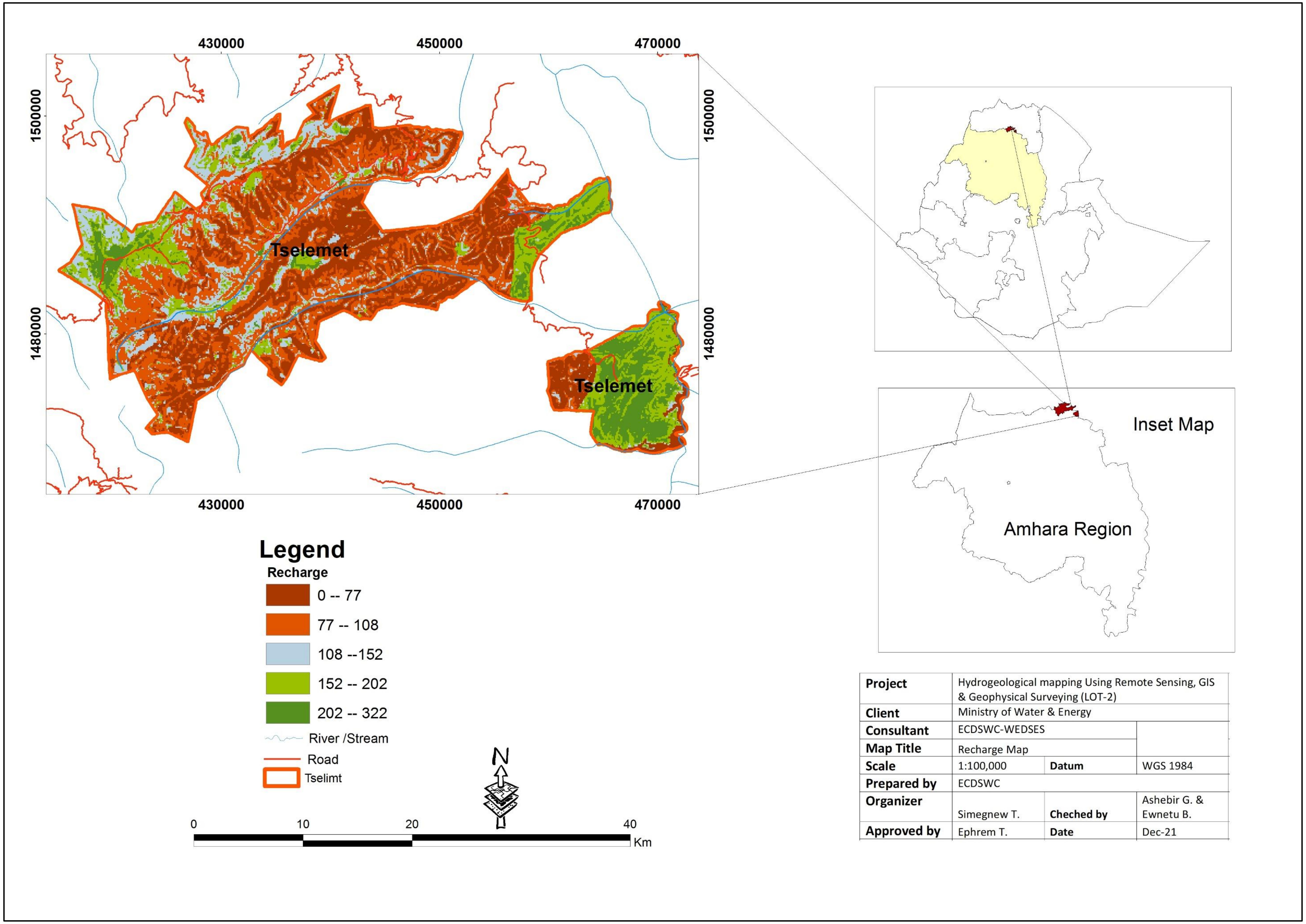


Figure 59: Groundwater recharge of Tselemit Wereda

4.2.3 TWI

Topographic Wetness Index (TWI) is used to compute topographic control on the hydrological process and reflects the potential groundwater infiltration caused by the effect of topography. The values were reclassified into five categories such as very low, low, moderate, high, and very high. The high weights have been assigned for high TWI and vice versa. Figure 60 - 73 shows the TWI maps of the project weredas.

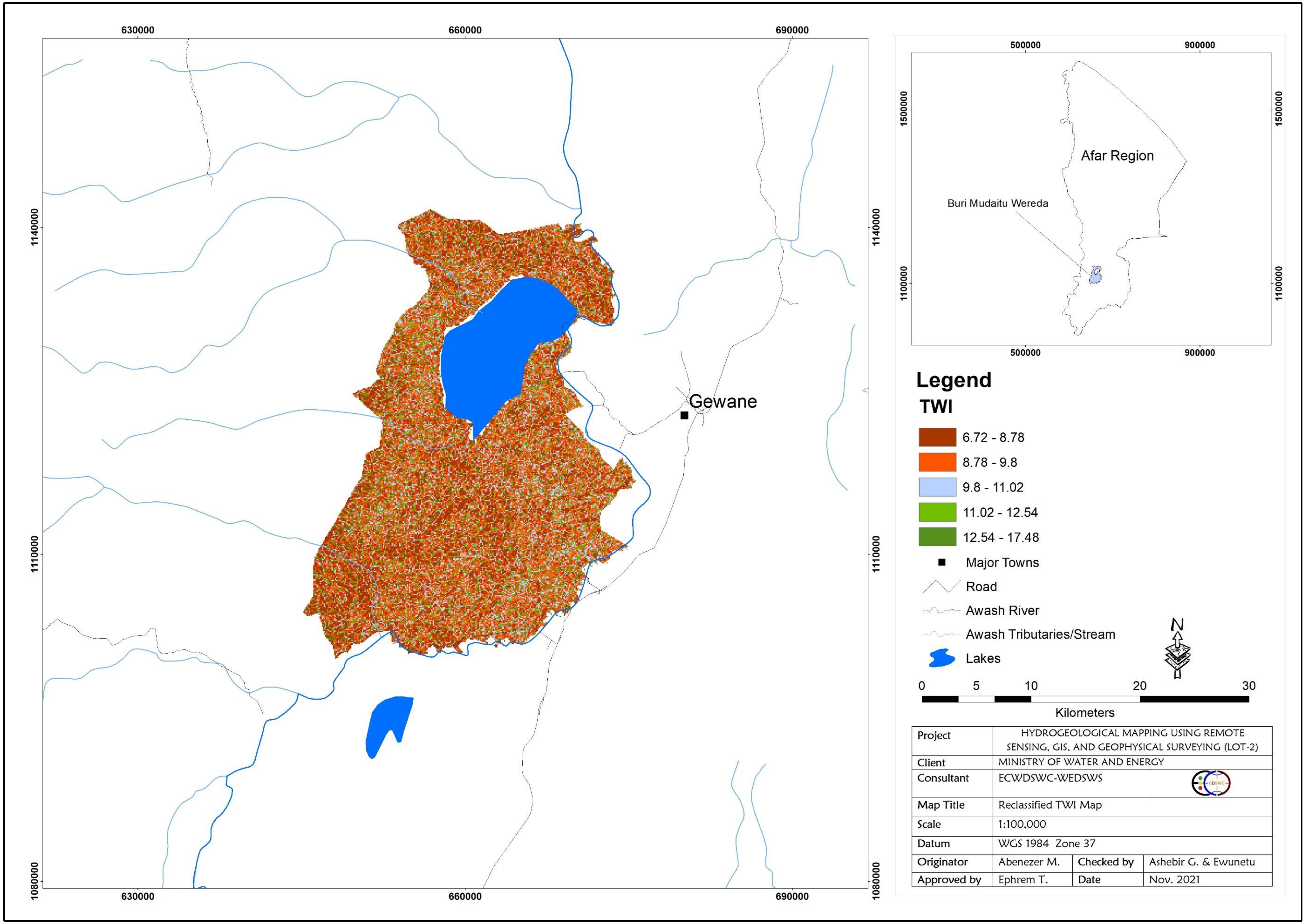


Figure 60 : TWI of Buri Mudaitu Wereda

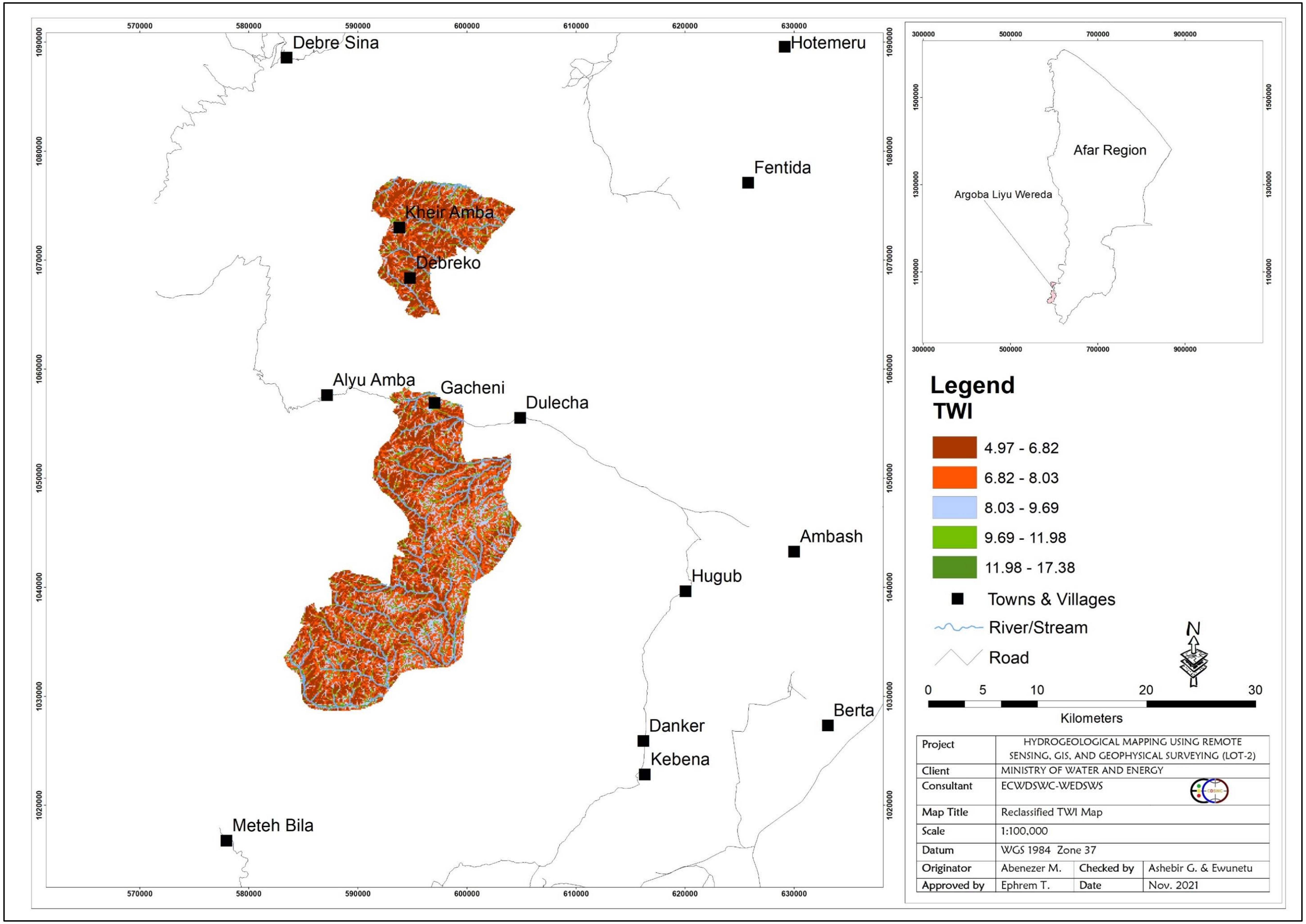


Figure 61: TWI of Argoba Liyu Wereda

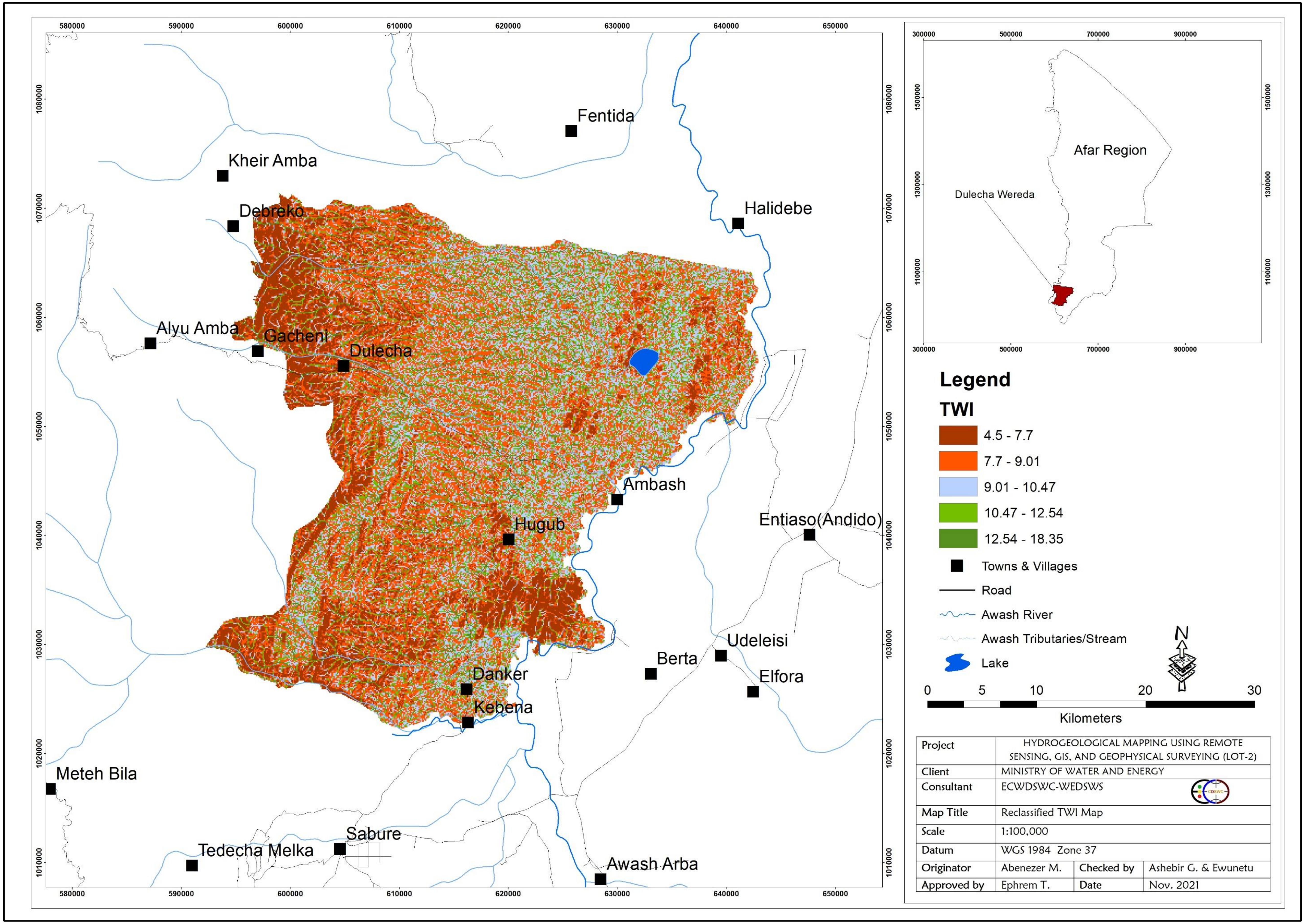


Figure 62: TWI of Dulecha Wereda

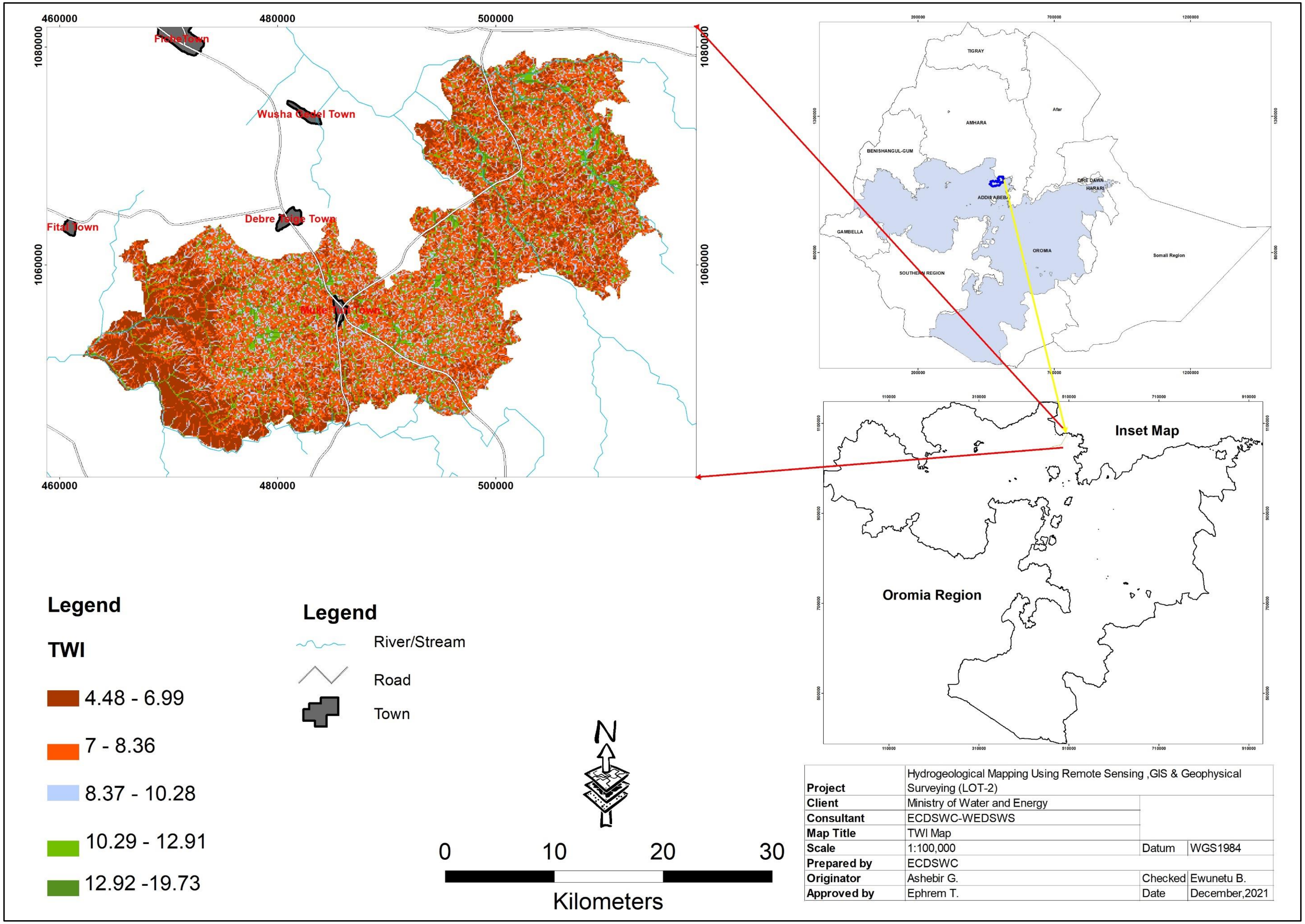
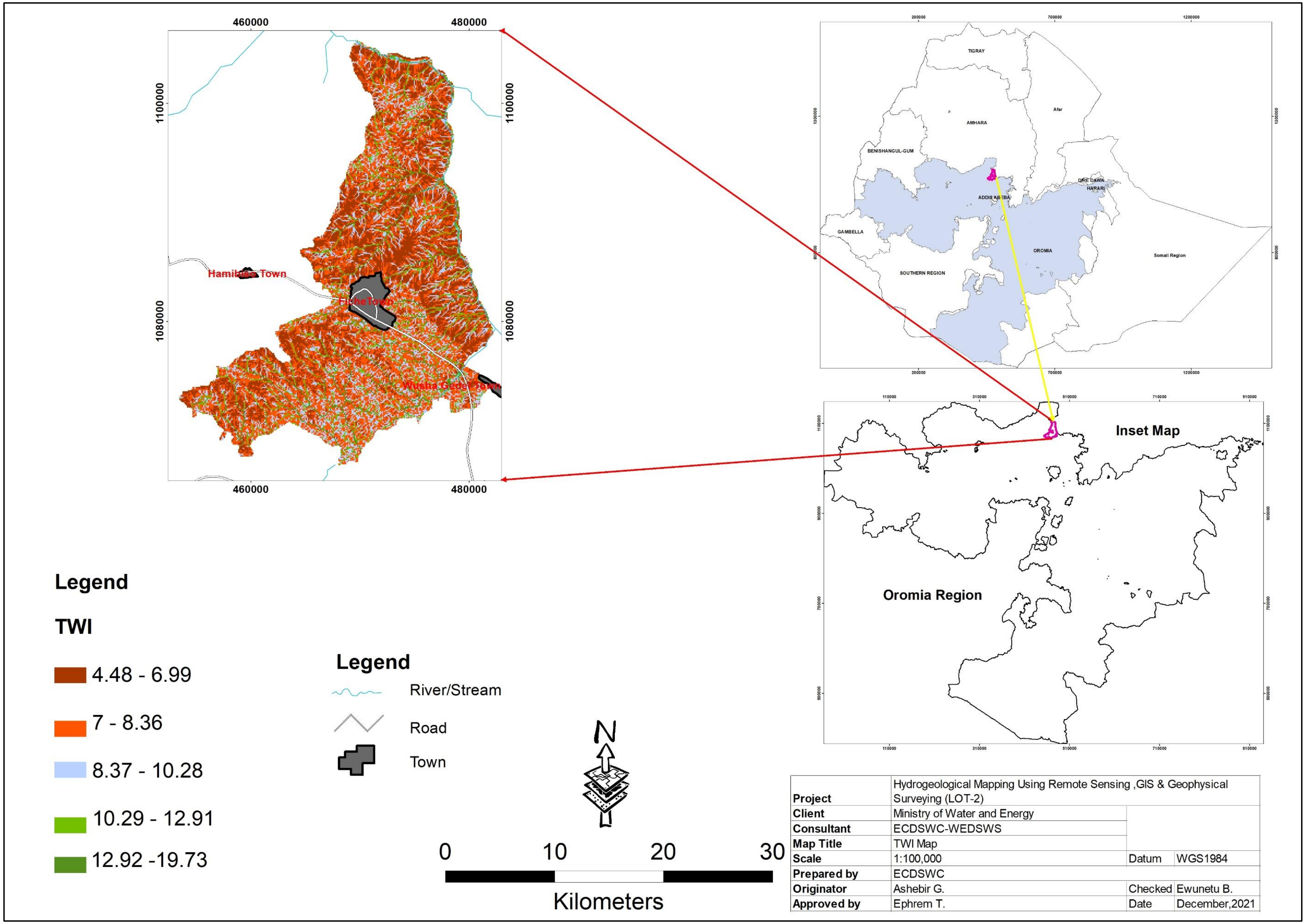


Figure 63: TWI of Wuchale Wereda



Project	Hydrogeological Mapping Using Remote Sensing ,GIS & Geophysical Surveying (LOT-2)		
Client	Ministry of Water and Energy		
Consultant	ECDSWC-WEDSWS		
Map Title	TWI Map		
Scale	1:100,000	Datum	WGS1984
Prepared by	ECDSWC		
Originator	Ashebir G.	Checked	Ewunetu B.
Approved by	Ephrem T.	Date	December,2021

Figure 64: TWI of Girar Jarso Wereda

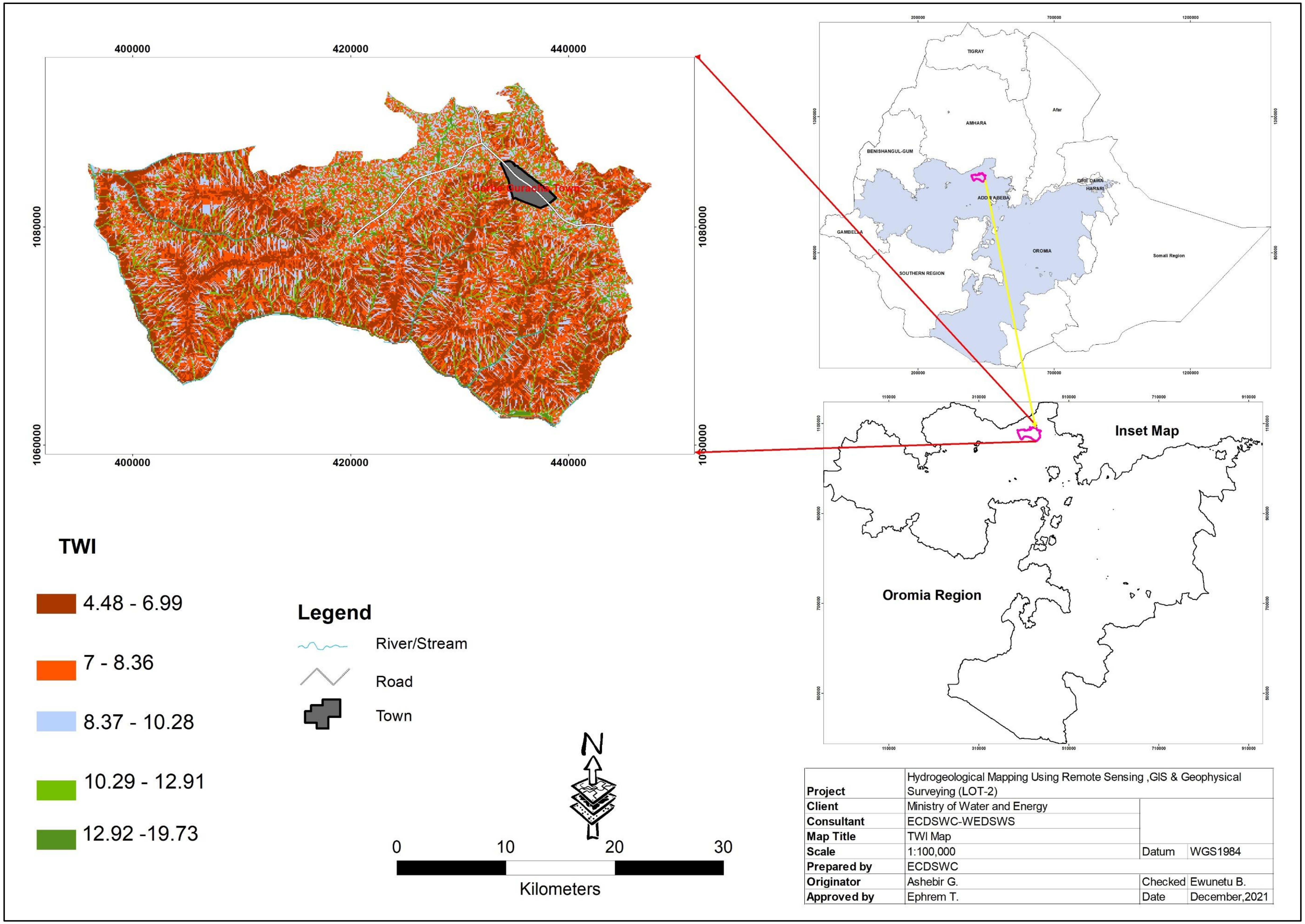


Figure 65: TWI of Kuyu Wereda

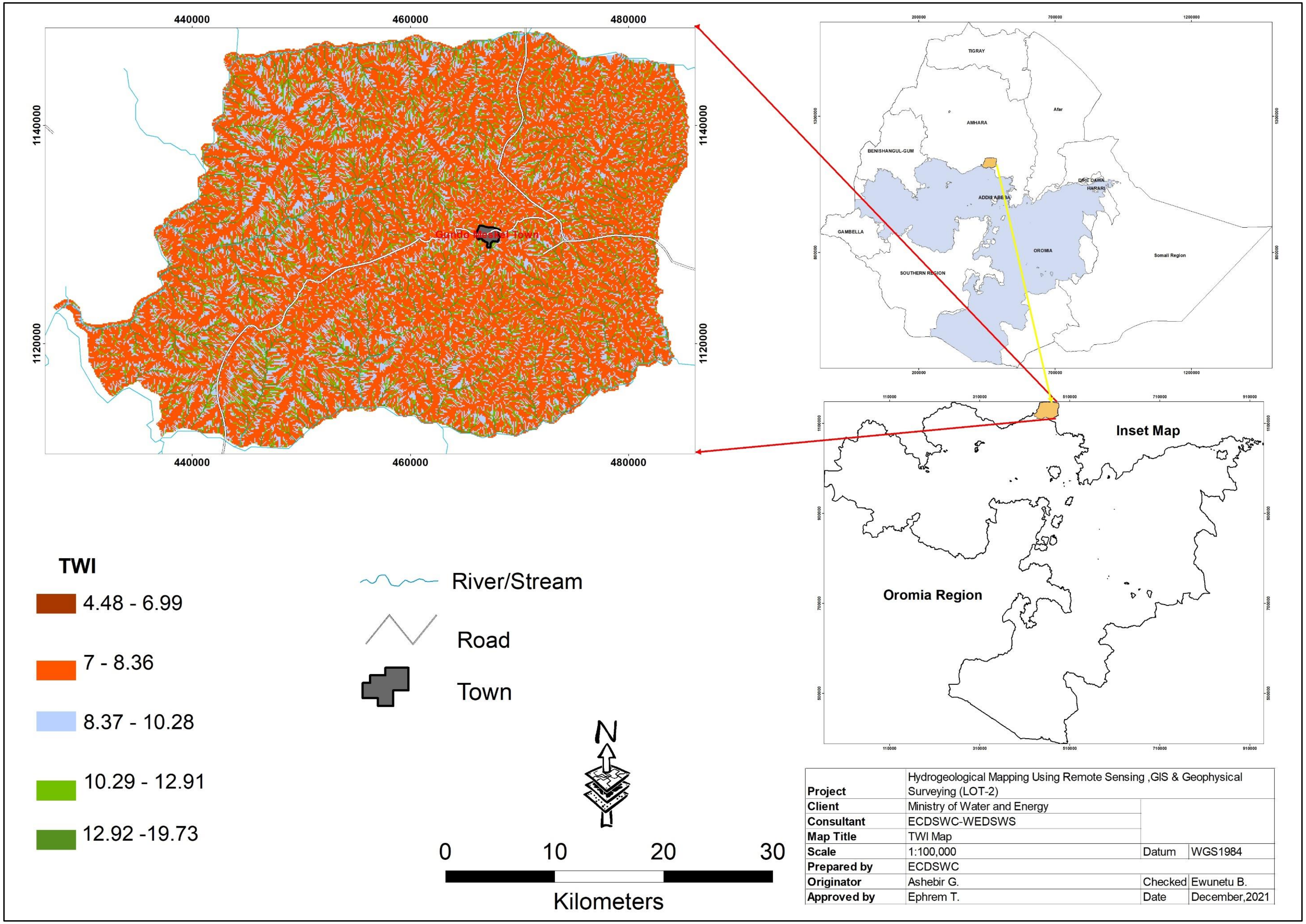
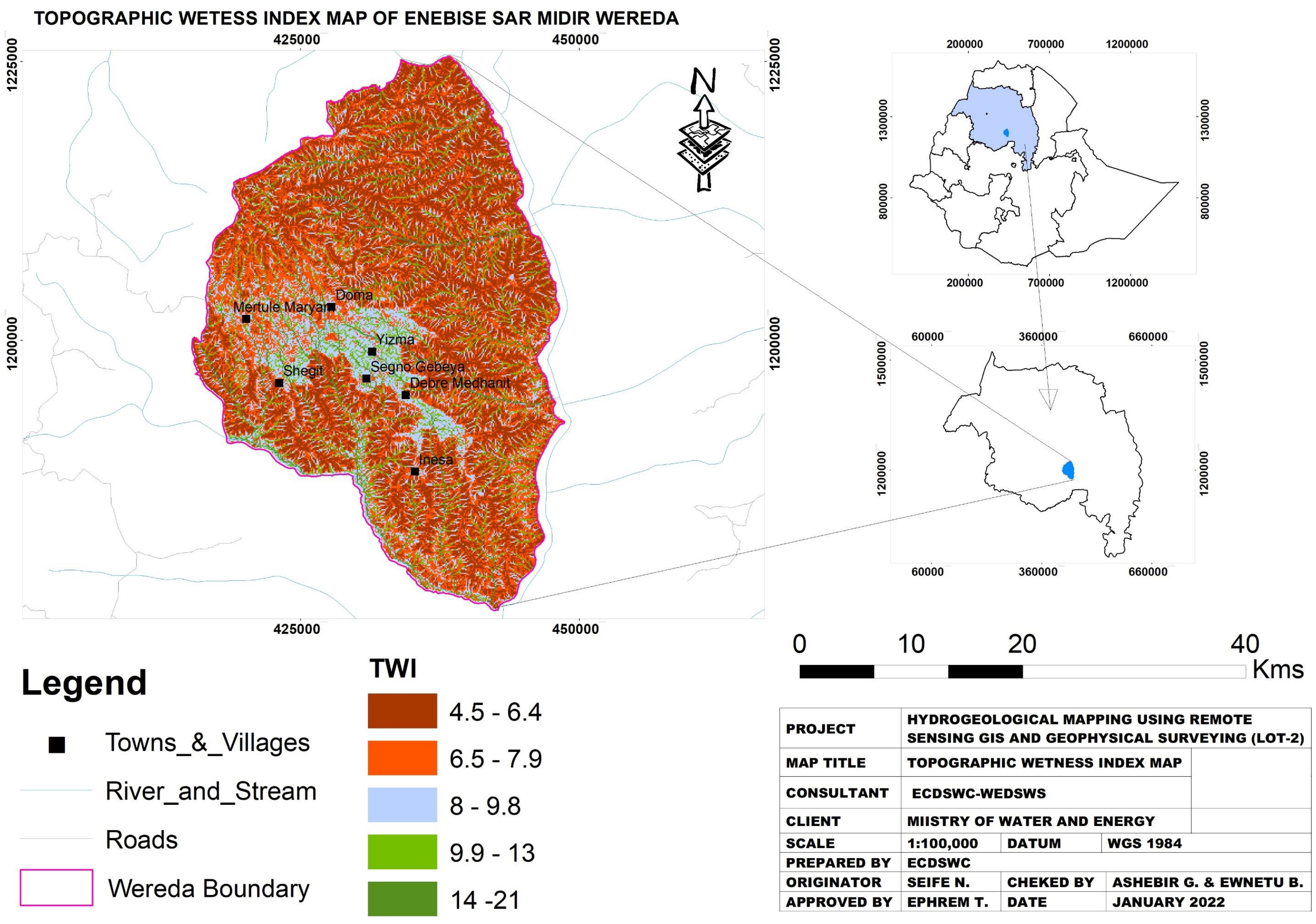


Figure 66: TWI of Dera Wereda



PROJECT	HYDROGEOLOGICAL MAPPING USING REMOTE SENSING GIS AND GEOPHYSICAL SURVEYING (LOT-2)		
MAP TITLE	TOPOGRAPHIC WETNESS INDEX MAP		
CONSULTANT	ECDSWC-WEDSWS		
CLIENT	MIISTRY OF WATER AND ENERGY		
SCALE	1:100,000	DATUM	WGS 1984
PREPARED BY	ECDSWC		
ORIGINATOR	SEIFE N.	CHEKED BY	ASHEBIR G. & EWNETU B.
APPROVED BY	EPHREM T.	DATE	JANUARY 2022

Figure 67: TWI of Enebise Sar Midir Wereda

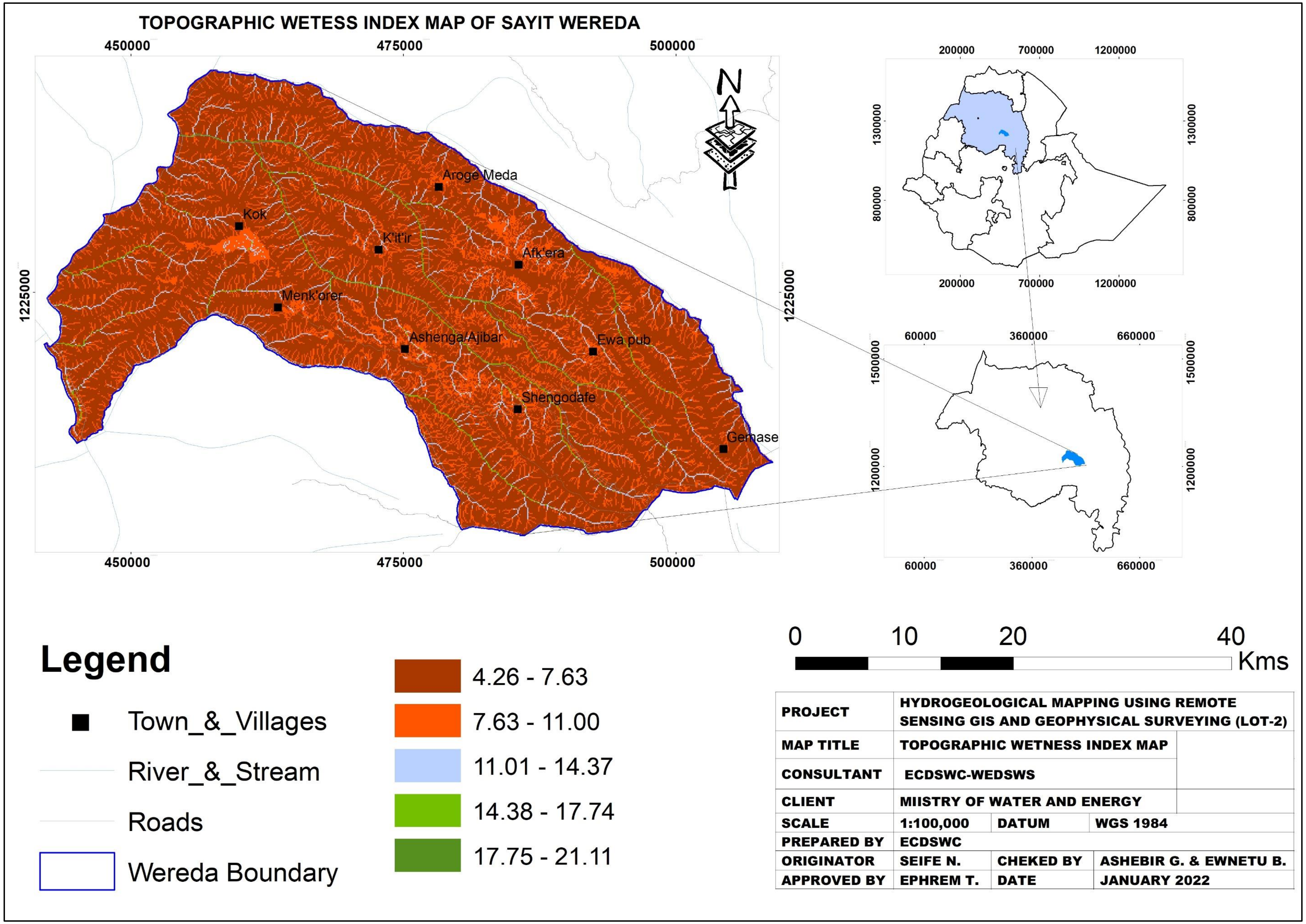


Figure 68: TWI of Sayit Wereda

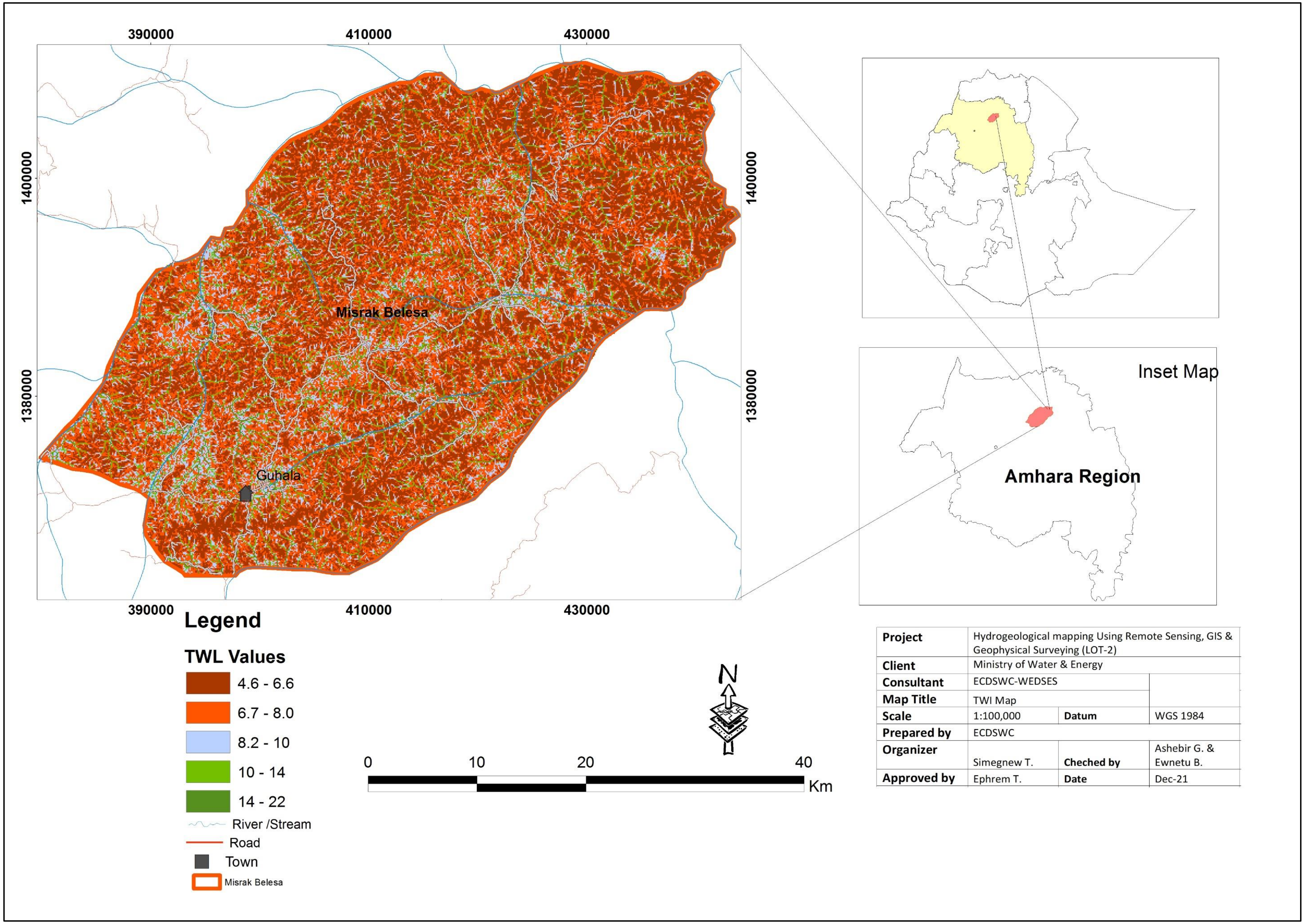


Figure 69: TWI of Misrak Belesa Wereda

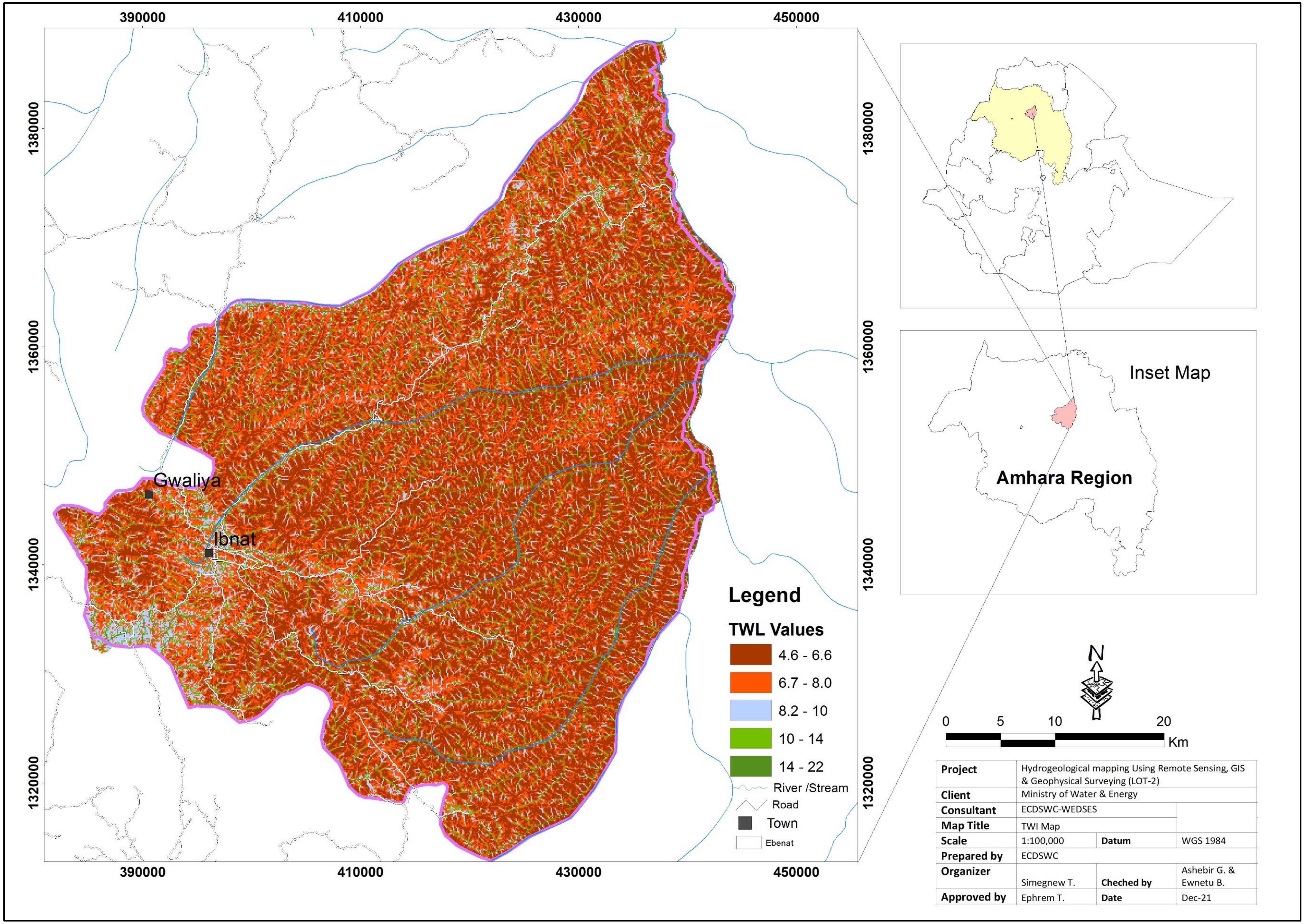


Figure 70: TWI of Ebenat Wereda

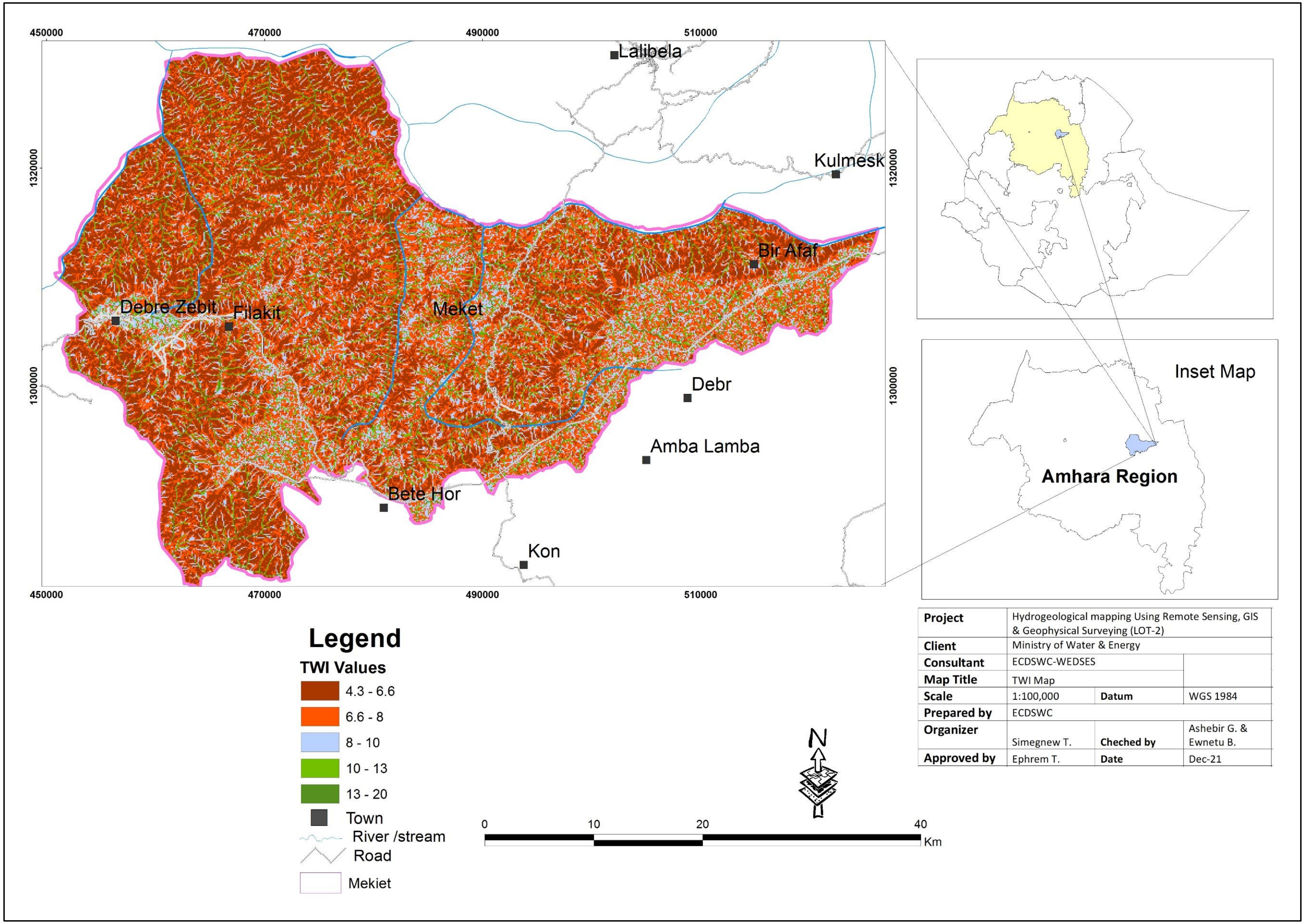


Figure 71: TWI of Mekiet Wereda

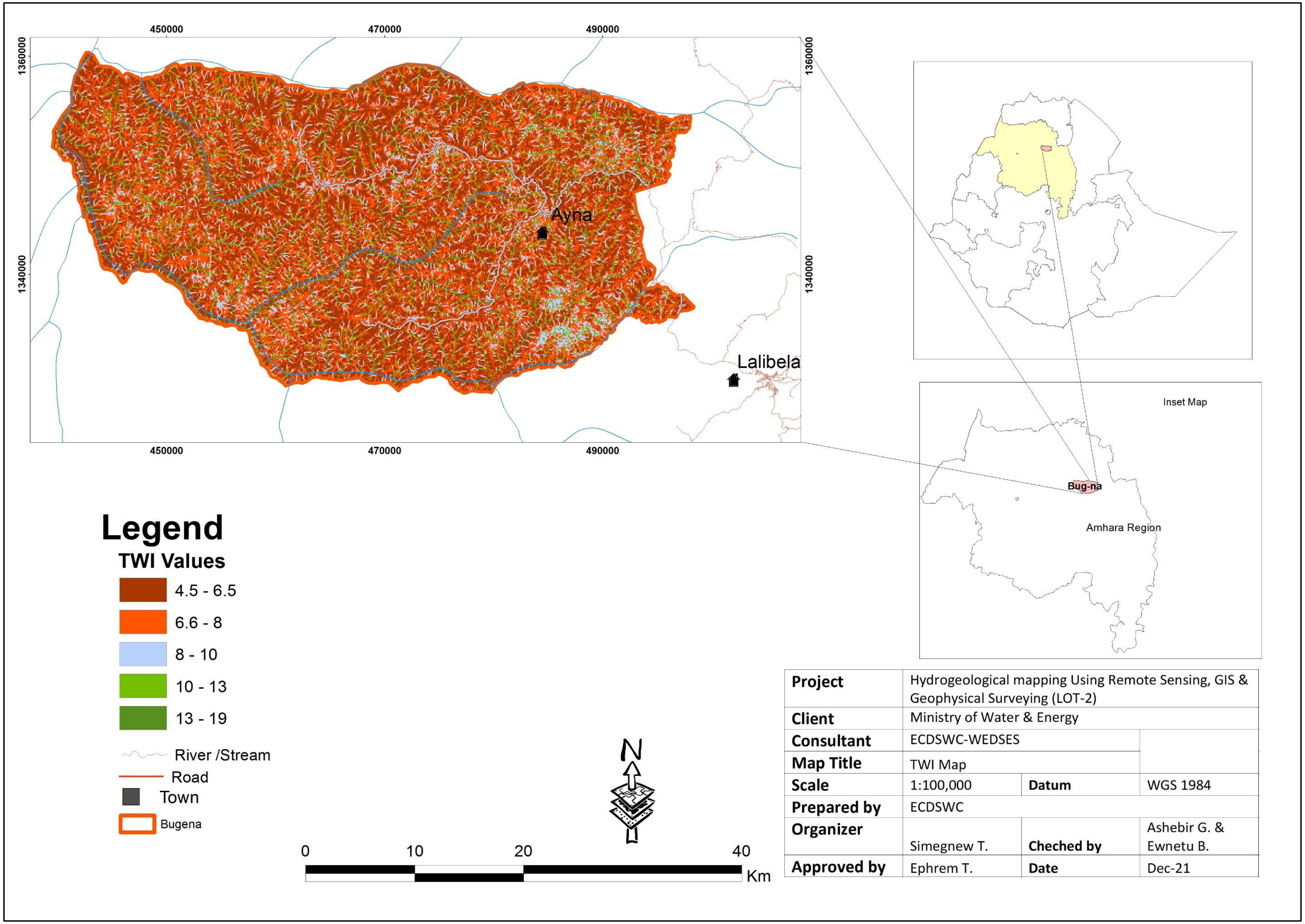


Figure 72: TWI of Bugna Wereda

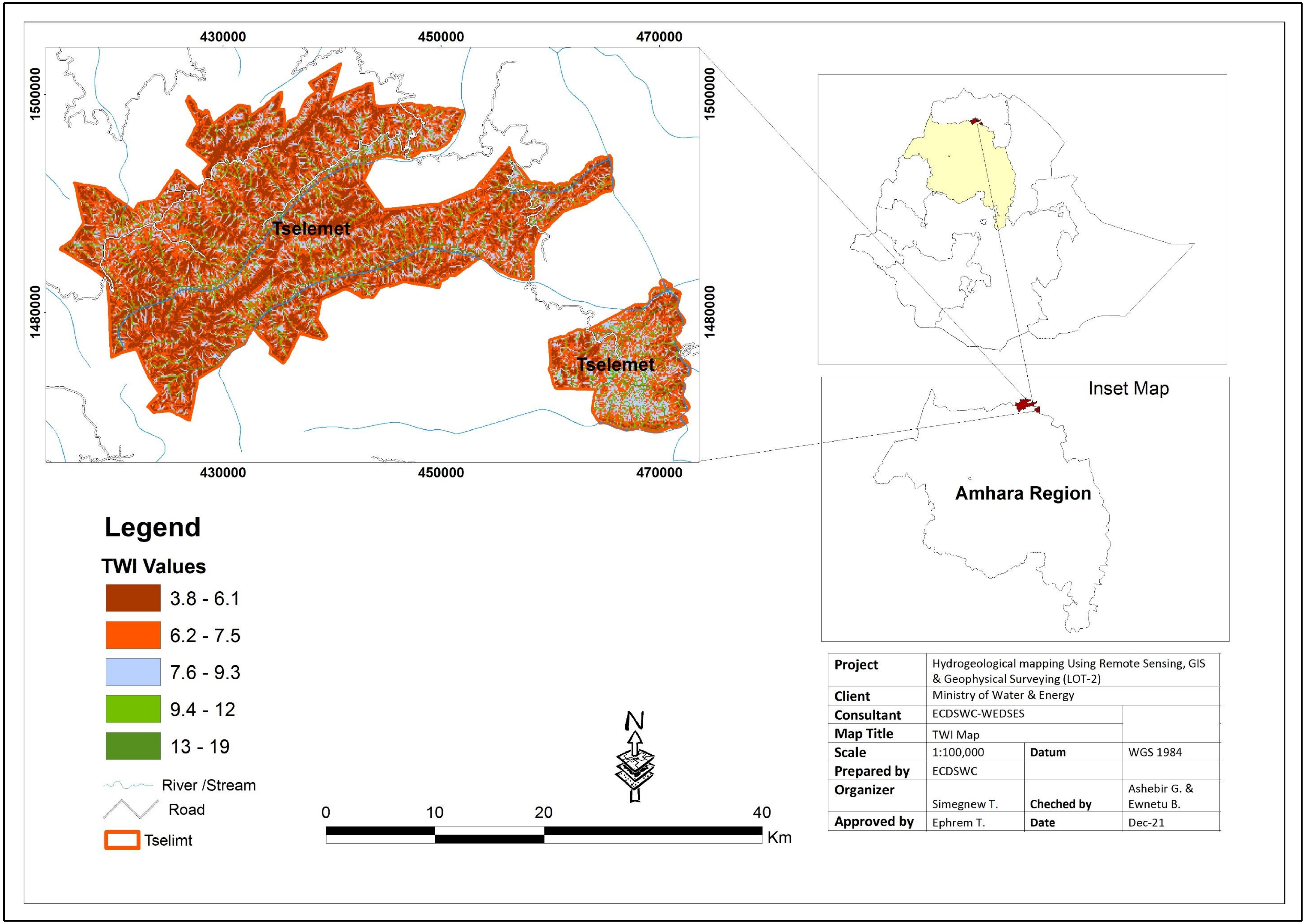


Figure 73: TWI of Tselemit Wereda

4.2.4 Lineament Density

Like primary porosity, secondary porosity is also essential for the determination of hydrogeological conditions. Lineaments represent secondary porosity and are linear features of tectonic origin. Due to their linear, direct, curvilinear form, they can easily be demarcated in satellite imagery. Some other indications like tone, texture, relief, drainage, and vegetation soil tone’s linearity also give valuable information for lineament differentiation.

The groundwater potential is expected to increase with increasing lineament density values. Thus, areas that are characterized by high lineament density values are expected to have high groundwater potential. This is because; lineament acts as conduits for groundwater flow and reservoir for groundwater storage .considering lineament map as a baseline, lineament density is defined as the total length of the lineament per unit area.

The lineament density of the project weredas was classified into five classes, in decreasing order of their relative infiltration capability. These classes were: 5, 4, 3, 2, and 1, representing very high, high, medium, low, and very low density, respectively (figure 74 to 87)

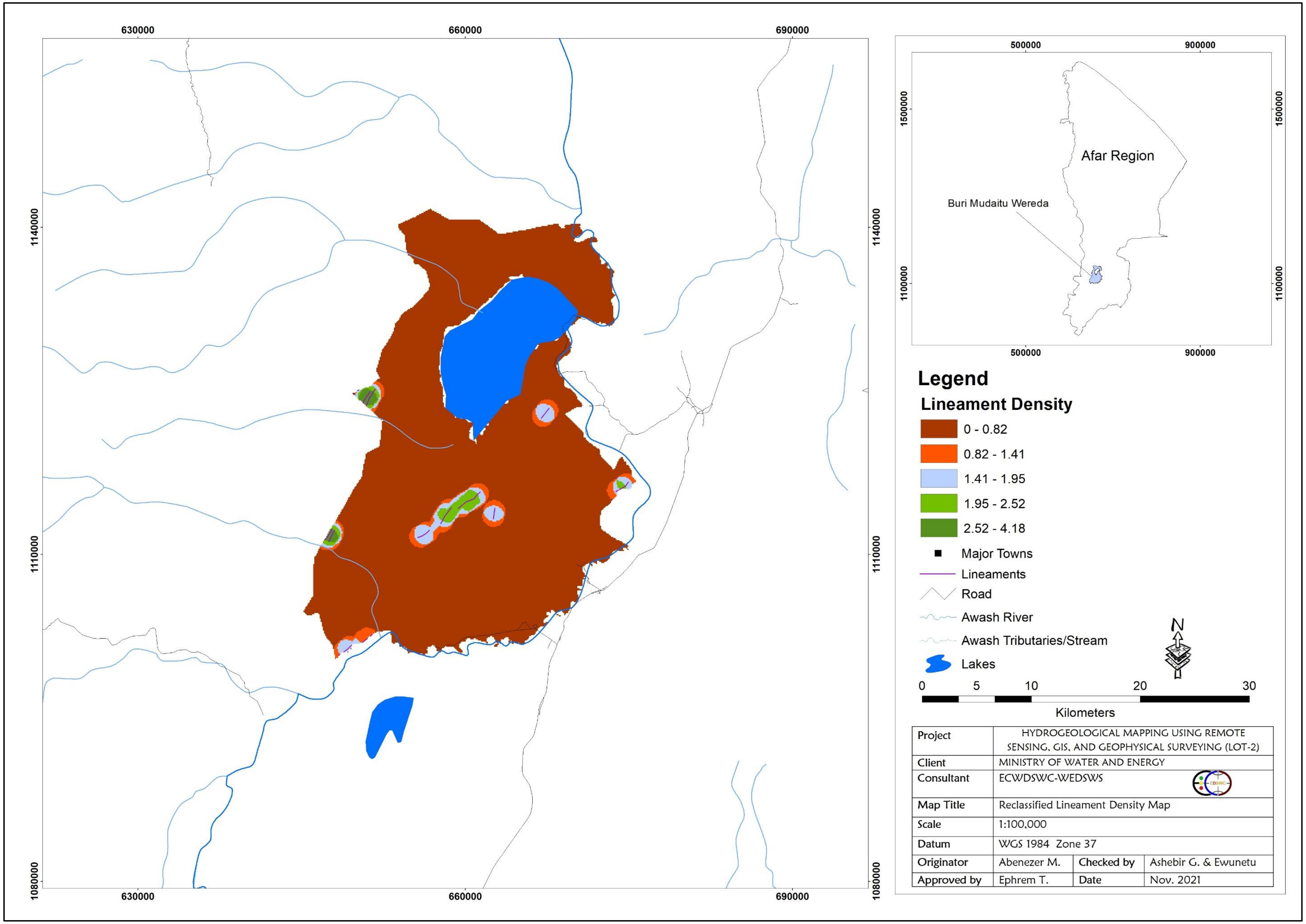


Figure 74: Lineament Density map of Buri Mudaitu Wereda

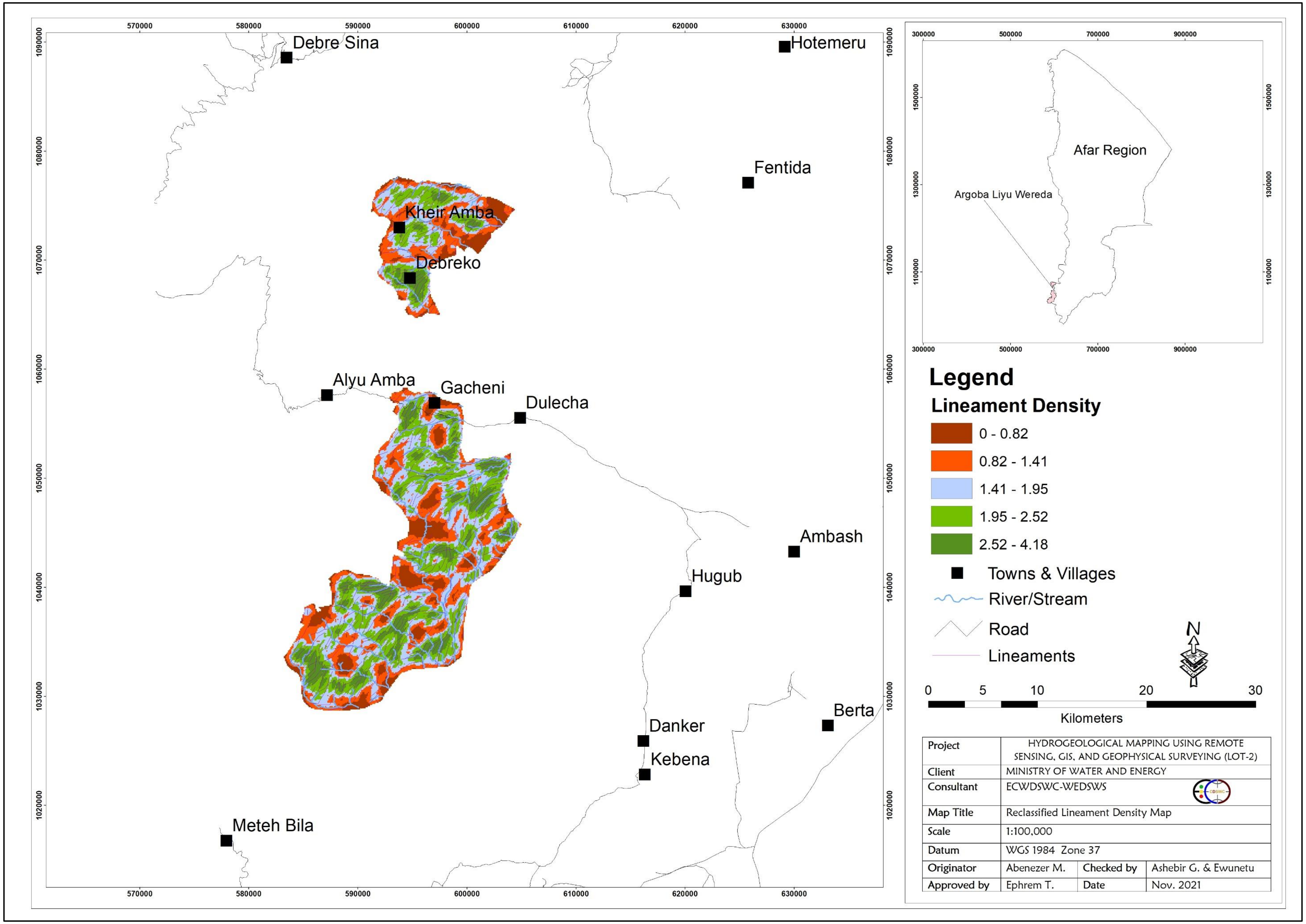


Figure 75: Lineament Density map of Argoba Liyu Wereda

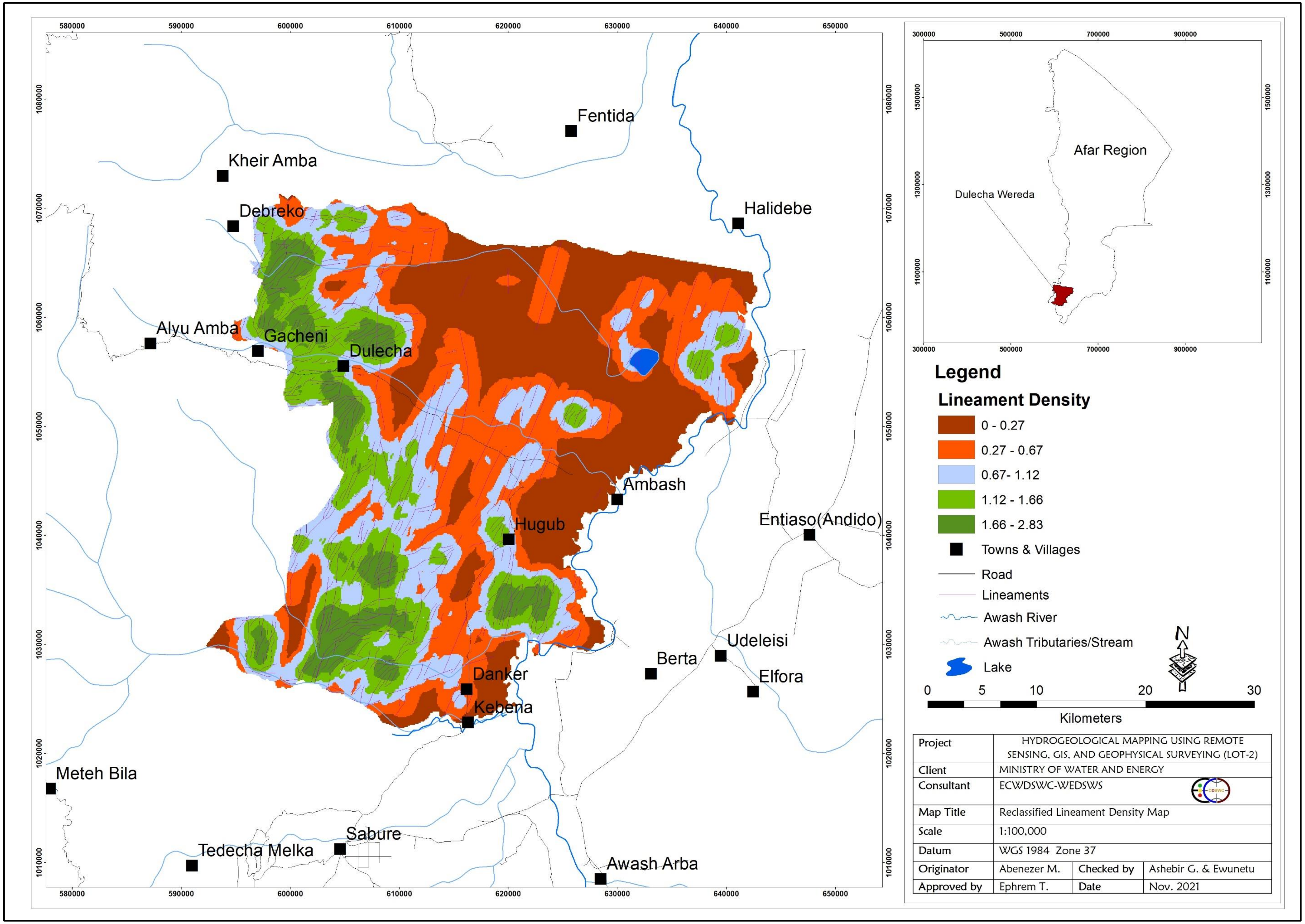


Figure 76: Lineament Density map of Dulecha Wereda

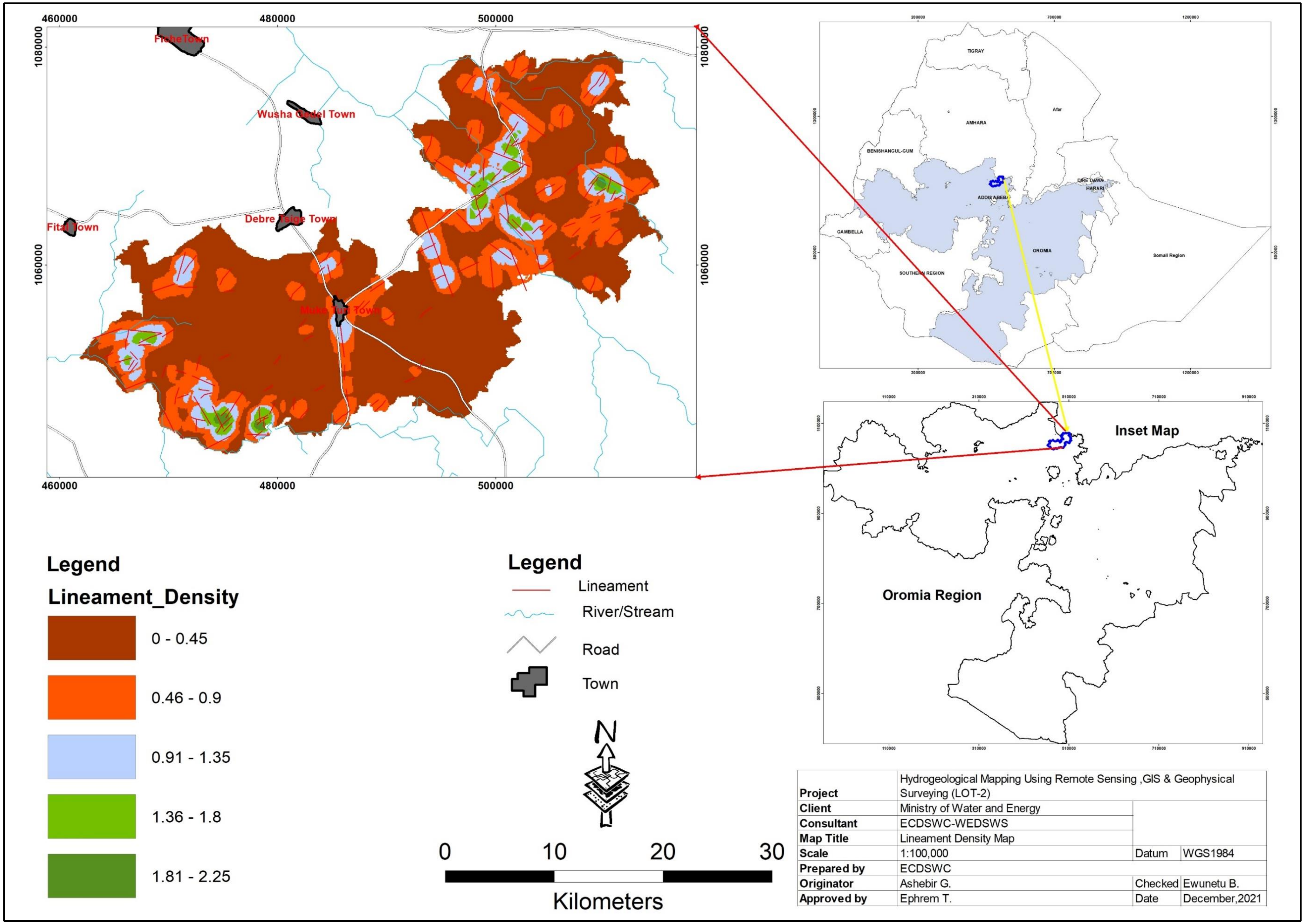


Figure 77: Lineament Density map of Wuchale Wereda

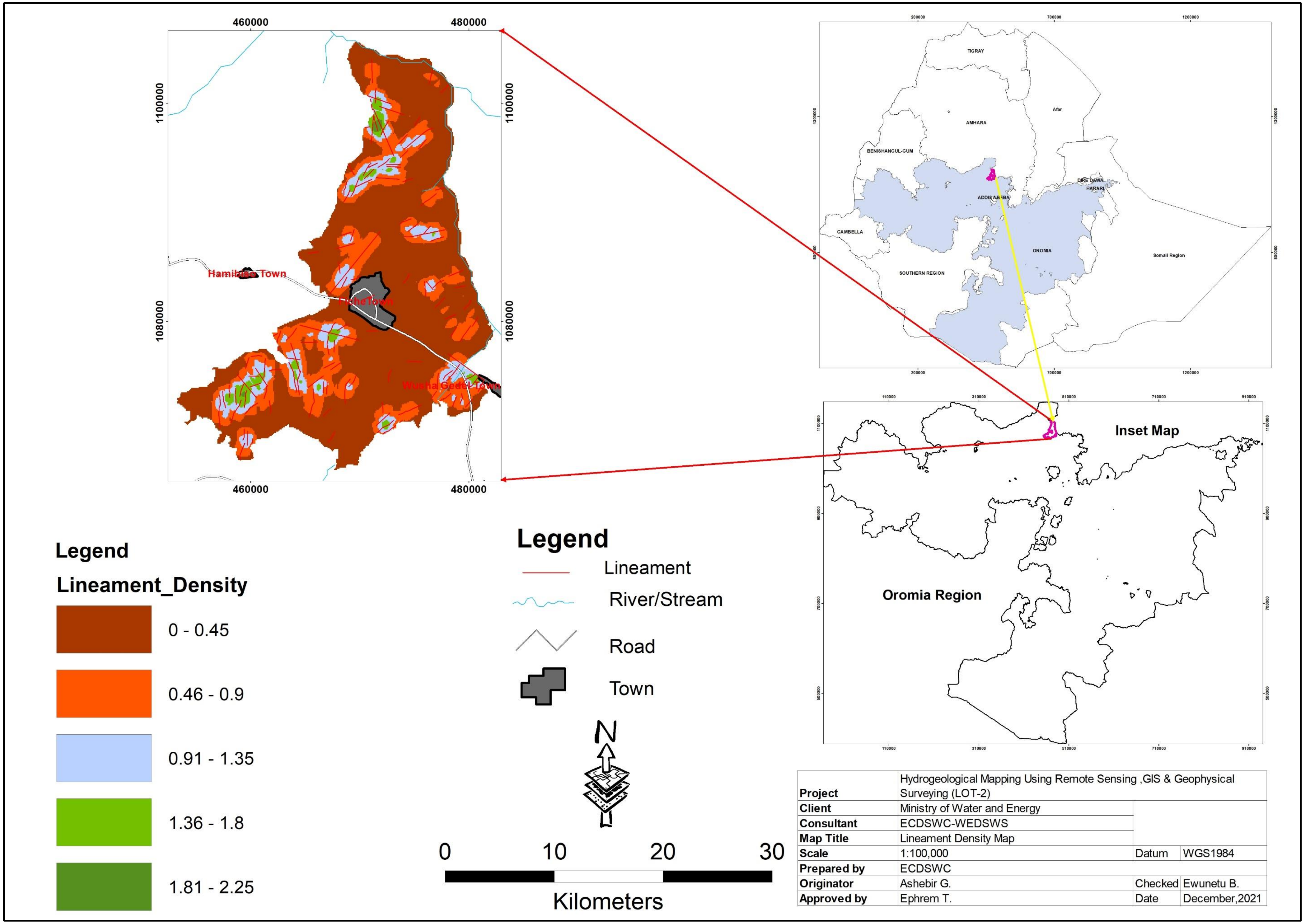


Figure 78: Lineament Density map of Girar Jarso Wereda

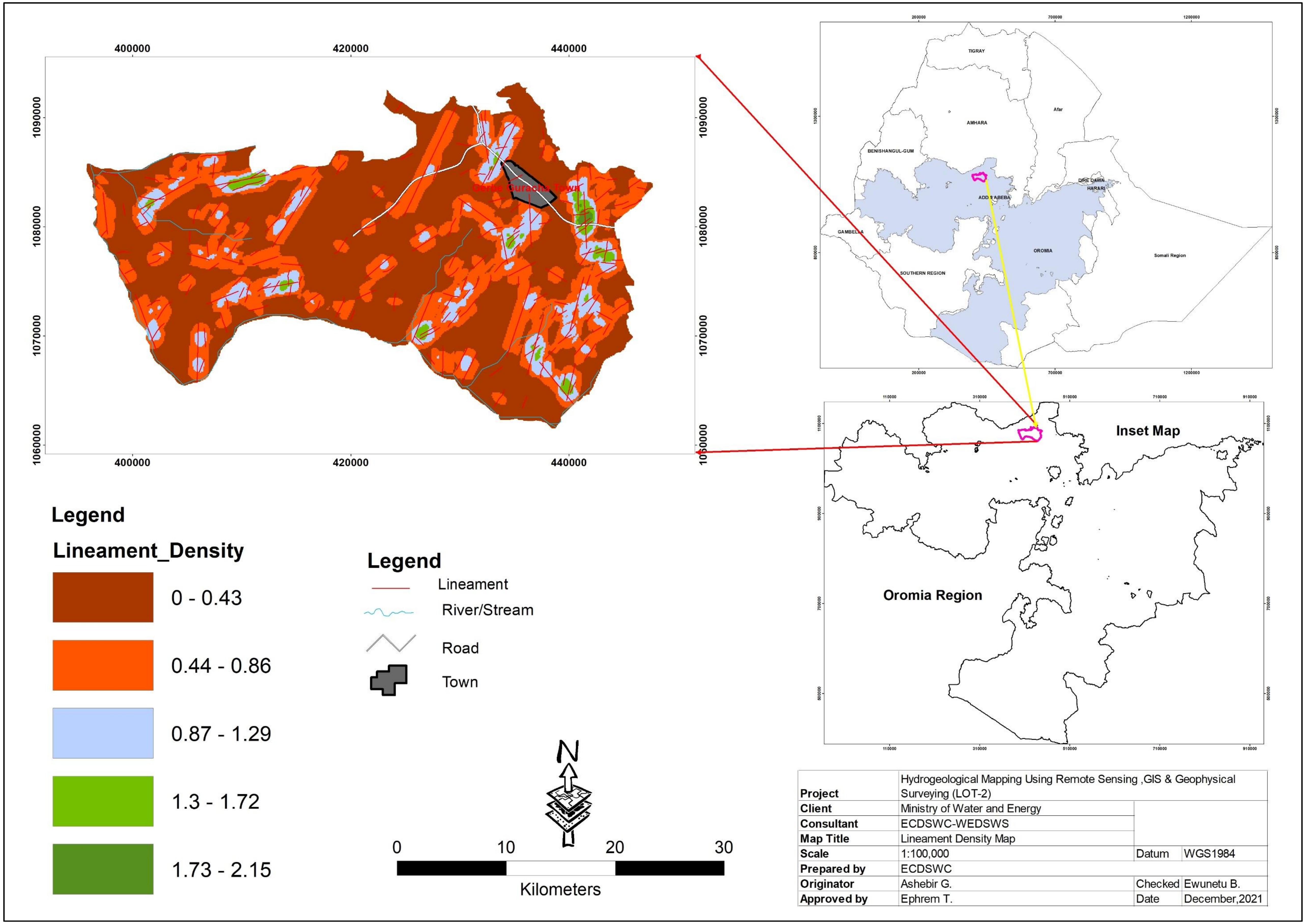


Figure 79: Lineament Density map of Kuyu Wereda

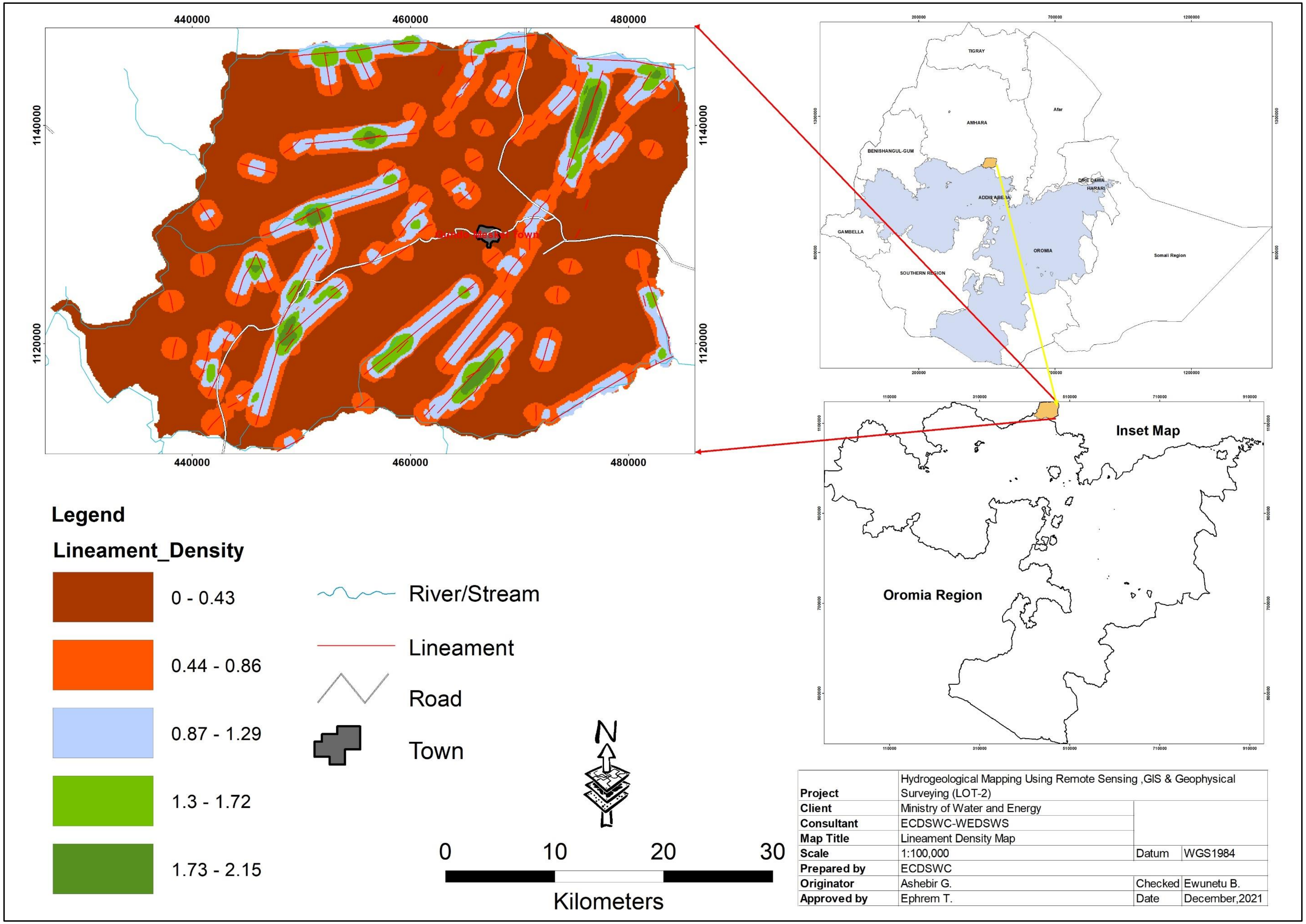


Figure 80: Lineament Density map of Dera Wereda

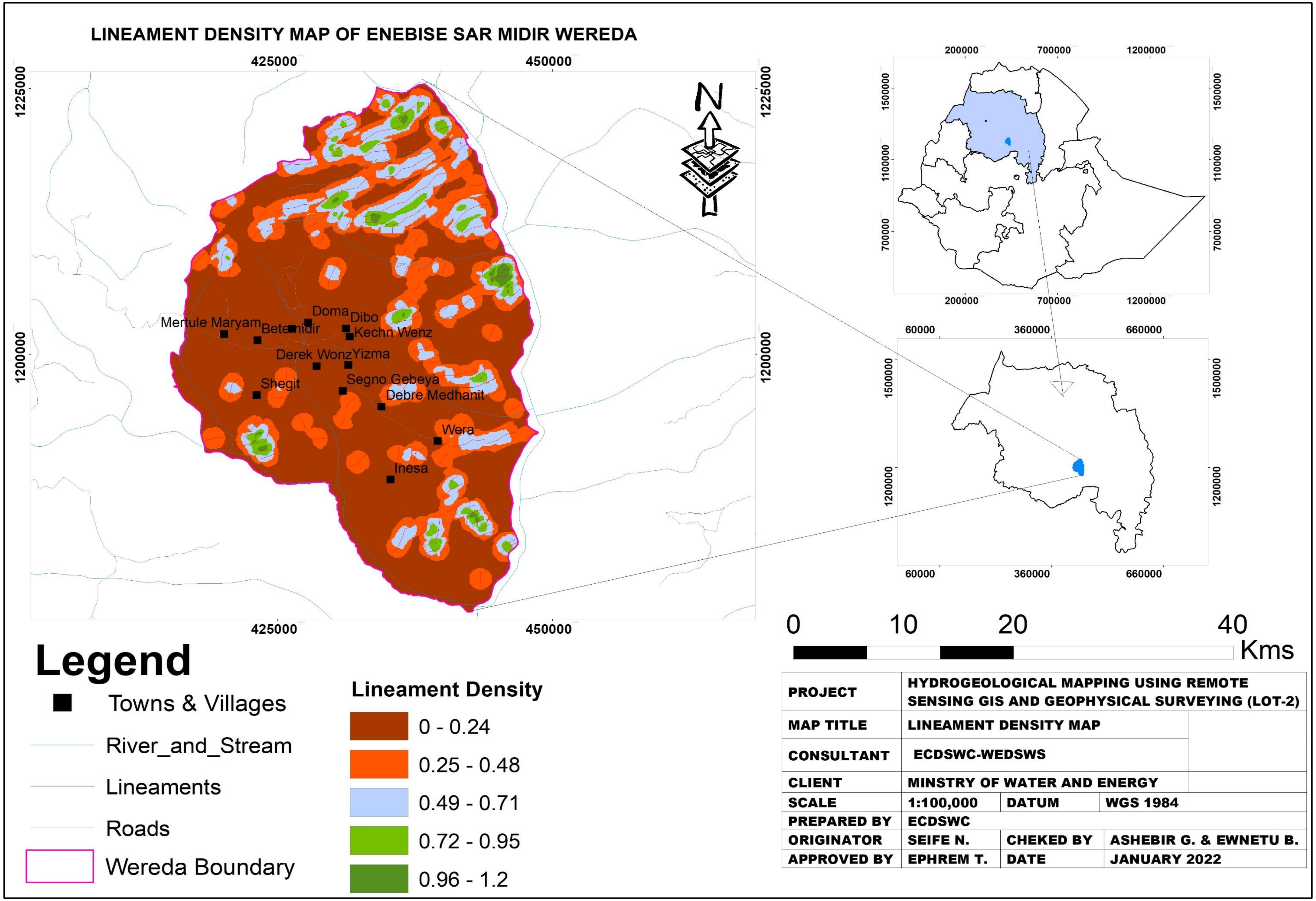


Figure 81: Lineament Density map of Enebise Sar Midir Wereda

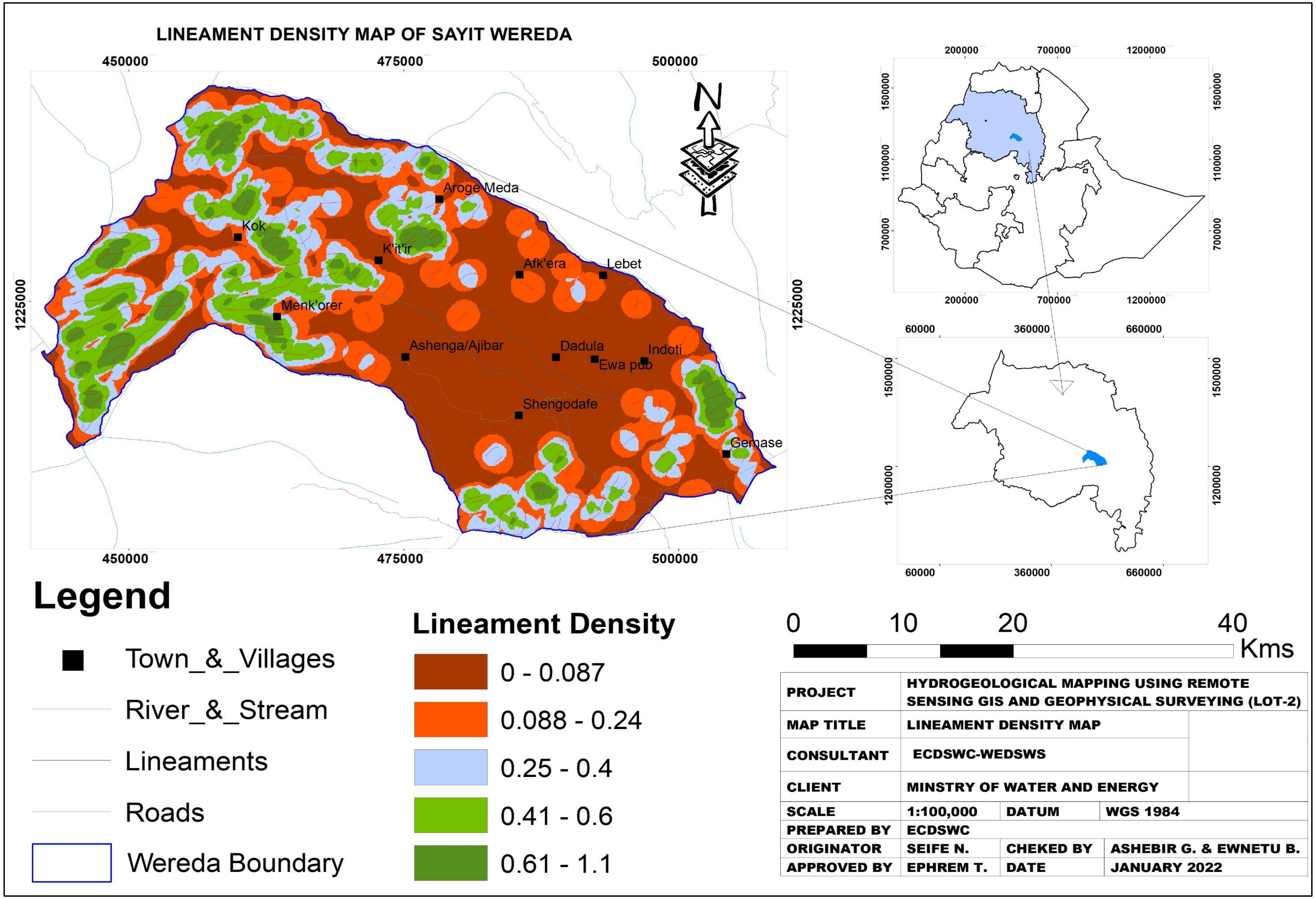


Figure 82: Lineament Density map of Sayit Wereda

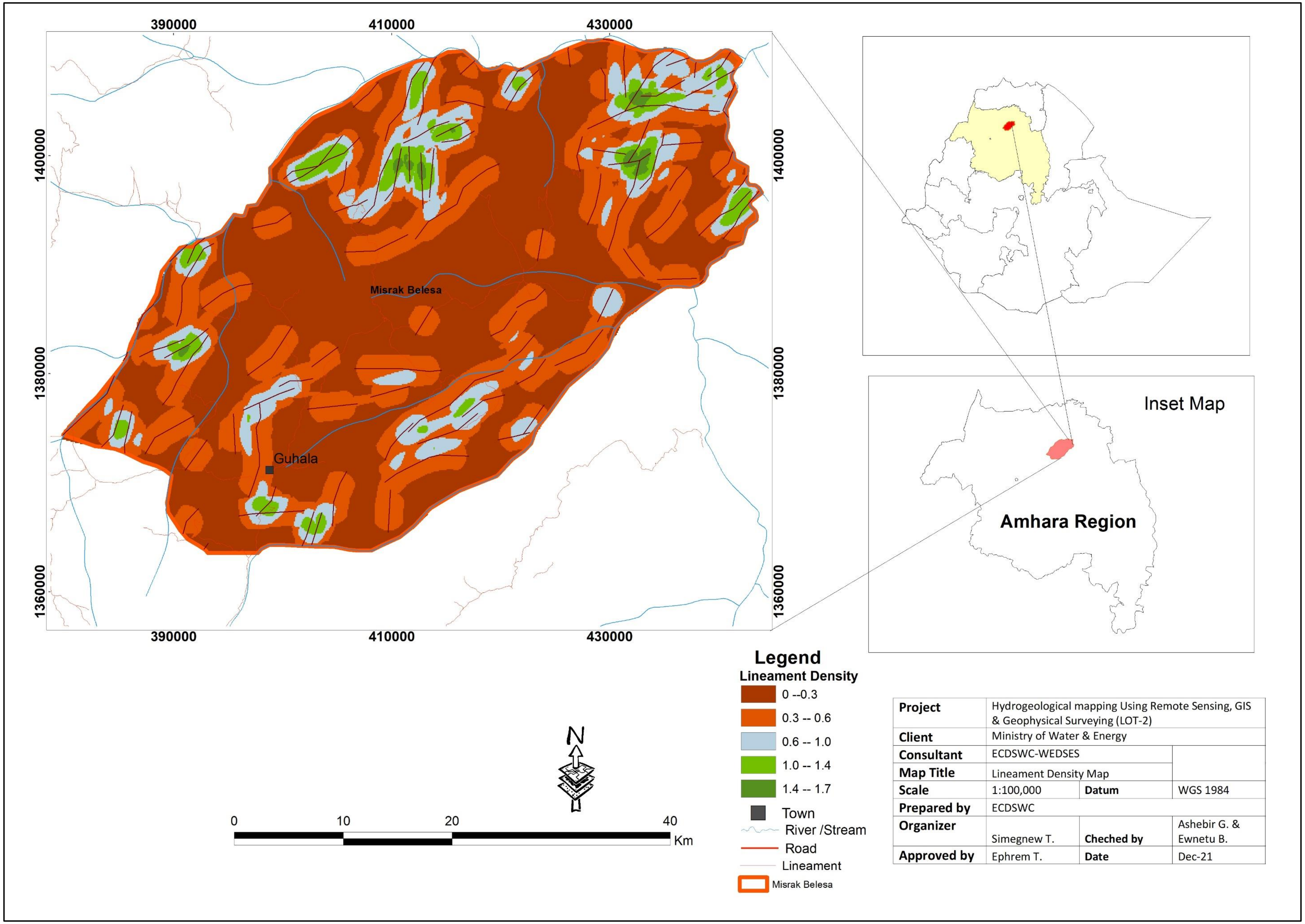
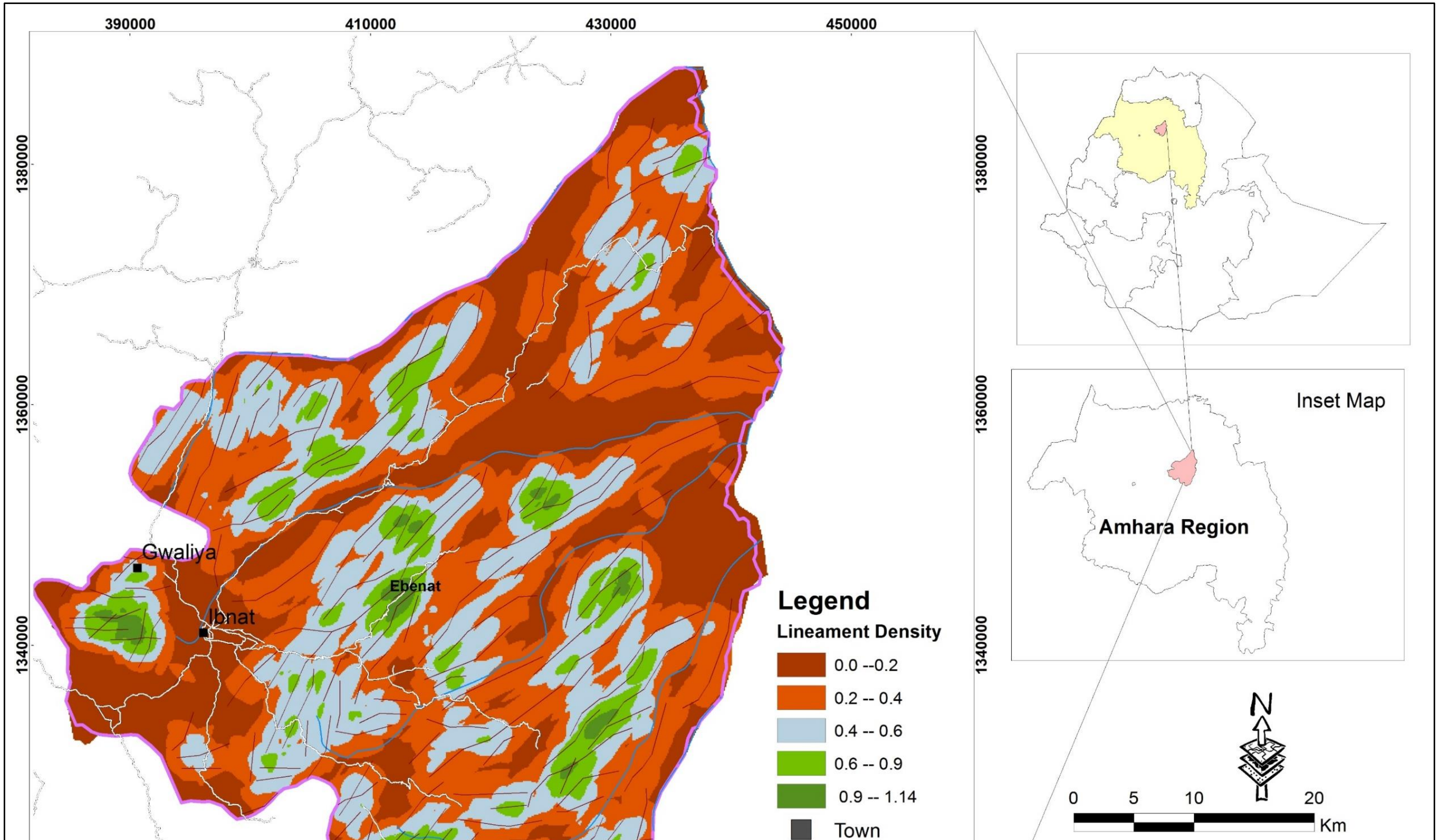


Figure 83: Lineament Density map of Misrak Belesa Wereda



Project	Hydrogeological mapping Using Remote Sensing, GIS & Geophysical Surveying (LOT-2)		
Client	Ministry of Water & Energy		
Consultant	ECDSWC-WEDSES		
Map Title	Lineament Density Map		
Scale	1:100,000	Datum	WGS 1984
Prepared by	ECDSWC		
Organizer	Simegnew T.	Cheched by	Ashebir G. & Ewnetu B.
Approved by	Ephrem T.	Date	Dec-21

Figure 84: Lineament Density map of Ebenat Wereda

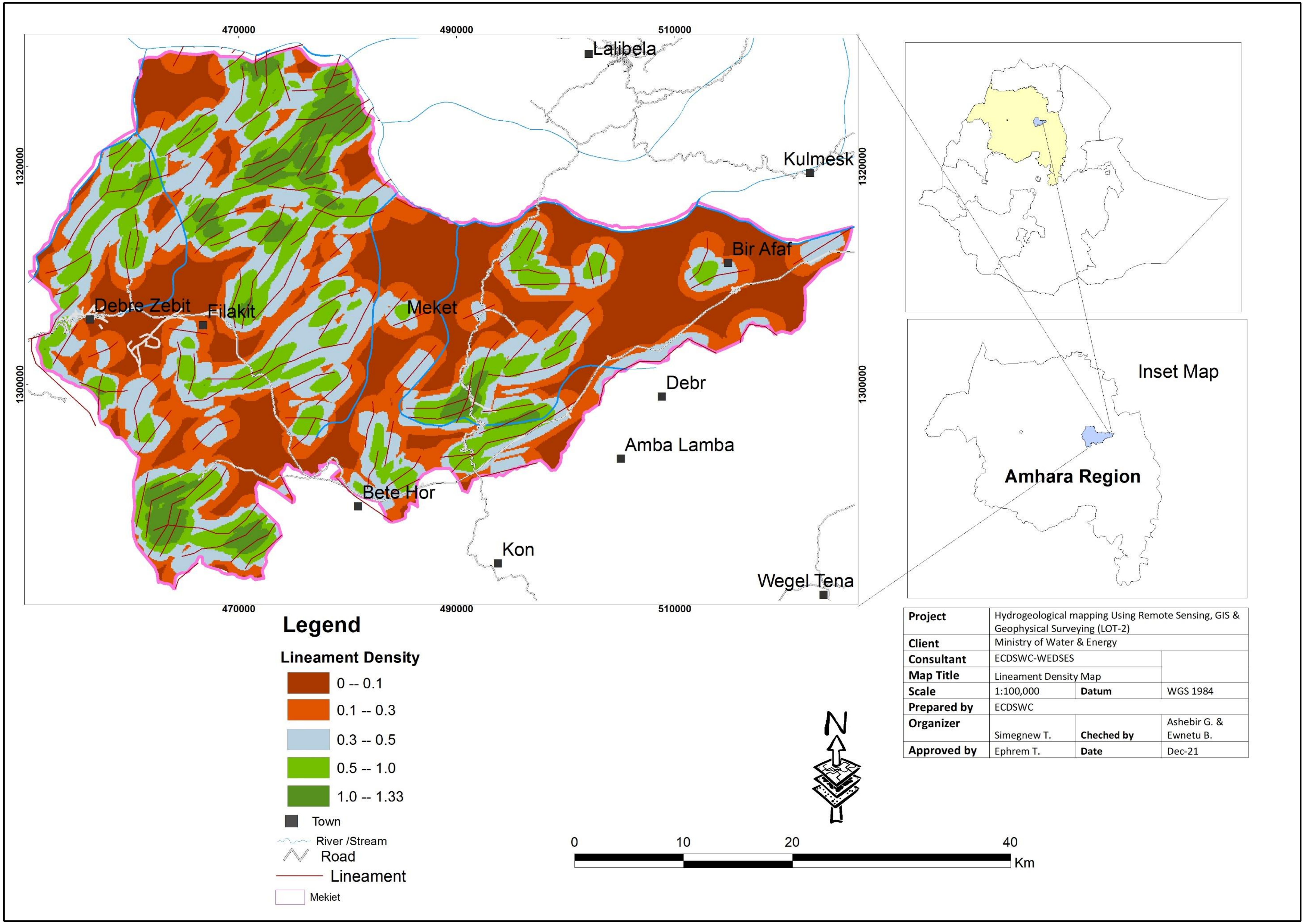


Figure 85: Lineament Density map of Mekiet Wereda

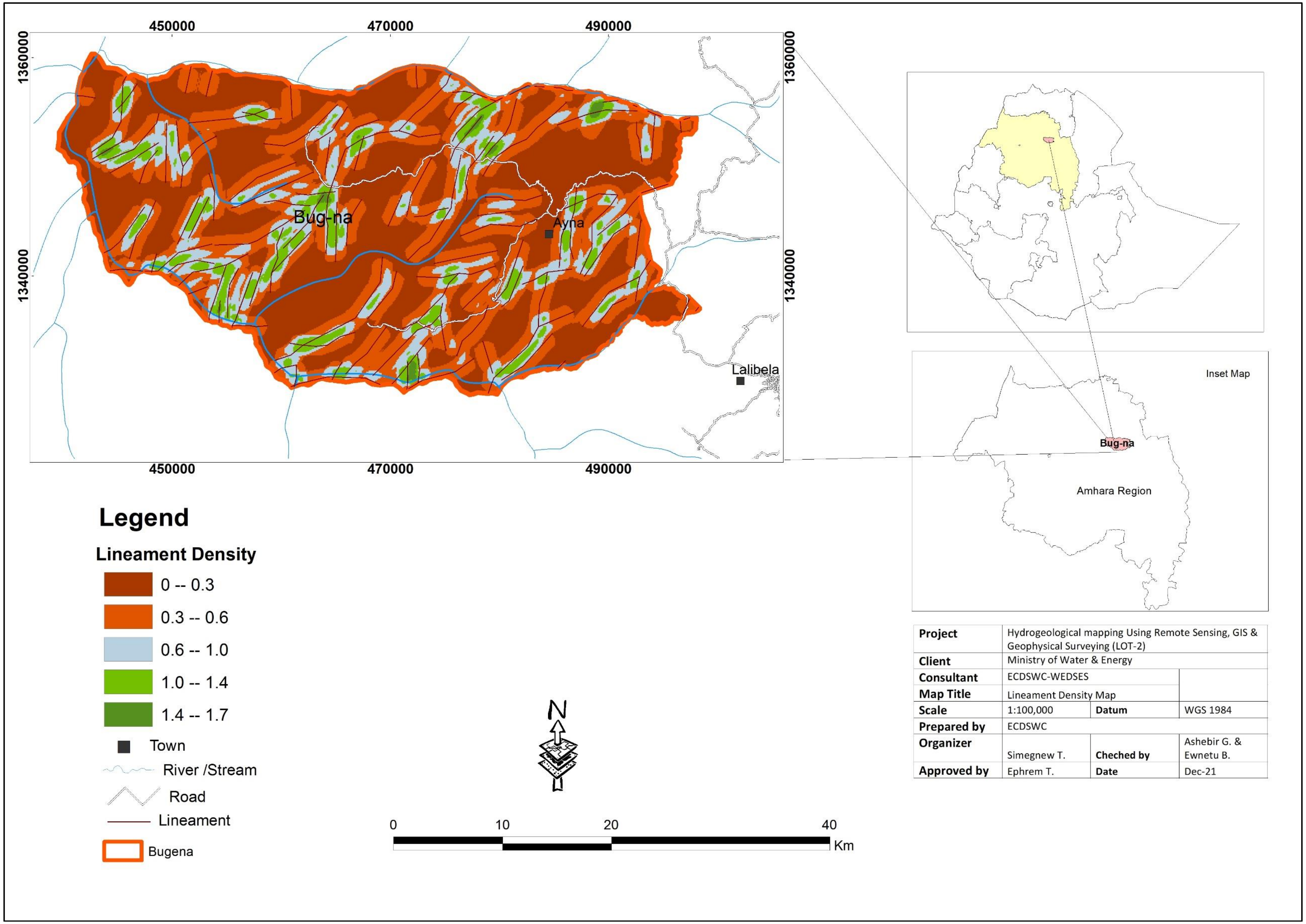


Figure 86: Lineament Density map of Bugna Wereda

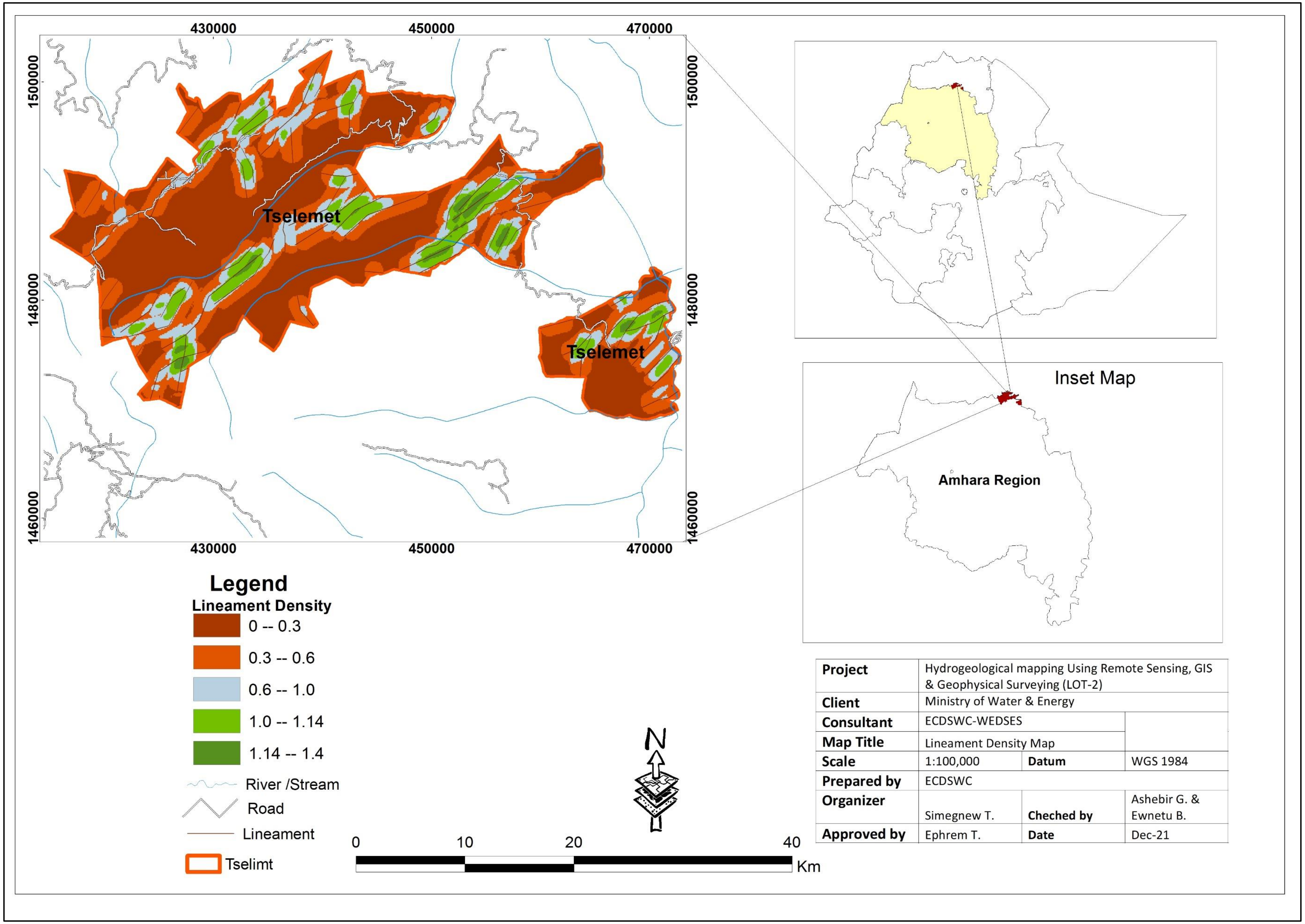


Figure 87: Lineament Density map of Tselemit Wereda

4.2.5 Lineament Proximity thematic layers

There is a close relationship between lineament proximity and groundwater potential. Thus, the intensity of groundwater potential decreases with increasing distance from the lineaments and increases with decreasing distance from the lineament. The proximity from the lineament was derived by creating buffers based on conceptual understanding of the specific project weredas. High weights are assigned to the areas nearby the lineament and low weights to distance locations. The proximity from lineament maps is shown in figures (88 to 101).

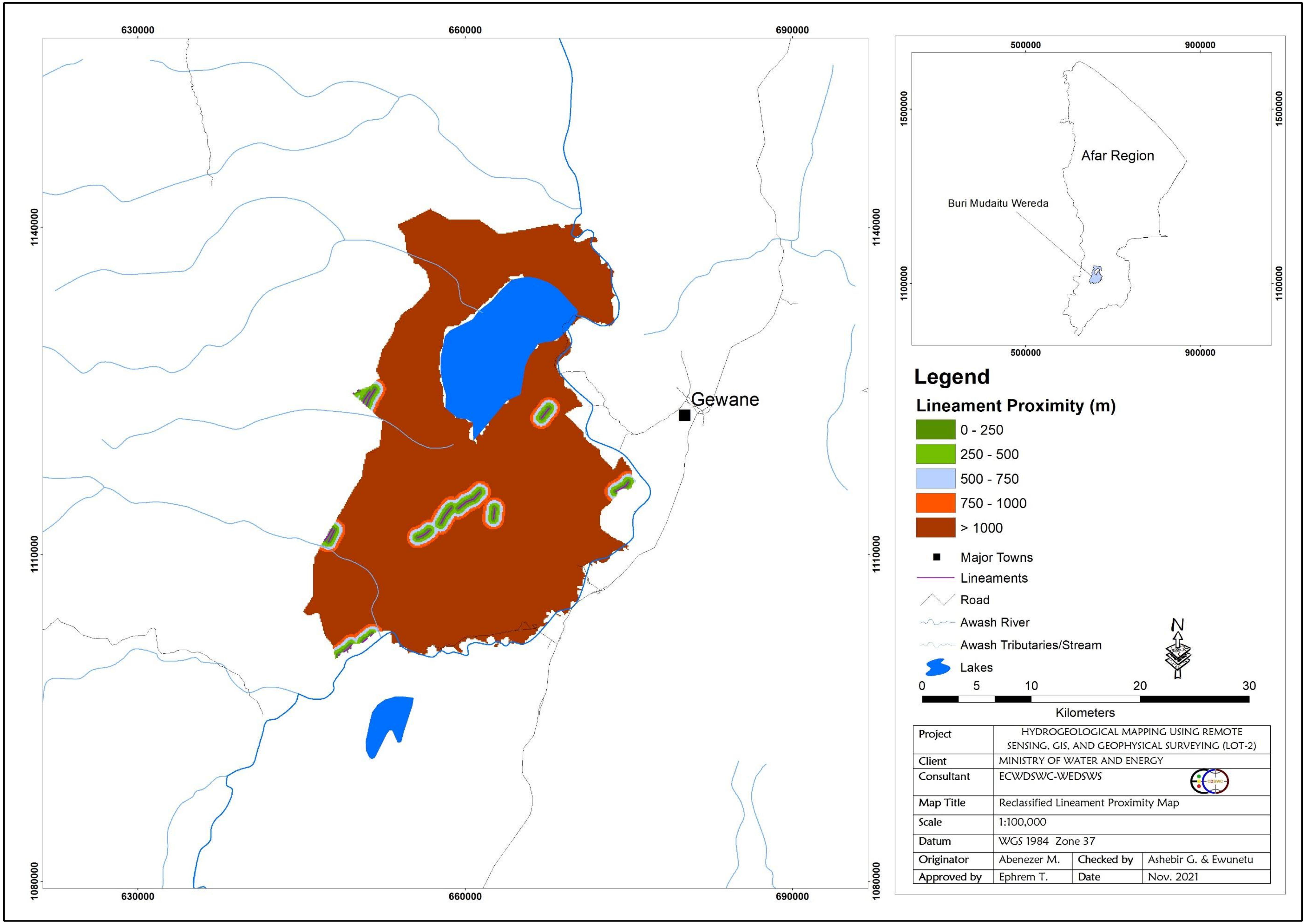


Figure 88: Lineament Proximity Map of Buri Mudaitu Wereda

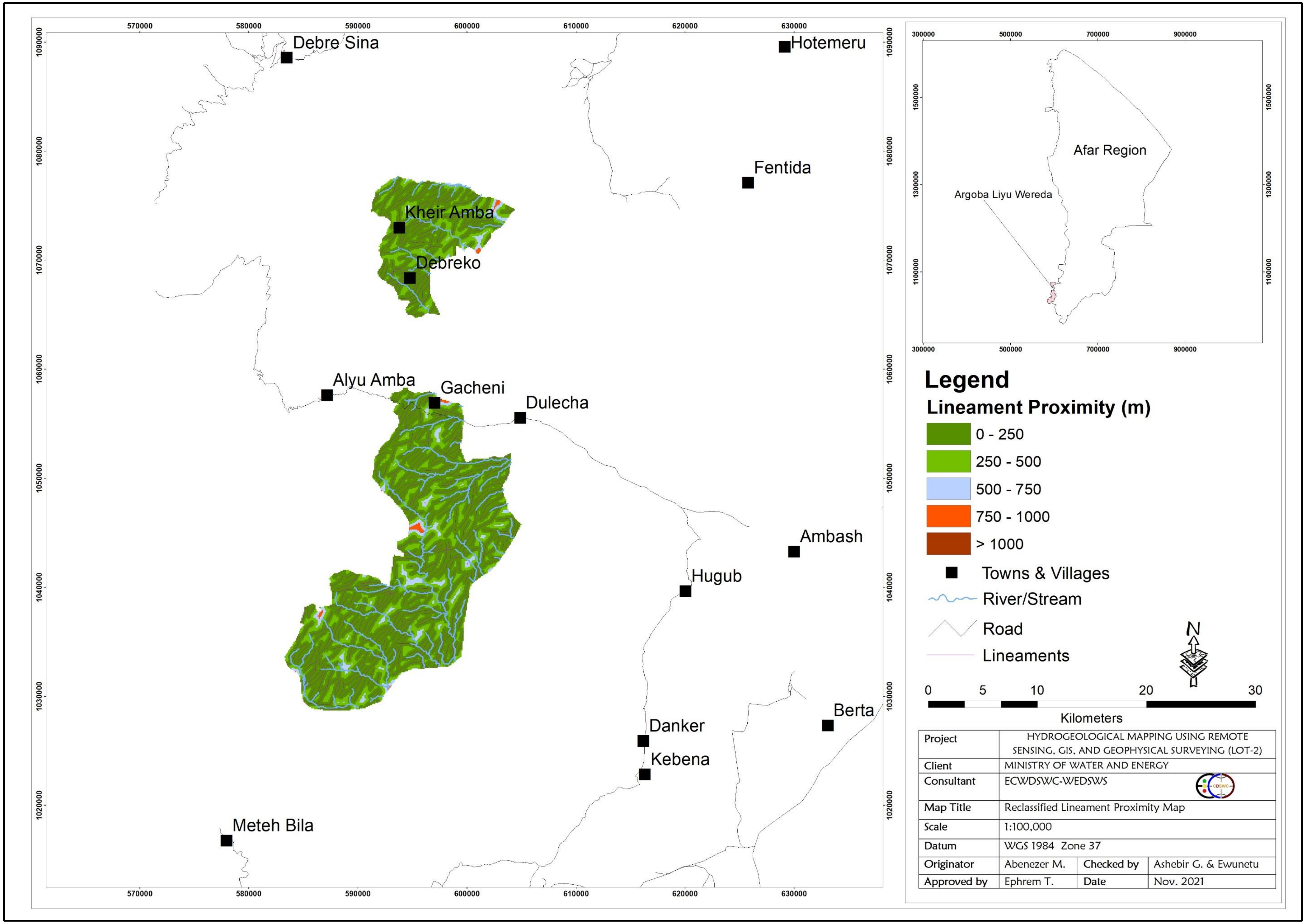


Figure 89: Lineament Proximity Map of Argoba Liyu Wereda

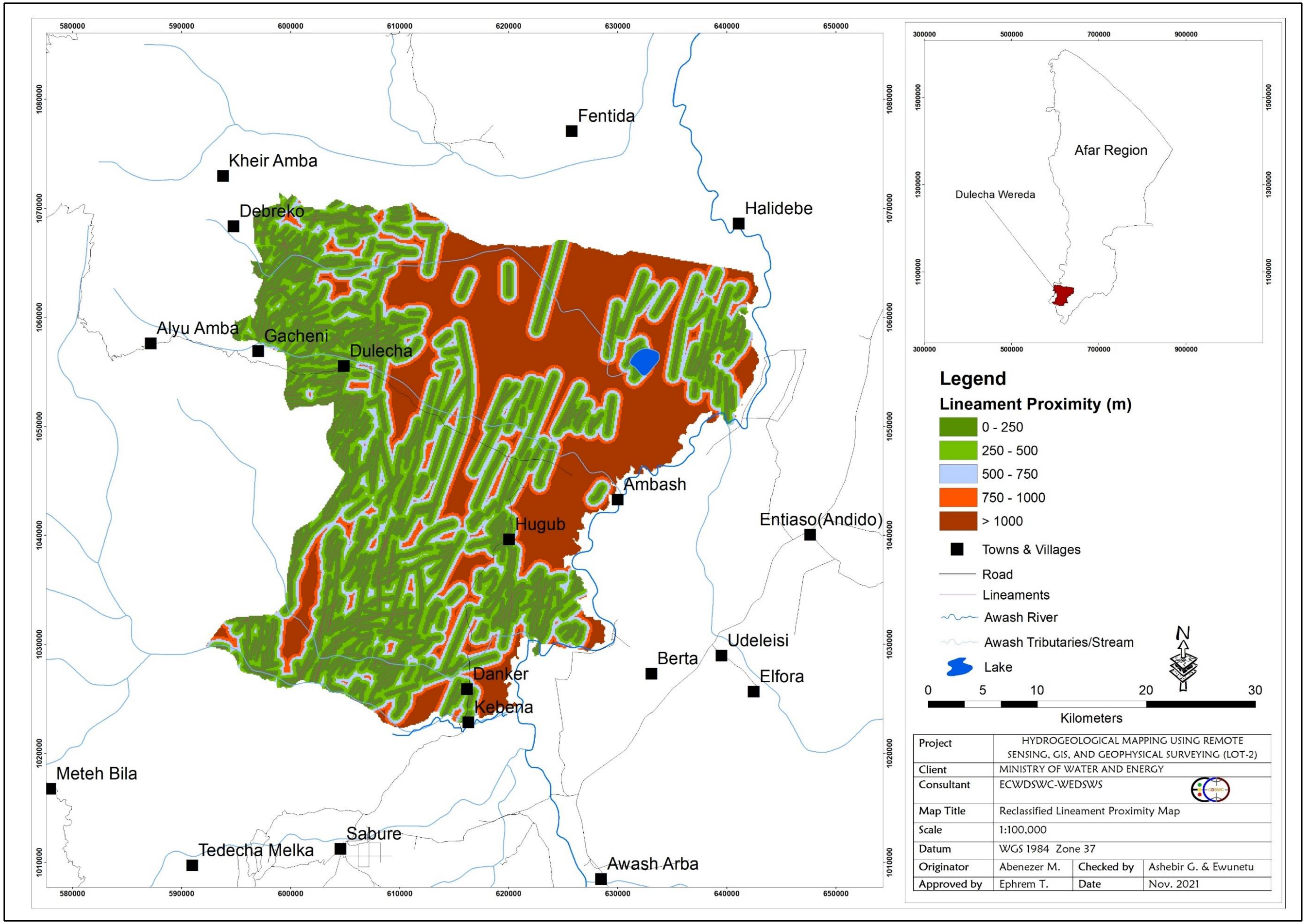
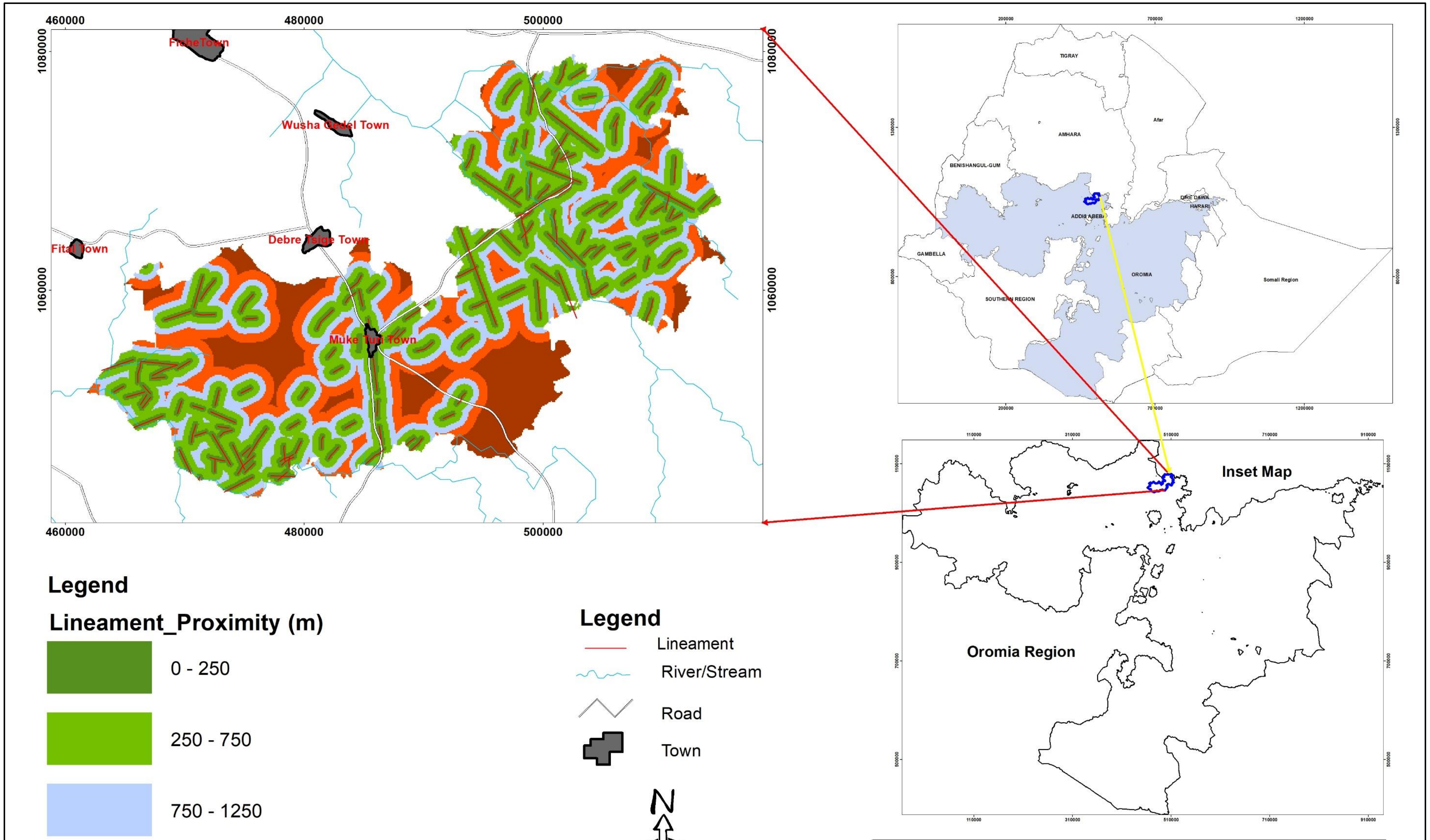


Figure 90: Lineament Proximity Map of Dulecha Wereda



Project	Hydrogeological Mapping Using Remote Sensing ,GIS & Geophysical Surveying (LOT-2)		
Client	Ministry of Water and Energy		
Consultant	ECDSWC-WEDSWS		
Map Title	Lineament Proximity Map		
Scale	1:100,000	Datum	WGS1984
Prepared by	ECDSWC		
Originator	Ashebir G.	Checked	Ewunetu B.
Approved by	Ephrem T.	Date	December,2021

Figure 91: Lineament Proximity Map of Wuchale Wereda

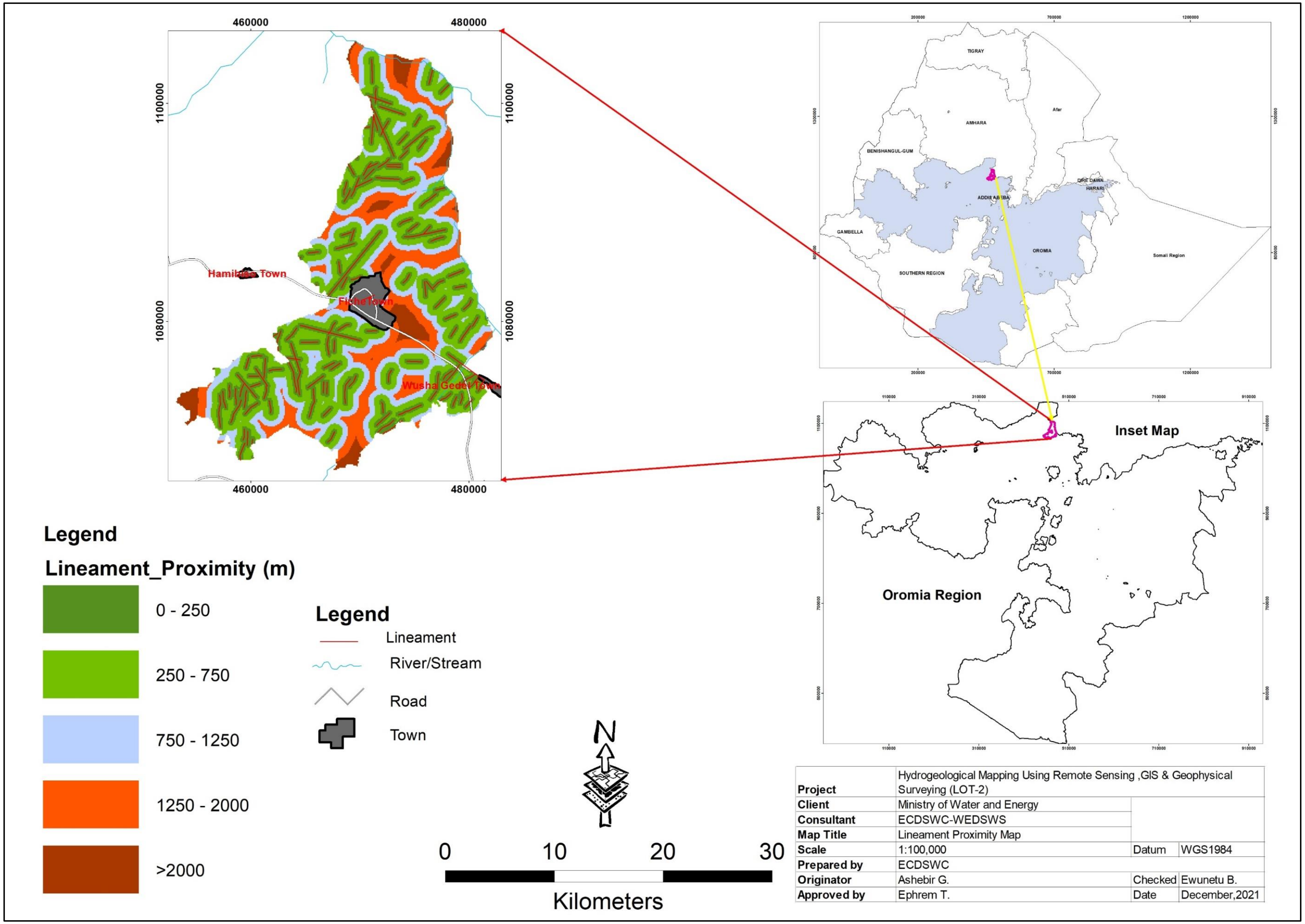


Figure 92: Lineament Proximity Map of Girar Jarso Wereda

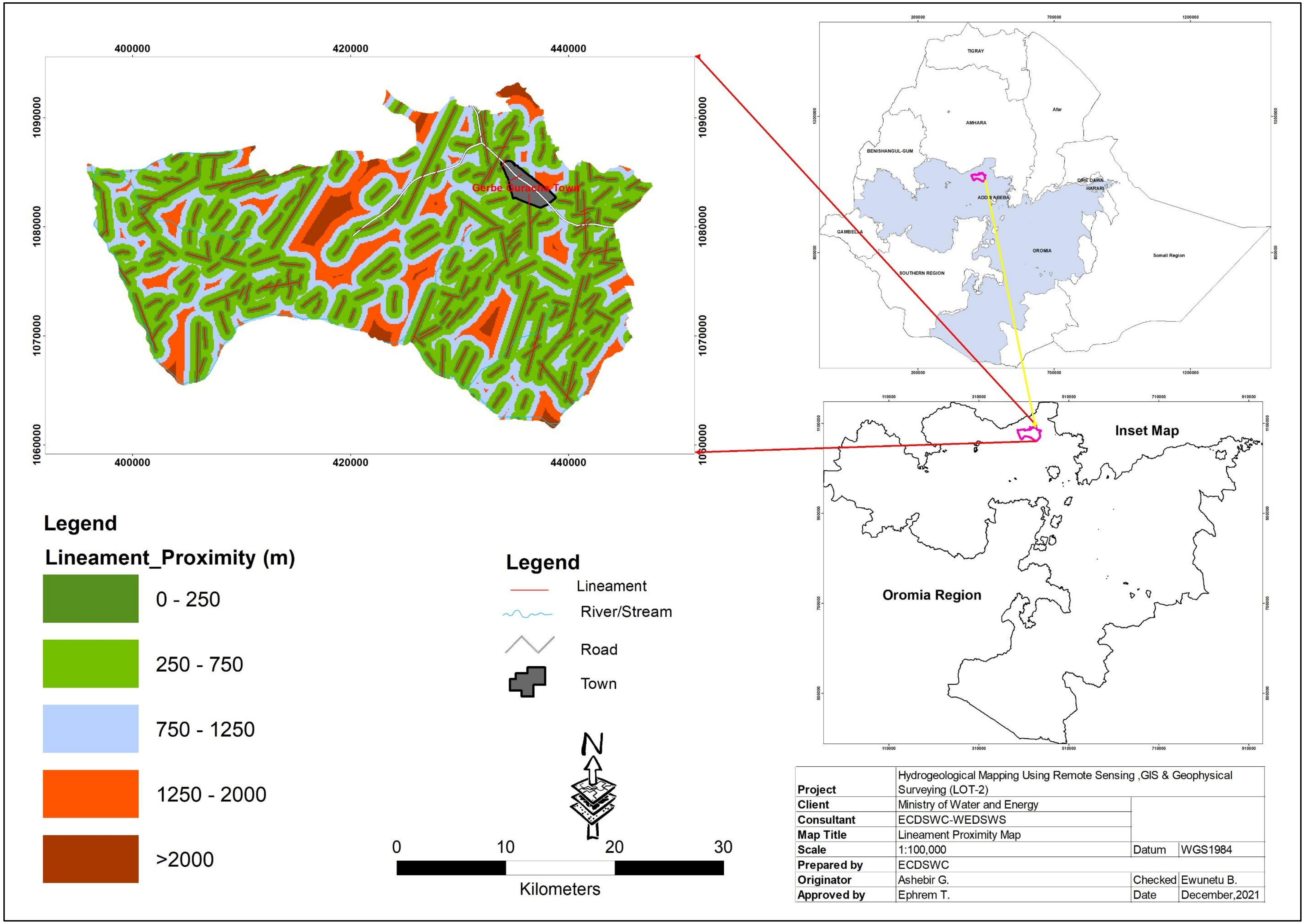


Figure 93: Lineament Proximity Map of Kuyu Wereda

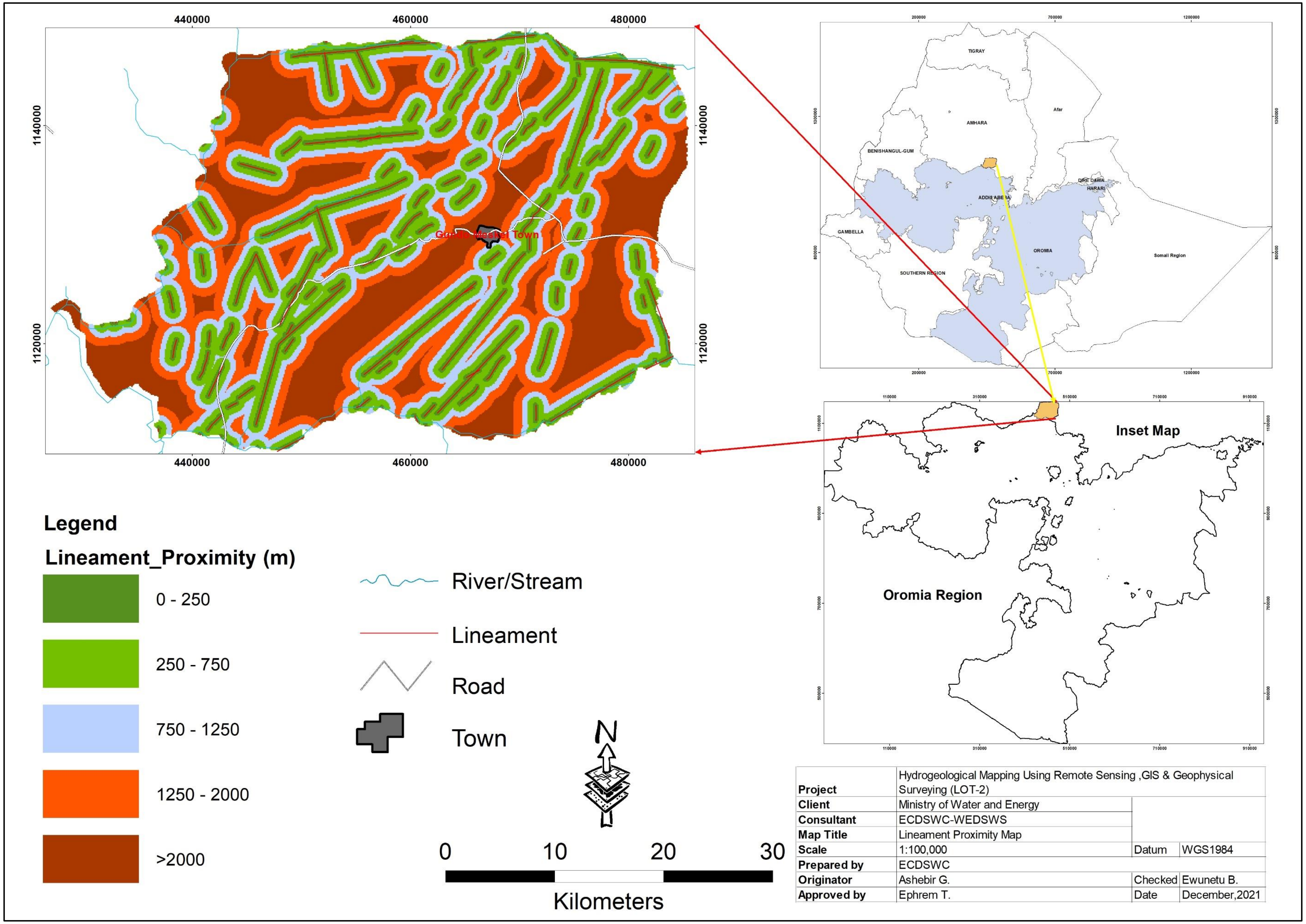


Figure 94: Lineament Proximity Map of Dera Wereda

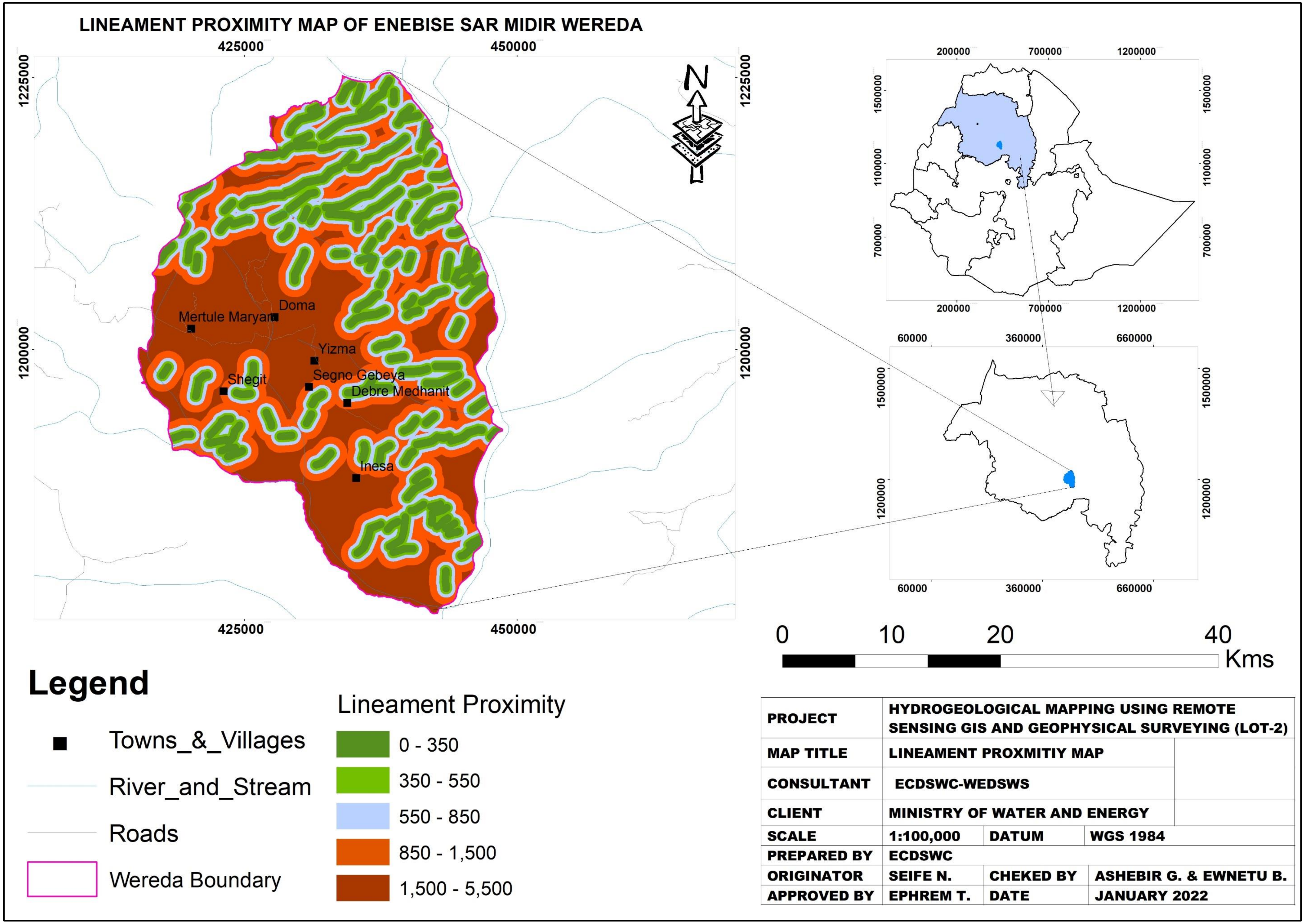


Figure 95: Lineament Proximity Map of Enebise Sar Midir Wereda

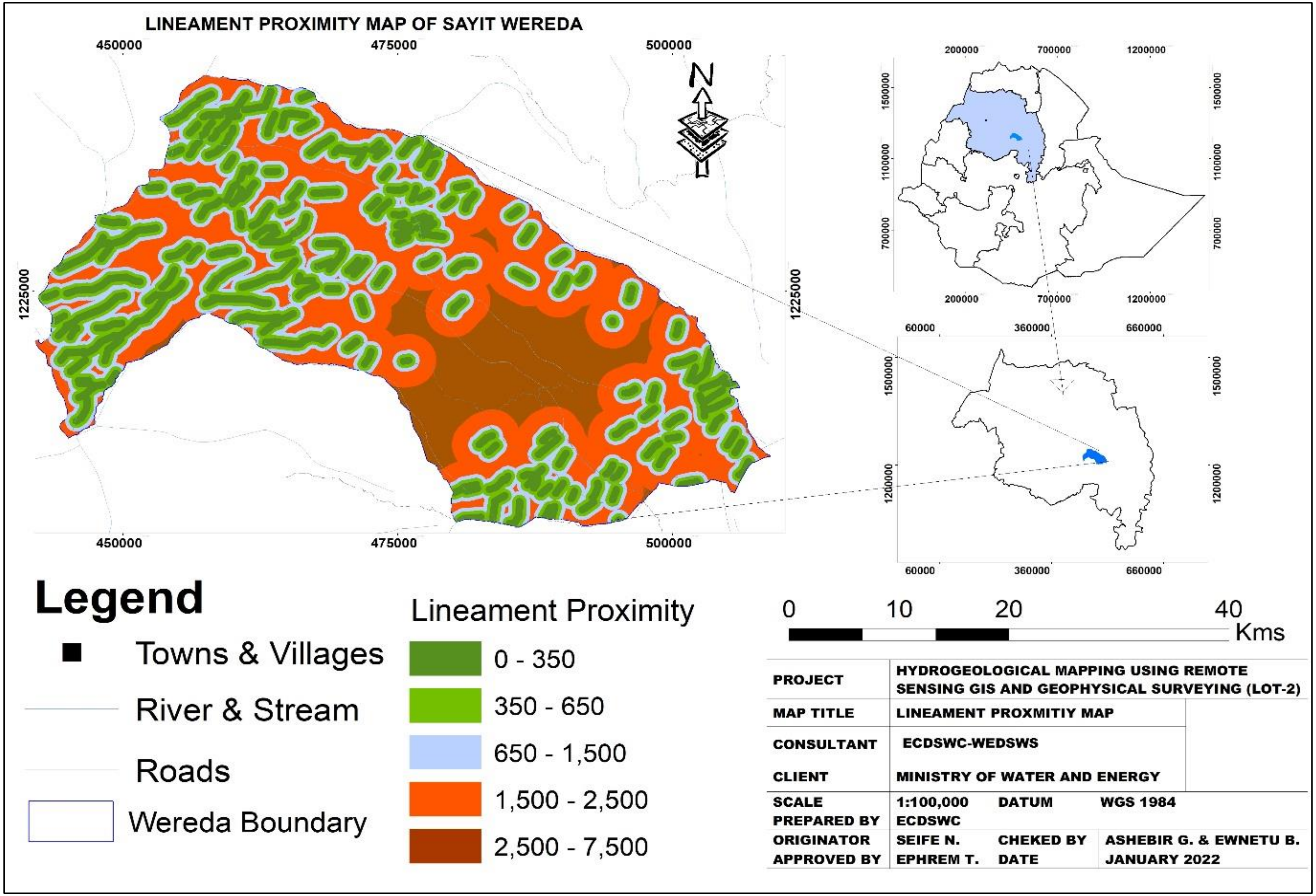


Figure 96: Lineament Proximity Map of Sayit Wereda

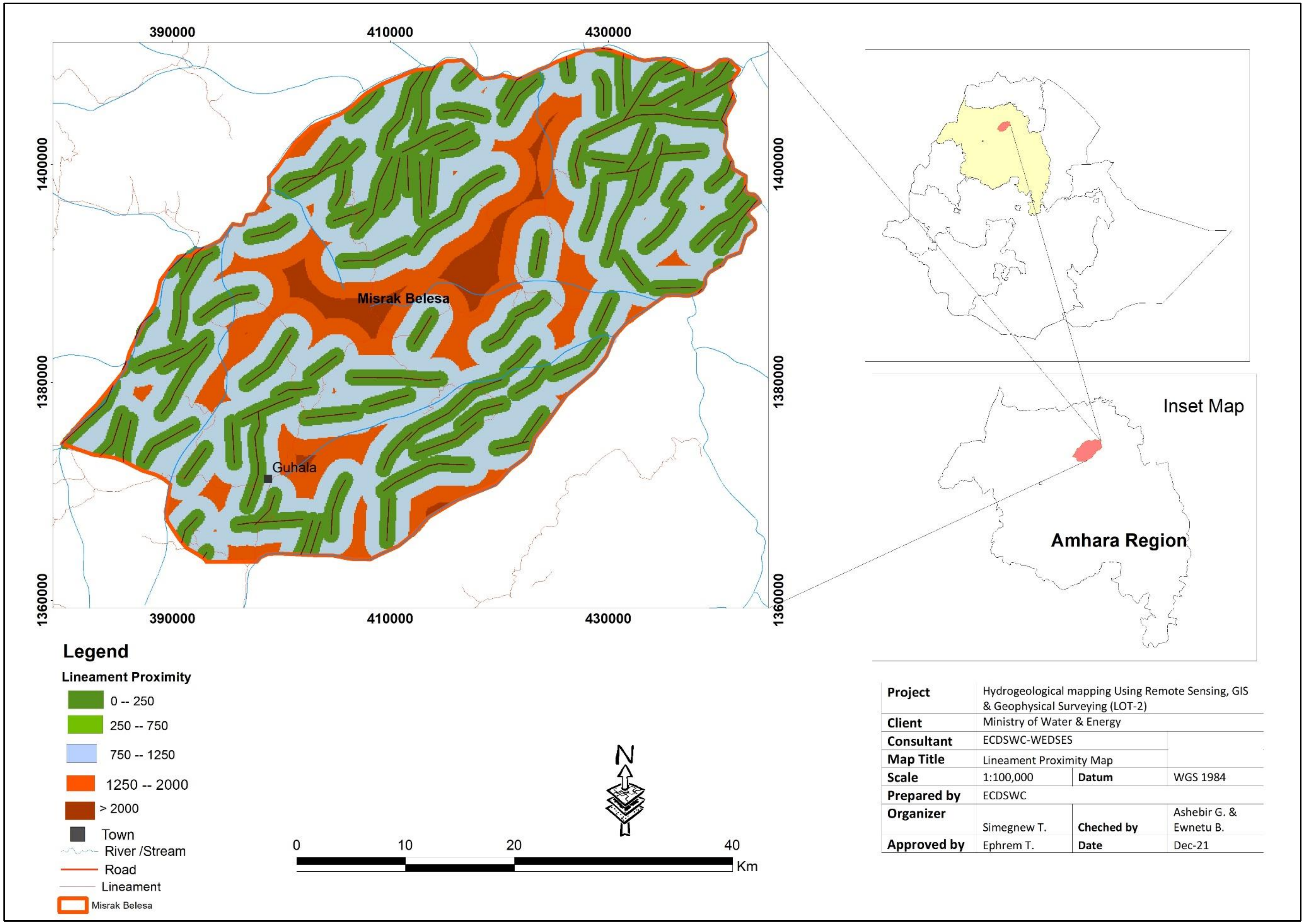


Figure 97: Lineament Proximity Map of Misrak Belesa Wereda

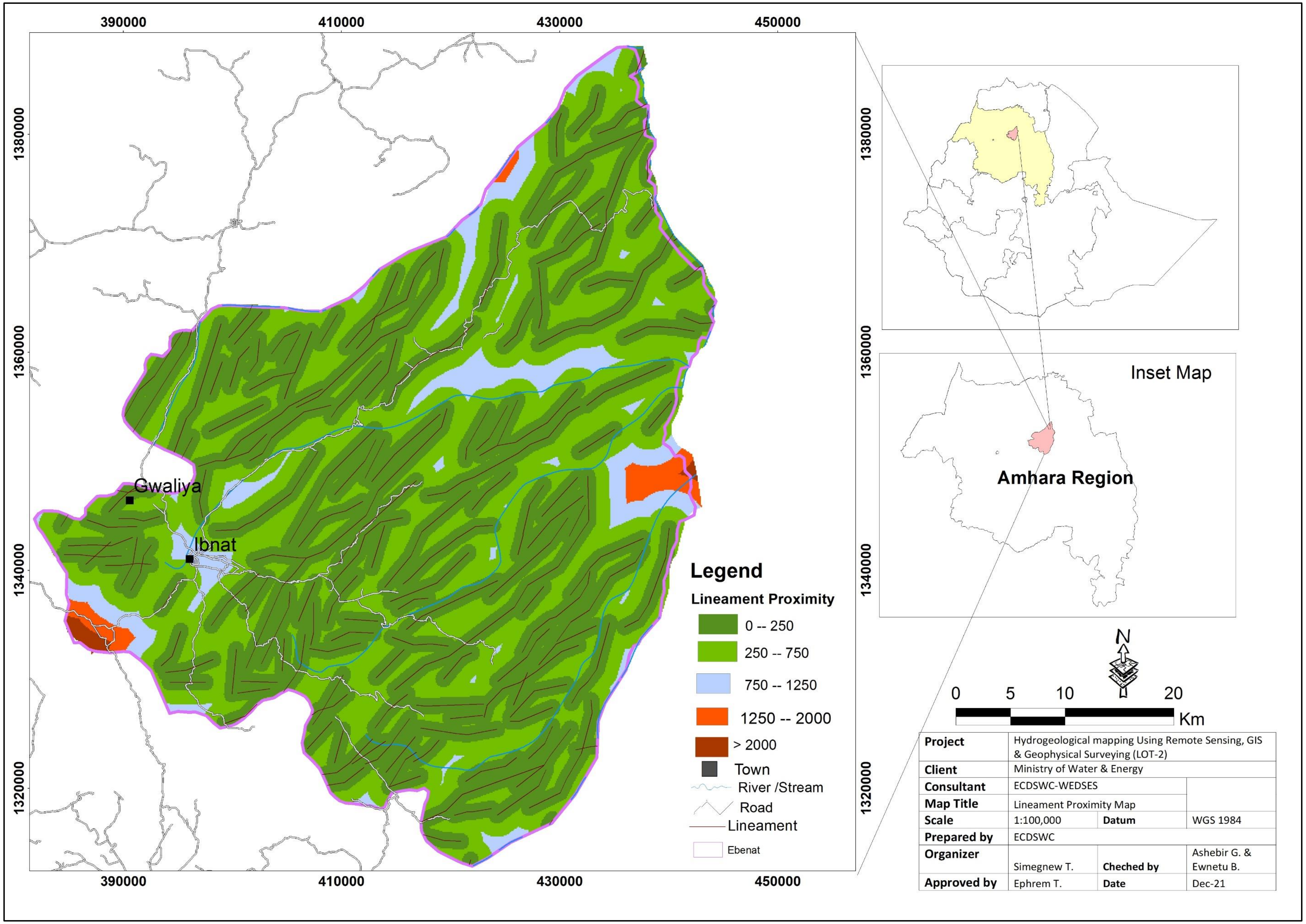


Figure 98: Lineament Proximity Map of Ebenat Wereda

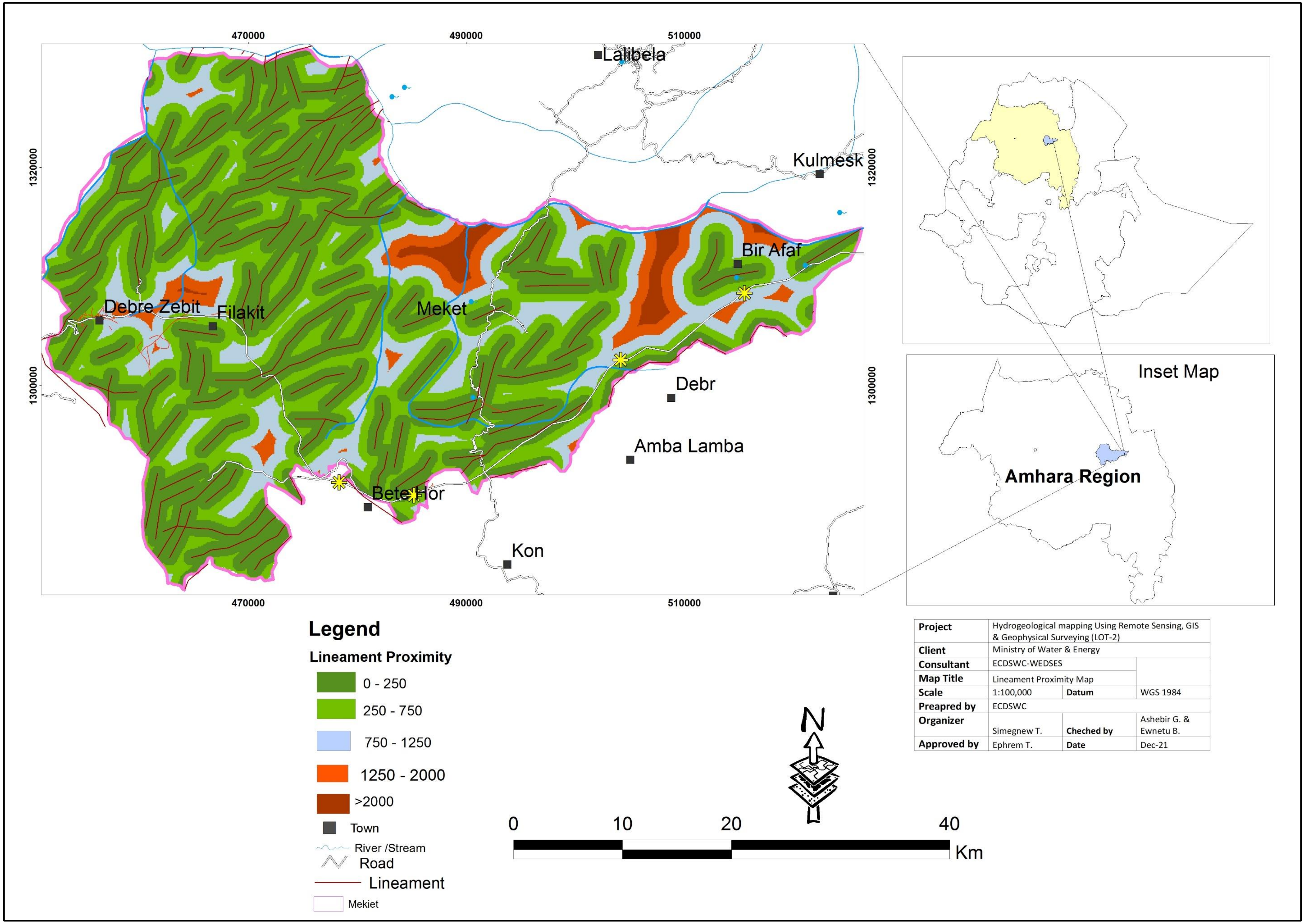


Figure 99: Lineament Proximity Map of Mekiet Wereda

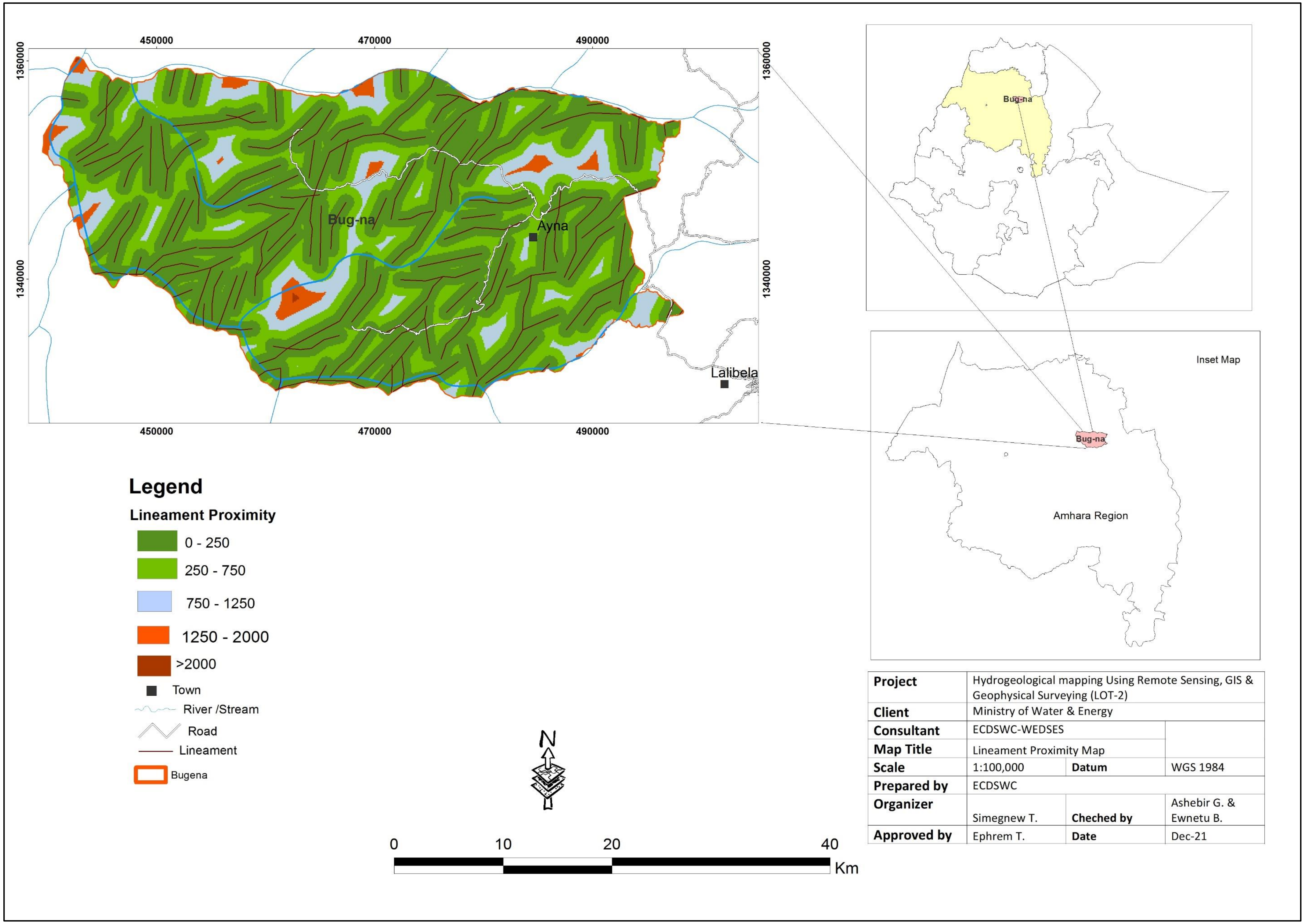


Figure 100: Lineament Proximity Map of Bugna Wereda

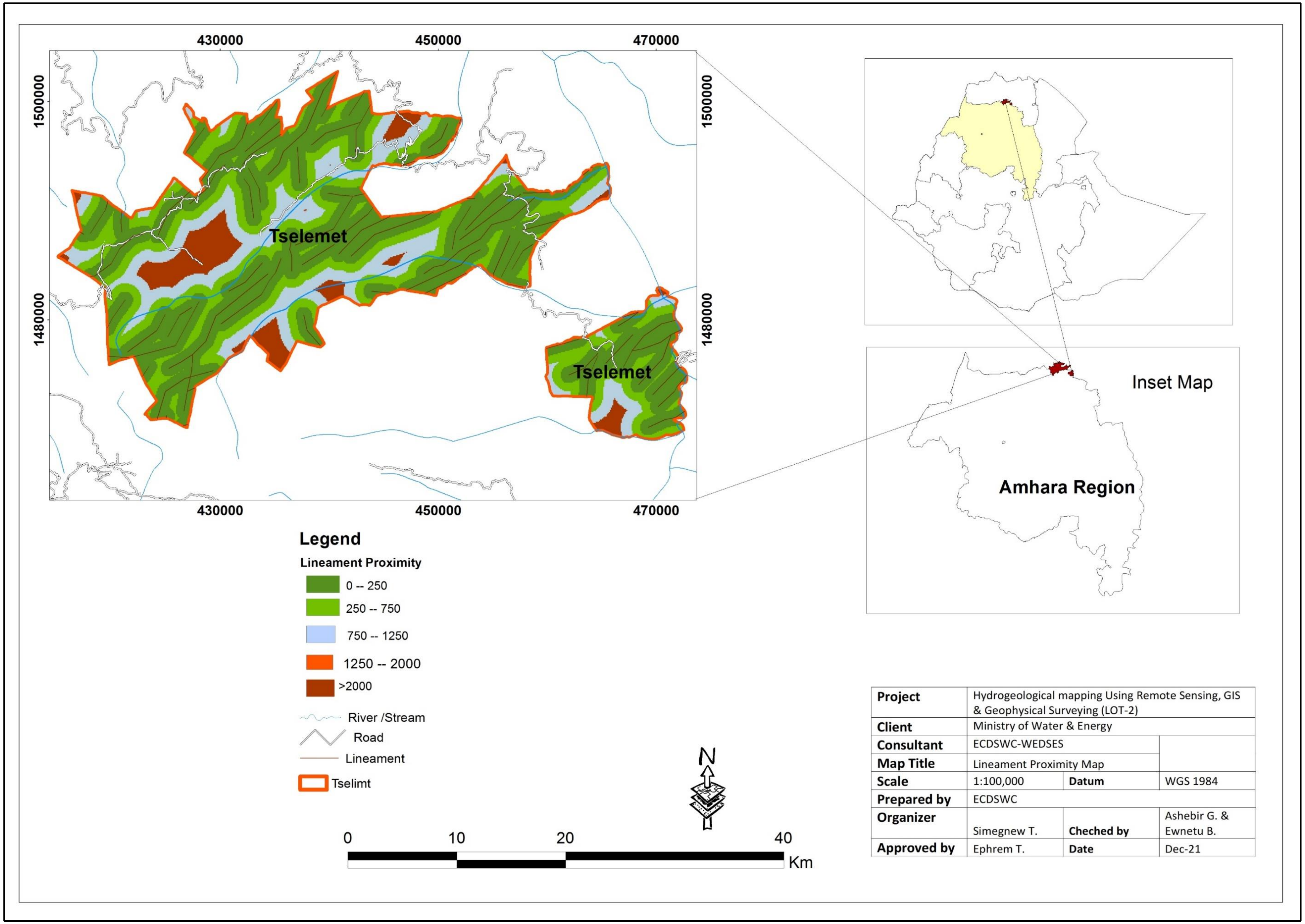


Figure 101: Lineament Proximity Map of Tselemit Wereda

4.3 Overlay analysis

All five thematic layer maps were integrated using ArcGIS 10.8 using the weighted overlay method in the GIS environment to produce the groundwater potential maps of the project weredas. The following formula was used to estimate the groundwater potential maps of the project weredas.

$$\mathbf{GWP} = \sum_{i=1}^{n} wixi \qquad \text{------Eq.7}$$

Where GWP = groundwater potential, Wi = weight for each thematic layer, and Xi = is the ranking of a thematic layer

4.4 Sensitivity analysis

Sensitivity analysis provides important information related to the influence of assigned weights to each thematic layer on the output GWP map. It can indicate which layer is the most / least significant in determining the output map. Hence, single parameter (Napolitano and Fabbri 19996) sensitivity analyses were carried out to justify the influence of thematic layers on the GWP map

The Single – parameter method examines the impact of each thematic layer on the GWP map. This test compares the ‘’effective “or “real” weight for each of the thematic layers with the “Empirical” weight assigned to the same layer in the GWP map. For each thematic layer, the effective weights were calculated using equation (8):

$$W = \frac{\mathbf{PrPw}}{\mathbf{GWP}} * \mathbf{100} \qquad \text{------Eq.8}$$

Where W is the effective weight of each thematic layer

Pr and Pw are the rates and weight values of each thematic layer

GWP is the groundwater potential map generated using all the thematic layers.

4.4.1 Single parameter Sensitivity analysis of Argoba Special

The statistics of the single-parameter sensitivity analysis of Argoba Wereda are shown in Table 43. There are some deviations in the effective weights when compared to the empirical weights. The single–parameter analysis of Argoba Wereda shows recharge as the most effective layer in GWP mapping with mean effective weights of 40%. The lineament proximity tends to be a less effective thematic layer with mean effective weightings of 3.3% compared with its empirical weights of 4.36%. The values of mean effective and empirical weight are different for all thematic layers.

Table 43: Effective weight of single parameter sensitivity analyses of Argoba wereda

The effective weight of Single parameter Sensitivity analysis of Argoba Wereda					
Effective Weight (%)					
	Empirical Weight (%)	Min	Mean	Max	SD
Lithology	51.63	20.8	32.2	46.3	0.195
Recharge	29.06	37.4	40.0	42.5	1.2
LD	10.59	15.2	19.2	23.0	1.2
LP	4.36	2.7	3.3	4.0	0.54
TWI	4.36	4.5	5.5	6.4	1.048

4.4.2 Single parameter Sensitivity analysis of Bure Mudayitu

The statistics of the single-parameter sensitivity analysis of Buri Mudayitu Wereda are shown in Table 44. There are some deviations in the effective weights when compared to the empirical weights. The single–parameter analysis of Buri Mudayitu Wereda shows Lithologic units as the most effective layer in GWP mapping with mean effective weights of 63.6%.The lineament density tends to be a less effective thematic layer with the mean effective weight of 4.8% compared with its empirical weights of 8.58%. The values of mean effective and empirical weight are close to each other for Lithologic units, recharge, and TWI layers.

Table 44: Effective weight of single parameter sensitivity analyses of Buri Mudayitu wereda

The effective weight of Single parameter Sensitivity analysis of Buri Mudayitu Wereda					
Effective Weight (%)					
	Empirical Weight (%)	Min	Mean	Max	SD
Lithology	66.1	58.4	63.6	68.9	1.11
Recharge	9.99	9.1	12.1	15.0	1.02
LD	8.58	4.2	4.8	5.5	0.5
LP	8.16	17.6	20.0	22.8	0.645
TWI	7.17	6.4	8.0	9.5	1.12

4.4.3 Single parameter Sensitivity analysis of Dulecha

The statistics of the single-parameter sensitivity analysis of Dulecha Wereda are shown in Table 45. There are some deviations in the effective weights when compared to the empirical weights. The single–parameter analysis of Dulecha Wereda shows Lithologic units as the most effective layer in GWP mapping with mean effective weights of 41.6%.The TWI and lineament proximity tend to be less effective thematic layers with the mean effective weight of 4.1% and 4.7%. The values of mean effective and empirical weight are close to each other for all layers.

Table 45: Effective weight of single parameter sensitivity analyses of Dulecha wereda

The effective weight of Single parameter Sensitivity analysis of Dulecha Wereda					
Effective Weight (%)					
	Empirical Weight (%)	Min	Mean	Max	SD
Lithology	35.65	29.9	41.6	53.5	1.42
Recharge	28.52	20.6	24.7	28.8	1.36
LD	26.84	19.6	24.8	29.9	1.27
LP	4.66	4.0	4.7	5.4	1.6
TWI	4.34	3.6	4.1	4.6	1.09

4.4.4 Single parameter Sensitivity analysis of Wuchale wereda

The statistics of the single-parameter sensitivity analysis of Wuchale Wereda are shown in Table 46. There are some deviations in the effective weights when compared to the empirical weights. The single–parameter analysis of Wuchale Wereda shows Lithologic units as the most effective layer in GWP mapping with mean effective weights of 56.8%.The TWI and Lineament density tend to be less effective thematic layers with mean effective weightings of 9.3% and 3.4% respectively compared with their empirical weights of 11.9% and 4.6%. The values of mean effective and empirical weight are close to each other for groundwater recharge and Lineament proximity layers.

Table 46: Effective weight of single parameter sensitivity analyses of Wuchale wereda

The effective weight of Single parameter Sensitivity analysis of Wuchale wereda					
Effective Weight (%)					
	Empirical Weight (%)	**Min**	**Mean**	**Max**	**SD**
Lithology	30.7	43.6	56.8	68.7	0.9
Recharge	25.1	19.0	25.3	31.8	2.3
TWI	11.9	7.9	9.3	10.8	0.4
LD	4.6	2.8	3.4	4.0	0.9
LP	4.5	4.2	4.7	5.3	0.3

4.4.5 Single parameter Sensitivity analysis of Girar Jarso Wereda

The statistics of the single-parameter sensitivity analysis of Girar Jarso Wereda are shown in Table 47. There are some deviations in the effective weights when compared to the empirical weights. The single–parameter analysis of Girar Jarso Wereda shows Lithologic units as the most effective layer in GWP mapping with mean effective weights of 52.9%.The next higher effective weighs of 27.4 % were recorded in the groundwater recharge layer. The TWI and Lineament density tend to be less effective thematic layers with mean effective weightings of 10.1% and 3.8% respectively compared with their empirical weights of 11.9% and 4.6%. The values of mean effective and empirical weight are close to each other for the Lineament proximity layers.

Table 47: Effective weight of single parameter sensitivity analyses of Girar Jarso wereda

The effective weight of Single parameter Sensitivity analysis of Girar Jarso Wereda					
Effective Weight (%)					
	Empirical Weight (%)	**Min**	**Mean**	**Max**	**SD**
Lithology	30.7	39.7	52.9	65.5	13.2
Recharge	25.1	20.7	27.4	34.2	4.7
TWI	11.9	8.5	10.1	11.7	1.5
LD	4.6	3.1	3.8	4.4	1.0
LP	4.5	5.2	5.9	6.6	0.5

4.4.6 Single parameter Sensitivity analysis of Kuyu Wereda

The statistics of the single-parameter sensitivity analysis of Kuyu Wereda are shown in Table 48. There are some deviations in the effective weights when compared to the empirical weights. The single–parameter analysis of Kuyu Wereda shows Lithologic units as the most effective layer in GWP mapping with mean effective weights of 47.2%.The next higher effective weighs of 26.7 % and 9.7% were recorded in groundwater recharge and Lineament proximity layers. The TWI and Lineament density tend to be less effective thematic layers with mean effective weightings of 9.3% and 6.6% respectively compared with their empirical weights of 11.7% and 7.6%.

Table 48: Effective weight of single parameter sensitivity analyses of Kuyu wereda

The effective weight of Single parameter Sensitivity analysis of Kuyu Wereda					
		Effective Weight (%)			
	Empirical Weight (%)	**Min**	**Mean**	**Max**	**SD**
Lithology	48.3	40.2	47.2	54.4	8.5
Recharge	25.4	21.2	26.7	32.2	5.6
TWI	11.7	7.1	9.3	11.6	1.0
LD	7.6	5.4	6.6	7.8	0.4
LP	7.1	8.5	9.7	10.9	0.5

4.4.7 Single parameter Sensitivity analysis of Wuchale Wereda

The statistics of the single-parameter sensitivity analysis of Wuchale Wereda are shown in Table 49. There are some deviations in the effective weights when compared to the empirical weights. The single–parameter analysis of Wuchale Wereda shows Lithologic units as the most effective layer in GWP mapping with mean effective weights of 48.2%.The next higher effective weighs of 25 % and 10.4% were recorded in groundwater recharge and Lineament density layers. The TWI and Lineament proximity tend to be less effective thematic layers with mean effective weightings of 9.6% and 6.3% respectively compared with their empirical weights of 11.7% and 7.1%.

Table 49: Effective weight of single parameter sensitivity analyses of Dera wereda

The effective weight of Single parameter Sensitivity analysis of Dera wereda					
		Effective Weight (%)			
	Empirical Weight (%)	**Min**	**Mean**	**Max**	**SD**
Lithology	48.3	41.1	48.2	55.2	5.95
Recharge	25.4	19.8	25.0	30.3	0.79
TWI	11.7	7.3	9.6	12.0	2.22
LD	7.6	8.5	10.4	12.4	1.75
LP	7.1	5.5	6.3	7.9	0.32

4.4.8 Single parameter Sensitivity analysis of Sayit

The statistics of the single-parameter sensitivity analysis of Sayit Wereda are shown in Table 50. There are some deviations in the effective weights when compared to the empirical weights. The single–parameter analysis of Sayit Wereda shows groundwater recharge as the most effective layer in GWP mapping with mean effective weights of 46.00%. The next higher effective weighs of 21.21 % and 13.62% were recorded in Lithologic units and TWI layers respectively. In addition, the Lineament density and Lineament proximity tend to be almost effective thematic layers with mean effective weightings of 9.80% and 9.67% when compared with its empirical weights of 8.4% and 5.8% respectively.

Table 50: Effective weight of single parameter sensitivity analyses of Sayit Wereda

Thematic Layers	Empirical Weight (%)	Effective Weight (%)			
		Min	Mean	Max	SD
Lithology	42.9	18.58	21.21	23.32	2.37
Recharge	30	41.06	46.00	47.58	3.40
TWI	12.9	10.98	13.62	15.40	2.22
Lineament Density	8.4	7.58	9.80	11.38	1.91
Lineament Proximity	5.8	7.83	9.67	10.89	1.54

4.4.9 Single parameter Sensitivity analysis of Enebsie Sar Midir

The statistics of the single-parameter sensitivity analysis of Enebise Sar Midir Wereda are shown in Table 51. There are some deviations in the effective weights when compared to the empirical weights. The single–parameter analysis of Enebise Sar Midir Wereda shows groundwater recharge and Lithologic units as the most effective layer in GWP mapping with mean effective weights of 44.55% and 29.45% respectively. The next higher effective weight of 8.90% was recorded in the Lineament proximity layer. The TWI and Lineament density tend to be less effective thematic layers with mean effective weightings of 11.10% and 6.01% when compared with their empirical weights of 12.9% and 8.4% respectively.

Table 51: Effective weight of single parameter sensitivity analyses of Enebise Sar Midir wereda

Thematic Layers	Empirical Weight (%)	Effective Weight (%)			
		Min	Mean	Max	SD
Lithology	42.9	25.22	29.45	31.65	3.27
Recharge	30	40.75	44.55	48.36	3.81
TWI	12.9	10.51	11.10	13.66	1.67
Lineament Density	8.4	4.67	6.01	7.08	1.21
Lineament Proximity	5.8	7.33	8.90	10.20	1.44

4.4.10 Single parameter Sensitivity analysis of Misrak Belesa

The statistics of the single-parameter sensitivity analysis of Misrak Belesa Wereda are shown in Table 52. There are some deviations in the effective weights when compared to the empirical weights. The single–parameter analysis of Misrak Belesa Wereda shows Lithologic units as the most effective layer in GWP mapping with a mean effective weight of 57.5%. The TWI tend to be less effective thematic layers with mean effective weightings of 2.5% compared with their empirical weights of lineament density, Lineament proximity, and groundwater recharge 13.6%, 13.3, and 13.0% respectively. The values of mean effective and empirical weight are close to each other for TWI and Lineament proximity layers.

Table 52: Effective weight of single parameter sensitivity analyses of Misrak Belesa wereda

Effective Weight (%)					
	Empirical Weight (%)	Min	Mean	Max	SD
Lithology	41.3	53.1	57.5	61.1	2.05
Recharge	21.5	13.8	13.0	12.2	0.14
LD	21.5	14.5	13.6	12.8	0.15
LP	11.3	14.2	13.3	12.5	0.32
TWI	4.4	2.6	2.5	2.3	0.12

4.4.11 Single parameter Sensitivity analysis of Ebenat

The statistics of the single-parameter sensitivity analysis of Ebenat Wereda are shown in Table 53. There are some deviations in the effective weights when compared to the empirical weights. The single–parameter analysis of Ebenat Wereda shows Lithologic units as the most effective layer in GWP mapping with mean effective weights of 44.8%. The next higher effective weighs of 19.4 % and 16.7% and 16.1% were recorded in Lineament density, Lineament proximity, and groundwater recharge layers respectively. In addition, the TWI tends to be almost effective thematic layers with mean effective weightings of 2.7% when compared with its empirical weights of 4.4% and.

Table 53: Effective weight of single parameter sensitivity analyses of Ebenat wereda

The effective weight of Single parameter Sensitivity analysis of Ebenat Wereda					
Effective Weight (%)					
	Empirical Weight (%)	Min	Mean	Max	SD
Lithology	41.3	41.0	44.8	48.7	0.1
Recharge	21.5	17.1	16.1	15.0	0.3
LD	21.5	20.6	19.4	18.0	0.3
LP	11.3	17.9	16.7	15.6	0.2

4.4.12 Single parameter Sensitivity analysis of Bugna

The statistics of the single-parameter sensitivity analysis of Bugna Wereda are shown in Table 54. There are some deviations in the effective weights when compared to the empirical weights. The single–parameter analysis of Bugna Wereda shows Lithologic units and groundwater recharge as the most effective layer in GWP mapping with mean effective weights of 35.00% and 26.6% respectively. The next higher effective weight of 18.1 and 16.5%% was recorded in Lineament proximity and lineament density layers respectively. In addition, the TWI tends to be almost effective thematic layers with mean effective weightings of 3.7% when compared with its empirical weights of 5.1%.

Table 54: Effective weight of single parameter sensitivity analyses of Bugna wereda

The effective weight of Single parameter Sensitivity analysis of Bugna Wereda					
Effective Weight (%)					
	Empirical Weight (%)	**Min**	**Mean**	**Max**	**SD**
Lithology	35.5	31.0	35.0	39.5	1.8
Recharge	31.4	28.2	26.6	24.9	1.5
LD	17.3	17.6	16.5	15.3	0.2
LP	10.7	19.8	18.1	16.5	0.6
TWI	5.1	4.0	3.7	3.5	0.2

4.4.13 Single parameter Sensitivity analysis of Meket

The statistics of the single-parameter sensitivity analysis of Meket Wereda are shown in Table 55. There is some deviation in the effective weights when compared to the empirical weights. The single–parameter analysis of Meket Wereda shows Lithologic units and groundwater recharge as the most effective layer in GWP mapping with mean effective weights of 42.0% and 26.3% respectively. The next higher effective weight of 14.0% and 13.6% was recorded in the Lineament proximity layer and lineament density respectively. In addition, the TWI tends to be almost effective thematic layers with mean effective weightings of 3.5% when compared with its empirical weights of 5.1%.

Table 55: Effective weight of single parameter sensitivity analyses of Meket wereda

The effective weight of Single parameter Sensitivity analysis of Meket wereda					
Effective Weight (%)					
	Empirical Weight (%)	**Min**	**Mean**	**Max**	**SD**
Lithology	35.5	37.7	42.0	46.6	2.6
Recharge	31.4	27.9	26.3	24.6	4.7
LD	17.3	14.4	13.6	12.7	0.4
LP	10.7	15.2	14.0	12.9	0.8
TWI	5.1	3.5	3.3	3.1	0.6

4.4.14 Single parameter Sensitivity analysis of Tselemit

The statistics of the single-parameter sensitivity analysis of Tselemit Wereda are shown in Table 56. There are no deviations in the effective weights when compared to the empirical weights. The single–parameter analysis of Tselemit Wereda shows Lithologic units and groundwater recharge as the most effective layer in GWP mapping with mean effective weights of 55.9% and 22.1 % respectively. The next higher effective weight of 15.7% was recorded in the Lineament density layer. The TWI and Lineament proximity tend to be less effective thematic layers with mean effective weightings of 5% and 2.5% respectively.

Table 56: Effective weight of single parameter sensitivity analyses of Tselemit wereda

The effective weight of Single parameter Sensitivity analysis of Tselemit wereda					
		Effective Weight (%)			
	Empirical Weight (%)	Min	Mean	Max	SD
Lithology	41.7	46.0	55.9	68.4	5.2
Recharge	28.9	25.0	22.1	19.1	1.8
TWI	21.8	17.8	15.7	13.5	1.8
LD	3.8	5.8	5.0	4.2	0.4
LP	3.8	2.9	2.5	2.1	0.4

4.5 Validation using well data

Introduction

Overlay analysis techniques based on GIS methods have been applied to evaluate the groundwater potential of project weredas. The technique involves setting overlay criteria for the five thematic layers (Lithology, recharge, lineaments density, lineaments proximity, and TWI) by using AHP methods. Layer weights and class have been established based on the developed conceptual model, hydrogeological set up of each wereda, and analysis of previously conducted works. The final output of the work is the production of a groundwater potential map for each wereda classified as very high, high, moderate, low, and very low to demarcate target areas for further detailed hydrogeological and geophysical investigations.

Before proceeding to detail hydrogeological and geophysical investigations, the output of the overlay analysis needs to be validated. In order to validate the overlay analysis results (maps), ground-truthing work has been conducted over each wereda.

To validate the result of overlay analysis, ground-truthing of the work is conducted by comparing it with local and regional hydrogeological and geomorphological conditions and also previously drilled shallow and deep wells. In order to validate produced groundwater potential map, the following steps are followed. Geological and hydrogeological observations

- Regional and local geomorphological settings observation
- Verifications of groundwater potential map with series of ground control
- Water point inventory and comparison of inventoried boreholes characteristics with groundwater potential map
- Checking groundwater potential map produced with general ground conditions

Buri Mudayitu Wereda

Most part of Buri Mudayitu Wereda has been classified as low to very low groundwater potential area except a small portion of moderate groundwater potential delineated in the southwestern part which suits the actual ground conditions.

According to inventoried data of boreholes from this wereda, most of the boreholes drilled on the plain are dry and sunk into clay and lacustrine deposits of low productivity that have a thickness of more than 460 meters. Whereas boreholes (Dengeligita and Gefrem) drilled on the western margin and southern border of the wereda is productive and fractured volcanic rocks are encountered at shallow depth (32m).

Most part of this wereda is swampy and covered by vegetation as observed during our field observation. In addition, lacustrine deposits of different ages covered the plain area and alluvial deposits are exposed on the western margin. From a hydrogeological point of view, hydro lithology of this wereda mapped as the lacustrine deposit is unfavourable for groundwater recharge, flow, and storage even though the topography is suitable. In addition, it fits with produced groundwater potential map (Very low groundwater potential zone).

Alluvial deposits mapped on the western margin and the existence of few lineaments together with its proximity to the western high land and also shallow thickness of alluvial deposit made the western edge of this wereda preferable for groundwater development relatively. However, this area is classified as a low groundwater potential zone on the produced map and requires detailed investigation for groundwater development.

Argoba Liyu Wereda

Most part of Argoba Liyu Wereda is classified as low, moderate, and high groundwater potential area. Topographically, Argoba Liyuwereda is rugged and sloppy and also a number of streams arise from this wereda and flow toward the rift floor. Observed outcrops such as basalt and rhyolite have high and moderate productivity.

Most of Argoba Liyu Wereda areas mapped as low groundwater potential zone are mountainous areas with high slopes. Whereas areas delineated as moderate and high groundwater potential on the produced map are rugged, sloppy, and topographically unsuitable for groundwater development, affected by dense lineament and also dense drainage density.

Deberko borehole (177 meters deep) drilled in the area of dense lineament, drainage density, and relatively low elevation has good yield (5l/s). This point is mapped as a high groundwater potential zone. Whereas areas of high slope within the vicinity of this borehole are mapped us low and moderate groundwater potential.

Dulecha Wereda

Dulecha Wereda is bounded by the Awash River gorge and major marginal faults in the east and west direction. Topographically, Dulecha wereda is plain. However, the plain slightly slopping up to an elevation of more than 1500 meters on the western margin.

According to overlay analysis made to map groundwater potential zones, the western edge of Dulecha wereda and the majority of the area of the central part is mapped as moderate groundwater potential zone. Ignimbrite affected by tectonic forces is observed outcrop on the western edge, whereas the central part is covered by alluvial deposits and less affected by geologic structures. However, validation made by boreholes drilled in the central part shows that boreholes drilled in this area have good yield at shallow depth and this area can be considered as a high to very high groundwater potential zone. The difference observed between potential zone mapped and borehole data deemed arises from high groundwater recharged from subsurface inflow from adjacent aquifers and bank infiltration and seepage of surface rivers.

As depicted on the produced map, areas affected by dense tectonic forces and lithologies of primary and secondary porosities are observed are delineated as high groundwater potential zone.

Wuchale wereda

The groundwater potential map of Wuchale wereda is classified as very low, low, moderate, high, and very high groundwater potential area. Topographical, Wuchale wereda plain land except for the western and southwestern part of the study which is bounded by Mugger gorge. The main lithologic unit exposed in the study area is Aiba basalt, Tarmaber basalt, Ashangi basalt, and alluvial formation as very high to low productivity aquifers.

Most of Wuchale wereda areas mapped as moderate to high groundwater potential zones are plain land with moderate groundwater recharge, moderate runoff potential characteristics, and high ability of aquifers (Aiba, Tarmaber basalt, and Alluvial aquifers) to store and convey groundwater through interconnected secondary and primary porosity which is exposed in the major part of the study area. Whereas areas delineated as very low and low groundwater potential is in deep gorge due to unfavourable topographic situation and low storage and transmissivity potential of the exposed Ashangi basalt in the study area.

A total of 10 wells were used for validation, the 9 wells yield values agree with the groundwater potential zone map of Wuchale wereda which fell within moderate to high potential zone. While the other well which fell within the high potential zone map has very high groundwater potential.

Girar Jarso wereda

Girar Jarso wereda aquifer system is classified as very low, low, moderate, high, and very high groundwater potential area. Topographically, the southern part of Girar Jarso wereda is plain land and the northern part is rugged and sloppy topographic setup. The main lithologic unit exposed in the study area is Aiba basalt, Tarmaber basalt, Ashangi basalt, alluvial formation, lower and upper sandstone, and Gohatsion formation mapped as very high to very low productivity aquifers.

The southern part of Girar Jarso wereda is mapped as moderate to high groundwater potential zones because these zones are plain land with moderate groundwater recharge, moderate runoff potential characteristics, and high ability of aquifers (Aiba and Tarmaber basaltic aquifers) to store and convey groundwater through interconnected secondary structures. While the Northern part of Girar Jarso wereda is mapped as a low to very low groundwater potential zone because of the unfavourable topographic setup and the ability of the aquifer to store and transmit groundwater is very low to low potential.

A total of 4 wells and springs were used for validation, the 4wells and 3 spring yield values agree with the groundwater potential zone map of Girar Jarso wereda which fell within low to moderate potential.

Kuyu wereda

Kuyu wereda aquifer system is classified as very low, low, moderate, high, and very high groundwater potential area. Topographical, the Northern part of Kuyu wereda is plain land and the Sothern part is a rugged and sloppy topographic setup. The main lithologic unit exposed in the study area is Aiba basalt, Tarmaber basalt, Ashangi basalt, alluvial formation, lower and upper sandstone, and Gohatsion formation mapped as very high to very low productivity aquifers.

The Northern part of Kuyu wereda is mapped as moderate to very high groundwater potential zones because these zones are plain land with moderate groundwater recharge, moderate runoff potential characteristics, and high ability of aquifers such as Aiba, Tarmaber, and Alluvial aquifers to store and convey groundwater through interconnected secondary and primary porosity. While the Southern part of Kuyu wereda is mapped as a low to very low groundwater potential zone because of the unfavourable topographic setup and the ability of the aquifer to store and transmit groundwater is very low to low potential natural.

A total of 2 wells and 2 springs were used for validation, the 2 wells and 1 spring yield values agree with the groundwater potential zone map of Kuyu wereda which fell within low to moderate potential. While the other spring which fell within a very high potential zone map has moderate groundwater potential, the unfit observed shall be verified during detailed investigation of Geophysical and Hydrogeological investigation.

Dera wereda

Dera wereda aquifer system is classified as very low, low, moderate, high, and very high groundwater potential area. Topographical, the central and southern central part of Dera wereda is plain land and the areas bound central and southern central land part is rugged and sloppy topographic setup. The main lithologic unit exposed in the study area is Aiba basalt, Tarmaber basalt, Ashangi basalt, lower and upper sandstone, and Gohatsion formation mapped as very high to very low productivity aquifers.

The central and southern central part of Dera wereda is mapped as High to very high groundwater potential zones because these zones are plain land with moderate groundwater recharge, moderate runoff potential characteristics, and high ability of aquifers such as Aiba and Tarmaber basaltic aquifers to store and convey groundwater through interconnected secondary structures. While the areas bound central and Southern central part of Dera wereda is mapped as moderate to very low groundwater potential zone because of the unfavourable topographic setup and the ability of the aquifer to store and transmit groundwater is moderate to very low natural.

A total of 2 shallow wells were used for validation, two wells that fell within the high potential zone map have moderate groundwater potential. The reason may be due to poor construction of wells and or the effect of the gorge surrounding the central and southern central prat of Dera wereda.

Enebise Sar MIdir Wereda

Most part of Enebise Sar Midir Wereda has been classified as low to very low groundwater potential area except a small portion of moderate groundwater potential zone delineated in the central part and high at the south-eastern and south-western periphery of the wereda which suits the actual ground conditions.

According to the inventoried existing boreholes, 1 well was found in a very low GWP zone (Q=0.01-0.5l/s), 8 wells sunk in the low GWP zone (Q=0.5 to 2l/s) with a depth of 55 to 70m and 3 wells at Gunaguna kebele and its surrounding nearby Mertule Maryiam town which are drilled on the north-western part of the wereda sunk in moderate GWP zone of the productive basaltic aquifer (Q=5.5-10l/s) with a depth of 153 to 181m.

Most part of this wereda especially in the northern and southern part is rugged with high drainage density and it is not suitable for groundwater exploration only a small portion of an area which is relatively plain land that extends from north-west to the central part which is suitable for groundwater exploration. In which most of the existing boreholes were drilled in this area. There is a scattered vegetation cover and most of the wereda is occupied by cultivated land as observed during a field visit. In addition, quaternary deposits of alluvial and alluvial sediments are covered the plain area which is exposed on the central part extending to the north-west and south-east direction.

From a hydrogeological point of view, the wereda is represented by rocks of various ages and lithology, starting from the youngest to most recent Quaternary superficial deposits and volcanic rocks, Tertiary basalts, and inter-bedding sediments, to Mesozoic sequences of sandstone, gypsum, and limestone.

Topographically higher plateau areas from the northern part of the area are considered to be the potential recharge areas. This is related to the average annual rainfall received by the highland areas which are characterized by fractured and faulted areas. The lowlands that extend from the north-west to the central part towards the east are considered to be the discharge zones for groundwater.

According to the lithology, the basaltic formation in the northern part gives rise to the existence of dense lineaments together with its proximity to the plain area of this wereda which is the preferable site for groundwater development. However, this area is classified as a moderate to high productive groundwater potential zone on the produced map.

The study area contains the primary structures (sedimentary beds), normal faults, strike-slip faults with associated folds, and lineaments. Lineaments in the area represent joint systems or concealed faults. The joint systems and concealed faults strike NW, NE, and N-S. The joint systems have a vertical dip.

Sayit Wereda

Most part of Sayit Wereda is classified as low and moderate groundwater potential areas, with very rare areas having very low and high groundwater potential. Topographically, this wereda is very rugged, which is part of the central Ethiopian plateau, having small hills and ridges, mountains, escarpments, deep gorges, and sloping topography. The plateau is formed by different flood lava flows of the Tertiary age.

The qualitative investigation includes field observation of the geological, hydrogeological, geomorphological, physical, and geographical setup. Whereas the quantitative investigation is more descriptive and is based on field inventory data, well logging, the yield of springs and wells, and pump test data including permeability, transmissivity, and aquifer thickness. Hence, the lithological units are characterized as porous and fissured permeability as well as impermeable ones. The groundwater flow is mainly through a regularly developed system of fissures of volcanic rocks. The aquifers consist of Upper basalt and pyroclastic rocks of Tarmaber formation.

According to inventoried data of around 33 boreholes from this wereda, which are all shallow in depth not more than 70m drilled on the plain area which sunk into the upper portion of tertiary volcanic of low to moderate productivity in the central and southern part of the wereda, in accordance with the produced map of groundwater potential zone. Out of the inventoried existing boreholes, 12 well were found in very low GWP zone, 13 wells sunk in low GWP zone, and 7 wells which are drilled on the south-western part of the wereda sunk in the low to moderate GWP zone of the productive basaltic aquifer with the depth of 55 to 70m and discharge 0.2 – 8l/s.

Most of Sayit Wereda areas mapped as moderate and high groundwater potential zone are in the plain area. Whereas areas are delineated as low and very low groundwater potential in the mountainous (rugged) and sloppy areas on the produced groundwater potential zone map and topographically unsuitable for groundwater development, affected by dense lineament and also dense drainage density.

As depicted on the produced map, areas affected by dense tectonic forces and lithologies of primary and secondary porosities are observed are delineated as high groundwater potential zone.

Misrak Belesa Weredas

The groundwater potential map of Misrak Belesa Wereda has been classified as a very low, low, moderate, and high groundwater potential area except for a small portion of very high groundwater potential delineated in the southwestern part which suits the actual ground conditions.

According to inventoried data of boreholes from this wereda, most of the boreholes drilled on volcanic rocks of low productivity that have a thickness of less than 70 meters. Whereas, boreholes (Woiba School and Fisoye) drilled on the western and southern border of the weredas is productive, and fractured volcanic rocks are encountered at shallow depth.

Most parts of these weredas are rugged topography and high gradient coupled with intensive deforestation. This environmental degradation has negatively affected the existence of surface water resources and has resulted in a decline in the productivity of groundwater to the extent that wells and springs have dried up during our field observation. From a hydrogeological point of view, hydro lithology of this wereda mapped as Adigrat sandstone, Lacustrine Sediments, Quaternary alluvium, and unfavourable topography for groundwater recharge, flow and storage even though volcanic rocks looks suitable.

According to overlay analysis made to map groundwater potential zones, the majority area of Misrak Belesa wereda is mapped as a moderate to high groundwater potential zone. However, validation made by boreholes drilled in the central part shows that boreholes drilled in this wereda area have low to very high yield at shallow depth and these areas can be considered as moderate to high groundwater potential zone. Except for a few wells, the groundwater potential map agrees with the yield wells. The difference observed between potential zone map and few borehole data deemed arises from poor well construction and or the effect of structure in which align SW – NE direction toward deep Tekeze gorge.

Ebenat Weredas

The groundwater potential map of Ebenat Wereda has been classified as a very low, low, moderate, and high groundwater potential area.

According to inventoried data of boreholes from this wereda, most of the boreholes drilled on volcanic rocks of low productive that have a thickness less than 70 meters. Whereas boreholes (Wegerie, Tuchamesk, Nill) drilled on the southern and western border of the wereda is productive, fractured volcanic rocks are encountered at shallow depth.

Most part of this wereda is rugged topography and high gradient coupled with intensive deforestation. This environmental degradation has negatively affected the existence of surface water resources and has resulted in a decline in the productivity of groundwater to the extent that wells and springs have dried up during our field observation. From a hydrogeological point of view, hydro lithology of this wereda mapped as Lacustrine Sediments, Quaternary alluvium, and unfavourable topography for groundwater recharge, flow and storage even though volcanic rocks look suitable.

According to overlay analysis made to map groundwater potential zones, the majority area of the most southern part of Ebenat wereda is mapped as low groundwater productive while most central Easter and northern parts of Ebenat wereda are mapped as moderate to high groundwater potential zone. However, validation made by boreholes drilled in most central and northern parts shows that boreholes drilled in this wereda have low to moderate yield at shallow depth and the south-western part of this area is moderate to high yield. Except for few wells the groundwater potential map agrees with the yield wells. The difference observed between potential zone map and few borehole data deemed arises from poor well construction and or the effect of structure in which align SW – NE direction toward deep Tekeze gorge.

Bugna Wereda

Bugna Wereda GWP map is classified as a very low, low, and moderate groundwater potential area. Topographically this wereda is rugged and sloppy and a number of streams arise from this wereda and flow toward the Tekeze. Observed outcrops such as basalt and trachyte have low to high productivity.

Most of these wereda areas mapped as low groundwater potential zone are mountainous areas with high slopes. Whereas areas delineated as moderate and high groundwater potential produced on the map are rugged, sloppy, and topographically unsuitable for groundwater development, affected by dense lineament and also dense drainage density.

Ayinan Eyesus (43-meter depth) drilled in an area of dense lineament, drainage density, and relatively low elevation has a high yield (7 l/s). This point is mapped as a moderate groundwater potential zone. Whereas areas of high slope within the vicinity of this borehole are mapped us low and moderate groundwater potential.

Meket Wereda

Mekiet Wereda is bounded by the water divide and major marginal faults in the east and west direction. Topographically, Mekiet wereda represents the high flatlands around Debre Zebith. It also includes other slightly denuded landscapes. This region is the result of erosion and degradation of remnants of volcanic rocks.

According to overlay analysis made to map groundwater potential zones, the western and most eastern edges of this wereda is mapped as low to moderate groundwater potential zone. Pyroclastic and trachytes are observed outcrop on the east western edge, whereas the central and most northern and the tip of the southern part is covered by basalt and less affected by geologic structures. Validation made by boreholes drilled in the east-west margin part shows that boreholes drilled in this area have low to high yield and this area can be considered as a moderate groundwater potential zone based on potential zone map and validation points.

Tselemit Wereda

The hydrogeological setup of the area shows the major sources of recharge for the study area (Tselemit Wereda) is assumed to be from Ras-Dashen Mountain composed of mainly tertiary trap volcanics to the northeastern direction toward Tekeze gorge through fractured, dissected intermountain valleys of erosional effects and jointed tertiary basalts.

In addition, geomorphological setup, geologic structures, NE river orientations in the Tselemit wereda shows that the groundwater recharged on the highland areas of Ras-Dashen Mountain is anticipated to get the highest annual rainfall and flows toward the Tekeze river gorge. According to the preliminary hydrogeological map of the area depicted below the study, wereda is found mainly within the extensive and moderately productive fissured aquifers of the tertiary trap basalts.

According to overlay analysis made to map groundwater potential zones, the northeastern and most central part of this wereda is mapped as moderate to very high groundwater potential zone. Validation made by boreholes drilled in the central and northeast part shows that boreholes drilled in this area have very high to moderate yield at shallow depth and these areas can be considered as high groundwater potential zone based on potential zone map and validation points.

As shown on produced map, areas affected by dense tectonic forces and lithologies of primary and secondary porosities are observed are delineated as moderate groundwater potential zone. A total of 3 wells were used for validation, the 2 wells yield values agree with the groundwater potential zone map of Tselemit wereda which fell within moderate to high potential. While the other well which fell within a low potential zone map has moderate groundwater potential, the unfit observed may be due to poor well construction and this study shall be verified during detailed investigation of Geophysical and Hydrogeological investigation. In addition, it is recommended that this study shall be supported by test well drilling.

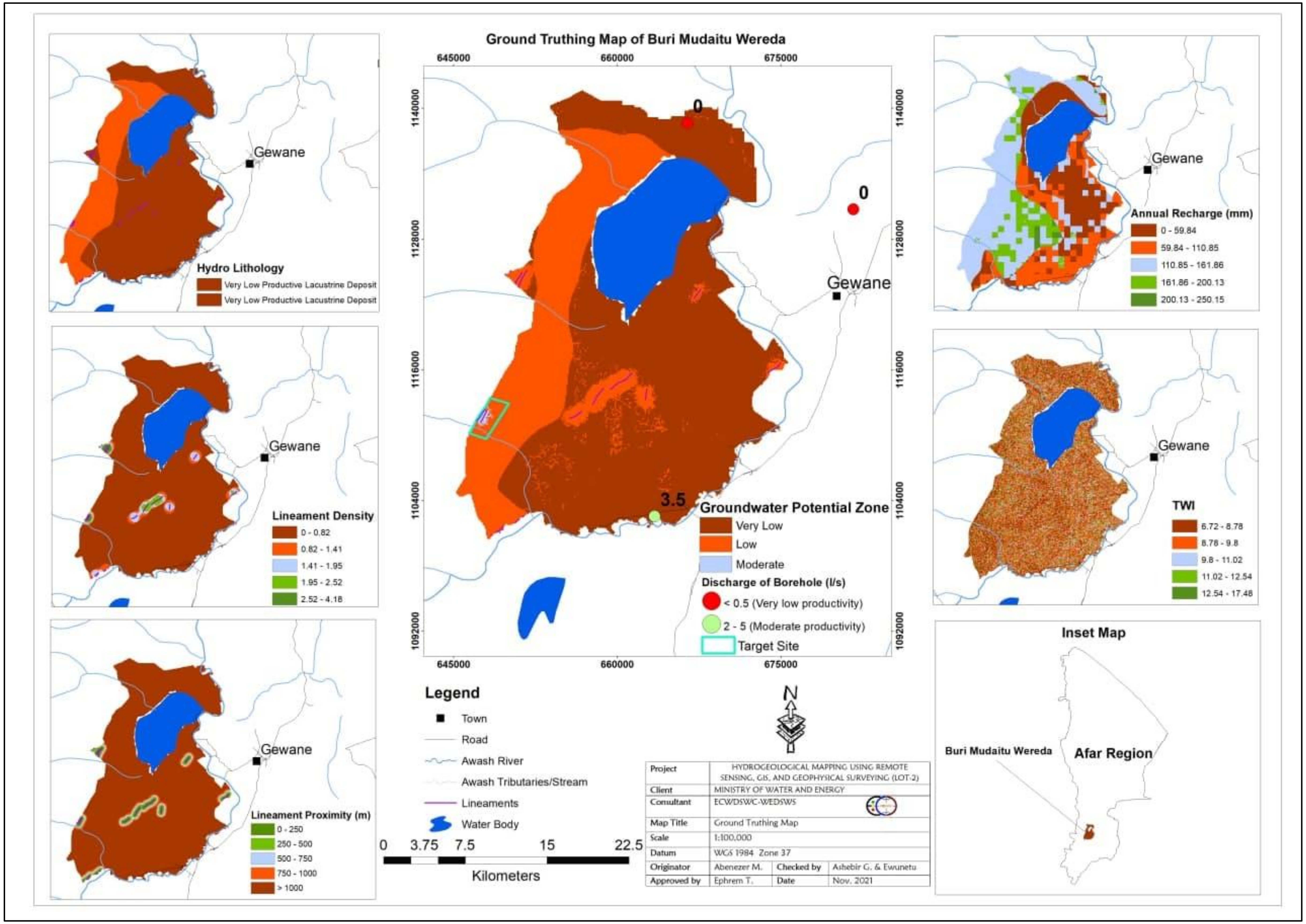


Figure 102 : Groundwater potential truthing of Buri Mudaitu Wereda

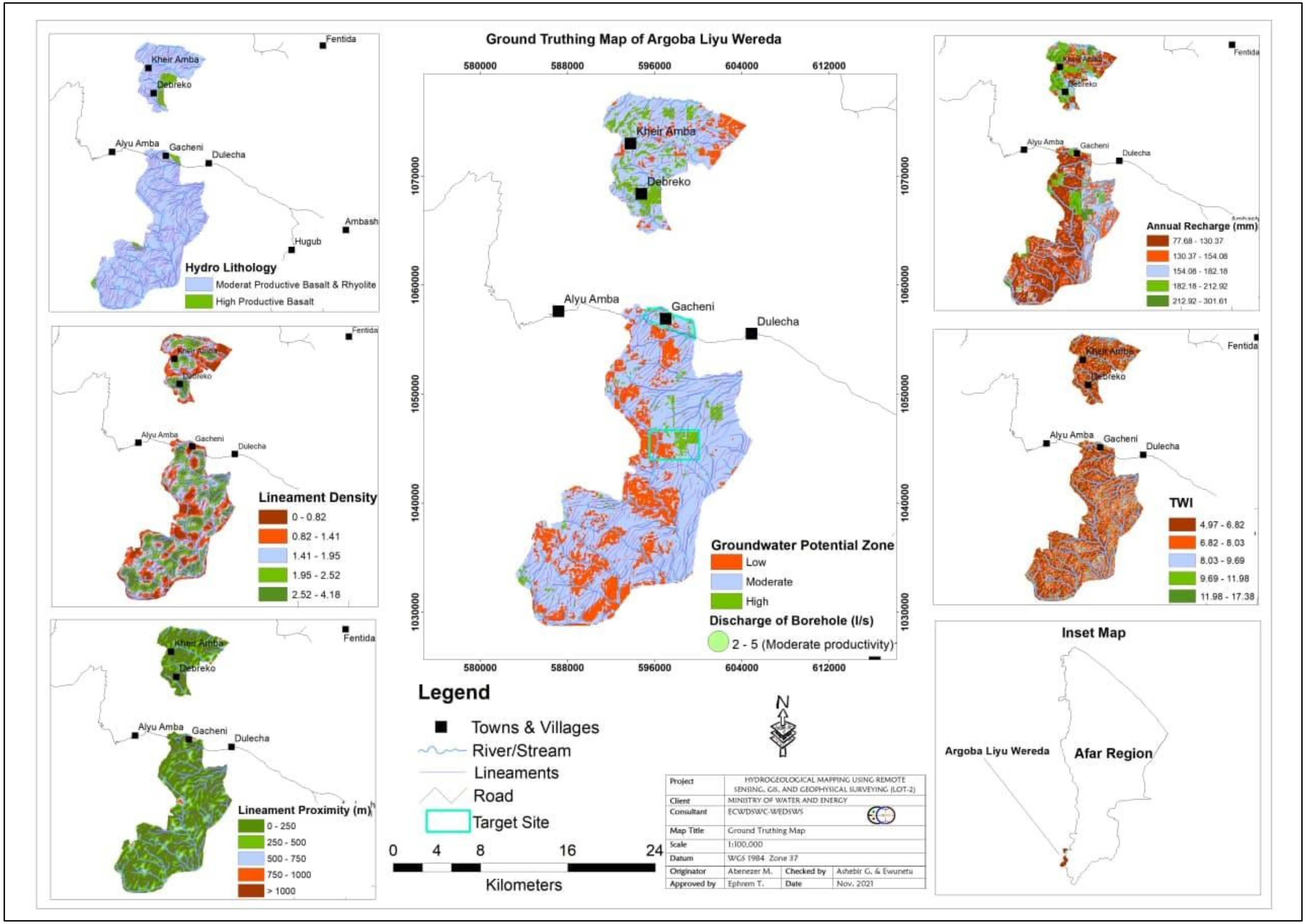


Figure 103: Groundwater potential truthing of Argoba Liyu Wereda

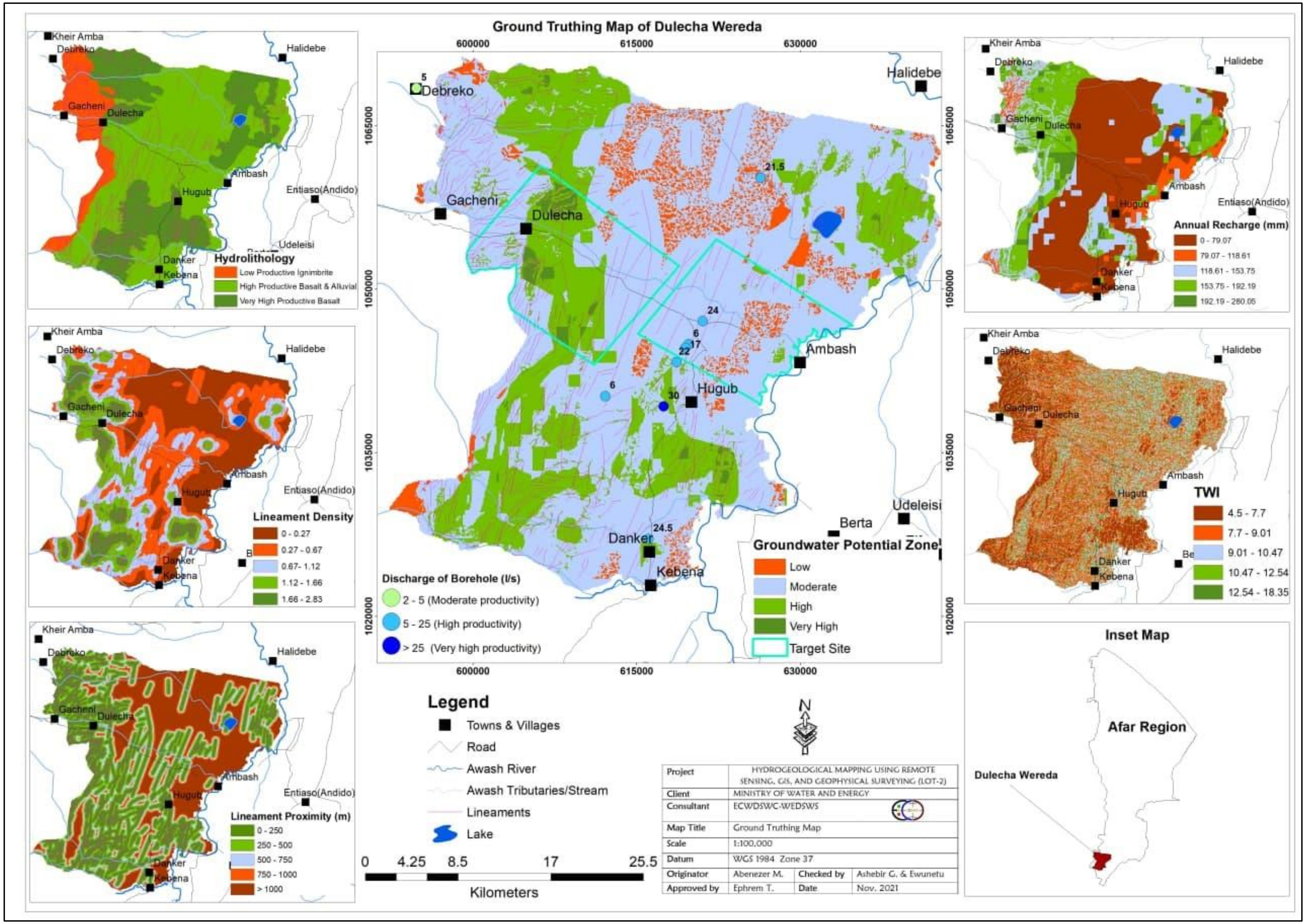


Figure 104: Groundwater potential truthing of Dulecha Wereda

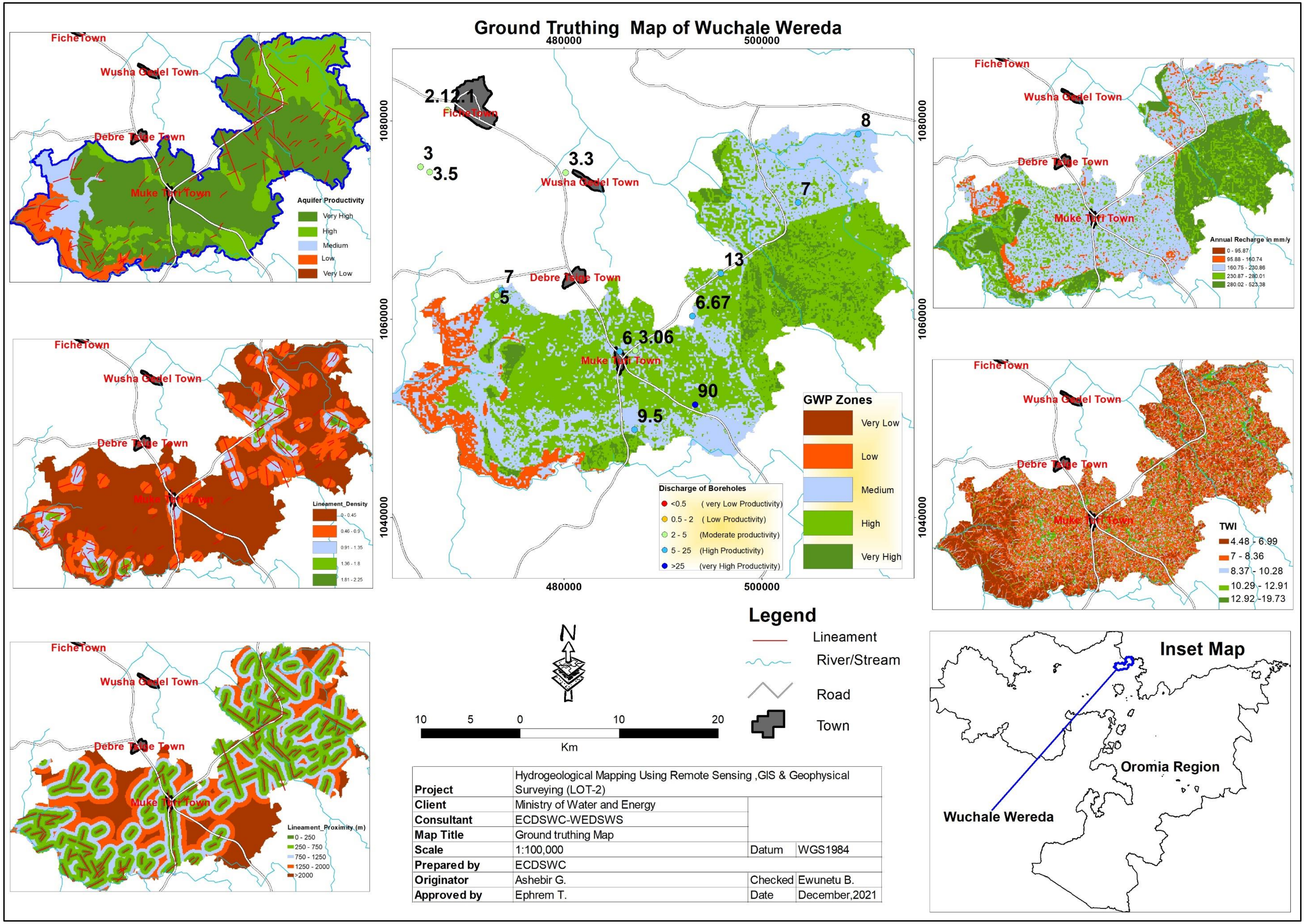


Figure 105: Groundwater potential truthing of Wuchale Wereda

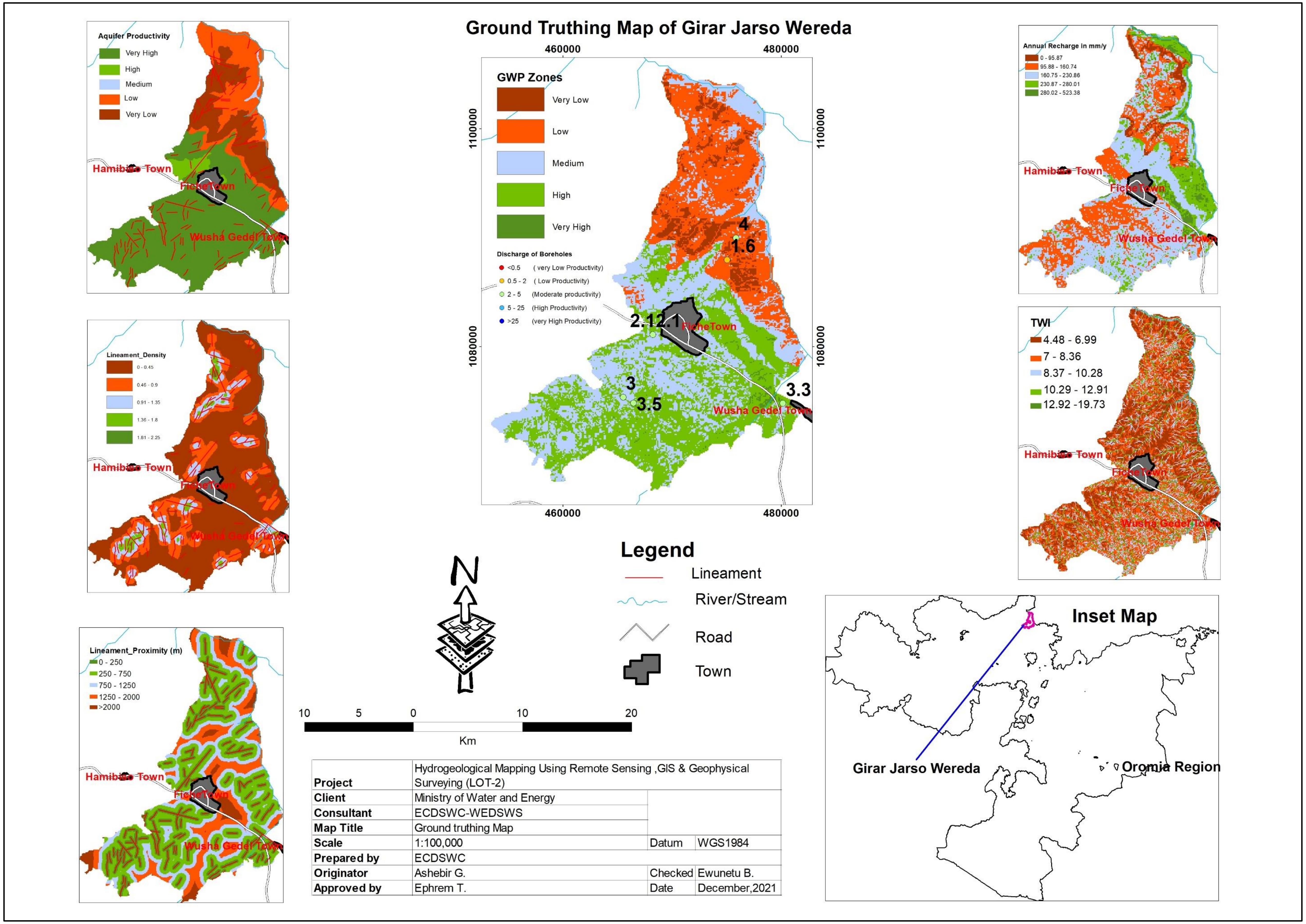


Figure 106: Groundwater potential truthing of Girar Jarso Wereda

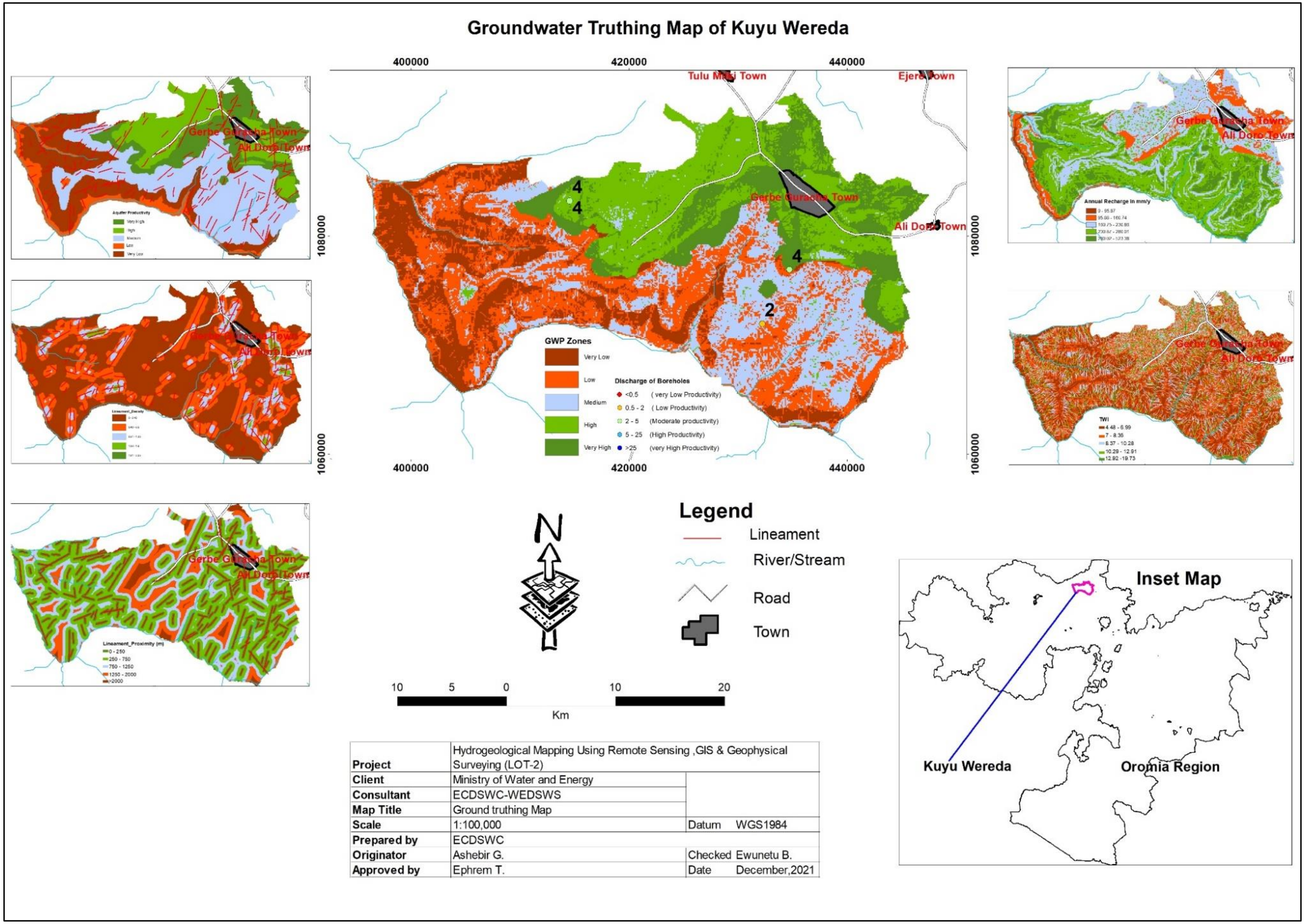
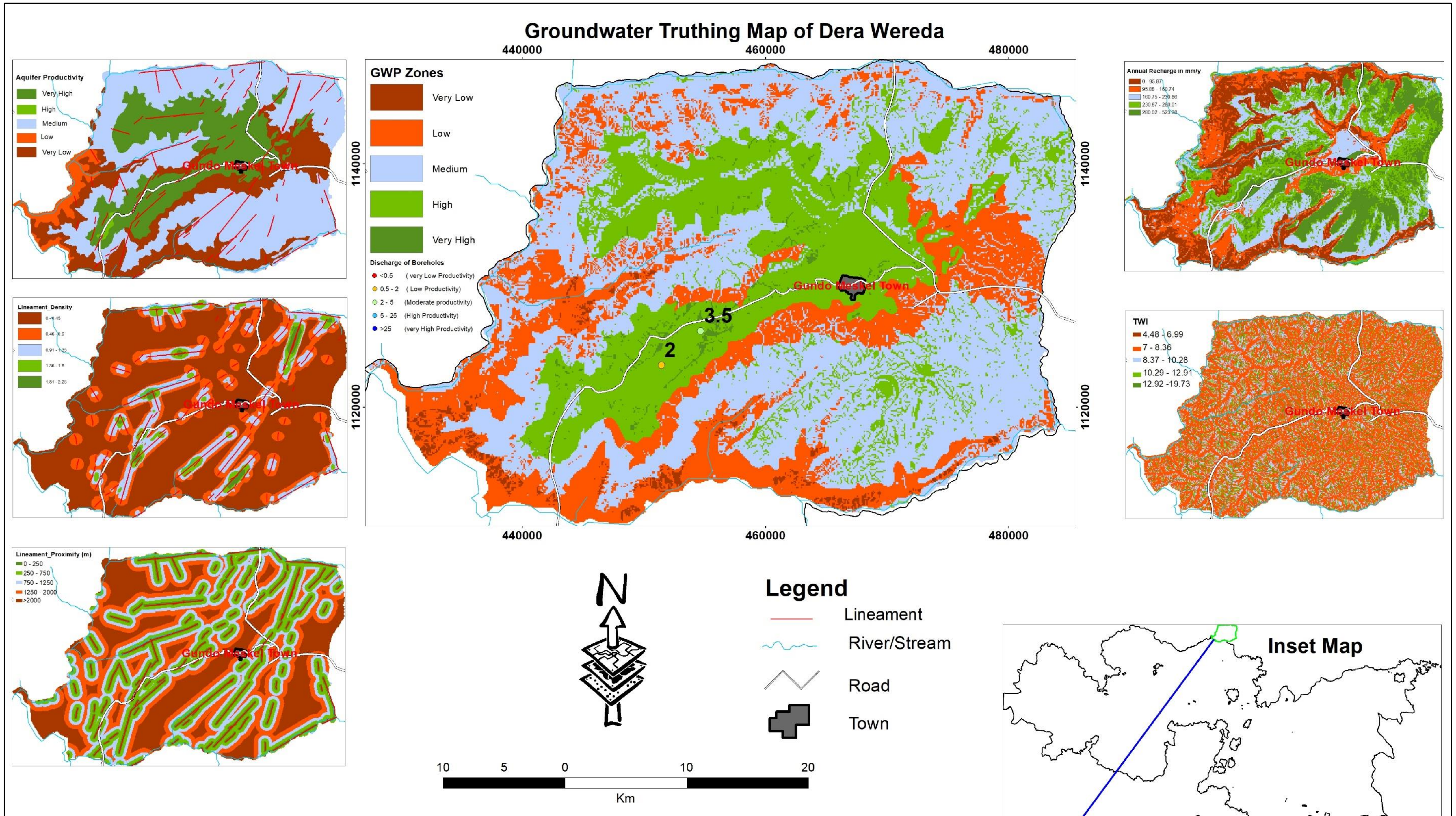


Figure 107: Groundwater potential truthing of Kuyu Wereda



Project	Hydrogeological Mapping Using Remote Sensing ,GIS & Geophysical Surveying (LOT-2)		
Client	Ministry of Water and Energy		
Consultant	ECDSWC-WEDSWS		
Map Title	Ground truthing Map		
Scale	1:100,000	Datum	WGS1984
Prepared by	ECDSWC		
Originator	Ashebir G.	Checked	Ewunetu B.
Approved by	Ephrem T.	Date	December,2021

Figure 108: Groundwater potential truthing of Dera Wereda

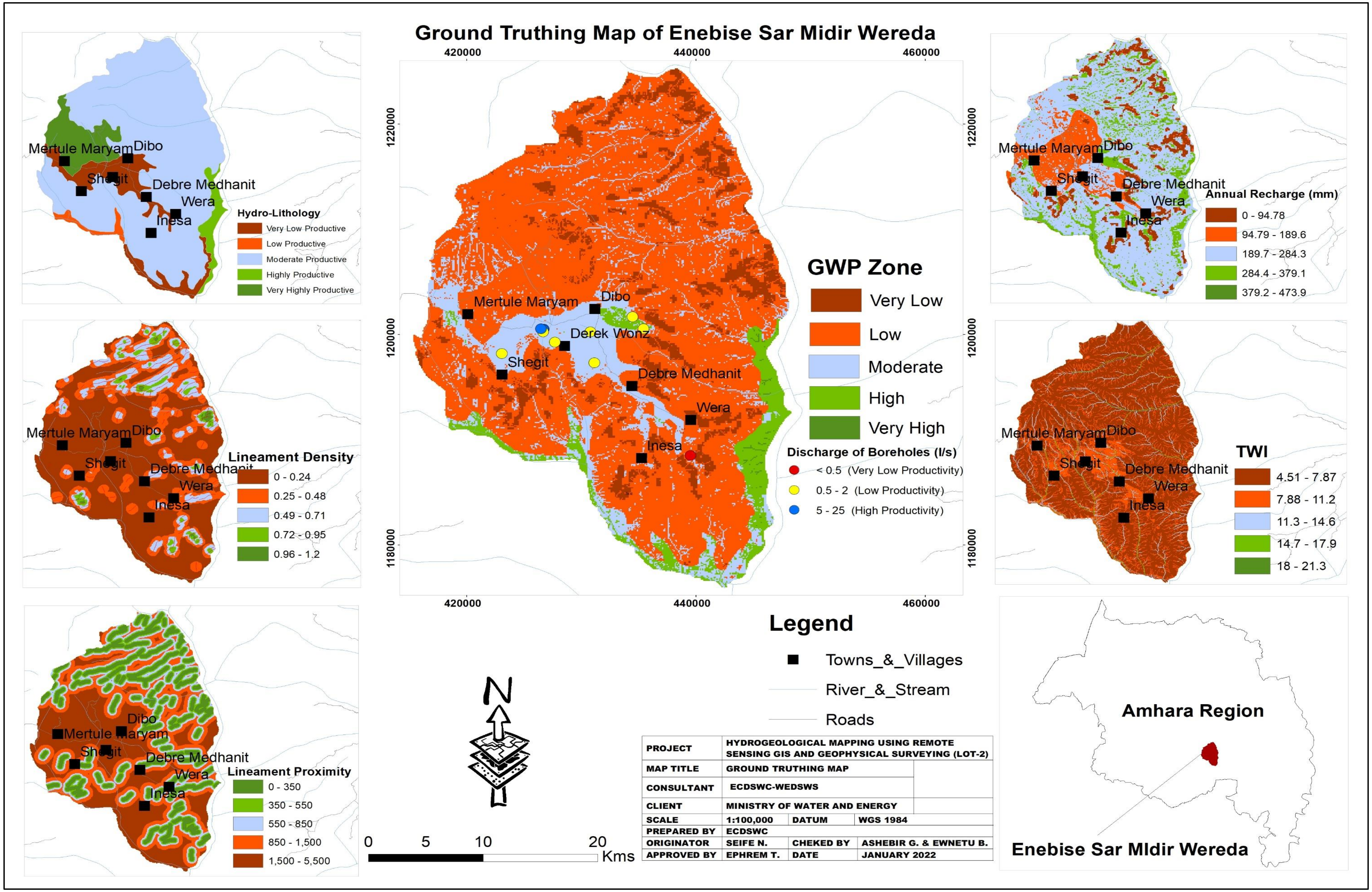


Figure 109: Groundwater potential truthing of Enebise Sar Midir Wereda

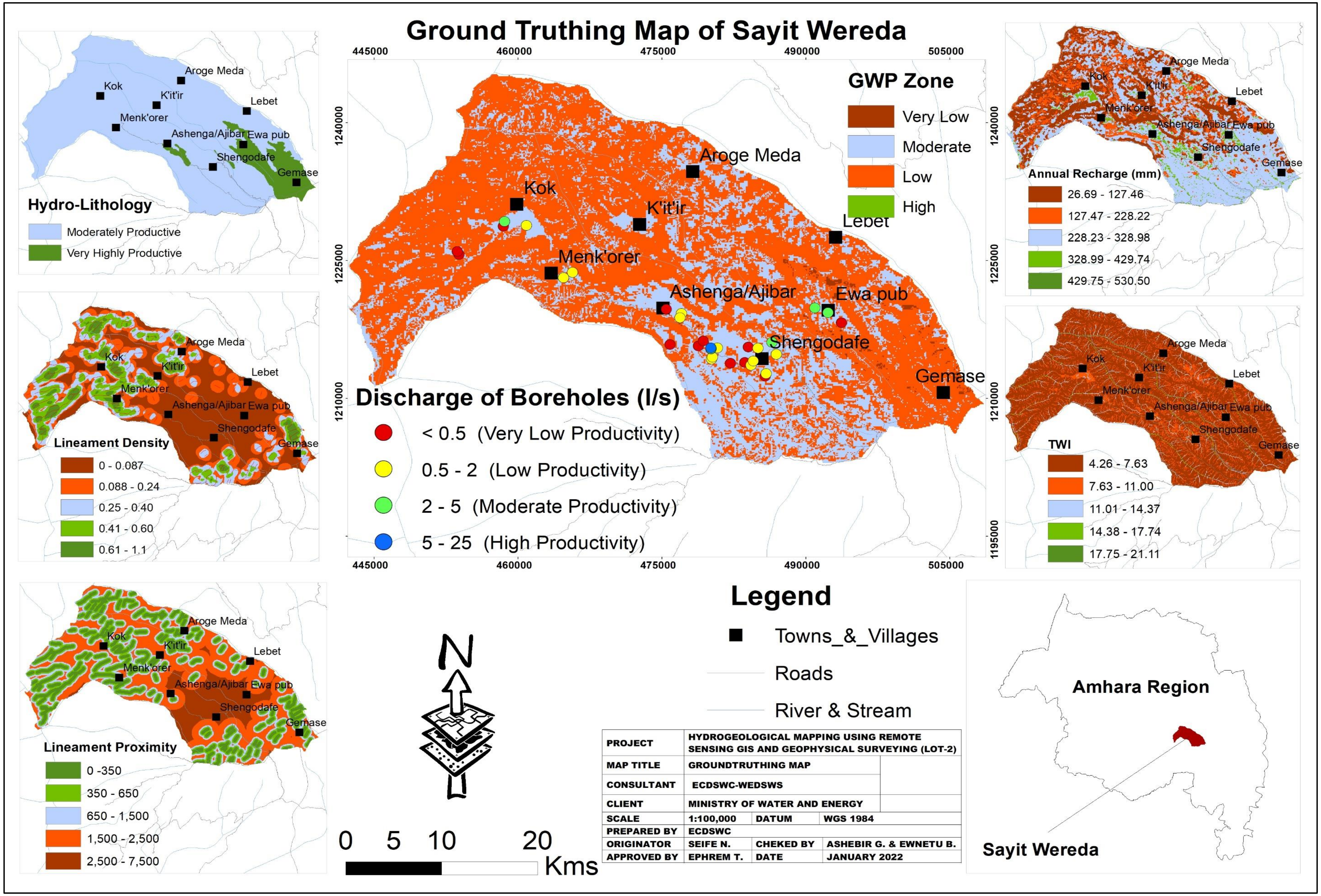
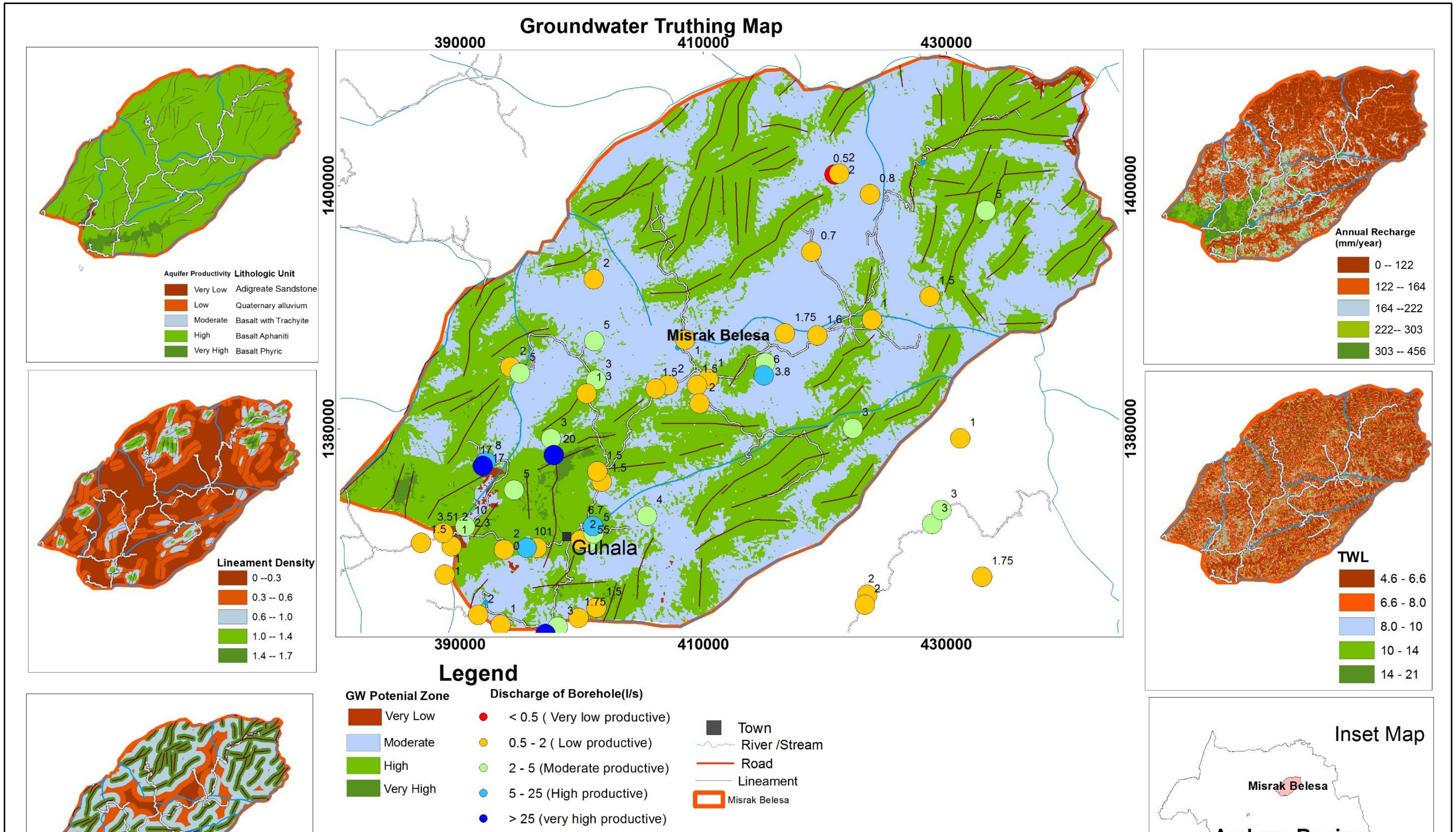


Figure 110: Groundwater potential truthing of Sayit Wereda



Project	Hydrogeological mapping Using Remote Sensing, GIS & Geophysical Surveying (LOT-2)		
Client	Ministry of Water & Energy		
Consultant	ECDSWC-WEDSES		
Map Title	Groundwater Truthing Map		
Scale	1:100,000	Datum	WGS 1984
Prepared by	ECDSWC		
Organizer	Simegnew T.	Cheched by	Ashebir G. & Ewnetu B.
Approved by	Ephrem T.	Date	Dec-21

Figure 111: Groundwater potential truthing of Misrak Belesa Wereda

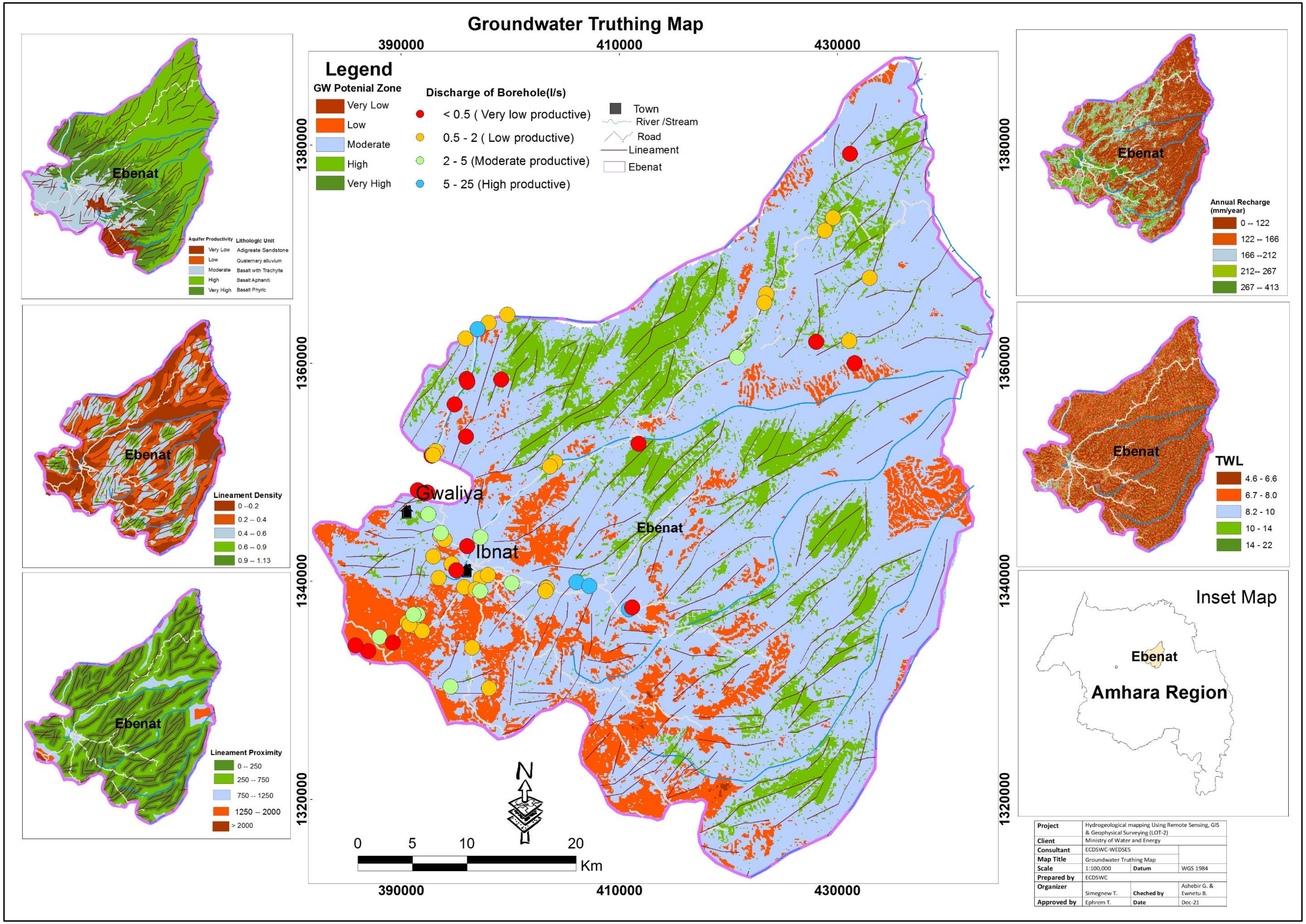


Figure 112: Groundwater potential truthing of Ebenat Wereda

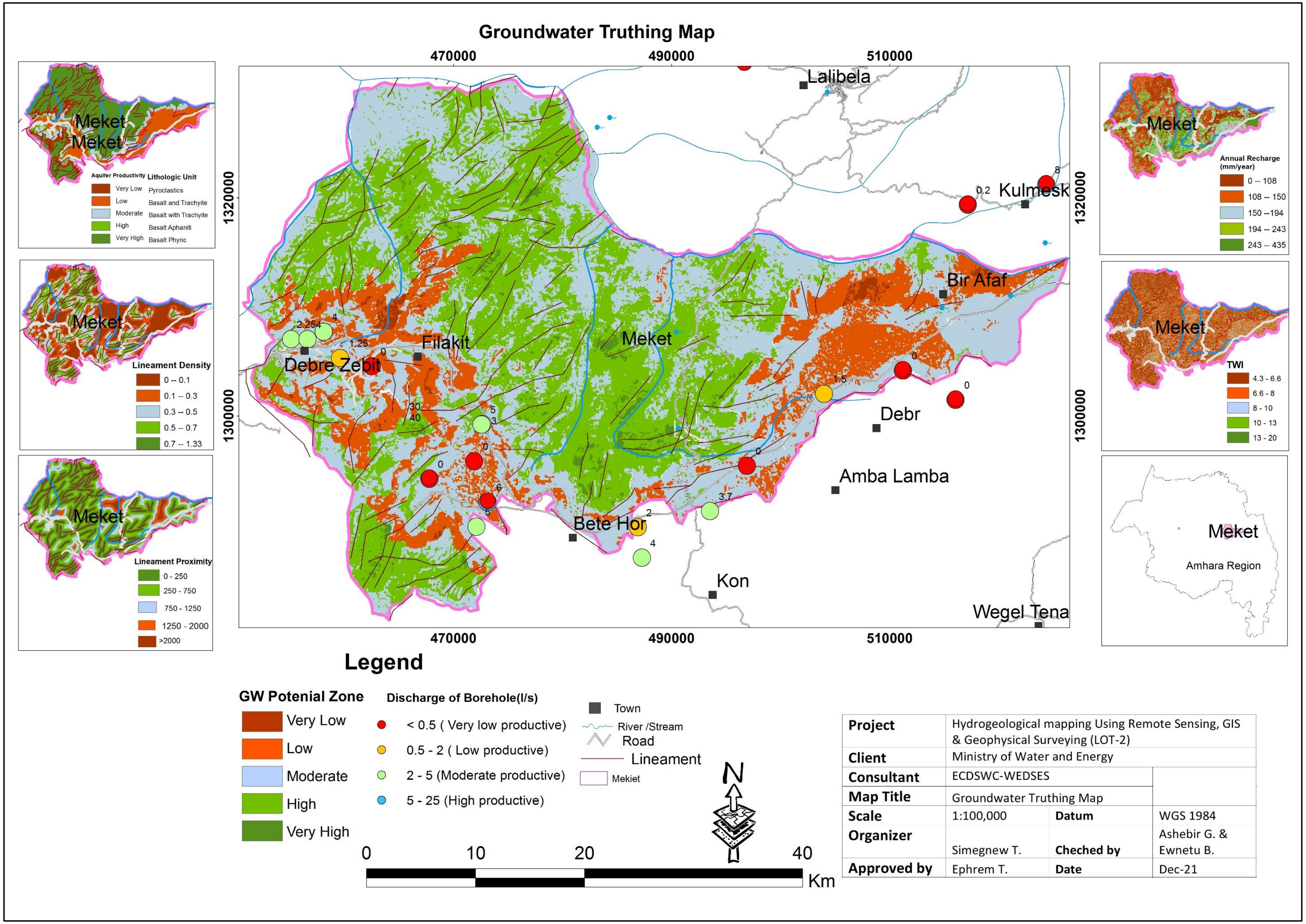


Figure 113: Groundwater potential truthing of Mekiet Wereda

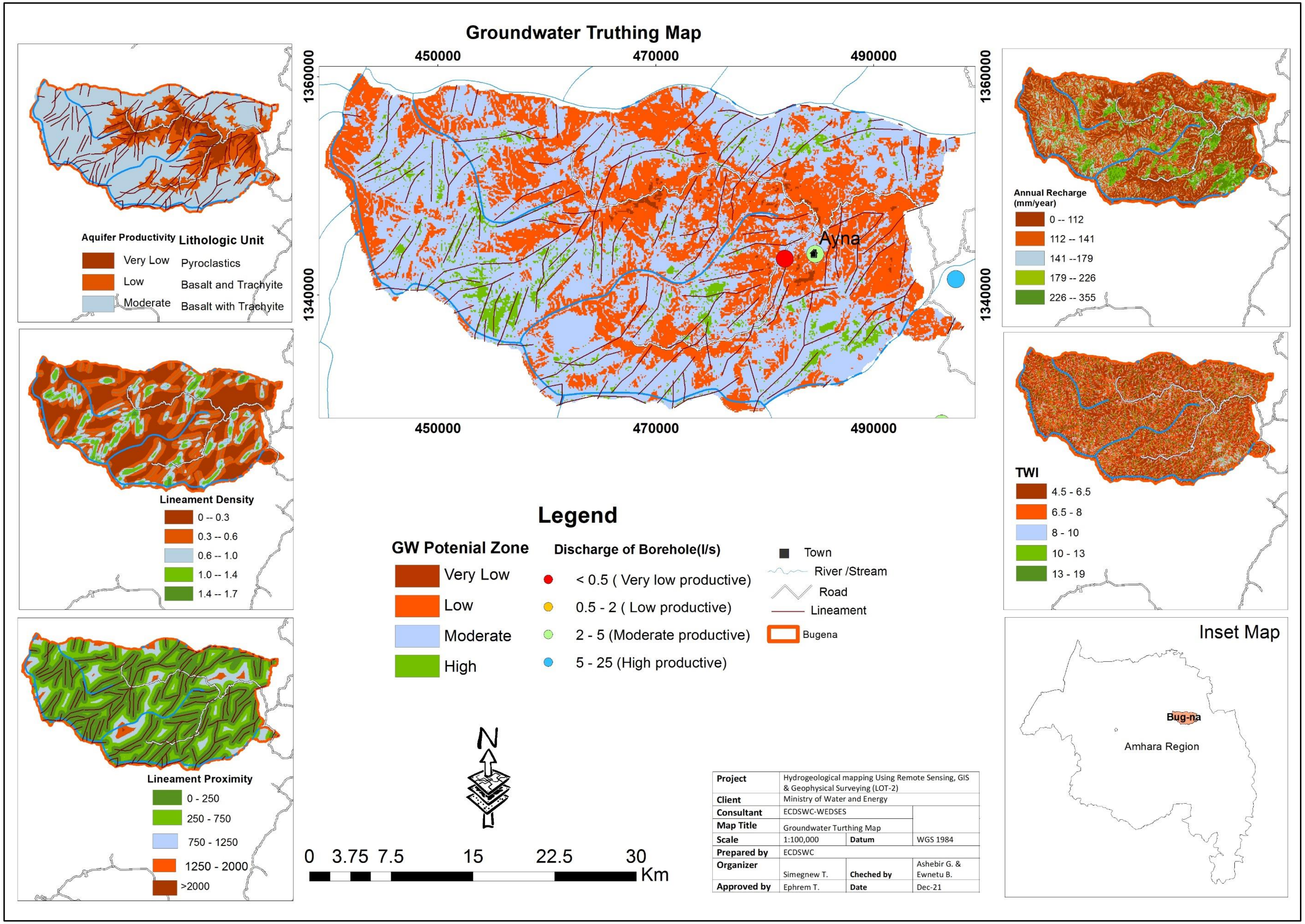


Figure 114: Groundwater potential truthing of Bugna Wereda

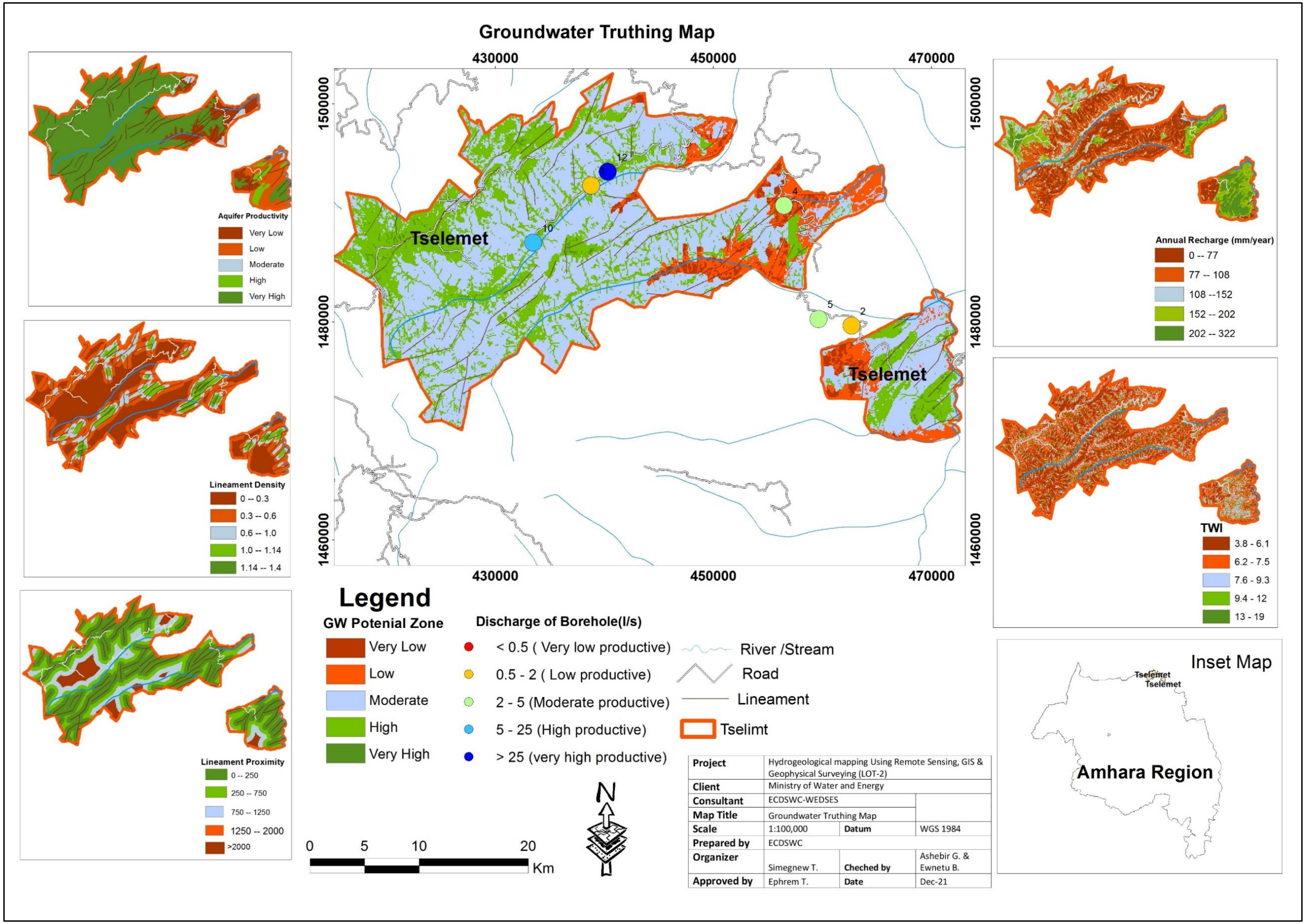


Figure 115: Groundwater potential truthing of Tselemit Wereda

4. 6. Socio - Economy and water demand of Project weredas

To estimate the water demand of the project weredas CSA projected population data of July 2021 is used. As per the GTP-2 (2016-2020) water supply service level standard, it is required to provide safe water in a minimum of 25 l/c/day within a distance of 1 km for rural areas while in urban areas it is required to provide safe water in a minimum of 100 l/c/day for category 1 towns/cities (towns/cities with a population more than 1 million), 80 l/c/day for category 2 towns/cities (towns/cities with a population in the range of 100,000-1million), 60 l/c/day for category 3 towns/cities (towns/cities with a population in the range of 50,000 -100,000), 50 l/c/day for category 4 towns/cities (towns/cities with a population in the range of 20,000-50,000) up to the premises, and 40 l/c/day for category-5 towns/cities (towns/cities with a population less than 20,000) within a distance of 250m.

The water demand of the project weredas for water supply of small-town, livestock & rural water supplies water demand are summarized in the table below.

4.6.1water demand of cluster 1

year	Dulecha Wereda	
	Dulecha rural average water demand m3/day	Dulecha town average water demand m3/day
2021	753	230
2025	865	264
2030	1005	306
2035	1147	349

Dulecha Wereda Livestock Category and Water Demand											
Shoats	0.01	Cattle	0.7	Camel	1	Donkey	0.6	Chicken	0.001	TLU	Water Demand in m3/day
57918	579	111014	77710	75206	75206	5669	3401	60000	60	156,896.38	3,922

year	Buri Mudaitu Wereda
	Buri Mudaitu rural average water demand m3/day
2021	1282
2025	1472
2030	1710
2035	1952

Livestock Category											
Shoats	0.01	Cattle	0.7	Camel	1	Donkey	0.6	Chicken	0.001	TLU	Water Demand in m3/day
162300.8	579	88811.2	77710	60164.8	75206	4535.2	3401	48000	60	126,676.77	3,167

year	Argoba Wereda	
	Argoba rural average water demand m3/day	Gachenie town average water demand m3/day
2021	793	338
2025	794	338
2030	795	338
2035	795	338

Argoba Livestock Category and Water demand											
Shoats	0.01	Cattle	0.7	Camel	1	Donkey	0.6	Chicken	0.001	TLU	Water Demand in m3/day
57918	579	111014	77710	75206	75206	5669	3401	60000	60	156,896.38	3,922

4.6.2 Water demand of cluster 2

	Dera Wereda	
year	Dera Rural AVG water Demand m3/day	Gundo Meskel town AVG water Demand m3/day
2021	7559	942
2025	8681	1081
2030	10080	1570
2035	11508	1792

	Girar Jarso Wereda	
year	Girar Jarso Rural AVG water Demand m3/day	Fiche town AVG water Demand m3/day
2021	1329	6858
2025	1331	6866
2030	1332	6872
2035	1333	6877

	Kuyu Wereda	
year	Kuyu Rural AVG water Demand m3/day	Gerba Guracha town AVG water Demand m3/day
2021	4414	2997
2025	5069	3442
2030	5887	3997
2035	6721	4563

	Wuchale Wereda	
year	Wuchale Rural AVG water Demand m3/day	Muke Turi town AVG water Demand m3/day
2021	3974	1721
2025	4564	1976
2030	5300	2295
2035	6051	2620

Wereda	Cluster 2 Livestock Category and water demand											Water Demand in m3/day
	Shoats	0.01	Cattle	0.7	Camel	1	Donkey	0.6	Chicken	0.001	TLU	
Dera	57918	579	173551	121486	0	0	28112	16867	60000	60	138,932.08	3,473
Girar Jarso	52366	523.66	225086	157560.2	0	0	180013	108007.8	76284	76.284	266091.66	6,652
Kuyu	70500	705	135333	94733.1	0	0	33827	20296.2	122443	122.443	115734.3	2,893
Wuchale	92654	926.54	182513	127759.1	0	0	62048	37228.8	60741	60.741	165914.44	4,148

Note: Ethiopia is home to about 35 million tropical livestock unit (TLU), and on average, one TLU requires about 25 liters of water per day, Ethiopia Agriculture research organization (EARO)

4.6.3 Water demand of cluster 3

	Enebise Sar Midir Wereda	
year	**Enebise Sar Midir Rural AVG water Demand m3/day**	**Mertule Maryiam town AVG water Demand m3/day**
2021	4604	1757
2025	5125	1955
2030	5793	2210
2035	6502	2481

	Sayit Wereda	
year	**Sayit Rural AVG water Demand m3/day**	**Ajibar town AVG water Demand m3/day**
2021	5282	699
2025	5880	778
2030	6646	880
2035	7460	987

Kebele	**Cluster 3 Livestock Category and Water Demand**											**Water Demand in m3/day**
	Sheep & Goats	**0.01**	**Cattle**	**0.7**	**Camel**	**1**	**Donkey & Mules**	**0.6**	**Chicken**	**0.001**	**TLU**	
Enebise Sar Midir	94787	948	67791	47454	0	0	18039	10823	42305	42	59,224.97	1,481
Sayit	332842	3328	142886	100020.2	0	0	25685	15411	213057	213	118,972.68	2,974

4.6.3 Water demand of cluster 4

Bug-na Wereda	
year	**Bug-na Rural AVG water Demand m3/day**
2021	2858
2025	2861
2030	2863
2035	2865

E.Belesa Wereda		
year	**E.Belesa Rural AVG water Demand m3/day**	**town AVG water Demand m3/day**
2021	3153	1779
2025	8681	2043
2030	4205	2965
2035	4801	3386

	Ebenat Wereda	
year	**Ebenat Rural AVG water Demand m3/day**	**Ebenat town AVG water Demand m3/day**
2021	7881	1959
2025	9051	2250
2030	10510	2613
2035	11999	2983

Mekiet Wereda		
year	**Mekiet Rural AVG water Demand m3/day**	**town AVG water Demand m3/day**
2021	8136	3411
2025	9344	3917
2030	10850	4549
2035	12387	5193

Tselimt Wereda	
year	**Bug-na Rural AVG water Demand m3/day**
2021	2858
2025	2861
2030	2863
2035	2865

Wereda	Livestock Category											Water Demand in m3/day
	Shoats	0.01	Cattle	0.7	Camel	1	Donkey	0.6	Chicken	0.001	TLU	
Bugna	77733	777	74524	52167	0	0	13126	7876	117827	118	60,819.73	1,520
Ebenat	242819	2428	238424	166896.8	0	0	29453	17672	358516	358.516	187355	4,684
Meket	99000	990	66356	46449.2	0	0	19313	11588	368057	368.057	59395	1,485
Misrak Belesa	174939	1749	106506	74554.2	0	0	17178	10307	122748	122.748	86733	2,168
Tselimt	106178	1061.78	106858	74800.6			13195	7917	78301	78.301	83857.681	2,096

4.7 Groundwater potential zone (GWPZ)

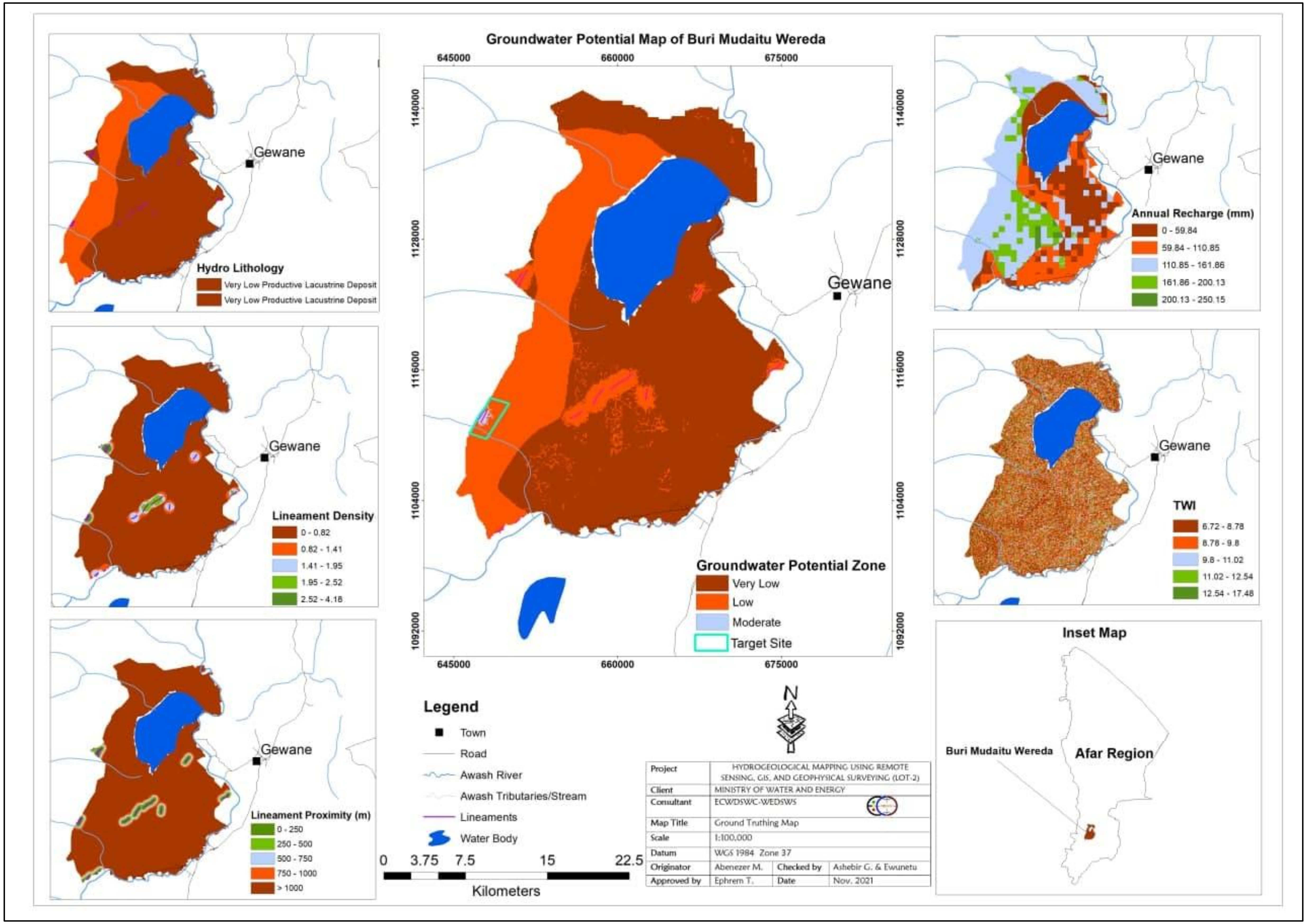


Figure 116: GWP map of Buri Mudaitu Wereda

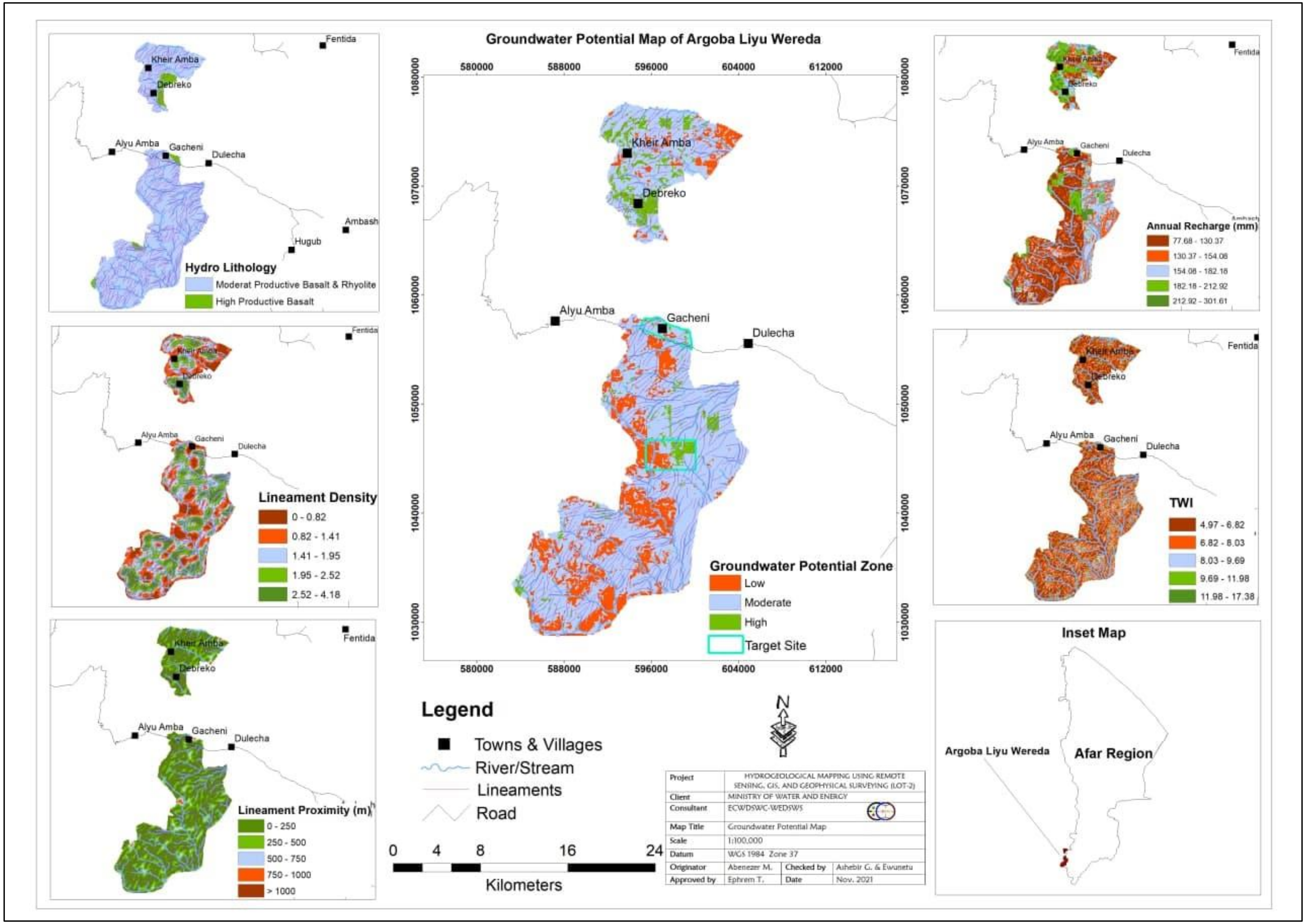


Figure 117: GWP map of Argoba Liyu Wereda

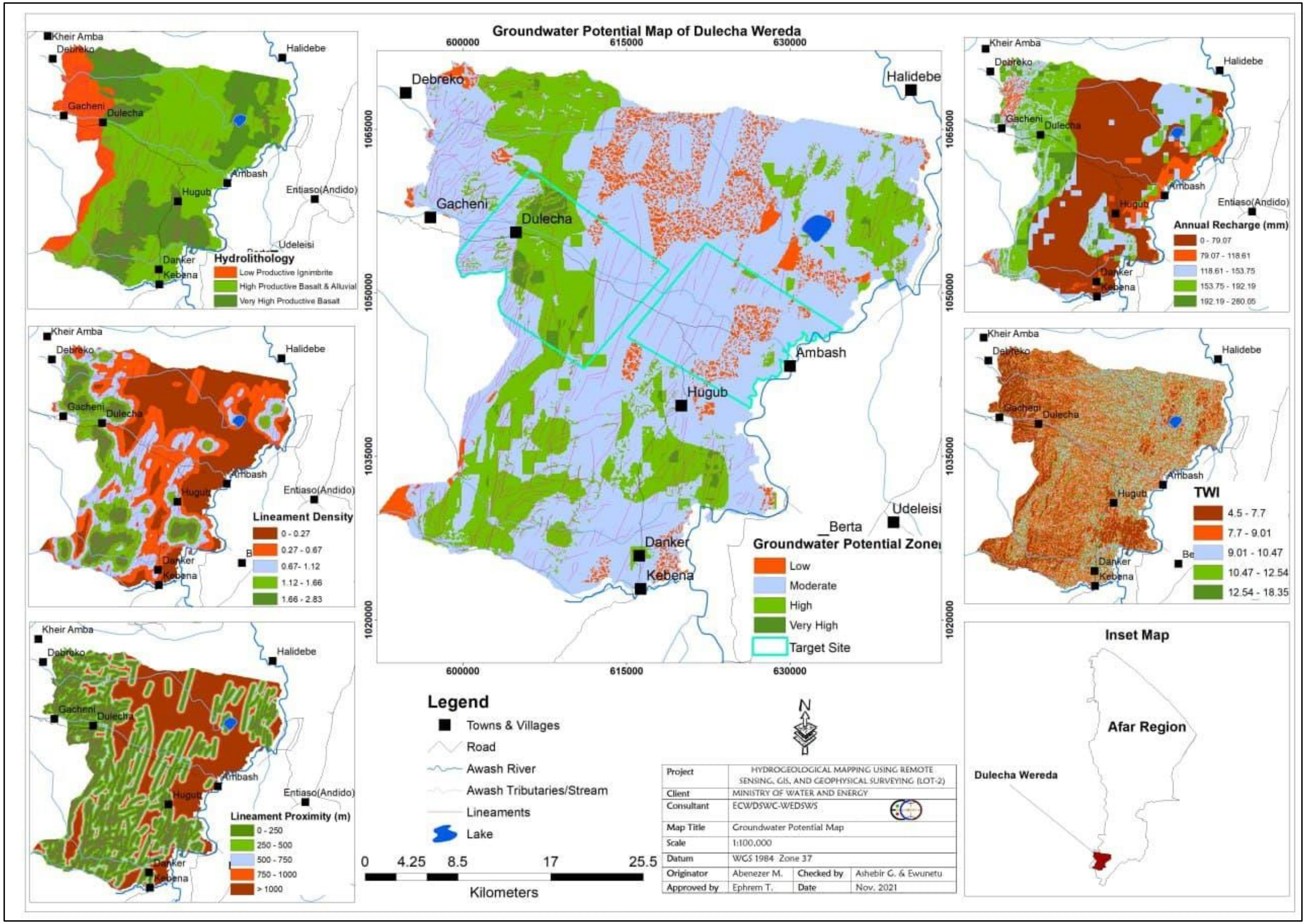


Figure 118: GWP map of Dulecha Wereda

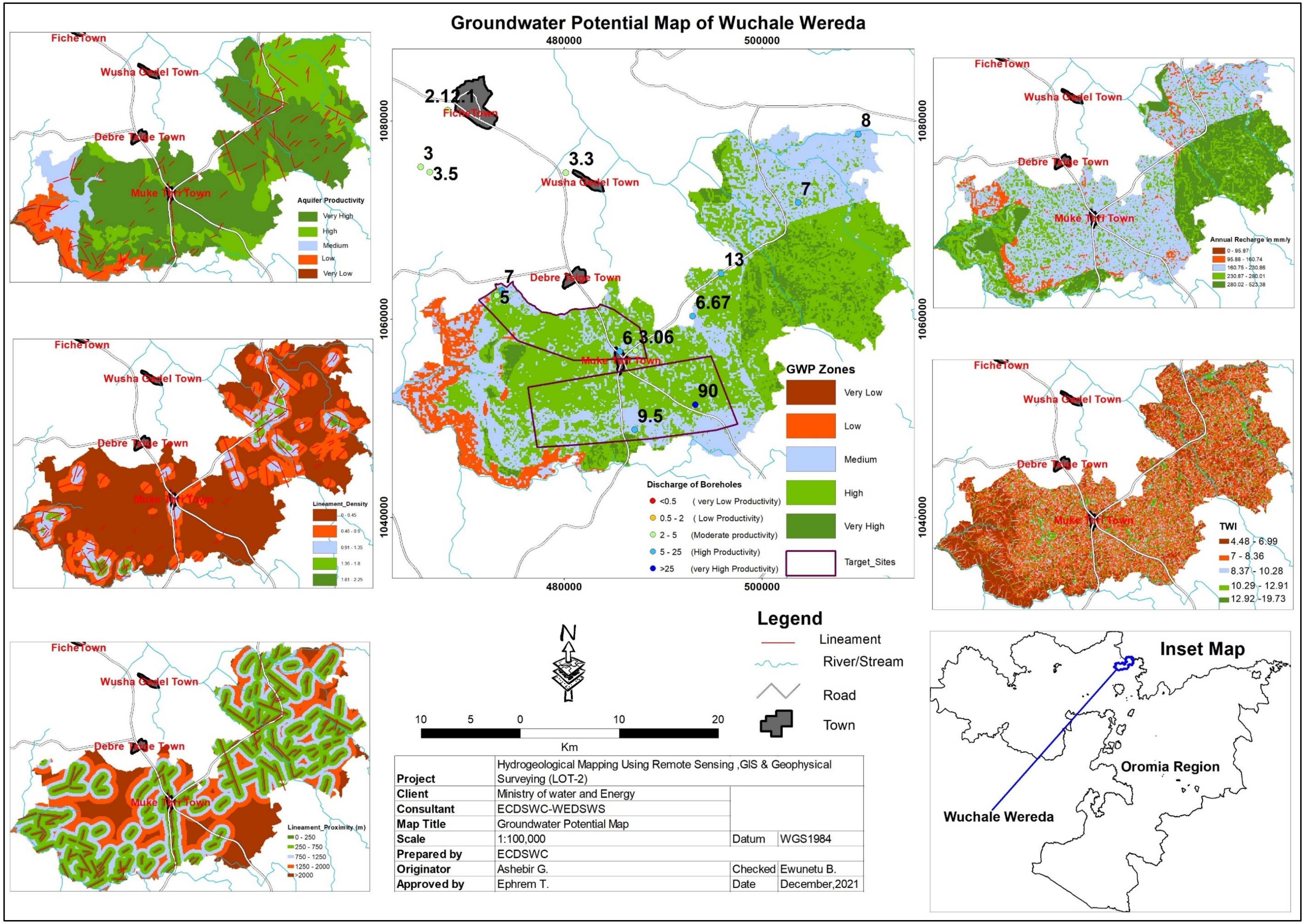
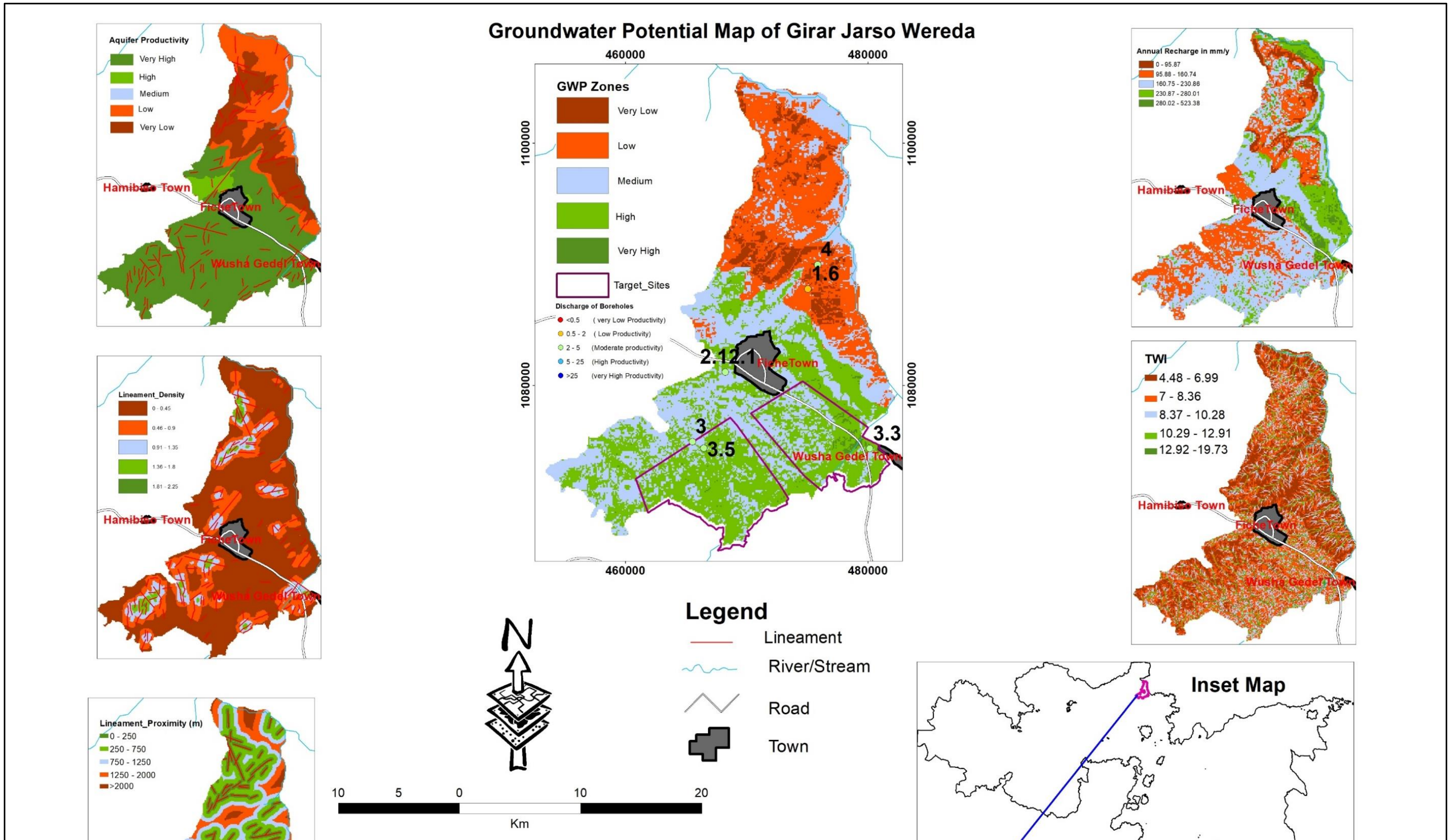


Figure 119: GWP map of Wuchale Wereda



Project	Hydrogeological Mapping Using Remote Sensing ,GIS & Geophysical Surveying (LOT-2)		
Client	Ministry of water and Energy		
Consultant	ECDSWC-WEDSWS		
Map Title	Groundwater Potential Map		
Scale	1:100,000	Datum	WGS1984
Prepared by	ECDSWC		
Originator	Ashebir G.	Checked	Ewunetu B.
Approved by	Ephrem T.	Date	December,2021

Figure 120: GWP map of Girar Jarso Wereda

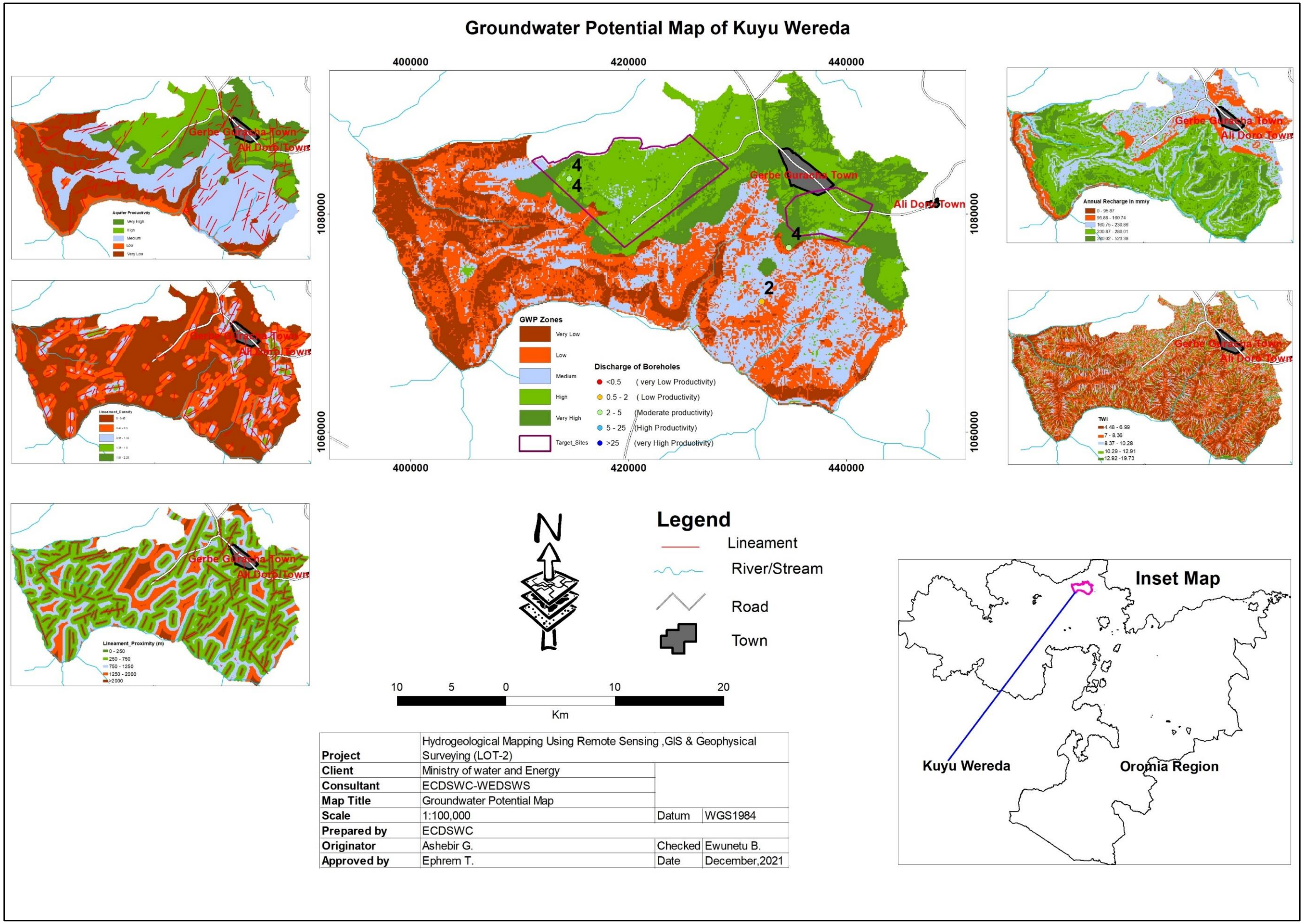


Figure 121: GWP map of Kuyu Wereda

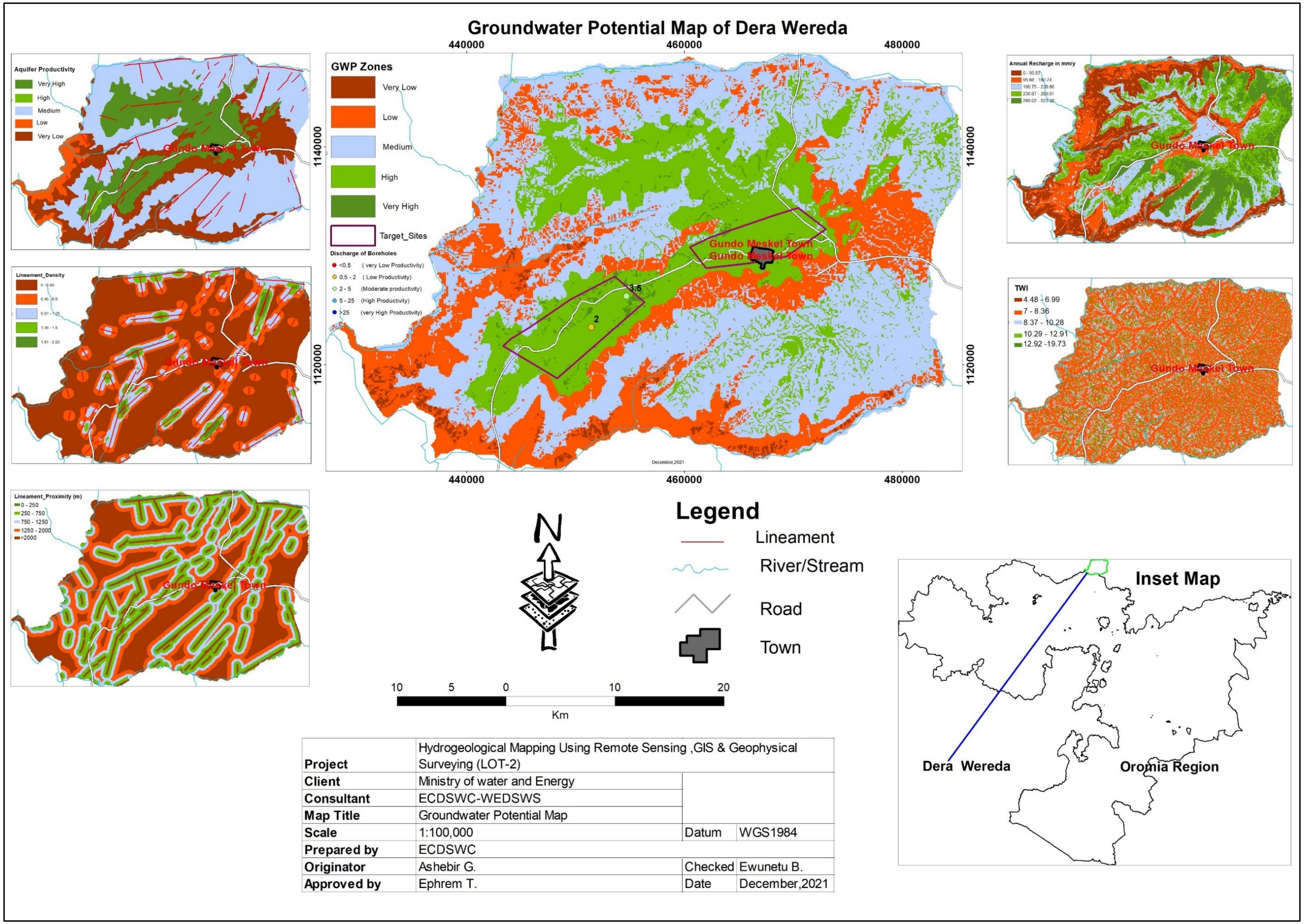
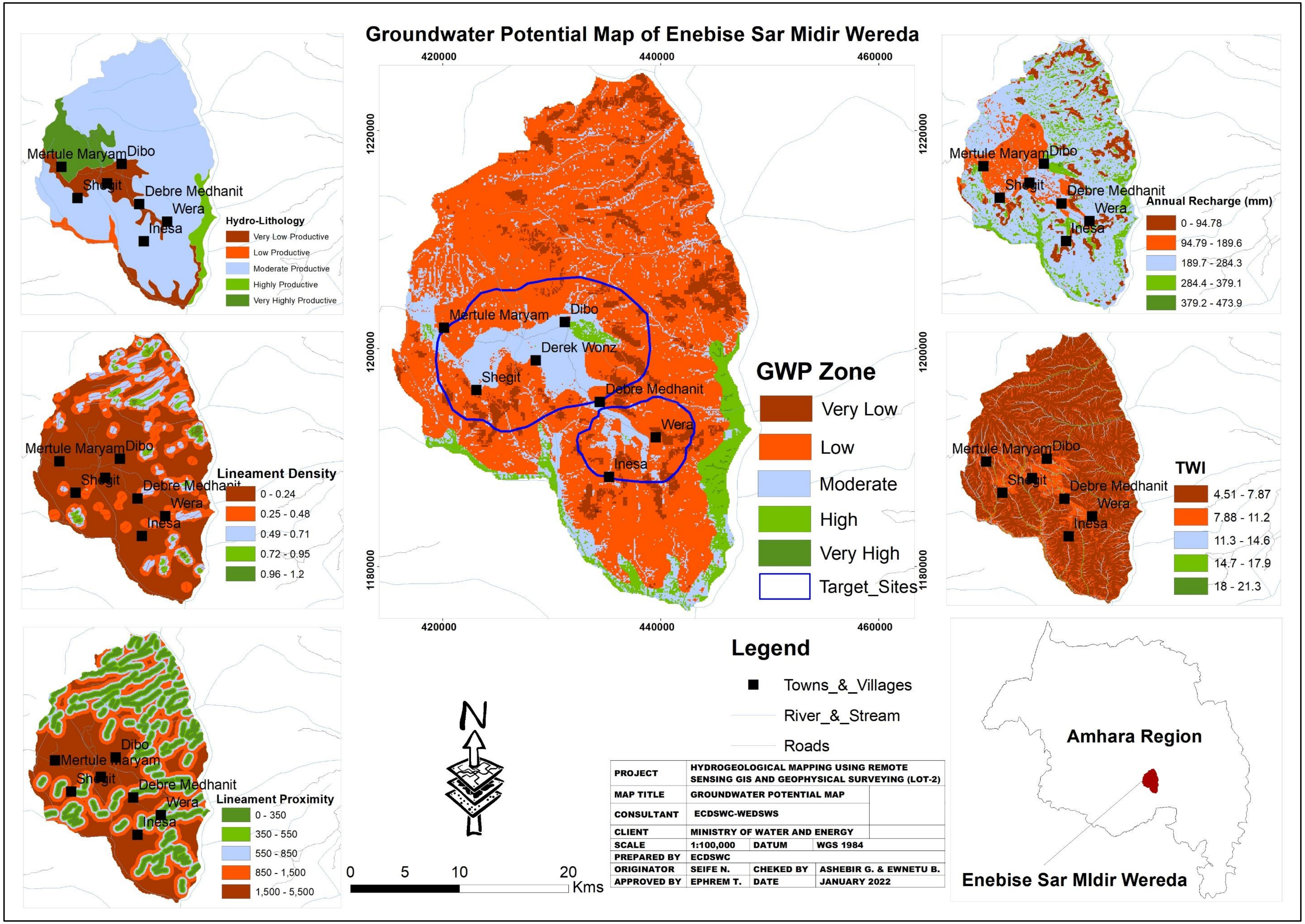


Figure 122: GWP map of Dera Wereda



PROJECT	HYDROGEOLOGICAL MAPPING USING REMOTE SENSING GIS AND GEOPHYSICAL SURVEYING (LOT-2)		
MAP TITLE	GROUNDWATER POTENTIAL MAP		
CONSULTANT	ECDSWC-WEDSWS		
CLIENT	MINISTRY OF WATER AND ENERGY		
SCALE	1:100,000	DATUM	WGS 1984
PREPARED BY	ECDSWC		
ORIGINATOR	SEIFE N.	CHEKED BY	ASHEBIR G. & EWNETU B.
APPROVED BY	EPHREM T.	DATE	JANUARY 2022

Figure 123: GWP map of Enebise Sar Midir Wereda

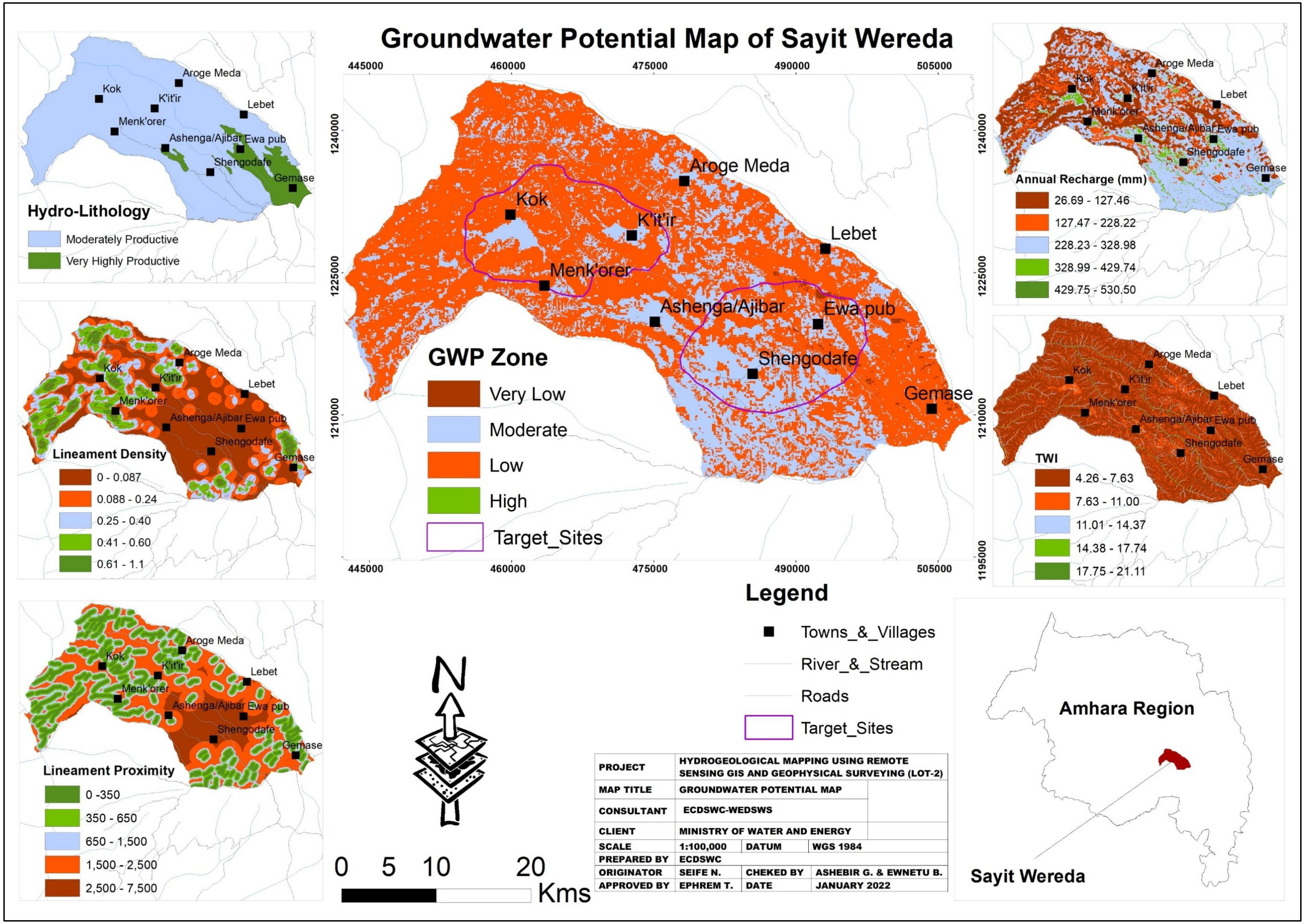


Figure 124: GWP map of Sayit Wereda

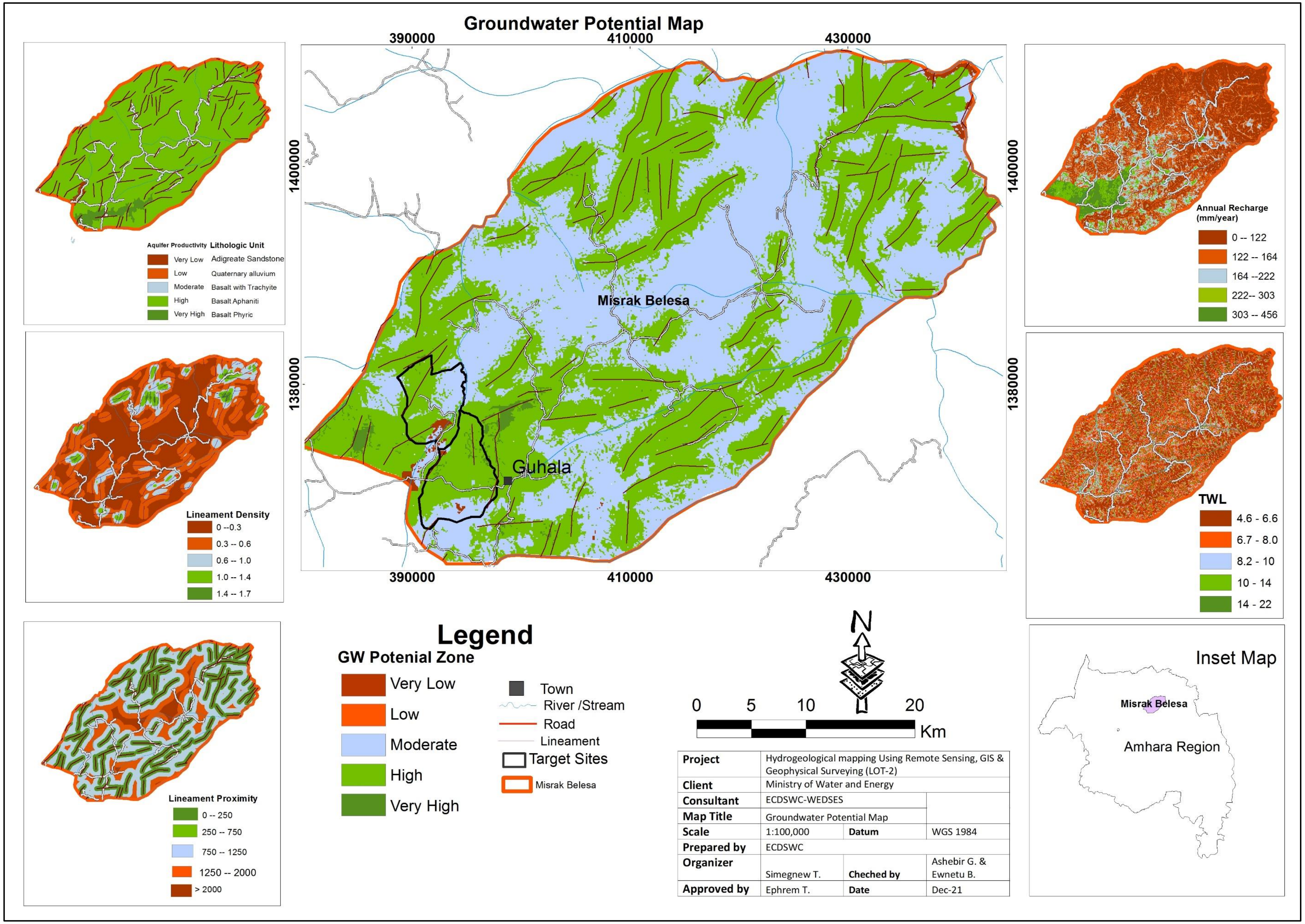


Figure 125: GWP map of Misrak Belesa Wereda

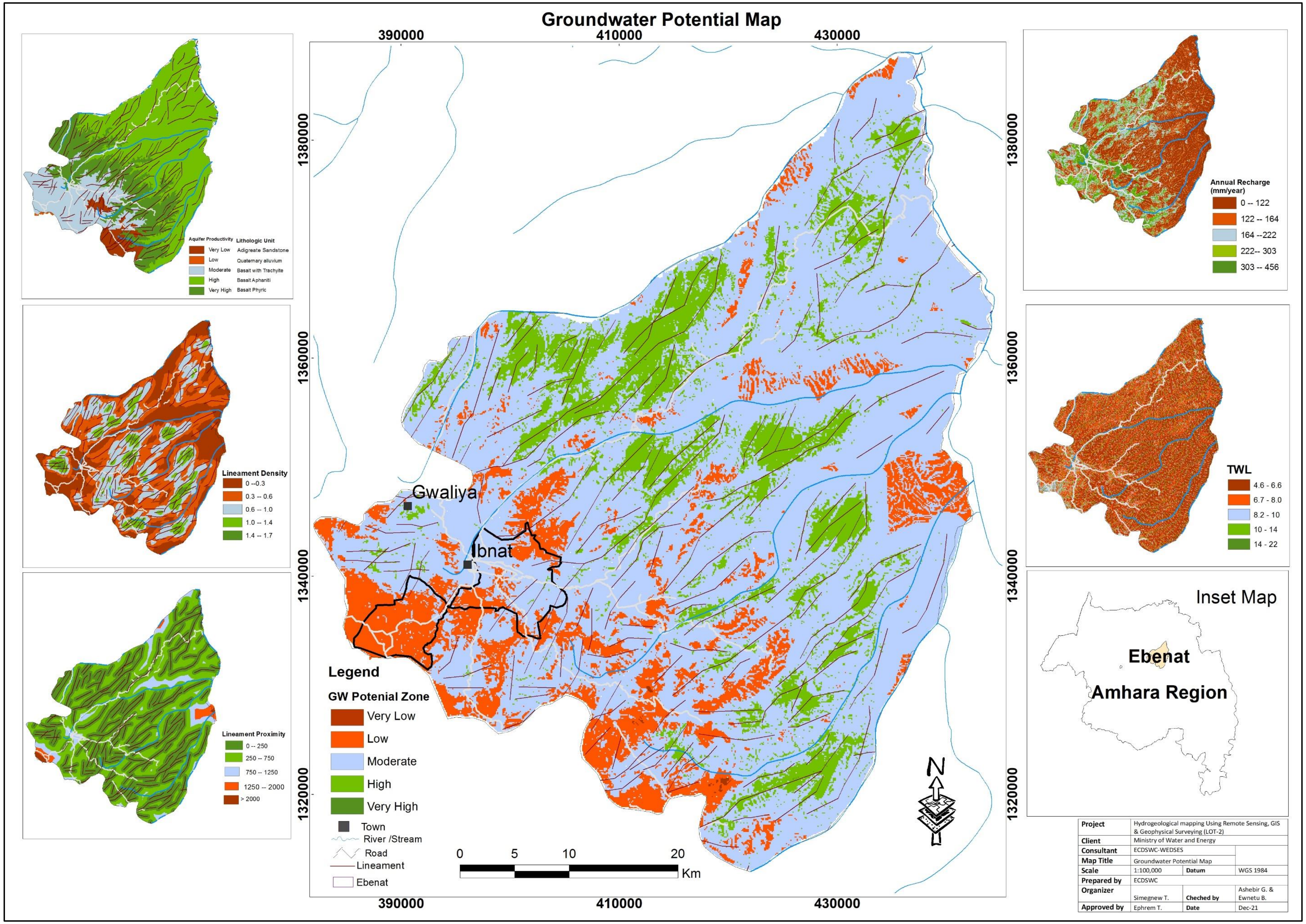


Figure 126: GWP map of Ebenat Wereda

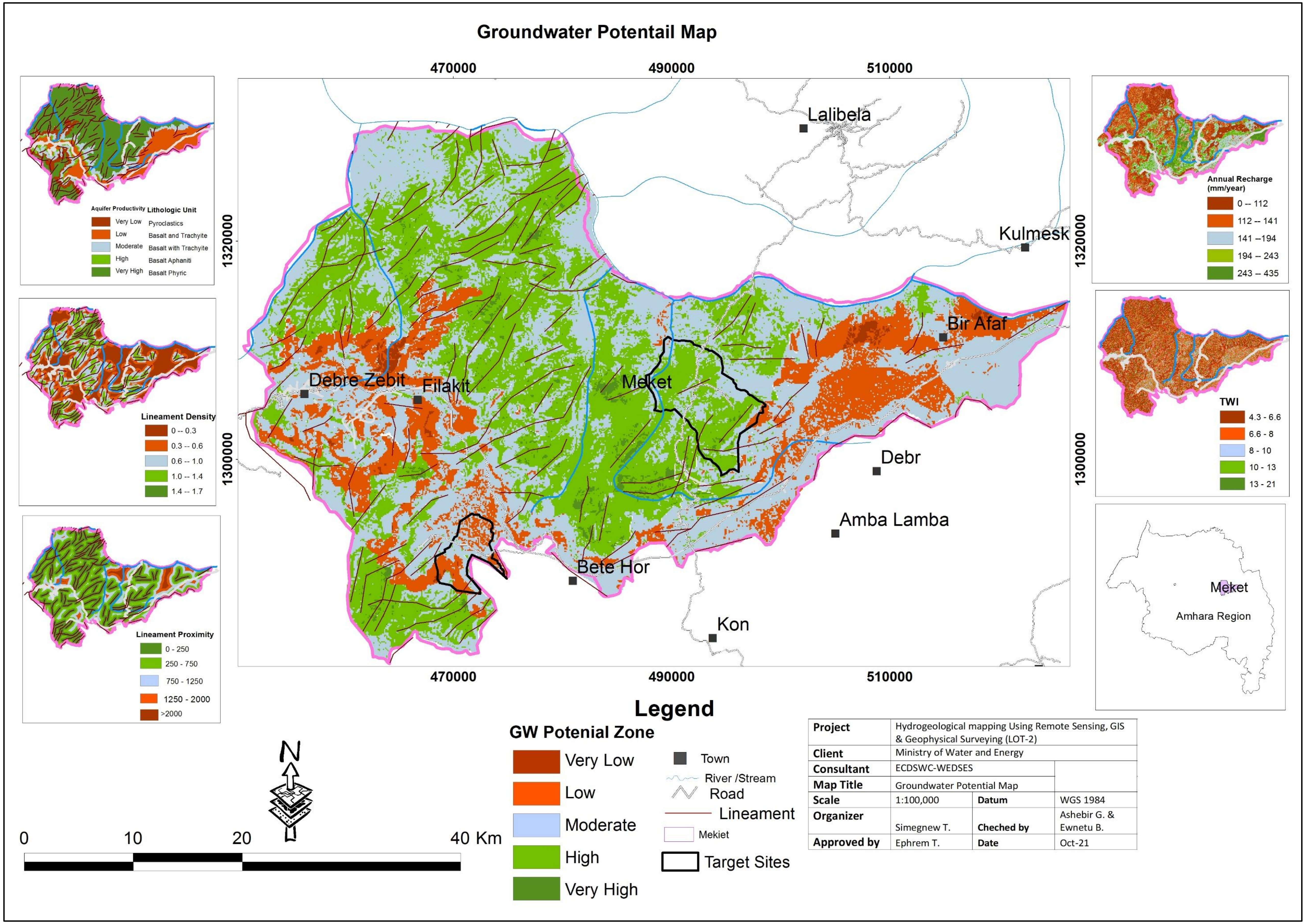


Figure 127: GWP map of Mekiet Wereda

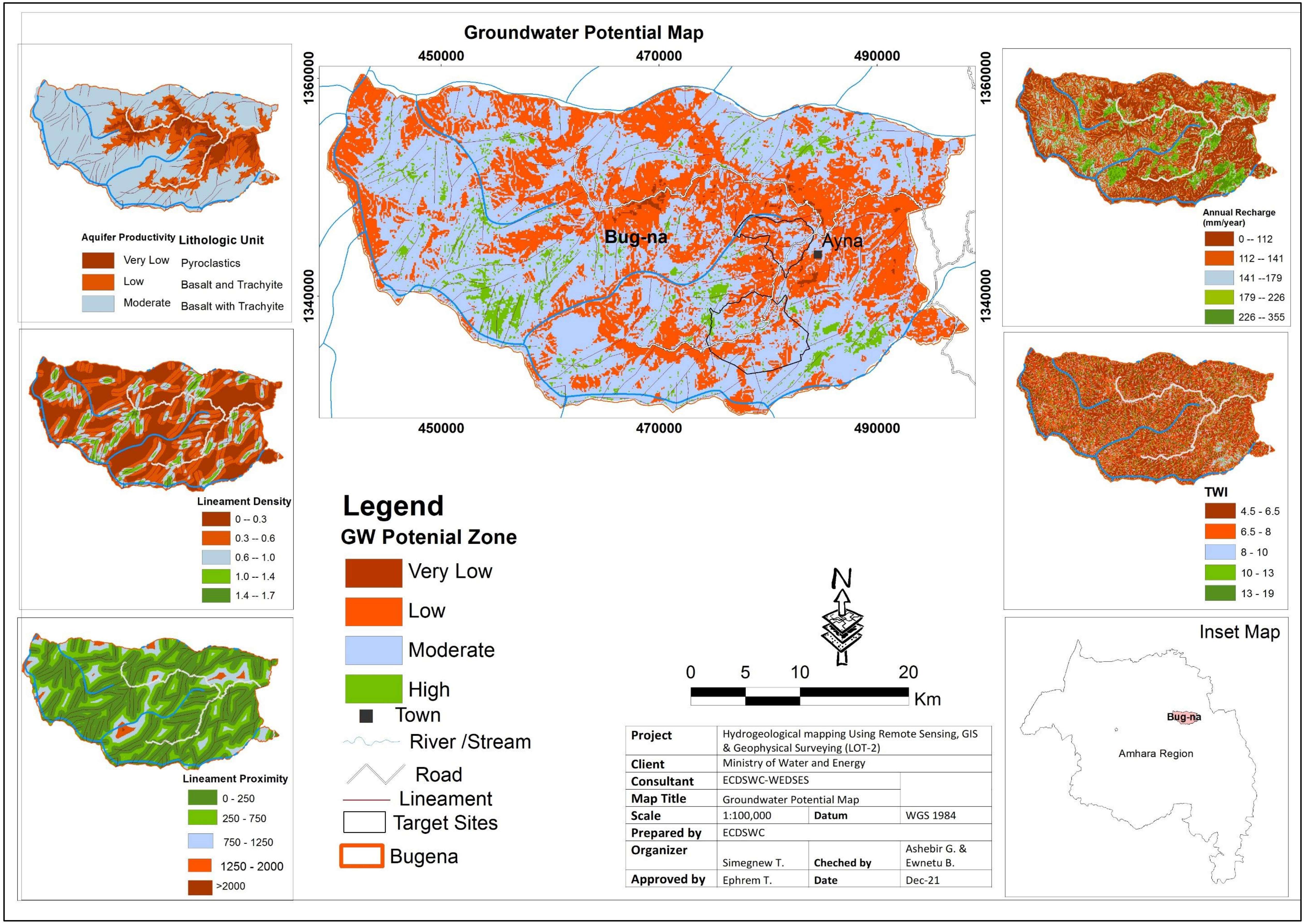


Figure 128: GWP map of Bugna Wereda

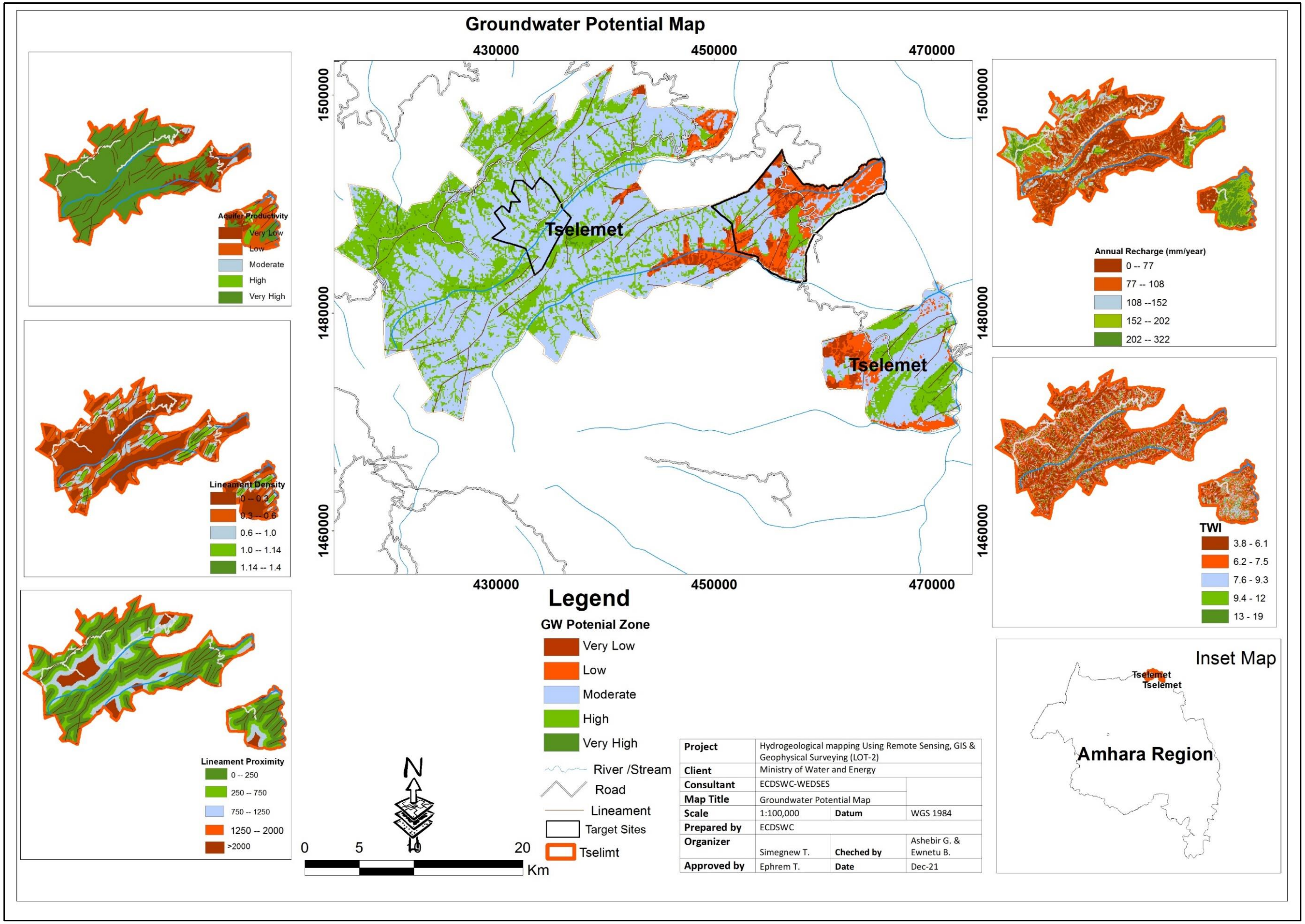


Figure 129: GWP map of Tselemit Wereda

5. Revised work plan for the phase – III

The Revised Work Programs for Phase III is prepared considering the remaining work volume. Accordingly, the revised work program is prepared for phase III and is given in Figure 130.

Hydrogeological mapping Using Remote Sensing,GIS and Geophysical Surveying (LOT-2)

Code	Activity(Work)	Nov	Dec	Jan	Feb	Mar
1	Phases	Phase III				
3.0	**Phase III:Detailed site Specific Hydrogeological and Geophysical investigation**					
3.1	Conduct detailed Hydorological field survey at the selected target area					
3.2	Conduct detailed Geological mapping at selected target area (1:50,000)					
3.3	Prepare Hydrogeological conceptual model map of target area (1: 50,000) in conjunction with the groundwater sanitation protocols to target area specific mapping such as: aquifer vulnerability mapping, aquifer susceptibility mapping, exclusion area maps					
3.4	Conduct detail Hydogeological study incorporated with the local climate change trends of selected target area					
3.5	Conduct Geophysics (VES, 2D Tomography magnetic) and Prepare Geophysical map (1: 5,000)					
3.6	Geophysical data processing ,analysis & integration					
3.7	Analyses of the most promising sites					
3.8	Select optimal site for drilling borehole and corresponding climatic Sensitivities resilience measures					
3.9	Validation of target sites					
3.10	Preparation of target dirilling site maps					
3.11	Produce well design, specification and select appropriate drilling technology and BOQ preparation for CR-boreholes					
3.12	Organize validation workshop of draft report					
3.13	Preparation and submission of final report and maps					
3.14	**Training and Capacity builiding activities**					
3.15	**Training 1 :** Groundwater resource mapping methodology					
3.16	**Training 2:** workshop to Ethiopia federal and reginal governments,NGO partners and other relevant stkakeholders.					
3.17	**Training 3** :Capacity building of 60 national counterparts					

LEGEND: Phase I; Phase III; Report; Worksho; Submission of Reports; Phase II; Field work; Office; Training

Figure 130: Revised Work Program for phase III work activities

6. Conclusion and Recommendation

The present study is an attempt to delineate the groundwater potential zones using RS, GIS, and MCDM techniques in 14 weredas, which are located in Afar, Amhara, and Oromia regional states. A total of five thematic layers such as Lithologic units, Lineament density, Lineament proximity, TWI, and Recharge were used in this study to delineate the groundwater potential zones. Different steps chosen for the study include the development of the thematic layers followed by GIS-based Multi-Criteria evaluation based on saaty's analytical hierarchy process (AHP) is used to compute weights for the thematic layers, the ranks from 1 to 5 allocated for each thematic layer which indicates very low, low, medium, high and very high in ascending order, associated with each class, were selected based on the influence of each factor on the groundwater potential, weighted overlay analyses for the demarcation of GWP zones, sensitivity analyses to understand effect weight of each thematic layer and validation of GWP zone by using well data and conceptual understanding of each project weredas.

The spatial distribution of the project weredas GWP zones generally matches with the conceptual understanding of the project weredas and well data during model validation. The good agreement of GWP map validation and well data indicate litho–structural control on groundwater recharge and movement process and factors affecting groundwater recharge were carefully analyzed during the development of thematic layers. Based on the result of sensitivity analysis, the effective weights for each thematic layer show some deviation from empirical weights. The GWP maps produced will be used to quickly identify the prospective GWP zones for conducting site-specific investigations.

This study generally demonstrates that GIS and remote sensing techniques coupled with field data can be used for mapping GWP zones, thereby narrowing down the target areas. Then, by conducting a detailed hydrogeological and geophysical survey at phase III, the most appropriate and optional sites will be selected for drilling.

It recommended that this study must be supported by detailed Hydrogeological, Geophysical, and test well drilling to more understand the groundwater system of the project areas.

7. REFERENCE

- Abbate, E. and Sagri, M. 1980. Volcanites of Ethiopian and Somali plateaus and major tectonic lines. Atti convegni Lincei 47, 219-227.
- Abdelsalam, M.G., Stern, R.J., 1996. Sutures and shear zones in the Arabian-Nubian Shield. Journal African Earth Sciences 23, 289-310.
- Abebe, T., Mazzarini, F., Innocentti, F., and Manetti, P. 1998. The Yerer-Tullu Wollel Volcano-tectonic Lineament: a transtensional structure in central Ethiopia and the associated magmatic activity. Journal of African Earth Sciences, 26, 135-150.
- Agostini, A., Bonini, M., Corti, G., Sani, F., Mazzarini, F., 2011. Fault architecture in the Main Ethiopian Rift and comparison with experimental models: Implications for rift evolution and Nubia–Somalia kinematics. Earth and Planetary Science Letters 301, 479–492.
- Amhara Design and Supervision Works Enterprise (ADSWE), 2013; Groundwater Potential Assessment of Eastern Amhara Development Corridor of Awash basin (Kobo-Robit-Minjar) Detail Reconnaissance Report.
- Ampe, E.M.; Vanhamel, I.; Salvadore, E.; Dams, J.; Bashir, I.; Demarchi, L.; Batelaan, O. Impact of urban land-cover classification on groundwater recharge uncertainty. IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens. 2012, 5, 1859–1867.
- Assefa, G., 1991. Lithostratigraphy and environment of deposition of Late Triassic to Early Cretaceous sequences of the central part of Northwestern Plateau, Ethiopia. N. Jb. Geol. Palaont. Abb. 182, (3): 255-284.
- Ayehu, G.T.; Tadesse, T.; Gessesse, B.; Dinku, T. Validation of new satellite rainfall products over the Upper Blue Nile Basin, Ethiopia. Atmos. Meas. Tech. 2018, 11, 1921–1936.
- Ayele Almaw Fenta & Addis Kifle & Tesfamichael Gebreyohannes & Gebrerufael Hailu (2015), Spatial analysis of groundwater potential using remote sensing and GIS-based multi-criteria evaluation in Raya Valley, northern Ethiopia
- B. Fentaw, M. Manayeand, and A. Tadese, GSE (2017), Hydrogeological and Hydrochemical Maps of Debre Tabor NC 37 – 2 Sheet
- B. Fentaw, M. Manayeand, and A. Tadese, GSE (2017), Hydrogeological and Hydrochemical Maps of Debre Tabor NC 37 – 2 Sheet
- Basavarajappa H.T, Dinakar s and Manjunatha M.C (2016), Validation of derived groundwater potential zones (GWPZ) using geo-informatics and actual yield from well points in parts of upper Cauvery basin of Mysuru and Chamarajanagara districts, Karntaka, India
- Basin water balance modeling, Tendaho Sugarcane Irrigation Expansion Project (WWDSE, 2013)
- Bereket Fentaw and Leta Alemayehu, GSE (2017), Hydrogeological and Hydrochemical Maps of Addis Ababa sheet NC 37-10 Sheet
- Bereket Fentaw, Mihret Manaye and Alemayehu Tadese (2017). Hydrogeological and Hydrochemical Maps of Debre Tabor NC 37-2 and Dessie NC 37-3 Sheet.
- Beyth, M., 1972. Paleozoic–Mesozoic sedimentary basin of Mekele Outlier, Northern Ethiopia. The American Association of Petroleum Geologists Bulletin 56, 2426–2439.
- Bonini, M., Corti, G., Innocenti, F., Manetti, P., Mazzarini, F., Abebe, T., Pecskay, Z., 2005.

- Central Statistical Agency (2013), Population Projection of Ethiopia for all Regions at wereda Level from 2014 – 2017.
- Central Statistical Agency (2013), Population Projection of Ethiopia for all Regions at wereda Level from 2014 – 2017.
- Charlotte MacAlister, Paul Pavelic, Callist Tindimugaya, Tenalem Ayenew, Mohamed Elhassan Ibrahim and Mohamed Abdel Meguid, (2012), Overview of groundwater in the Nile River Basin.
- Charlotte MacAlister, Paul Pavelic, Callist Tindimugaya, Tenalem Ayenew, Mohamed Elhassan Ibrahim and Mohamed Abdel Meguid, (2012), Overview of groundwater in the Nile River Basin.
- Corti, G., 2009. Continental rift evolution: from rift initiation to incipient break-up in the Main Ethiopian Rift, East Africa. Earth Sci. Rev. 96, 1–53.
- Ebinger, C., 2005. Continental breakup: the East African perspective. Astron. Geophys. 46, 2.16–2.21. Ebinger, C., Casey, M., 2001 Continental breakup in magmatic provinces: an Ethiopian example, Geology 29, 527– 530.
- Engida Zemedagegnehu, Yelma Sileshi, Albert Tuinhof (2007), Groundwater Resources in Lake Tana Sub Basin and Adjacent Areas rapid Assessment and Terms of Reference of Further Study; Federal Republic of Ethiopia/ World bank.
- Engida Zemedagegnehu, Yelma Sileshi, Albert Tuinhof (2007), Groundwater Resources in Lake Tana Sub Basin and Adjacent Areas rapid Assessment and Terms of Reference of Further Study; Federal Republic of Ethiopia/ World bank.
- Ermias Hagos, Tenalem Ayenew,Seifu Kedede and Mulugeta Alene, (2015). Review of hydrogeology Tekeze River Basin: Implication for rural and urban water supply in the region.
- FAO. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements- Irrigation and drainage paper 56. Rome, Italy.
- Fedlu Hassen and Aschalew Gurmu, GSE (2017), Hydrogeological and Hydrochemical Maps of Debre Markos NC 37-6 Sheet
- Fedlu Hassen and Aschalew Gurmu, GSE (2017), Hydrogeological and Hydrochemical Maps of Debre Markos NC 37-6 Sheet
- Fedlu Hassen, Aschalew Gurmu, GSE (2012), Geological Survey of Ethiopia Integrated Groundwater Resource Assessment of Debre-Markos Sheet (NC 37–6)
- Fedlu Hassen, Aschalew Gurmu, GSE (2012), Geological Survey of Ethiopia Integrated Groundwater Resource Assessment of Debre-Markos Sheet (NC 37–6)
- Fedlu Hassen, Aschalew Gurmu, GSE (2012), Integrated Groundwater Resource Assessment of Debre-Markos Sheet (NC 37 – 6)
- Fedlu Hassen, Aschalew Gurmu, GSE (2012), Integrated Groundwater Resource Assessment of Debre-Markos Sheet (NC 37 – 6)
- Fenta, A.A.; Yasuda, H.; Shimizu, K.; Ibaraki, Y.; Haregeweyn, N.; Kawai, T.; Belay, A.S.; Sultan, D.; Ebabu, K. Evaluation of satellite rainfall estimates over the Lake Tana basin at the source region of the Blue Nile River. Atmos. Res. 2018, 212, 43–53.
- Gamachu, D. (1977). The aspect of Climate Change and Water Budget in Ethiopia. A Technical Monograph for Addis Ababa University. Addis Ababa, Ethiopia: Addis Ababa University Press.
- Gani, N.D.S., Gani, M., Abdelsalam, M.G., 2008. Blue Nile incision on the Ethiopian Plateau: pulsed plateau growth, Pliocene uplift, and hominin evolution. GSA Today 17, 4–11.

- Geleta, S. 1998. Biostratigraphy, depositional environment, basin evolution and hydrocarbon potential of the Late Triassic to Late Jurassic succession, Ogaden Basin, Ethiopia. Ph.D. thesis, Eberhard-Karls-Universität, Erlangen.NRDECO, 1998. Tekeze River Basin Integrated Development Master Plan Project, Reconnaissance Phase Report and Hydrogeological Report, 1998 MoWR
- Geological investigation of Allaidege plain-volume-II, Allaidege groundwater resources assessment project, WWDSE 2011
- Geophysical investigation of Allaidege plain-volume-III, Allaidege groundwater resources assessment project, WWDSE 2014
- GSE (2010), Geology, Geochemistry and Gravity Survey of the Debre Tabor area.
- GSE (2010), Geology, Geochemistry, and Gravity Survey of the Debre Tabor area.
- H, B.Coye , Kennedy.R and Donkin, 1998. Tekeze Medium Hydropower Project, Feasibility Study MoWR.
- Hallstein lie & Agust Gudmundsson (2002), the importance of hydraulic gradient, lineament trend, proximity to lineaments, and surface drainage pattern for the yield of groundwater wells on Askoy, West Norway.
- Hydrogeological and Hydrochemical Maps of Yifag ND 37-14 Sheet by Jiri Sima and Yonas Mulugeta (2017)
- Hydrogeological investigation of Allaidege plain-volume-I, Allaidege groundwater resources assessment project, WWDSE 2011
- Hydro-geological Map of Ayelu Terara Sheet NC37-8; compiled by Bawoke Birhan, Robel Asamnew, and Marta Wegu (GSE, 2007)
- Hydro-geological Map of Debrebirhan Map Sheet NC37-11; compiled by Tsehay Amare, Thomas Agzew, Habtamu Yaze (GSE, 2016)
- Hydrogeological Investigation of Domestic water supply source in Misrak Belesa Wereda for nine kebeles Residents, ADSWE September 5, 2016
- Hydrogeological survey and investigation in Gelealo/ Burimodaitu wereda, Drought Resilience, and Sustainable Livelihoods Program Phase I (DRSLP- I), ECDSWEC-WEDSWS, October 2018
- Jiri Sima and Muhuddin Abdella (2018). Hydrogeological and Hydrochemical Maps of Maychew ND 37-15 Sheet
- Khalid Benjmel, Fouad Amraoui, Said Boutaleb, Mohammed Ouchchen, Amine Tahiri and Amine Touab, Mapping of Groundwater Potential Zones in Crystalline Terrain Using Remote Sensing, GIS Techniques, and Multicriteria Data Analysis (Case of the Ighrem Region, Western Anti-Atlas, Morocco).
- Kobayashi, S., Ota, Y., Harada, Y., Ebita, A., Moriya, M., Onoda, H., Onogi, K., Kamahori, H., Kobayashi, C., Endo, H., Miyaoka, K., and Takahashi, K., 2015. The jra-55 reanalysis, General specifications and basic characteristics. Journal of the Meteorological Society of Japan. Ser. II, 93(1), 5–48.
- Mahamat Ouchar Al-Djazouli . Karim Elmorabiti. Abdelmejid Rahimi Omayma Amellah. Omer Abdelrahim Mohammed Fadil (2020), Delineating of groundwater potential zones based on remote sensing, GIS and analytical hierarchical process: a case of Waddai, eastern Chad
- Maidment, R.I.; Grimes, D.I.F.; Allan, R.P.; Greatrex, H.; Rojas, O.; Leo, O. Evaluation of satellite-based and model re-analysis rainfall estimates for Uganda. Meteorol. Appl. 2013, 20, 308–317

- Mutreja, K.N. (1995) Applied Hydrology. Tata Mcgraw-Hill Publishing Company Limited, New Delhi.
- R. H. McCuen, 1998, Hydrologic Analysis and design, Department of Civil engineering University of Maryland, USA.
- R.K Linsley, L.H, (1983), PAULHUS, Hydrology for Engineers, McGraw-HILL
- Shaw E.M. (1994). Hydrology in Practice. Second Edition, Chapman and Hall, New York, USA
- Sima, Jiri et al. (2009): Water Resources Management and Environmental Protection Studies of the Jemma River Basin for Improved Food Security. ISBN 978-80-254-5021-5. AQUATEST a.s., Prague, Czech Rep.
- Sir Alexander GIBB & Partners (1988). Gelana Irrigation Project Feasibility Study Final Report, volume 2.
- T. Alemayehu, 2006, Groundwater Occurrence in Ethiopia, Addis Ababa University, Ethiopia.
- T. Grabs, J. Seibert, K. Bishop, H. Laudon, (2009) Modeling spatial patterns of saturated areas: A comparison of the tophographic wetness index and a dynamic distributed model.
- T.Azagegn et al, A.Asrat et al,T.Ayenew et al ,S.Kebede et al : Litho-structural control on interbasin groundwater transfer in central Ethiopia. Journal of African Earth Science, Volume 101, January 2015, pages 383-395
- Tadesse Dagnew, (2020). Delineate the groundwater potential zones of Nile river catchment in Tekeze river basin using the application of integrated Geographical Information System and Remote Sensing techniques.
- Tesfaye, Chernet (1993): Hydrogeology of Ethiopia and Water Resources Development – MS EIGS, Ministry of Mines and energy, Addis Ababa (Library 880-051-17).
- The evolution of the Main Ethiopian Rift in the frame of Afar and Kenya rifts propagation. Tectonics 24, TC1007. doi:10.1029/2004TC001680.
- Thomas Agezew and Tsehay Amare, GSE (2018), Hydrogeological and Hydrochemical Maps of Debre Birhan sheet NC 37-11 Sheet
- Tilahun, Azagegn, Tafere (2008): Hydrogeochemical Characterization of Aquifer Systems in upper Awash and Adjacent Abay Plateau using Geochemical Modeling and Isotope Hydrology. Addis Ababa University, School of Graduate Studies, Department of Earth Sciences.
- Tilahun, Azagegn, Tafere (2014): Groundwater Dynamics in the Left Bank Catchments of the Middle Blue Nile and the Upper Awash River Basins, Central Ethiopia
- Tis Isat Water Works PLC (TIWWPLC), (2016).7 (Seven) shallow wells completion report in Ebinat wereda (Emergency wells).
- Ven Te Chow, David R. Maindment and Larry W. Mays, 1988, Applied Hydrology, McGraw-HILL International Editions for Civil Engineering Series.
- Well completion report of drlp1w-06-18 (Buri abandoned well site), drought resilience and sustainable livelihood program (DRSLP -1 PROJECT), ECDSWEC-WEDSWS, May 2021
- Well completion report of Gewane (TCVTW-03-19) test well, groundwater resources assessment of south Teru-Chifra areas and surroundings, ECDSWEC-WEDSWS May 2021
- WMO-NO 168, Guide to hydrological practice, Data Acquisition and processing, Analysis, Forecasting, and other applications. Fifth edition, 1994.

- WWDE (2008): Evaluation of water resources of Adaa and Becho plains groundwater resource for irrigation. Addis Ababa, Ethiopia.
- WWDSE (2006): Evaluation of water resources of the Ada'a and Becho plains groundwater basin for the irrigation development project, April 2006, Water Works Design and Supervision Enterprise.
- Yates D. (1994), WatBal- An Integrated Water Balance Model for Climate Impact Assessment of River Basin Runoff IIASA Working Paper WP-94-064,
- Yerer Engineering, 2004. Hydrogeological Condition of Lalibella Area
- Zelalem L, Melkamu M., Getnet T., Alebachew T., Mulugeta Ch., Minyahl T.(2019) Appraising groundwater potential zones using geospatial and multi-criteria decision analysis (MCDA) techniques in Andasa-Tul watershed, Upper Blue Nile basin, Ethiopia
- 100 deep production wells drilling supervision project of groundwater resources evaluation of Allaidege plain

Annex 1: Observation during groundwater truthing and validation

Cluster 1

No.	Wereda	Locality	UTM E	UTM N	Elv.	Characteristic of validation point
1	Buri Mudayitu wereda	Dengeligita	649387	1115566	638	▪ The observation point is mountain side, there is one deep well with unknown discharge but currently functional, no shallow well, no hand dug well, no spring and alluvial deposit is the observed formation ▪ The area is mapped as low groundwater potential zone
2		Buri	666420	1138650	562	▪ The observation point is on flat plain sloping up to NE areas. There is one deep (400 meter) and dry well, no shallow well, no hand dug well & no spring. Lacustrine deposit and clay is observed formations of the area. ▪ The area is mapped as very low groundwater potential zone
3		Gefrem	663399	1102584		▪ The observation point is close to Awash river. There is one borehole of unknown depth and 3.5 l/s yield. Lacustrine deposit is observed formations of the area. ▪ The area is mapped as very low groundwater potential zone. However, promising yield (3.5) and shallow static water level (3m) of inventoried borehole shows that bank infiltration of nearby Awash River deemed to recharge the groundwater.
4	Argoba Liyu Wereda	Deberko	594802	1068439	1561	▪ The observation point is rugged, sloppy and there are dense drainage and lineament density. Borehole of 177 meter depth & yields 5 l/s exists in the area. ▪ The area is mapped as high groundwater potential zone
5		Gacheni	597044	1057270	716	▪ The observation point is close Gacheni town at junction of two rivers, there is one well with unknown depth but currently functional, no shallow well, no hand dug well, no spring and basalt and rhyolite covered by top soil is the observed formations. ▪ The area is mapped as moderate groundwater potential zone
6		Metekleya	596124	1045870	1187	▪ The observation point is mountainous, sloppy and located in river valley. Borehole of 150 meter depth exists in the area. The vicinity of observation point is close to head water of the area. ▪ The area is mapped as low groundwater potential zone
7	Dulecha	Dulecha Town	604874	1055711	1026	▪ The observation point is close to Dulecha town. Tophographically the area is gently sloping and rivers that flows in almost W-E direction exists. Alluvial deposit is observed exposure and there are numerous NE-SW trending marginal faults and lineaments with in the vicinity. One borehole (unknown depth & discharge) currently serving Dulecha town is located at this observation point. From hydrogeological point of view, the observed point has good water potential due to hydrogeological set up of the area. ▪ The area is mapped as High groundwater potential zone
8		Lalaba/ Hurunto	621058	1047070	749	▪ Alluvial deposit is exposure that covers this observation point. The area is gently sloping, a number of streams arises from western margin flows through the area towards Awash river. NE-SW major faults are observed within the vicinity and one borehole (100 m deep) drilled on the edge of this fault yields 24l/s. In terms of groundwater potential the observation point is deemed to be good due to existence good productive lithologies that exhibit primary and secondary porosities, high groundwater recharge from subsurface inflow from adjacent aquifers, river bank infiltration and direct rainfall. ▪ The area is mapped as moderate groundwater potential zone due to the fact that only recharge from direct rainfall is considered for the overlay analysis recharge estimation.
9		Western area	600668	105492		▪ The observation point is mountainous, sloppy and located in river valley. No deep & shallow well, no hand dug well, no spring and Ignimbrite affected by tectonic force is the observed outcrop. ▪ The area is mapped as Moderate groundwater potential zone

Cluster 2

No.	Wereda	Locality	UTM E	UTM N	Characteristic of validation point
1	Wuchale Wereda	Tulu Gerbicho	509685	1078701	▪ The observation point is plain land with moderate groundwater recharge and Runoff potential. ▪ One well is observed with discharge of 8l/s. ▪ Alluvial aquifer with moderate to high groundwater potential is observed lithological unit in this area. ▪ The area is mapped as high groundwater potential zone. ▪ The groundwater potential map show there is good agreement between the well discharge and groundwater potential map.
2		Burka Dandi	495822	1064653	▪ The observation point is plain land with moderate groundwater recharge and Runoff potential. ▪ One well is observed with discharge of 13 l/s. ▪ Aiba basalt is lithological unit observed in this area. ▪ The area is mapped as high groundwater potential zone which highly agree with the well discharge observed in this zone.
3		Halko	473683	1062937	▪ The observation point is plain land with moderate groundwater recharge and Runoff potential. ▪ Two well is observed with discharge of 5 & 7 l/s. ▪ Alluvial aquifer is lithological unit observed in this area. ▪ The area is mapped as moderate to high groundwater potential zone which highly agree with the well discharge observed in this zone.
4		Sadan	487195	1056852	▪ The observation point is plain land with moderate groundwater recharge and Runoff potential. ▪ One well is observed with discharge of 3.06 l/s. ▪ Aiba basalt is lithological unit observed in this area. ▪ The area is mapped as moderate groundwater potential zone which highly agree with the well discharge observed in this zone.
5	Girar Jarso Wereda	Wisi Biriqe	475032	1087994	▪ The observation point is plain land and Tarmaber basalt is the lithological unit mapped in this area. Spring discharge of 3.5 & 3 l/s exists in the area. ▪ The area is mapped as moderate to high groundwater potential zone
6		Changel	480142	1074817	▪ The observation point is plain land with low to moderate groundwater potential and recharge potential. ▪ One borehole taped in basaltic aquifer with yield 3.3 l/s. ▪ The area is mapped as moderate groundwater potential ▪ The area is mapped as moderate groundwater potential zone which highly agree with the well discharge observed in this zone.
7		Mesk woha	475032	1087994	▪ The observation point is mountainous, sloppy and located at contact of Ashangi basalt and Gypsum. ▪ The observation point is low groundwater potential and recharge potential. ▪ One spring with discharge of 1.6 l/s exist in the area. ▪ The area is mapped as low groundwater potential zone which highly agree with the spring discharge observed in this zone
8	Kuyu Wereda	Derach cagi	414526	1083262	▪ The observation point is plain land with moderate recharge and runoff potential. ▪ Alluvial aquifer with moderate permeability is observed lithological unit in this area. ▪ The observation point is mapped as high groundwater potential zone .However one borehole drilled in this area with moderate groundwater discharge about 4l/s. This miss match may be observed may be due to poor construction of borehole, pumping test and Limited lineament density in this area. ▪ Generally, further geophysical investigation and detail hydrogeological mapping will verify the groundwater potential map of this area.
9		Dawicha Kerensa	434702	1076942	▪ The observation point is mountainous and sloppy land. ▪ One spring is observed with discharge of 4 l/s at contact of Aiba basalt and Antalo Limestone. ▪ The area is mapped as high to very high groundwater potential zone. Generally, further test well drilling , detail hydrogeological and geophysical investigation will be required to verify the aquifer potential of this area.
10		Jila Keransa	432189	1071983	▪ The observation point is mountainous and sloppy land. The area is characterized as high runoff potential and low recharge potential. ▪ One spring is observed with discharge of 2 l/s at contact of Antalo Limestone and gypsum.

No.	Wereda	Locality	UTM E	UTM N	Characteristic of validation point
					▪ The area is mapped as low to moderate groundwater potential zone which highly agree with the spring discharge observed in this zone.
11	Dera wereda	Ceka genet	451428	1123457	▪ The observation point is plain land with moderate groundwater recharge and runoff potential. ▪ Aiba basalt with high permeability is observed lithological unit in this area. ▪ The observation point is mapped as high groundwater potential zone .However one borehole drilled in this area with moderate groundwater discharge about 2l/s. This miss match may be observed may be due to poor construction of borehole, pumping test and Limited lineament density in this area. ▪ Generally, Groundwater potential map is surficial map and it gives clue for further investigation. Hence, further geophysical investigation, test well drilling and detail hydrogeological mapping will be required to verify the groundwater potential map of this area.
12		salayish	454656	1126297	▪ The observation point is plain land with moderate recharge and runoff potential. ▪ Aiba basalt with High permeability is observed lithological unit in this area. ▪ The observation point is mapped as high groundwater potential zone .However one borehole drilled in this area with moderate groundwater discharge about 3.5l/s. This miss match may be observed may be due to poor construction of borehole, pumping test and Limited lineament density in this area. ▪ Generally, Groundwater potential map is surficial map and it gives clue for further investigation. Hence, further geophysical investigation, test well drilling and detail hydrogeological mapping will be required to verify the groundwater potential map of this area.the groundwater potential map of this area.

Cluster 3

No.	Wereda	Locality	UTM E	UTM N	Elv.	Characteristic of validation point
1	Enebise Sar Midir	Mertule maryam well#*4*	426727	1200526	2440	▪ The observation point is an outcrop of basalt with trachyte in the north-west side of the wereda, there are three wells with discharge of 5.5 to 10l/s which are currently functional. In addition one shallow well and one spring with discharge 1.75 and 0.7l/s respectively. The observed formation is Tarmaber - Megezez formation. ▪ The area is mapped as high groundwater potential zone
2		Mertule maryam well#1	426667	1200469	2440	
3		mertulemaryam#2	426481	1200552	2445	
4	Sayit	Mehal gote	480113	1215500	2783	▪ The observation point is rugged, sloppy and there are dense drainage and lineament density. Wells at Yegoda school about 70m depth & yields 8l/s exists in the area. ▪ The area is mapped as high groundwater potential zone
5		Shengodefe	485797	1212422	3011	▪ The observation point is close Shengodefe town around 15 wells were drilled in the surrounding of this town depth ranges b/n 40 to 70m give discharge 0.2 to 0.5l/s The formation in this area is Tarmaber-Megezez Formation. ▪ The area is mapped as very low to moderate groundwater potential zone
6		Ewa 1 & 4	490954	1219857	2911	▪ The observation point is rugged and, sloppy which located in the south-eastern part of the wereda. Wells of 30 & 26m depth both yields 5l/s. with Basalt and pyroclastics formation. ▪ The area is mapped as moderate groundwater potential zone

Cluster 4

No.	Wereda	Locality	UTM E	UTM N	Elv.	Characteristic of validation point
1	Misrak Belesa	Woiba School	397711	1377860	1717	▪ The observation point is mountain side, there is one shallow well with discharge20l/se, no spring and basalt aphanite texture is the observed formation ▪ The area is mapped as very high groundwater potential zone
2						▪ The observation point is on flat plain sloping up to NE areas. There is one deep (400 meter) and dry well, no shallow well, no hand dug well & no spring. Lacustrine deposit and clay is observed formations of the area. ▪ The area is mapped as very low groundwater potential zone
3	Ebenat Wereda	Wegerie	407237	1339587	2594	▪ The observation point is rugged, sloppy and there are dense drainage and lineament density. Borehole depth 52 meter & 17.5 l/sec yields exists in the area. ▪ The area is mapped as moderate groundwater potential zone.
5	Bugna	Kobe	462977	1350351	2536	▪ The observation point is mountainous, sloppy. No deep & shallow well, no hand dug well, no spring and basalt and trachyte is the observed outcrop. ▪ The area is mapped as low to moderate groundwater potential zone
7	Bugna	Ayinan Eyesus	481743	1345948	2495	▪ The observation point topographically the area is steep sloping and rivers that flows in almost NW direction exists. Basalt and Trachyte is observed exposure. One borehole (43 depth & 7 L/sec discharge) is located at this observation point. From hydrogeological point of view and overlay analysis the observed point has moderate groundwater potential due to hydrogeological set up of the area. ▪ The area is mapped as moderate groundwater potential zone
8	Mekiet wereda	Weketa	474605	1294191	2878	▪ The observation point is close to Filakit town. Topographically the area is on the plateau. Basalt and pyroclastic deposit is observed exposure and there are numerous NE-SW trending marginal faults and lineaments with in the vicinity. One borehole (127m depth & 6 l/sec discharge & 30.95m SWL) located around this observation point. From hydrogeological point of view and based on overlay analysis, the observed point has at the contact of moderate and high groundwater potential.
8	Tselemit wereda	Dejach	433508	1487291	1818	▪ Exposured Trap volcanics covers this observation point. The area is near the gorge, a number of streams arises from south flows through the area towards Tekeze River. NE-SW major faults are observed within the vicinity and one borehole (40 m deep) drilled on the edge of the river yields 10l/s. In terms of groundwater potential the observation point is deemed to be good due to existence good productive lithologies that exhibit primary and secondary porosities, high groundwater recharge from subsurface inflow from adjacent aquifers, river bank infiltration and direct rainfall. ▪ The area is mapped as high to very high groundwater potential zone.
9		Abera	419184	1486367	3073	▪ The observation point is mountainous, sloppy and located in river valley. No deep & shallow well, no hand dug well, no spring and Trap volcanics is the observed outcrop. ▪ The area is mapped as high groundwater potential zone

Annex 2: Water point inventory data

Cluster 1

ID	Locality	Region	Wereda	UTM E	UTM N	Elv	Depth	SWL	Q, l/s
Eboye	Gacheni	Afar	Argoba	597044	1057270	716		12.80	
Metekleya1	Metekleya	Afar	Argoba	596124	1045870	1187	150	48.61	
Metekleya2	Metekleya	Afar	Argoba	596147	1045381	1307		4.60	
Fanel vilage	Deberko	Afar	Argoba	594802	1068439	1561	177	55.00	5
Gelalo	Gelalo tawon	Afar	Buri Mudayitu	663997	1092186	572	100	29.00	
Debel	Debel	Afar	Buri Mudayitu	666571	1103508	2463			
Buri		Afar	Buri Mudayitu	666420	1138650	562	400		
Gefrem	Gefrem	Afar	Buri Mudayitu	663190	1102147	558		artesian	
Debel	Debel	Afar	Buri Mudayitu	666571	1103508	2463		artesian	
Hingig	Hingig	Afar	Buri Mudayitu	648123	1100973	600		13.60	
Dengeligita		Afar	Buri Mudayitu	649387	1115566	638	161		
Debel	Debel	Afar	Buri Mudayitu	666637	1103684	572	60		
Gefrem	Gefrem	Afar	Buri Mudayitu	663399	1102584			3	3.5
Dulecha	Dulecha towen	Afar	Dulecha	604874	1055711	1026		19.30	
Megela	Hurunto	Afar	Dulecha	611798	1051232	895	78		
Lalaba	Hurunto	Afar	Dulecha	621058	1047070	749	100	33.60	24
Edeli	Edeli	Afar	Dulecha	619774	1044956	735	68	20.00	6
Merento tabiya	Segento	Afar	Dulecha	616089	1027101	754	80	14.30	24.5
Kile tabiya	Segento	Afar	Dulecha	614531	1031772	745	100	29.80	
Segento	Segento	Afar	Dulecha	616181	1025983	750	12	10.50	
Burteli	Burteli	Afar	Dulecha	618649	1043317	748	100	18.90	22
Asbahari	Asbahari	Afar	Dulecha	626352	1060210	753	120	45.2	21.5
Lihamo	Lihamo	Afar	Dulecha	612112	1040204	793	150	23.4	6
Hugub	Hugub	Afar	Dulecha	617470	1039252	761	136	22.24	30
Kafis	Kafis	Afar	Dulecha	619452	1044620	746	100	18.1	17
TCVTW-03-19		Afar		681626	1130742		456		

Cluster 2

SN	UTME	UTMN	ELEV, M	Site_Name	Region	Wereda	Well Type	Depth, m	SWL, m	DWL, m	DD, m	Q, l/s	K, m/day	T, m²/day
1	448787	1123980	2423	ada'a	Oromia	Dera	spring							
2	468311	1129973	2506	ada'a dirre	Oromia	Dera								
3	444969	1124810	2422	adaadi	Oromia	Dera	HDW							
4	450657	1124321	2442	adisu gebaya	Oromia	Dera	HDW							
5	464772	1132370	2466	adisu gebaya 1	Oromia	Dera	HDW							
6	466601	1129970	2478	adisu gebaya 2	Oromia	Dera	HDW							
7	447804	1122678	2406	adoola	Oromia	Dera	HDW							
8	466553	1132035	2457	alaltu	Oromia	Dera	HDW							
9	454162	1138123	2246	ana kure	Oromia	Dera	HDW							
10	444910	1125658	2436	anxuree	Oromia	Dera	HDW							
11	451139	1122485	2415	bisati	Oromia	Dera	HDW							
12	456508	1138976	2222	buritti	Oromia	Dera	HDW		8.00					
13	451368	1123574	2404	burka ako	Oromia	Dera	HDW							
14	464488	1130201	2484	burka basho	Oromia	Dera	HDW							
15	451446	1122326	2419	burka curree	Oromia	Dera	HDW							
16	450899	1123793	2421	burka lemi	Oromia	Dera	HDW		8.00					
17	450937	1124034	2427	burka lemi 2	Oromia	Dera	HDW		0.00					
18	468565	1135476	2486	burkitu	Oromia	Dera	HDW		7.00					
19	468487	1135356	2489	cabare	Oromia	Dera	HDW		5.00					
20	468530	1135318	2490	cabare 2	Oromia	Dera	HDW		10.00					
21	455775	1128660	2475	caf ├	Oromia	Dera	HDW		0.00					
22	468502	1135064	2483	cangee	Oromia	Dera	HDW		9.00					
23	468511	1133094	2488	cangee2	Oromia	Dera	HDW		8.00					
24	451428	1123457	2399	ceka genet	Oromia	Dera	BH		1.10		26.3	2		1.43*10-3
25	462986	1130086	2500	darabbaa	Oromia	Dera	HDW		0.00					
26	465005	1130017	2500	darabbaa2	Oromia	Dera	HDW		7.00					
27	467273	1130549	2493	dire dawa	Oromia	Dera	HDW							
28	471453	1131665	2434	G/Arabuu	Oromia	Dera	spring							
29	470096	1131725	2492	G/qarree	Oromia	Dera	HDW							
30	471099	1132841	2495	G/SH/Useen	Oromia	Dera	HDW							
31	470332	1131805	2496	ganda qarree	Oromia	Dera	HDW		10.00					
32	470192	1131933	2500	ganda qarree2	Oromia	Dera	HDW		0.00					
33	471192	1133048	2499	ganga she useen	Oromia	Dera	HDW		5.00					
34	451140	1122485	2415	golalee	Oromia	Dera	HDW							
35	467559	1130467	2507	gulti	Oromia	Dera	HDW		14.00					
36	455227	1137883	2227	haxe	Oromia	Dera	HDW		0.40					
37	448786	1123979	2423	Indiko	Oromia	Dera	HDW		4.00					
38	448013	1123180	2407	indikoo 1ffaa	Oromia	Dera	HDW							
39	448186	1123921	2420	indikoo 2ffaa	Oromia	Dera	HDW							
40	444977	1121196	2450	jojoke 1	Oromia	Dera	HDW							

SN	UTME	UTMN	ELEV, M	Site_Name	Region	Wereda	Well Type	Depth, m	SWL, m	DWL, m	DD, m	Q, l/s	K, m/day	T, m²/day
41	444894	1121140	2452	jojoke2	Oromia	Dera	HDW							
42	444882	1120984	2447	jojokee	Oromia	Dera	HDW							
43	455432	1138493	2215	karsa	Oromia	Dera	HDW		3.00					
44	448105	1123386	2412	kusaye	Oromia	Dera	HDW							
45	447804	1122678	2417	kusaye	Oromia	Dera	HDW							
46	445375	1120397	2427	laga jiilsii	Oromia	Dera	HDW							
47	444907	1126105	2426	M/gobana	Oromia	Dera	HDW							
48	444971	1120843	2466	masgida	Oromia	Dera	HDW							
49	444902	1121089	2444	membera tsehay 3	Oromia	Dera	HDW							
50	444416	1120617	2470	naannawa beteskaanaa	Oromia	Dera	HDW							
51	466410	1130003	2484	o1	Oromia	Dera	HDW							
52	467071	1130413	2482	o2	Oromia	Dera	HDW							
53	467336	1129855	2492	o3	Oromia	Dera	HDW							
54	458001	1127900	2462	qoro	Oromia	Dera	HDW		3.00					
55	450823	1123926	2424	rako	Oromia	Dera	HDW							
56	455324	1138262	2246	sagno gebaya	Oromia	Dera	HDW							
57	465863	1134138	2249	sagno gebaya	Oromia	Dera	HDW							
58	454656	1126297	2433	salayish	Oromia	Dera	BH		2.4			3.5		
59	467909	1129256	2371	saqa	Oromia	Dera	HDW							
60	455760	1128660	2394	satayii	Oromia	Dera	HDW							
61	467917	1130307	2506	shola bari	Oromia	Dera	HDW		10.00					
62	444565	1121211	2435	suluula	Oromia	Dera	HDW							
63	444857	1125059	2461	waglo 1ffaa	Oromia	Dera	HDW							
64	444933	1125155	2441	waglo 2ffaa	Oromia	Dera	HDW							
65	444857	1125426	2442	waglo 3ffaaa	Oromia	Dera	HDW							
66	444378	1119502	2453	wallo 1ffaa	Oromia	Dera	HDW							
67	444246	1119601	2471	wallo 2 ffaa	Oromia	Dera	HDW							
68	461831	1129712	2494	wayyuu	Oromia	Dera	HDW		5.00					
69	444623	1120862	2445	xunjitii 1ffaa	Oromia	Dera	HDW							
70	444550	1120072	2470	xunjitii 2ffaa	Oromia	Dera	HDW							
71	468540	1135522	2496	yaya	Oromia	Dera	HDW		7.00					
72	468365	1135998	2491	yaya gama	Oromia	Dera	HDW		7.00					
73	478232	1075129	2577	abayyii gorgiis	Oromia	Girar Jarso	HDW							
74	468000	1075509	2706	annasoo	Oromia	Girar Jarso	BH							
75	469127	1076182	2735	annasoo	Oromia	Girar Jarso	spring							
76	476680	1077182	2651	b/boruu	Oromia	Girar Jarso	HDW							
77	463242	1072874	2790	boniya	Oromia	Girar Jarso	BH							
78	471590	1078504	2765	Boosee	Oromia	Girar Jarso	HDW							
79	460926	1070930	2844	chafe	Oromia	Girar Jarso	HDW							
80	461137	1070924	2823	chafe/koticha	Oromia	Girar Jarso	HDW							
81	480142	1074817		Changel	Oromia	Girar Jarso	BH	199	38.72			3.3		

SN	UTME	UTMN	ELEV, M	Site_Name	Region	Wereda	Well Type	Depth, m	SWL, m	DWL, m	DD, m	Q, l/s	K, m/day	T, m^2/day
82	475829	1089995		chefe 2	Oromia	Girar Jarso	sw	120	4.94			4		53.28
83	472604	1076710	2724	doyyoo	Oromia	Girar Jarso	BH							
84	474112	1078613	2723	falaase	Oromia	Girar Jarso	BH							
85	475440	1078208	2679	g/farda	Oromia	Girar Jarso	HDW							
86	472790	1077855	2729	g/laga	Oromia	Girar Jarso	BH							
87	465158	1071990	0	G/muxxee	Oromia	Girar Jarso	spring							
88	470589	1073549	2696	gatira 1fa	Oromia	Girar Jarso	BH							
89	470117	1072393	2684	gatira 2fa	Oromia	Girar Jarso	HDW							
90	478456	1075531	2562	kambii	Oromia	Girar Jarso	spring							
91	466981	1078993	3000	karraa walee	Oromia	Girar Jarso	spring							
92	466441	1074859	2760	Killele	Oromia	Girar Jarso	Spr.					3.5		
93	466101	1074284	2794	kinbir	Oromia	Girar Jarso	spring							
94	475032	1087994	1954	Mesk woha	Oromia	Girar Jarso	Spr.					1.6		
95	471468	1070243	2688	mukaba fi caancoo 1	Oromia	Girar Jarso	HDW							
96	471265	1070371	2686	mukaba fi caancoo 2	Oromia	Girar Jarso	HDW							
97	467386	1079629	2971	riisee	Oromia	Girar Jarso	spring							
98	477082	1077687	2625	safaani	Oromia	Girar Jarso	HDW							
99	474939	1078120	2692	safaani	Oromia	Girar Jarso	HDW							
100	464033	1073097	2758	sayyoo	Oromia	Girar Jarso	BH							
101	465315	1072956	2722	shoobbe	Oromia	Girar Jarso	HDW							
102	478495	1078156	2576	shunkurti	Oromia	Girar Jarso	HDW							
103	471713	1077697	2745	solool tokkee 1ffa	Oromia	Girar Jarso	BH							
104	471967	1077713	2738	solool tokkee 2ffa	Oromia	Girar Jarso	BH							
105	472033	1075546	2658	tambaro	Oromia	Girar Jarso	BH							
106	468227	1081132	0	Torba Nashe Gerar Jarso	Oromia	Girar Jarso	DW	110	15			2		
107	465505	1075390	2814	Wisi Briqe	Oromia	Girar Jarso	Spr.					3		
108	422683	1081808	2527	"	Oromia	Kuyu	HDW							
109	415471	1076931	2370	" 1ffaa	Oromia	Kuyu	HDW							
110	412978	1079239	2561	abdarii barkoo	Oromia	Kuyu	HDW							
111	419815	1080198	2516	abdarii ko'etii	Oromia	Kuyu	HDW							
112	410912	1079462	2517	alaltu	Oromia	Kuyu	HDW							
113	420870	1079363	2526	b/guddina	Oromia	Kuyu	HDW							
114	425511	1086060	2545	B/hawaas 1ffaa	Oromia	Kuyu	HDW							
115	426092	1087718	2549	B/hawaas 2ffaa	Oromia	Kuyu	HDW							
116	423524	1081361	2543	B/iyyaasoo	Oromia	Kuyu	HDW							
117	425657	1085579	2561	B/milkii	Oromia	Kuyu	HDW							
118	435586	1091951	2201	B/shibuu	Oromia	Kuyu	HDW							
119	424102	1081864	2569	bantuu	Oromia	Kuyu	HDW							
120	424179	1082396	2557	bantuu 1ffaa	Oromia	Kuyu	HDW							
121	424178	1082151	2560	bantuu 2ffaa	Oromia	Kuyu	HDW							
122	422830	1081725	2526	borcoska	Oromia	Kuyu	HDW							

SN	UTME	UTMN	ELEV, M	Site_Name	Region	Wereda	Well Type	Depth, m	SWL, m	DWL, m	DD, m	Q, l/s	K, m/day	T, m²/day
123	425968	1082263	2519	burqa gada	Oromia	Kuyu	HDW							
124	425673	1081545	2508	burqa muni	Oromia	Kuyu	HDW							
125	433785	1092229	2334	burqaa akalee	Oromia	Kuyu	spring							
126	425832	1083890	2565	burqaa boorii 1ffaa	Oromia	Kuyu	HDW							
127	425864	1083877	2563	burqaa boorii 2ffaa	Oromia	Kuyu	HDW							
128	425890	1083878	2562	burqaa boorii 3ffaa	Oromia	Kuyu	BH							
129	436587	1088886	2311	burqaa borinee	Oromia	Kuyu	HDW							
130	423946	1083354	2540	burqaa galee	Oromia	Kuyu	HDW							
131	426093	1079535	2284	C/alaltuu	Oromia	Kuyu	HDW							
132	424883	1084683	2563	caancoo	Oromia	Kuyu	BH							
133	436403	1091524	2201	cabaree	Oromia	Kuyu	HDW							
134	411952	1079565	2528	caffee kuchuu	Oromia	Kuyu	HDW							
135	406560	1083914	1847	caffee laaloo	Oromia	Kuyu	HDW							
136	427915	1080725	2342	cimoo	Oromia	Kuyu	HDW							
137	428500	1079445	2534	darara	Oromia	Kuyu	HDW							
138	427573	1082257	2585	daree 2ffaa	Oromia	Kuyu	HDW							
139	434702.7	1076943	2375	Dawicha keransa	Oromia	Kuyu	Sp.f					4		
140	414526	1083262	2575	derach cagi	Oromia	Kuyu	BH		18			4		
141	414526	1083262	2575	Derodannisa	Oromia	Kuyu	SW		18			4		
142	417640	1077628	2550	dimoo	Oromia	Kuyu	HDW						0	
143	415922	1077192	2381	ejersa maye	Oromia	Kuyu	HDW							
144	418579	1077184	2558	ejersa warjii 1ffaa	Oromia	Kuyu	HDW							
145	419151	1077788	2534	ejersa warjii 2ffaa	Oromia	Kuyu	BH							
146	425090	1082650	2539	finoo 1ffaa	Oromia	Kuyu	HDW							
147	424817	1082586	2554	finoo 2ffaa	Oromia	Kuyu	HDW							
148	425054	1082707	2547	finoo 3ffaa	Oromia	Kuyu	HDW							
149	424323	1085250	2551	gatira fi simbo	Oromia	Kuyu	HDW							
150	415922	1077192	2382	gora dinquu 2ffaa	Oromia	Kuyu	HDW							
151	426585	1080239	2342	H/meettaa	Oromia	Kuyu	spring							
152	422740	1085325	2543	haqaqoo	Oromia	Kuyu	HDW							
153	416133	1077026	2357	hara waaxuu	Oromia	Kuyu	HDW							
154	421083	1079545	2537	harbu ko'etii	Oromia	Kuyu	HDW							
155	422017	1084944	2547	harbu lodee	Oromia	Kuyu	HDW							
156	406370	1082233	1883	haroo	Oromia	Kuyu	HDW							
157	428117	1085297	2573	harsadii 1ffaa	Oromia	Kuyu	HDW							
158	427980	1085067	2588	harsadii 2ffaa	Oromia	Kuyu	HDW							
159	427684	1082207	2592	husoo	Oromia	Kuyu	HDW							
160	421002	1082824	2553	iyaso 1ffaa	Oromia	Kuyu	HDW							
161	423951	1082713	2553	iyaso 1ffaa	Oromia	Kuyu	HDW							
162	424217	1082566	2552	iyasoo 3ffaa	Oromia	Kuyu	HDW							
163	432189.7	1071984	2300	Jila Keransa	Oromia	Kuyu	Sp.d					2		

SN	UTME	UTMN	ELEV, M	Site_Name	Region	Wereda	Well Type	Depth, m	SWL, m	DWL, m	DD, m	Q, l/s	K, m/day	T, m²/day
164	436430	1090827	2208	katabaa	Oromia	Kuyu	HDW							
165	423067	1081808	2545	ko'a fi iyasoo 1ffaa	Oromia	Kuyu	HDW							
166	427606	1083419	2578	kolobo fi warji 1ffaa	Oromia	Kuyu	HDW							
167	427596	1083398	2577	kolobo fi warji 2ffaa	Oromia	Kuyu	HDW							
168	427417	1083114	2602	kolobo fi warji 3ffaa	Oromia	Kuyu	HDW							
169	427059	1084729	2562	kombolcha	Oromia	Kuyu	BH							
170	406287	1082477	1932	laga badhaasa	Oromia	Kuyu	HDW							
171	406110	1082413	1907	laga hundee	Oromia	Kuyu	HDW							
172	408670	1082079	1914	laga macaa	Oromia	Kuyu	HDW							
173	429349	1080651	2220	laga nisee	Oromia	Kuyu	HDW							
174	419194	1079284	2517	laga qallaa	Oromia	Kuyu	BH							
175	423735	1084627	2557	M/B/bondee	Oromia	Kuyu	HDW							
176	427237	1081924	2585	M/B/H/boosee	Oromia	Kuyu	HDW							
177	428694	1081339	2329	M/B/H/darso	Oromia	Kuyu	HDW							
178	421065	1079909	2547	M/B/H/school	Oromia	Kuyu	HDW							
179	427962	1084777	2584	M/B/L/gulanta	Oromia	Kuyu	HDW							
180	420101	1079344	2530	M/B/lakk 1	Oromia	Kuyu	HDW							
181	420111	1079269	2530	M/B/lakk 2	Oromia	Kuyu	HDW							
182	420044	1079224	2528	M/B/lakk 3	Oromia	Kuyu	HDW							
183	435144	1089797	2662	M/B/logee	Oromia	Kuyu	HDW							
184	420501	1079233	2529	M/looni lakk 1	Oromia	Kuyu	HDW							
185	420451	1079137	2530	M/looni lakk 2	Oromia	Kuyu	HDW							
186	420594	1079230	2532	M/looni lakk 3	Oromia	Kuyu	HDW							
187	406476	1080939	1642	madabii (heekoo)	Oromia	Kuyu	HDW							
188	420978	1078711	2526	maram mangasha	Oromia	Kuyu	HDW							
189	427007	1080605	2365	micaa	Oromia	Kuyu	spring							
190	420938	1079485	2534	network	Oromia	Kuyu	HDW							
191	423846	1081134	2530	oddoo 1ffaa	Oromia	Kuyu	HDW							
192	423830	1081138	2540	oddoo 2ffaa	Oromia	Kuyu	HDW							
193	421693	1079213	2519	q/meettaa 1ffaa	Oromia	Kuyu	HDW							
194	421863	1079345	2519	q/meettaa 2ffaa	Oromia	Kuyu	HDW							
195	421486	1079077	2525	q/meettaa 3ffaa	Oromia	Kuyu	BH							
196	421051	1079806	2555	qaban	Oromia	Kuyu	BH							
197	420110	1078259	2535	qaree qimissi	Oromia	Kuyu	BH							
198	423089	1079932	2520	qumburee 1ffaa	Oromia	Kuyu	HDW							
199	423084	1079942	2519	qumburee 2ffaa	Oromia	Kuyu	HDW							
200	421605	1085120	2550	sayoo	Oromia	Kuyu	HDW							
201	423490	1084715	2549	shixuu	Oromia	Kuyu	HDW							
202	425410	1079726	2357	shunqurii	Oromia	Kuyu	HDW							
203	412617	1079534	2520	siisuu fi arsame	Oromia	Kuyu	HDW							
204	421247	1079565	2515	tulluu boombii	Oromia	Kuyu	HDW							
205	422779	1083135	2523	tuutii	Oromia	Kuyu	HDW							

SN	UTME	UTMN	ELEV, M	Site_Name	Region	Wereda	Well Type	Depth, m	SWL, m	DWL, m	DD, m	Q, l/s	K, m/day	T, m²/day
206	420122	1078234	2535	ula booyiv	Oromia	Kuyu	HDW							
207	421711	1079752	2535	urgee	Oromia	Kuyu	BH							
208	422205	1080186	2539	urgee 3ffaa	Oromia	Kuyu	HDW							
209	414200	1083318	2566	urufa qillee	Oromia	Kuyu	HDW							
210	414131	1083383	2583	urufa qillee	Oromia	Kuyu	HDW							
211	412976	1079239	2565	wallensuu	Oromia	Kuyu	HDW							
212	417842	1077033	2505	waraba bulee	Oromia	Kuyu	spring							
213	420773	1085499	2540	xarusee 1ffaa	Oromia	Kuyu	HDW							
214	421079	1085389	2548	xarusee 2ffaa	Oromia	Kuyu	HDW							
215	478591	1052002	2648	"	Oromia	Wuchale	HDW							
216	478710	1052129	2645	:	Oromia	Wuchale	Rope pump							
217	490738	1057102	2675	abdi	Oromia	Wuchale	HDW		4					
218	489426	1058497	2649	allamosh	Oromia	Wuchale	BH							
219	480599	1057725	2656	babochi	Oromia	Wuchale	HDW							
220	501966	1069103	2571	bidaru	Oromia	Wuchale	spring							
221	488100	1057648	2663	boko fi tigiri	Oromia	Wuchale	HDW		3					
222	492711	1055214	2669	buko	Oromia	Wuchale	HDW							
223	492957	1054962	2674	buko 2	Oromia	Wuchale	HDW							
224	490846	1056970	2674	buko tigiri 2	Oromia	Wuchale	HDW		2					
225	495822	1064653	2600	burka dadi	Oromia	Wuchale	BH					13		
226	494577	1050294	2664	dabibo	Oromia	Wuchale	BH							
227	494414	1049979	2654	denbibo	Oromia	Wuchale	spring							
228	492953	1060333	2639	gabaa roobii	Oromia	Wuchale	BH		9.5		27.65	6.67		2.80E-04
229	498696	1066985	2539	galmo gora	Oromia	Wuchale	HDW							
230	497432	1050221	2709	gordoma	Oromia	Wuchale	BH							
231	495226	1050565	2671	gordoma	Oromia	Wuchale	HDW							
232	488097	1057647	2660	gudo	Oromia	Wuchale	HDW							
233	473201	1062406	2649	gumbichu	Oromia	Wuchale	BH		35	54		5		
234	474628	1061809	2656	halko	Oromia	Wuchale	HDW							
235	473683	1062937	2658	halko	Oromia	Wuchale	BH		35	98		7		
236	478162	1059062	2643	harcho	Oromia	Wuchale	HDW							
237	473507	1062878	2649	harkiso	Oromia	Wuchale	HDW							
238	502227	1068467	2559	heto	Oromia	Wuchale	BH							
239	491441	1059369	2672	ijaara fi qarsaa	Oromia	Wuchale	HDW		10					
240	491449	1055297	2663	ilala	Oromia	Wuchale	BH		34					
241	486950	1056672	2631	jamaica	Oromia	Wuchale	HDW		5					
242	486901	1056672	2633	jamaica 2	Oromia	Wuchale	HDW							
243	487104	1048881	2606	jatani 2	Oromia	Wuchale	BH		3	28.6		9.5		
244	477471	1059284	2650	kata koshomi	Oromia	Wuchale	BH							
245	495802	1050054	2676	kombu	Oromia	Wuchale	HDW							
246	503607	1071796	2576	kowit	Oromia	Wuchale	BH		55	78		7		

SN	UTME	UTMN	ELEV, M	Site_Name	Region	Wereda	Well Type	Depth, m	SWL, m	DWL, m	DD, m	Q, l/s	K, m/day	T, m^2/day
247	478632	1051830	2645	koyit	Oromia	Wuchale	Rope pump							
248	503055	1071415	2588	koyit 1	Oromia	Wuchale	BH							
249	502497	1071010	2596	KOYIT 2	Oromia	Wuchale	BH							
250	493215	1051415	2663	Likime	Oromia	Wuchale	BH	90	5.7	57.89		90		165
251	478804	1057533	2656	machallaa	Oromia	Wuchale	HDW							
252	475816	1051624	2640	madera	Oromia	Wuchale	HDW							
253	496829	1049948	2687	meta	Oromia	Wuchale	HDW							
254	494250	1053436	2665	oborra gama	Oromia	Wuchale	BH							
255	494828	1051320	2665	odee	Oromia	Wuchale	BH							
256	487195	1056852		sadan well 2	Oromia	Wuchale	sw	21				3.06		
257	475437	1059973	2644	sadeqo(boshi)	Oromia	Wuchale	HDW							
258	492072	1055372	2675	siso likime	Oromia	Wuchale	HDW		2					
259	509685	1078701	2580	tulu gerbicho	Oromia	Wuchale	BH		82.95			8		7.85*10-3
260	485608	1056759	2663	wasarbi	Oromia	Wuchale	BH		13.8			6		

Cluster 3

SN.	WELL ID	UTME	UTMN	ELEV, M	LOCAL/SITE NAME	REGION	WEREDA	WELL TYPE	BH DEPTH, M	SWL, M	Q, L/S
1	SBH-1	480137	1215414	2970	yegoda school sh.well	Amhara	Sayit	SHW	59	6	5
2	SBH-2	480113	1215500	2783	yegoda sh. well	Amhara	Sayit	SHW	70	6	8
3	SBH-3A	472785	1220167	2750	Ganch sh. well	Amhara	Sayit	SHW	77		
4	SBH-4	480135	1215370	2834	yegoda sh. well	Amhara	Sayit	SHW	47	6	3
5	SBH-5	485874	1212684	2974	Tana School	Amhara	Sayit	SHW	58	6	1
6	SBH-6	486950	1214800	2937	Feres bar	Amhara	Sayit	SHW	61	20	1
7	SBH-7	458608	1229240	2479	Mesk	Amhara	Sayit	SHW	55		4
8	SBH-8	460881	1228819	2490	Wenz egir	Amhara	Sayit	SHW	59	10	1
9	SBH-9A	460961	1227775	2483	Derekwenz	Amhara	Sayit	SHW	45		
10	SBH-10A	460994	1229435	2487	Addifer	Amhara	Sayit	SHW	47		
11	SBH-11A	461099	1229112	2474	Guwameda	Amhara	Sayit	SHW	40		
12	SBH-12A	461165	1229346	2477	Adefen	Amhara	Sayit	SHW	74		
13	SBH-13	458496	1228730	2471	Mesk	Amhara	Sayit	SHW	40	5	0.3
14	SBH-14	480177	1214266	2818	Tay bara	Amhara	Sayit	SHW	61	3.4	1
15	SBH-16	453856	1225656	2410	Hamusit	Amhara	Sayit	SHW	40	5	0.3
16	SBH-17	453694	1225983	2403	Hamusit #1	Amhara	Sayit	SHW	40	5	0.3
17	SBH-18	480784	1215486	2801	Mush	Amhara	Sayit	SHW	67	20	1
18	SBH-19A	488668	1223811	2320	Degnie 023	Amhara	Sayit	SHW	60		
19	SBH-20A	475383	1220634	2787	Zemlalie	Amhara	Sayit	SHW	60		
20	SBH-21	482172	1213809	2946	Esatagory	Amhara	Sayit	SHW	65		0.5
21	SBH-22A	494902	1217337	3245	Ewa#5(Gudy)	Amhara	Sayit	SHW	32		
22	SBH-23	475466	1219675	2821	Ashenga 01	Amhara	Sayit	SHW	65	50	0.5
23	SBH-24	465710	1223703	2552	Digitit-meko	Amhara	Sayit	SHW	38	10	2
24	SBH-25	464746	1223117	2551	Yerat-meko	Amhara	Sayit	SHW	35	13	2
25	SBH-26	478802	1215708	2804	Yegureza	Amhara	Sayit	SHW	53	40	0.5
26	SBH-27	480268	1214478	2820	Chewmatecha	Amhara	Sayit	SHW	53	39	2
27	SBH-28	477060	1219242	2821	Ashenga	Amhara	Sayit	SHW	68	8	1
28	SBH-29	490954	1219857	2911	Ewa#4(ketema)	Amhara	Sayit	SHW	30	2	5
29	SBH-30	493714	1218218	3169	Ewa#2	Amhara	Sayit	SHW	62	2	0.5
30	SBH-31	492317	1219311	3112	Ewa#1	Amhara	Sayit	SHW	26	2	5
31	SBH-32A	492836	1219678	3112	Ewa#3	Amhara	Sayit	SHW	55		
32	SBH-33A	466504	1222686	2511	Tinjut	Amhara	Sayit	SHW	68		
33	SBH-34	485797	1212422	3011	Shengo deffer04	Amhara	Sayit	SHW	62	40	0.5
34	SBH-35A	488940	1215843	2870	018 Amba metay	Amhara	Sayit	SHW	60		
35	SBH-36	484278	1213598	2895	Anshahula	Amhara	Sayit	SHW	50	4	1.2

SN.	WELL ID	UTME	UTMN	ELEV, M	LOCAL/SITE NAME	REGION	WEREDA	WELL TYPE	BH DEPTH, M	SWL, M	Q, L/S
36	SBH-37A	460798	1229702	2508	yegodo mesik	Amhara	Sayit	SHW	62		
37	SBH-38	486485	1216111	2786	Mehal gote	Amhara	Sayit	SHW	41	4	3
38	SBH-39	484545	1214057	2877	Anshahula	Amhara	Sayit	SHW	41	8	2
39	SBH-40	484020	1215575	2786	Shengodeffer p. school	Amhara	Sayit	SHW	70	4	0.3
40	SBH-41	479321	1216261	2755	Yegoda#1	Amhara	Sayit	SHW	40	9	0.5
41	SBH-42	475857	1215857	2773	yegoda#2	Amhara	Sayit	SHW	60	16	0.35
42	SBH-43A	486012	1212778	2952	Shengodeffer #1	Amhara	Sayit	SHW	64		
43	SBH-44	476893	1218766	2817	Asete	Amhara	Sayit	SHW	53	12	1
44	SBH-45	472380	1220520	2728	Gounche	Amhara	Sayit	SHW	55	3	0.1
45	SBH-46	483645	1213902	2862	Shengodeffer#2	Amhara	Sayit	SHW	61	6	0.2
46	SBH-47	485013	1215465	2783	Agual weha#2	Amhara	Sayit	SHW	41	6	2
47	SHDW-1	462660	1228245	2463	Senkor HDW	Amhara	Sayit	HDW			
48	SHDW-2	488119	1216764	2862	Melese Tegegne hdw	Amhara	Sayit	HDW			
49	SSP-1	485055	1214604	2872	Yetint spring	Amhara	Sayit	SP			
50	SSP-2	486904	1215418	2849	Yejerokuter 1 spring	Amhara	Sayit	SP			
51	SSP-3	490990	1218901	2986	ketema spring	Amhara	Sayit	SP			
52	SSP-4	489852	1216194	2935	Enat hodie spring	Amhara	Sayit	SP			

No.	Well ID	UTME	UTMN	Elev, m	Local/Site Name	Region	Wereda	Well Type	Well Depth, m	Drilled Year	Static Water Level, m	Well Discharge, l/s
1	EBH-1	435438	1200542	2386	Enebre	Amhara	Enebsie Sar midir	SHW	60	2017	18	1.25
2	EBH-2	434488	1201688	2436	Yeguchi	Amhara	Enebsie Sar midir	SHW	60	2017	21	1.25
3	EBH-3	426727	1200526	2440	Mertule maryam well*#4*	Amhara	Enebsie Sar midir	MW	153.5	2016	12	10
4	EBH-4	426667	1200469	2440	Mertule maryam well#1	Amhara	Enebsie Sar midir	MW	156.5	2016	4	10
5	EBH-5	427699	1199276	2351	Derekwenz	Amhara	Enebsie Sar midir	SHW	65	2015	1	1.75
6	EBH-6	439518	1188521	2366	Worya Meskel School	Amhara	Enebsie Sar midir	SHW	65	2015	7.2	0.2
7	EBH-7	426676	1200247	2455	Gibo	Amhara	Enebsie Sar midir	SHW	37	2015	4	1.5
8	EBH-8	430806	1200249	2412	Yezma	Amhara	Enebsie Sar midir	SHW	75	2015	9	1.5
9	EBH-9A	435544	1200595	2395	Enebre H. Center Sh.well	Amhara	Enebsie Sar midir	SHW	60	2018		
10	EBH-10A	427599	1203474	2580	Domma School Sh.well	Amhara	Enebsie Sar midir	SHW	60	2018		
11	ESP	428531	1198936	2384	derekwenz spring	Amhara	Enebsie Sar midir	SP				0.7
12	EBH-11	439594	1190757	2361	Gul mesk HDW	Amhara	Enebsie Sar midir	HDW	6	2020		
13	EBH-12	431132	1197316	2413	Segno gebeya	Amhara	Enebsie Sar midir	MW	180.5		0.5	2
14	EBH-13	426481	1200552	2445	Mertule maryam #2	Amhara	Enebsie Sar midir	MW	181	2016	9	5.5
15	EBH-14	423069	1198190	2431	Mertule maryam	Amhara	Enebsie Sar midir	MW	153	2012	15	0.8

Cluster 4

	Well ID	UTME	UTMN	Elev, m	Local/Site Name	Region	Wereda	Well Type	Well Depth, m	Drilled Year	Static Water Level, m	Well Discharge, l/s
1	Amesetya	398052	1330214	2080	Amesetya	Amhara	Ebenat	SW	57	2012	10	2
2	Akotana	401180	1384038	1688	Akotana	Amhara	Ebenat	SW	60	2012	5.5	3
3	Akayna	412130	1336861	2521	Akayna	Amhara	Ebenat	SW	60	2012		
4	Tuchamesek	406072	1339935	2545	Tuchamesek	Amhara	Ebenat	SW	43	2012	Aretsian	12.5
5	wegerie	407237	1339587	2594	wegerie	Amhara	Ebenat	SW	52		15	17.5
6	Shumgie school	410875	1337468	2610	Shumgie school	Amhara	Ebenat	SW	67	2012	25	10
7	Dengima	392100	1348075	2273	Dengima	Amhara	Ebenat	SW	55		13.5	1
8	Hazuri	428821	1372199	1682	Hazuri	Amhara	Ebenat	SW	60		7	3
9	Deber Tekle Hayimanot	394624	1341611	2205	Deber Tekle Hayimanot	Amhara	Ebenat	SW	60		9	2
10	Akayna#2	394024	1344023	2198	Akayna#2	Amhara	Ebenat	SW	70		1	1.5
11	Lamsan	390890	1334760	1909	Lamsan	Amhara	Ebenat	SW	60		5	
12	genzoyi	391864	1341789	2136	genzoyi	Amhara	Ebenat	SW	70		Aretsian	
13	Mikile	390563	1336260	1962	Mikile	Amhara	Ebenat	SW	57.5		3	2
14	Gerarwuha	394554	1344823	2169	Gerarwuha	Amhara	Ebenat	SW	55		13.5	1
15	Minchi	392498	1346175	2252	Minchi	Amhara	Ebenat	SW	70		15	4
16	Worgaja	396254	1358558	1963	Worgaja	Amhara	Ebenat	SW	72			
17	Qualisa AfetiraSchool	429583	1373356	1609	Qualisa AfetiraSchool	Amhara	Ebenat	SW	59		20	3
18	Gelametatebia H.Center	407592	1351219	1892	Gelametatebia H.Center	Amhara	Ebenat	SW	66			
19	Nichila	423483	1366382	1668	Nichila	Amhara	Ebenat	SW	50		3	2
20	Feresmesk	394512	1330362	1962	Feresmesk	Amhara	Ebenat	SW	52		8	4
21	Ambober school	396508	1333943	2203	Ambober school	Amhara	Ebenat	SW	60	2012	8	1.5
22	Ebenat school	397300	1340302	2198	Ebenat school	Amhara	Ebenat	SW	60	2012	6	2
23	Zeha School	389293	1334716	1922	Zeha School	Amhara	Ebenat	SW	60	2012	26	1.5
24	Akoha	404090	1350945	1973	Akoha	Amhara	Ebenat	SW	73	2012	7	2
25	Deber Abajalie School	395047	1341048	1892	Deber Abajalie School	Amhara	Ebenat	SW	73	2012	11	0.5
26	Abaseriho	430240	1363094	1743	Abaseriho	Amhara	Ebenat	SW	61	2011		Abandand
27	Tikuya	431579	1360044	1661	Tikuya	Amhara	Ebenat	SW	61	2011		Abandand
28	Ayeremarefia	395765	1339478	2196	Ayeremarefia	Amhara	Ebenat	SW	58	2011	9	2
29	Kidanemehert	396837	1339279	2225	Kidanemehert	Amhara	Ebenat	SW	61	2011	20	2
30	Asamatebiya	391068	1334708	1919	Asamatebiya	Amhara	Ebenat	SW	61	2011	11	1
31	Bariyawonze	391067	1335954	1948	Bariyawonze	Amhara	Ebenat	SW	58	2011	10	2
32	Semen	388008	1334911	1958	Semen	Amhara	Ebenat	SW	55	2011	15	5
33	Deregiha	428045	1361980	1813	Deregiha	Amhara	Ebenat	SW	58	2011	6	1
34	Atufata	403315	1339446	2291	Atufata	Amhara	Ebenat	SW	52	2011	10	2
35	Checheho school	403345	1339406	2301	Checheho school	Amhara	Ebenat	SW	49	2011	15	2
36	Worgaja H.Center	395983	1358594	1980	Worgaja H.Center	Amhara	Ebenat	SW	60	2011		Abandand
37	Etiyadfa	428672	1361201	1791	Etiyadfa	Amhara	Ebenat	SW	60	2011		Abandand
38	Dinkan	431056	1362097	1695	Dinkan	Amhara	Ebenat	SW	62	2011	3.2	2
39	Ebenat Hospital	396018	1339940	2188	Ebenat Hospital	Amhara	Ebenat	SW	65	2010	6	1
40	Erebereb	397730	1338326	2266	Erebereb	Amhara	Ebenat	SW	70	2010	2	1

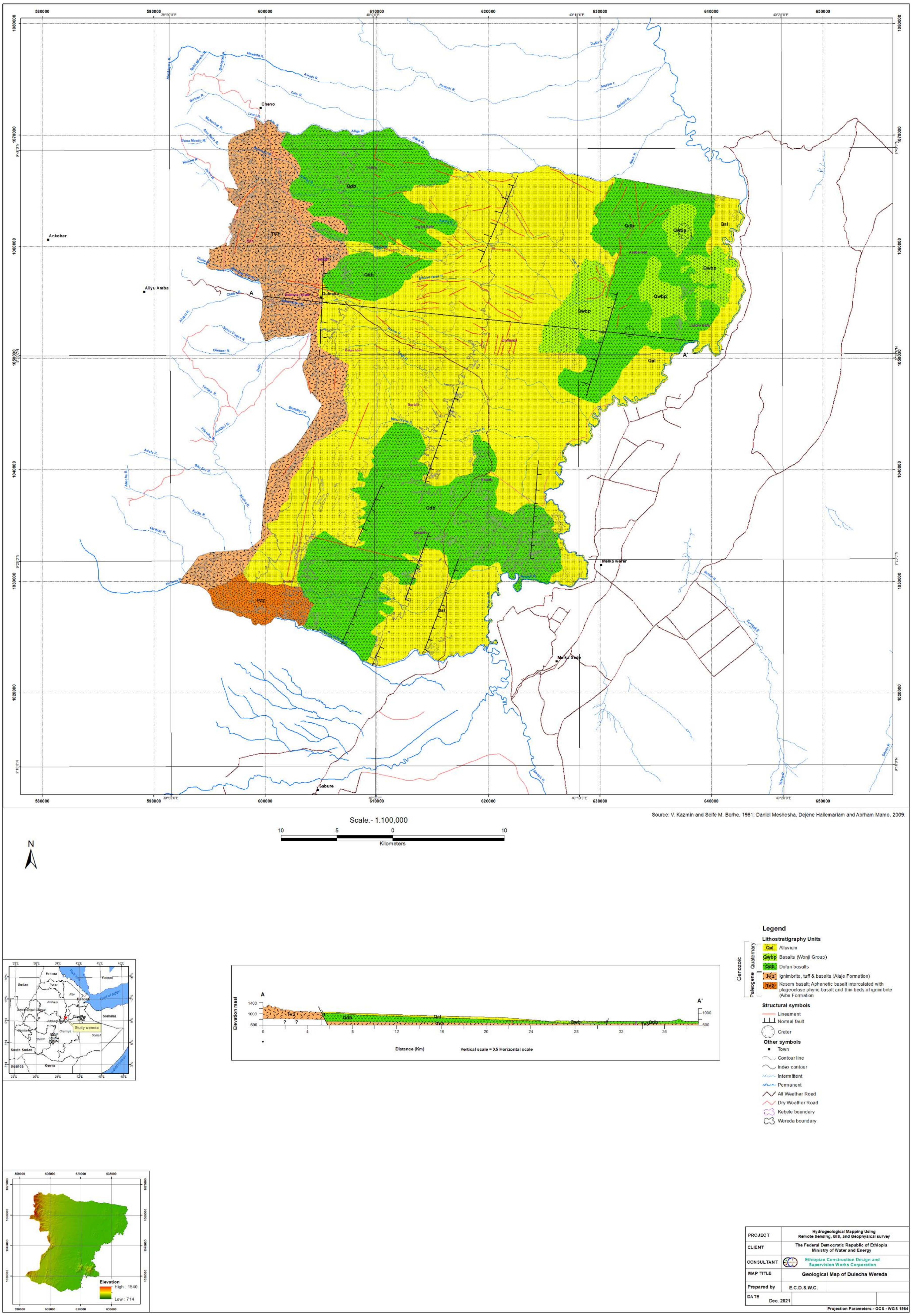
	Well ID	UTME	UTMN	Elev, m	Local/Site Name	Region	Wereda	Well Type	Well Depth, m	Drilled Year	Static Water Level, m	Well Discharge, l/s
41	Ayiha	403649	1350555	1935	Ayiha	Amhara	Ebenat	SW	50	2010	10	2
42	Agamoch	390297	1335577	1953	Agamoch	Amhara	Ebenat	SW	55		12	1.75
43	Dibua	386967	1333634	1872	Dibua	Amhara	Ebenat	SW	60		12	1.25
44	Abadur	385817	1334164	1903	Abadur	Amhara	Ebenat	SW	65	2009	3	0.5
45	Zevdijn	396055	1343258	2127	Zevdijn	Amhara	Ebenat	SW	60		6	1
46	Dengima	391519	1348375	2226	Dengima	Amhara	Ebenat	SW	65			Abandand
47	Akayna	393582	1344248	2195	Akayna	Amhara	Ebenat	SW	40		5	1.75
48	Ehud Gebiya	392911	1351594	2945	Ehud Gebiya	Amhara	Ebenat	SW	60		6	1.9
49	Kidus Yohannes	392952	1342320	2126	Kidus Yohannes	Amhara	Ebenat	SW	50		4	1.75
50	Ehud Gebiya1	392789	1351556	2145	Ehud Gebiya1	Amhara	Ebenat	SW	60		6	1.25
51	Menawkia	396073	1358312	1982	Menawkia	Amhara	Ebenat	SW	60		2	1.25
52	Dengima#2	392379	1348186	2246	Dengima#2	Amhara	Ebenat	SW	60		2	1.25
53	Smoge	394896	1356239	2120	Smoge	Amhara	Ebenat	SW	60		12	1.25
54	Aualisa	420809	1360559	1888	Aualisa	Amhara	Ebenat	SW	60	2008	2	4
55	Dilidy	393422	1340331	2250	Dilidy	Amhara	Ebenat	SW	45	2010	5	2.5
56	Tamro	391932	1335474	1919	Tamro	Amhara	Ebenat	SW	60	2008	2	2
57	Hodgebiya	392793	1351656	2144	Hodgebiya	Amhara	Ebenat	SW	60	2010	36	1.5
58	Akayna Town	393957	1343864	2196	Akayna Town	Amhara	Ebenat	SW	65	2008	25	1.5
59	Nichila	423283	1365570	1667	Nichila	Amhara	Ebenat	SW	69	2008	7	2
60	Fukir SW	389553	1335295	1945	Fukir SW	Amhara	Ebenat	SW	63	2009	10	1
61	Zeha SW	389244	1334406	1924	Zeha SW	Amhara	Ebenat	SW	57	2009	16	1
62	Tumant	405578	1374481	1530	Tumant	Amhara	Ebenat	SW	65	2008		Abandand
63	Mesk	431143	1379242	1581	Mesk	Amhara	Ebenat	SW	65	2008	14	1
64	China	429258	1372854	1623	China	Amhara	Ebenat	SW	65	2008		Abandand
65	Menawkia	395947	1353305	1983	Menawkia	Amhara	Ebenat	SW	70		15	0.4
66	Duranb#1	432944	1367867	1642	Duranb#1	Amhara	Ebenat	SW	70	2008	7	1.75
67	Duranb#2	433318	1368597	1618	Duranb#2	Amhara	Ebenat	SW	65	2008	20	1
68	Qulinziba	421241	1362574	1838	Qulinziba	Amhara	Ebenat	SW	70	2008	45	0.2
69	Shumge	411171	1337646	2597	Shumge	Amhara	Ebenat	SW	60	2008	10	1
70	China	429019	1372460	1643	China	Amhara	Ebenat	SW	70			Abandand
71	China	428677	1372013	1651	China	Amhara	Ebenat	SW	70	2008	46	0.2
72	Tiratra	423837	1365691	1703	Tiratra	Amhara	Ebenat	SW	60			Abandand
73	Yeymeret	431234	1373999	1564	Yeymeret	Amhara	Ebenat	SW	70		4.6	1
74	Serdomesk	400128	1339856	2269	Serdomesk	Amhara	Ebenat	SW	64		7	6.5
75	Smegie	391525	1336964	1951	Smegie	Amhara	Ebenat	SW	37		1.7	8
76	Agamoch	390752	1336045	1963	Agamoch	Amhara	Ebenat	SW	28		5	3
77		397236	1339131	2234		Amhara	Ebenat	SW	40		3	6
78		358172	1318732	2083		Amhara	Ebenat	SW	43		4	4
79	Buhait	403233	1339122	2301	Buhait	Amhara	Ebenat	SW	43	2001	8	2
80	UTSP71	408114	135195	1870		Amhara	Ebenat	Spring				4.5
81	UTSP70	398611	1346938	2175		Amhara	Ebenat	Spring				0.5

	Well ID	UTME	UTMN	Elev, m	Local/Site Name	Region	Wereda	Well Type	Well Depth, m	Drilled Year	Static Water Level, m	Well Discharge, l/s
82	UTSP68	406036	1339154	2033		Amhara	Ebenat	Spring				0.2
83	UTSP69	408523	1339125	2211		Amhara	Ebenat	Spring				0.3
84	Gabjiho	407113	1383650	1776	Gabjiho	Amhara	Misrak Belesa	SW	53	2013	1.5	2
85	Shumeldye	400494	1370731	1923	Shumeldye	Amhara	Misrak Belesa	SW	58	2013	6	5
86	Guhala02	399889	1370862	1921	Guhala02	Amhara	Misrak Belesa	SW	48	2013	4	2
87	Sewlye	401419	1393912	1547	Sewlye	Amhara	Misrak Belesa	SW	60	2013	4	0.5
88	Geentlo#2	401202	1391644	1596	Geentlo#2	Amhara	Misrak Belesa	SW	60	2013	24	0.6
89	Gelametatebia	394425	1374993	1749	Gelametatebia	Amhara	Misrak Belesa	SW	42	2013	3	5
90	Adorgie	391829	1370275	1870	Adorgie	Amhara	Misrak Belesa	SW	50	2013	9	0.8
91	Awa	395034	137089	1813	Awa	Amhara	Misrak Belesa	SW	50	2013	10	1
92	Akotana School	401180	1384038	1688	Akotana School	Amhara	Misrak Belesa	SW	60	2012	9	3
93	Addis Ala	397489	1379224	1714	Addis Ala	Amhara	Misrak Belesa	SW	37		8	3
94	Lomie	391492	1364743	2056	Lomie	Amhara	Misrak Belesa	SW	58	2012	10	2
95	Yesenibet Gebeya	393328	1363924	1982	Yesenibet Gebeya	Amhara	Misrak Belesa	SW	74		15	1
96	Genda Wuha	397831	1368771	1977	Genda Wuha	Amhara	Misrak Belesa	SW	52	2012	14	0.5
97	Chelekaina	400400	1382938	1714	Chelekaina	Amhara	Misrak Belesa	SW	60	2012	10	1
98	Marye Wenz	386789	1370644	1921	Marye Wenz	Amhara	Misrak Belesa	SW	60	2012	5	1.5
99	Akelelush SHW#1	398036	1363737	1854	Akelelush SHW#1	Amhara	Misrak Belesa	SW	60	2012	12	3
100	Washika	405684	1382702	1831	Washika	Amhara	Misrak Belesa	SW	60	2012	5	1.5
101	Tiliku Mesik	388797	1373601	1857	Tiliku Mesik	Amhara	Misrak Belesa	SW	70	2012		
102	Qubiewonze	388752	1368034	1902	Qubiewonze	Amhara	Misrak Belesa	SW	55	2010	12	1
103	FTC(Zandi)	392118	1377341	1762	FTC(Zandi)	Amhara	Misrak Belesa	SW	40	2010	4	8
104	Bergie	389310	1370383	1864	Bergie	Amhara	Misrak Belesa	SW	60	2010	4	1
105	Tilk Meda	401297	1384826	1692	Tilk Meda	Amhara	Misrak Belesa	SW	40	2012	6	0.7
106	Acheken Tebazela	400485	1377786	1789	Acheken Tebazela	Amhara	Misrak Belesa	SW	59	2012	20	0.7
107	Guhakotana-Bafti	401297	1384826	1692	Guhakotana-Bafti	Amhara	Misrak Belesa	SW	62	2012		0.1
108	Mitish Kayina	393607	1370099	1887	Mitish Kayina	Amhara	Misrak Belesa	SW	50	2008		Abdandoned
109	Disisty	424563	1397851	1564	Disisty	Amhara	Misrak Belesa	SW	69	2008		Abdandoned
110	Mesk	406012	1397976	1741	Mesk	Amhara	Misrak Belesa	SW	69	2008		Abdandoned
111	Genet Terara well	415577	1387315	1712	Genet Terara well	Amhara	Misrak Belesa	SW	75	2008		Abdandoned
112	Taybay	402045	1379419	1843	Taybay	Amhara	Misrak Belesa	SW	70			Abdandoned
113	Bugna	391420	1380339	1742	Bugna	Amhara	Misrak Belesa	SW	55	2007	11	
114	Atilkayina	396313	1370243	1913	Atilkayina	Amhara	Misrak Belesa	SW	46	2010	3	1
115	Adirtat	422543	1400970	1533	Adirtat	Amhara	Misrak Belesa	SW	70	2010		Abdandoned
116	Tibilaha	399735	1364481	1847	Tibilaha	Amhara	Misrak Belesa	SW	74	2010	12	1.75
117	Banbit	389434	1375660	1815	Banbit	Amhara	Misrak Belesa	SW	65			Abdandoned
118	Cheba	391916	1371102	1851	Cheba	Amhara	Misrak Belesa	SW	72		39	0.5
119	Asagot	401217	1365322	1836	Asagot	Amhara	Misrak Belesa	SW	55	2010	5	1.5
120	Agicha	416718	1387880	1571	Agicha	Amhara	Misrak Belesa	SW	65		32	1.75
121	Fisoye	391853	1376980	1764	Fisoye	Amhara	Misrak Belesa	SW	47	2010	5	17
122	Qasena	405406	1381501	1789	Qasena	Amhara	Misrak Belesa	SW	75	2010	19	1.5

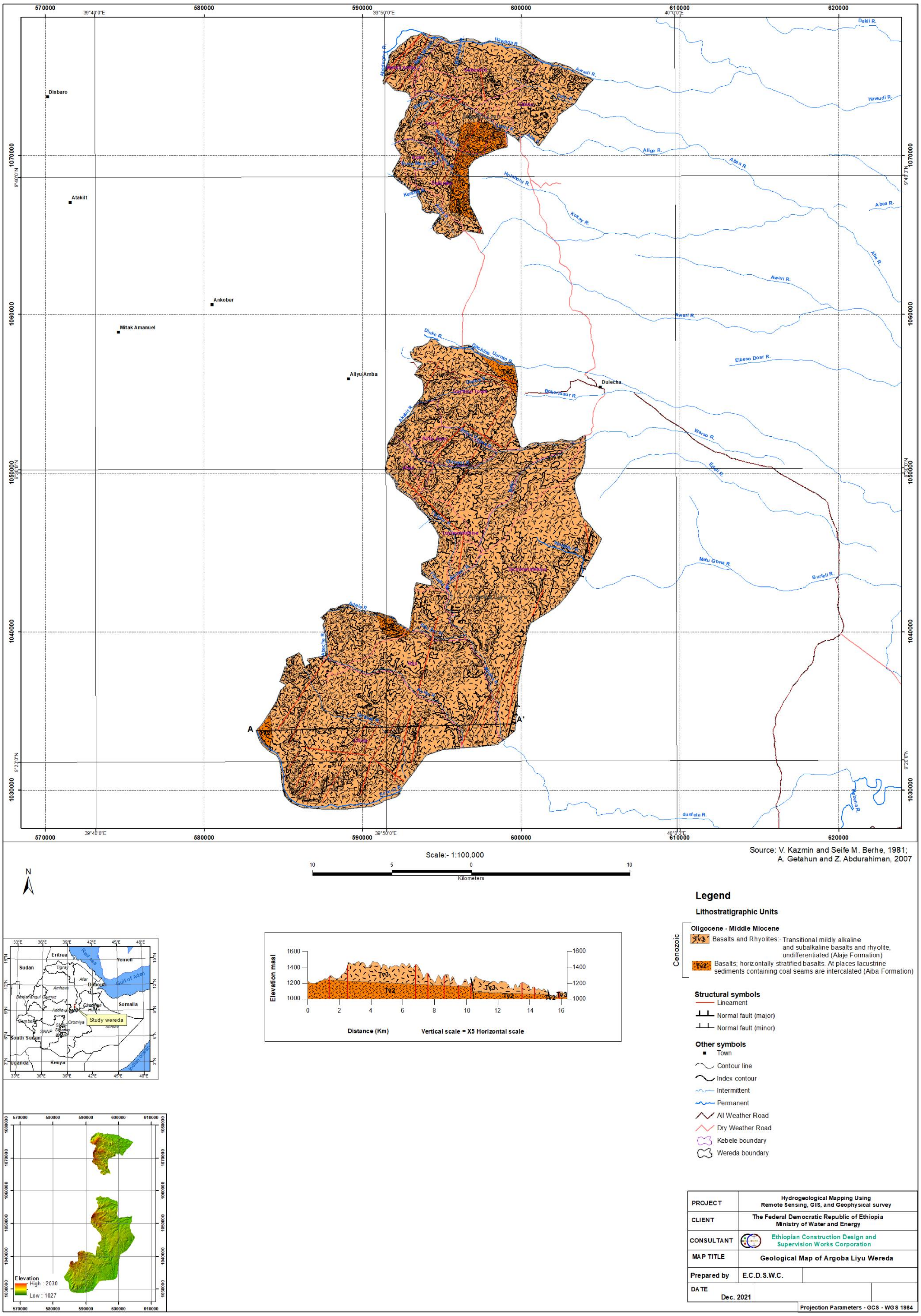
	Well ID	UTME	UTMN	Elev, m	Local/Site Name	Region	Wereda	Well Type	Well Depth, m	Drilled Year	Static Water Level, m	Well Discharge, l/s
123	Menderchincha	393038	1370105	1875	Menderchincha	Amhara	Misrak Belesa	SW	70	2010	17	1
124	Dimshalla	390539	1376718	1778	Dimshalla	Amhara	Misrak Belesa	SW	60	2010	9	2.5
125	Hamusit	410398	1384129	1795	Hamusit	Amhara	Misrak Belesa	SW	50	2010	3	1
126	Adusha	414853	1387195	1709	Adusha	Amhara	Misrak Belesa	SW	55	2010		Abdandoned
127	Gulla	428627	1390894	1445	Gulla	Amhara	Misrak Belesa				8	1.5
128	Shira	420790	1400943	1589	Shira	Amhara	Misrak Belesa	SW	70	2009	2	0.5
129	Gira	421181	1401018	1563	Gira	Amhara	Misrak Belesa	SW	64	2009	2	2
130	Mitishkayina	393607	1370099	1887	Mitishkayina	Amhara	Misrak Belesa	SW	50	2008	47	2
131	Talakmeda	401644	1375694	1920	Talakmeda	Amhara	Misrak Belesa	SW	60	2008	5	1.5
132	Tikure	401285	1376520	1876	Tikure	Amhara	Misrak Belesa	SW	60	2008	1	1.5
133	Sherie Anget	423717	1399313	1546	Sherie Anget	Amhara	Misrak Belesa	SW	45	2008	7.5	0.8
134	Quna Kayina	409493	1383620	1784	Quna Kayina	Amhara	Misrak Belesa	SW	35	2008	2.5	1.5
135	Addisalem well	388610	1371466	1863	Addisalem well	Amhara	Misrak Belesa	SW	49	2008	4	3.5
136	Darwuha	415103	1385450	1834	Darwuha	Amhara	Misrak Belesa	SW	33	2008	2	3.8
137	Lebete	422294	1380067	1622	Lebete	Amhara	Misrak Belesa	SW	52	2008	6	3
138	Shamesh	406092	1383340	1798	Shamesh	Amhara	Misrak Belesa	SW	65	2008	6	1.5
139	Niguse Bahir	400575	1381847	1740	Niguse Bahir	Amhara	Misrak Belesa	SW	65	2008		
140	Chichil Wiha	409038	1385469	1813	Chichil Wiha	Amhara	Misrak Belesa	SW	58	2008		
141	Selaho	401009	1371844	1896	Selaho	Amhara	Misrak Belesa	SW	60	2008	13	5
142	Bitashka	405369	1372878	1882	Bitashka	Amhara	Misrak Belesa	SW	57	2008	16	4
143	Gorebamba	408022	1386401	1829	Gorebamba	Amhara	Misrak Belesa	SW	64	2008	33	Abdandoned
144	Golgota	395901	1362303	1641	Golgota	Amhara	Misrak Belesa	SW	66	2008	30	1.5
145	Shunkerak	401362	1387239	1691	Shunkerak	Amhara	Misrak Belesa	SW	62	2008		Abdandoned
146	Gibtara	395468	1370262	1875	Gibtara	Amhara	Misrak Belesa	SW	43	2008	20	10
147	Chiwarkan	394137	1385103	1589	Chiwarkan	Amhara	Misrak Belesa	SW	52	2011	9	2
148	Addisalem school	400995	1392338	1560	Addisalem school	Amhara	Misrak Belesa	SW	40	2011	6	2
149	Millinium	399332	1372154	1924	Millinium	Amhara	Misrak Belesa	SW	70		42	0.4
150	Woiba school	397711	1377860	1717	Woiba school	Amhara	Misrak Belesa	SW	49	2011	Aretsian	20
151	CSP3	401586	1372065	1890		Amhara	Misrak Belesa	Spring				2
152	CSP4	392033	1365630	2103		Amhara	Misrak Belesa	Spring				0.1
153	UTSP77	401577	1372078	1828		Amhara	Misrak Belesa	Spring				1
154	UTSP78	428283	1401781	1551		Amhara	Misrak Belesa	Spring				1
155	kulmesk1	517169	1319392	2168		Amhara	Meket	DW	250		38	0.2
156	Kulmesk3	524356	1321245	2286		Amhara	Meket	MW	200		2.77	8
157	Segno-Gebeya	496686	1332293	1948		Amhara	Meket	MW	180		8.06	28
158	Weketa	473135	1292111	2836		Amhara	Meket	SW	127		30.95	6
159	Estayish1	516048	1301496	3174		Amhara	Meket	SW	144			0
160	Estayish2	511221	1304183	3163		Amhara	Meket	MW	200			0
161	Hanamekuat	467789	1294254	2807		Amhara	Meket	MW	220			0
162	Kulmesk2	532200	1322501	2475		Amhara	Meket	DW	250		36.58	0
163	Akat2	486899	1289808	2907		Amhara	Meket	SW	30		3	2

	Well ID	UTME	UTMN	Elev, m	Local/Site Name	Region	Wereda	Well Type	Well Depth, m	Drilled Year	Static Water Level, m	Well Discharge, l/s
164	Arbit	493534	1291283	2899		Amhara	Meket	MW	184		13	3.7
165	Boyaa	503988	1302053	3197		Amhara	Meket	SW	25		1	1.5
166	Meket	472663	1299262	2810		Amhara	Meket	SW	73.45		18	3
167	Sorat	481843	1343187	2494		Amhara	Meket	SW	43			1
168	Timtimat	496914	1295448	3035		Amhara	Meket	SW	55			0
169	FGW2	465981	1299532	2078		Amhara	Meket	SW	124		8	40
170	FGW1	465965	1300334	2098		Amhara	Meket	SW	137		13	30
171	Akat	487278	1287011	2906		Amhara	Meket	MW	153		44	4
172	Bewa	565766	1343830	1565		Amhara	Meket	MW	165		15	35
173	Guba Lafto	566092	1300913	1807		Amhara	Meket	MW	203.3		26	12.5
174	Bichiro	560175	1353877	1563		Amhara	Meket	SW	66		12	4
175	Atamober	455110	1307065	2874		Amhara	Meket	SW	30		3	2.25
176	Yekoso	459604	1305326	2882		Amhara	Meket	SW	38		6	1.25
177	Tsebelat	472107	1289854	2843		Amhara	Meket	SW	39		7	5
178	Goneja	458090	1307743			Amhara	Meket	SW	22		8	4
179	Aymati	456612	1307049	2872		Amhara	Meket	SW	66		4	4
180	Warkaye	471901	1295869	2860		Amhara	Meket	SW	67			0
181	Tsebelat no-2	462527	1304575	2888		Amhara	Meket	SW	60			0
182	CSP26	490847	1298816	2367		Amhara	Meket	Spring				0.01
183	CSP27	490663	1307617	2017		Amhara	Meket	Spring				10
184	UTSP1	515033	1309826	3220		Amhara	Meket	Spring				0.1
185	UTSP2	521323	1310927	3311		Amhara	Meket	Spring				5
186	Ayina Mechael	484614	1343643	2495		Amhara	Bugna	SW	46		12	2
187	Sora well	481743	1345948	2495		Amhara	Bugna	SW	43		7	7
188	shenete wuha well	481843	1343187	2494		Amhara	Bugna	SW	67			0
189	CSP17	477348	1344267	2056		Amhara	Bugna	Spring				8.5
190	ayebahir	438813	1492532	1602	ateba	Amhara	Tselimt	SW	90			1
191	dejach	433508	1487291	1818	tara	Amhara	Tselimt	SW	40		4	10
192	tsedamud	440329	1493799	1615	negada meshageria	Amhara	Tselimt	SW	57		9	12
193	shasherna	456478	1490688	1492	degibe	Amhara	Tselimt	SW	39		7	4
194	amhalane	455015	1491229	1506	degibe	Amhara	Tselimt	SW	75			0
195	TARIYAMEDA	455737	1491088	1527	dereba	Amhara	Tselimt	SW	63		37	0
196	ambbo	459662	1480290	1238	merrow	Amhara	Tselimt	SW	45		9	5
197	Tisegini	49077	1480055	1751	merrow	Amhara	Tselimt	SW	42		11	3
198	Mygassa	462673	1479665	1239	merrow	Amhara	Tselimt	SW	42		21	2
199	Geregra meda	472577	1299238	2806		Amhara	Tselimt	SW	75		24	5
200	Esetayish-1	516048	1301496	3174	Alalay(019)	Amhara	Tselimt	SW	144			0
201	Esetayish-2	511221	1304183	3163	Derkewenze	Amhara	Tselimt	MW	200			0

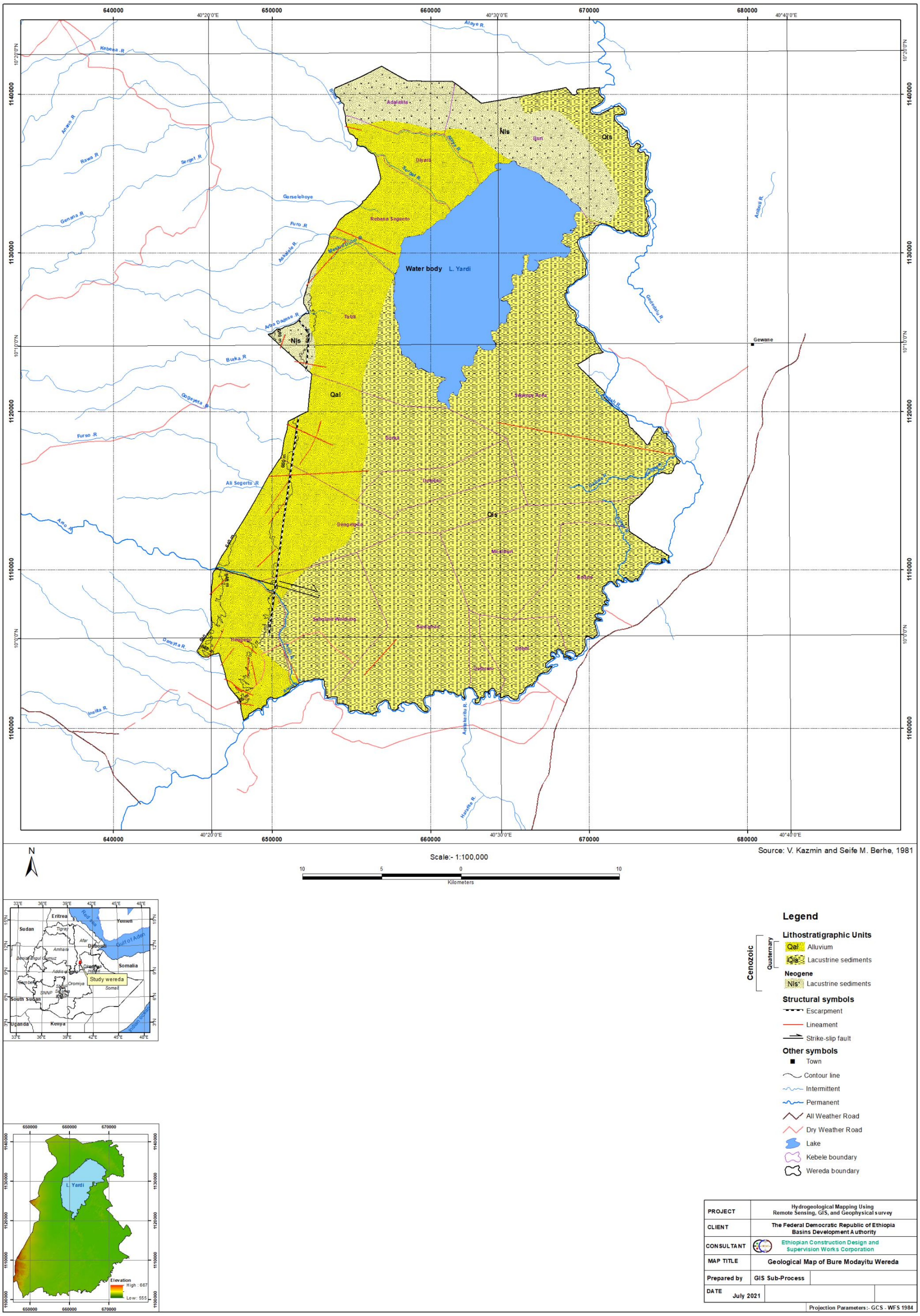
Annex 3: Geologic map and cross section of Project Weredas



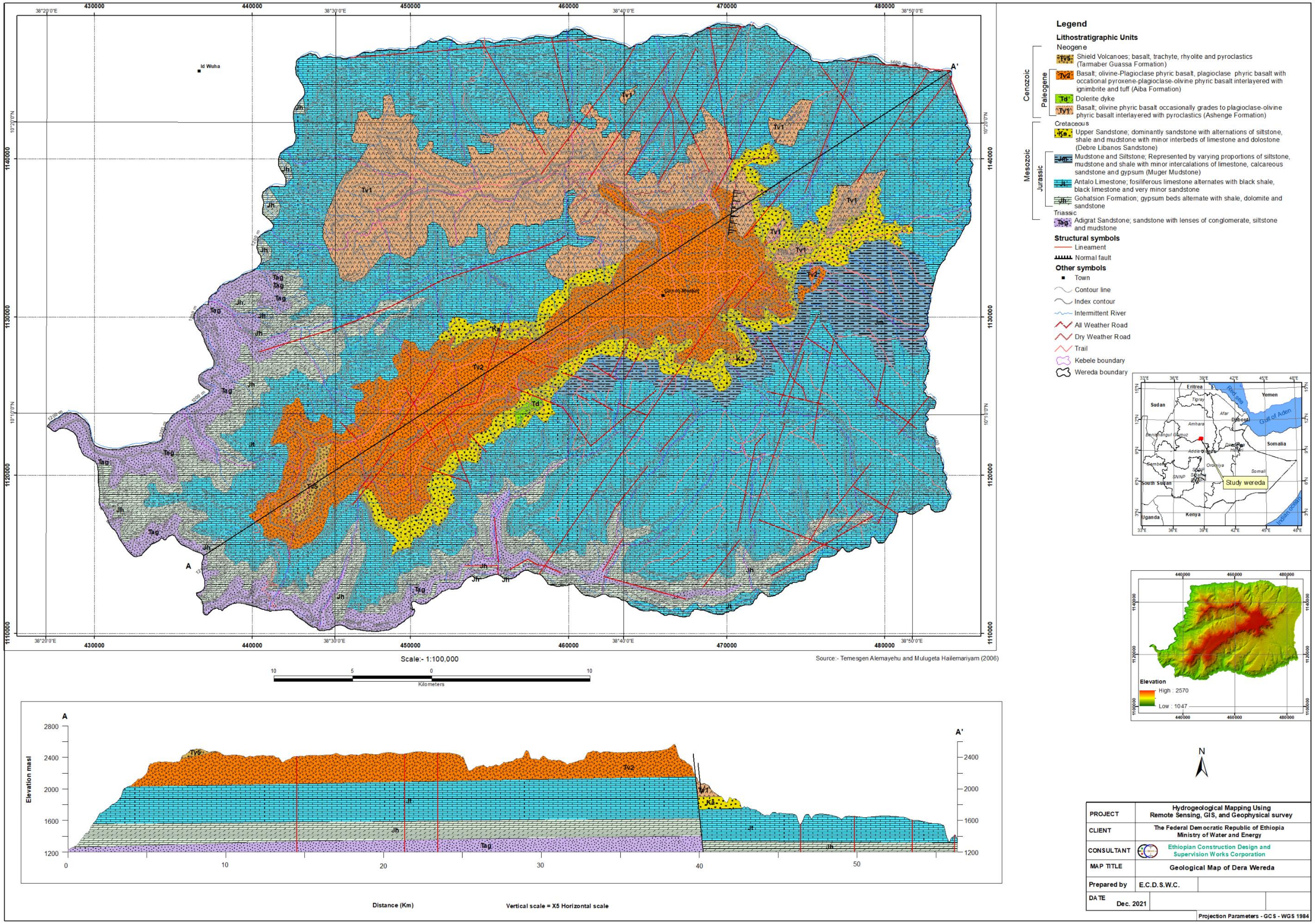
Geological map and cross section of Dulecha Wereda



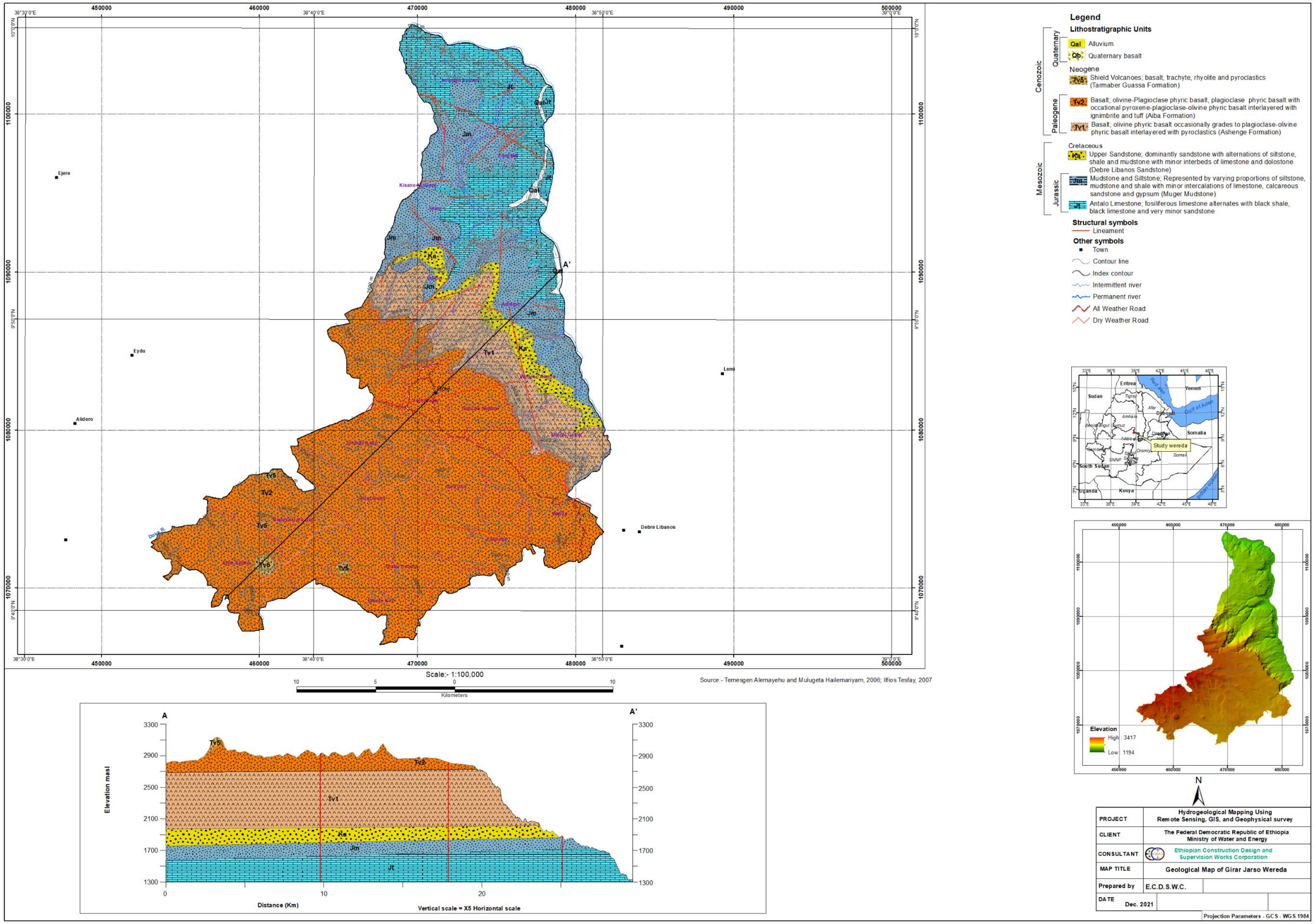
Geological map and cross section of Argoba Liyu Wereda



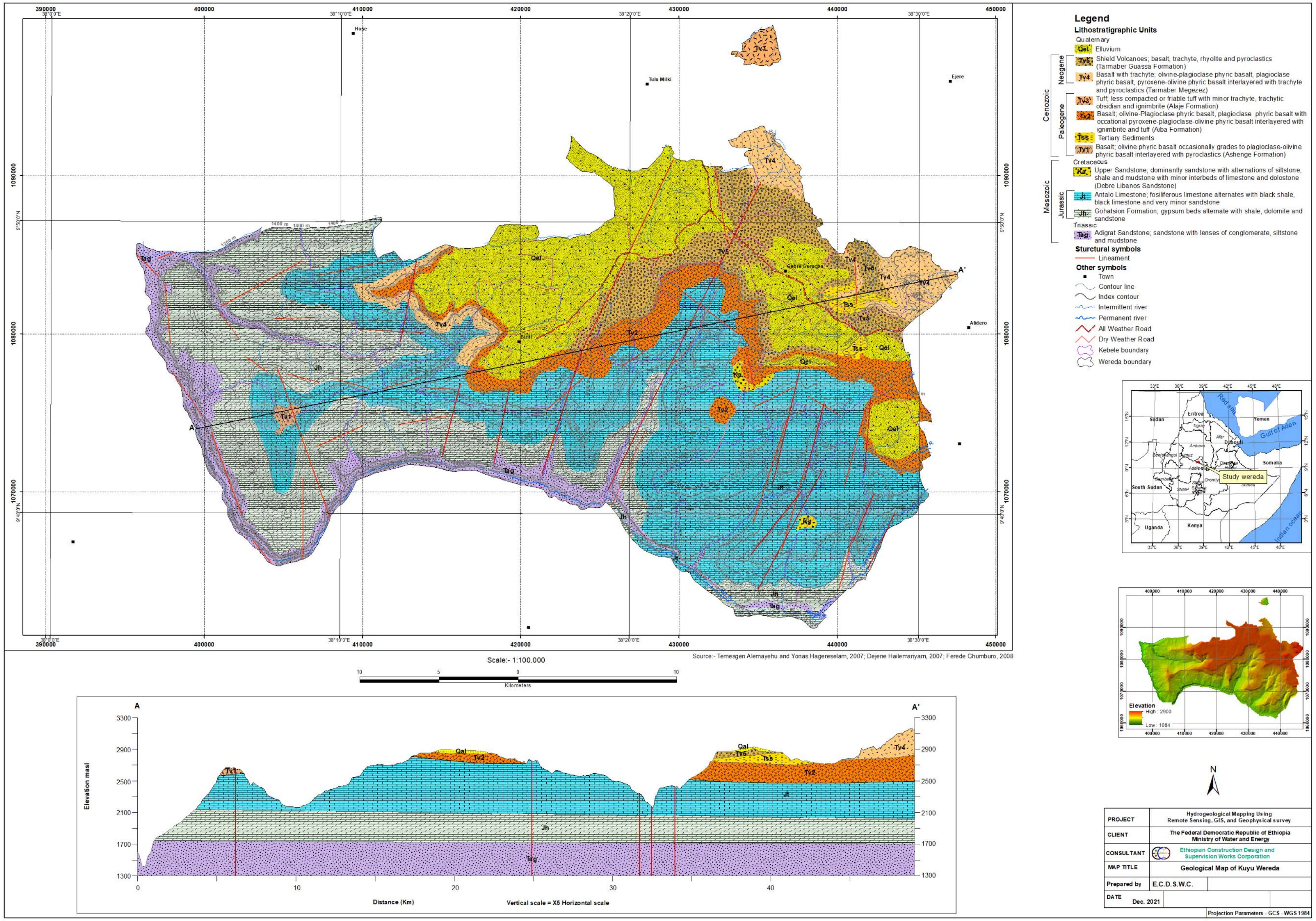
Geological map of Bure Mudayitu Wereda



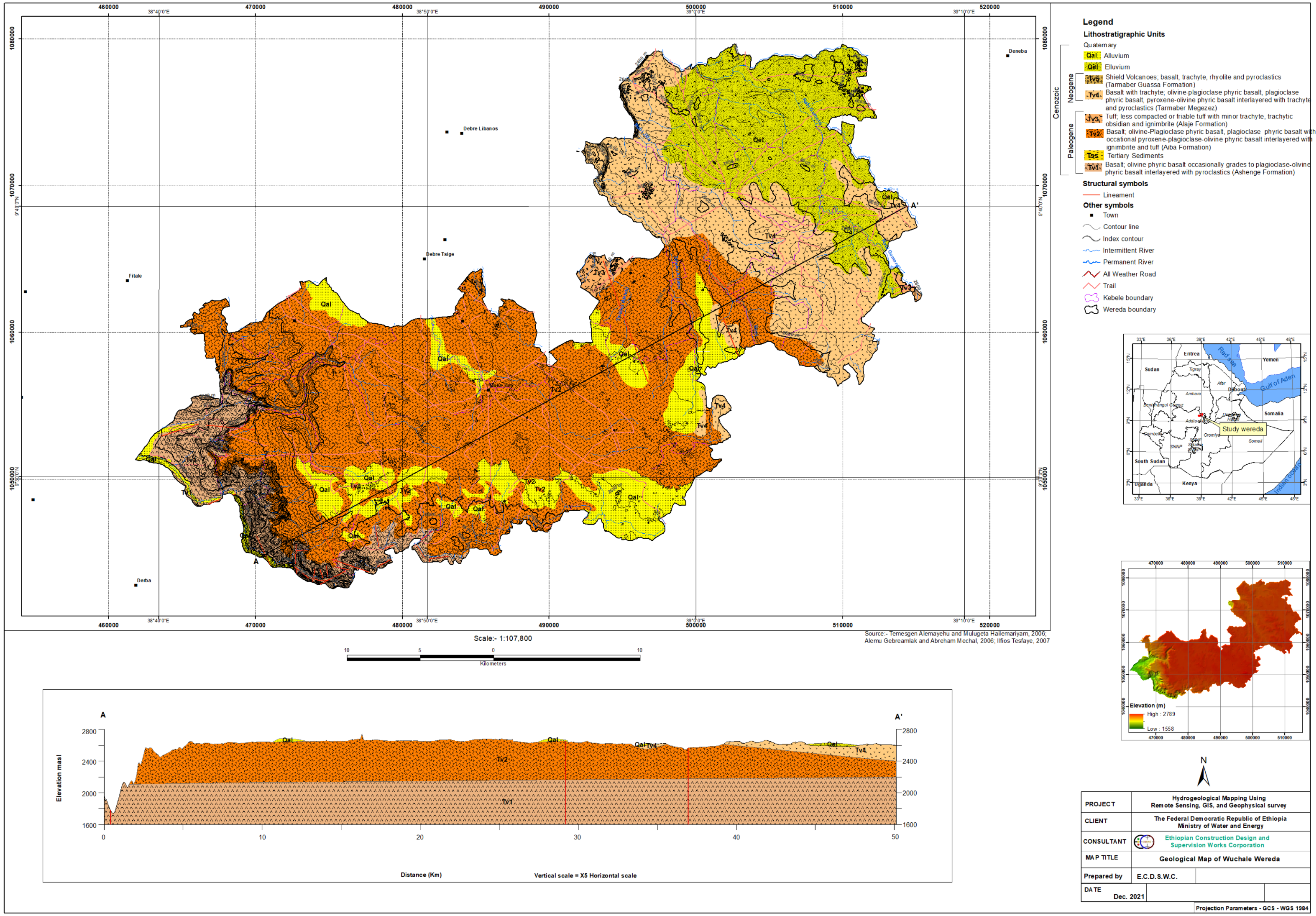
Geologic map and cross section of Dera Wereda



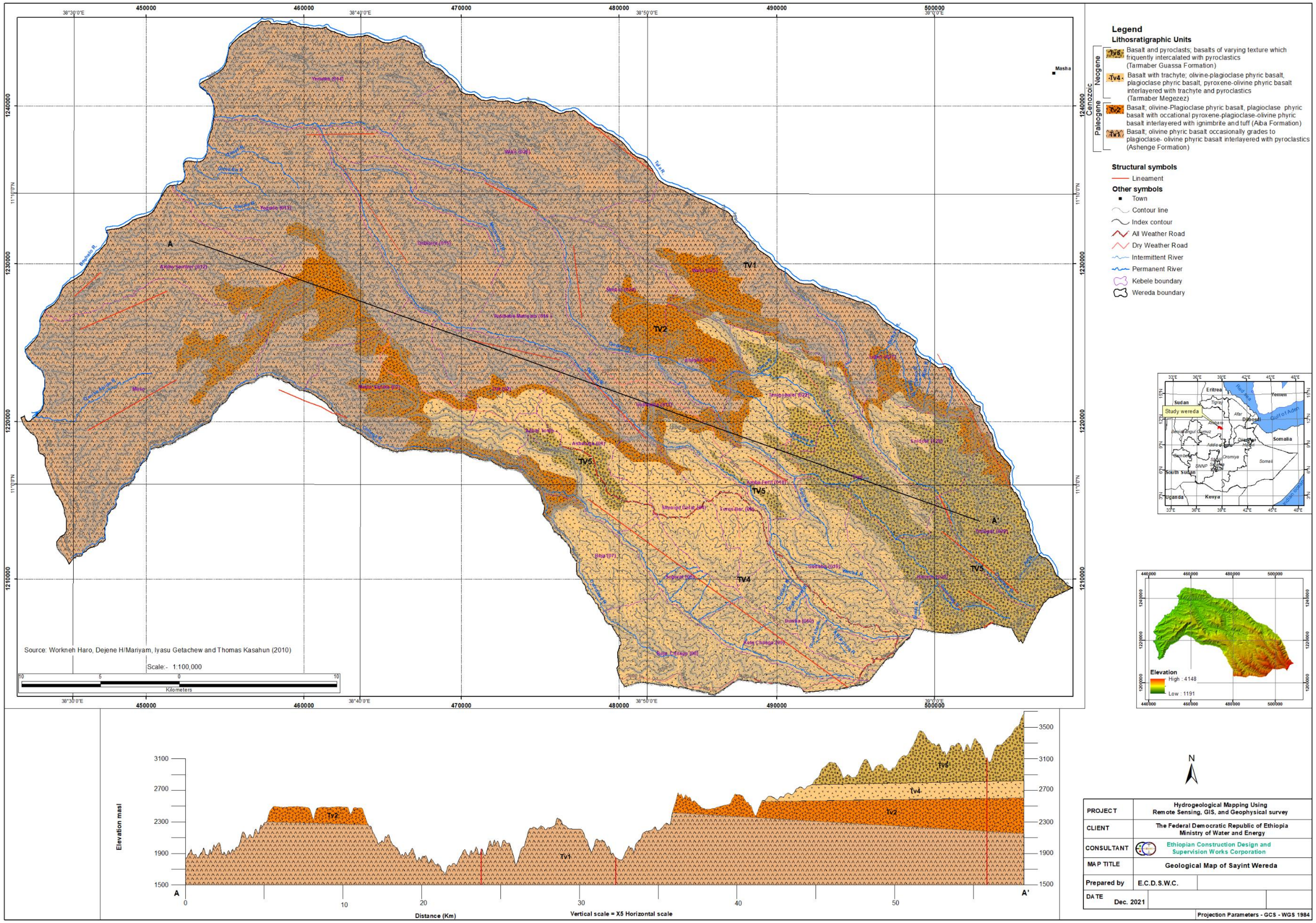
Geologic map and cross section of Girar Jarso Wereda.



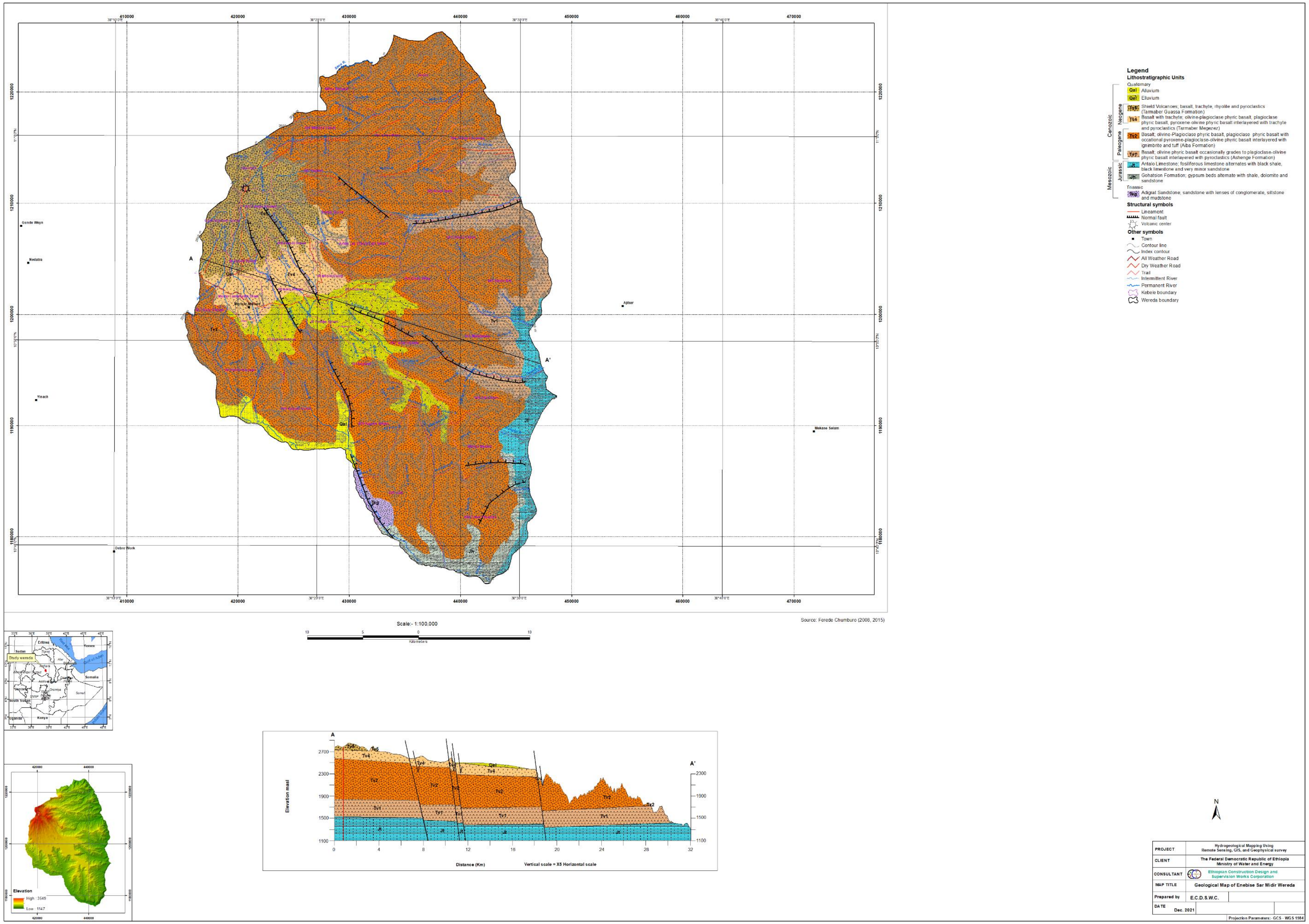
Geological map and cross section of Kuyu Wereda.



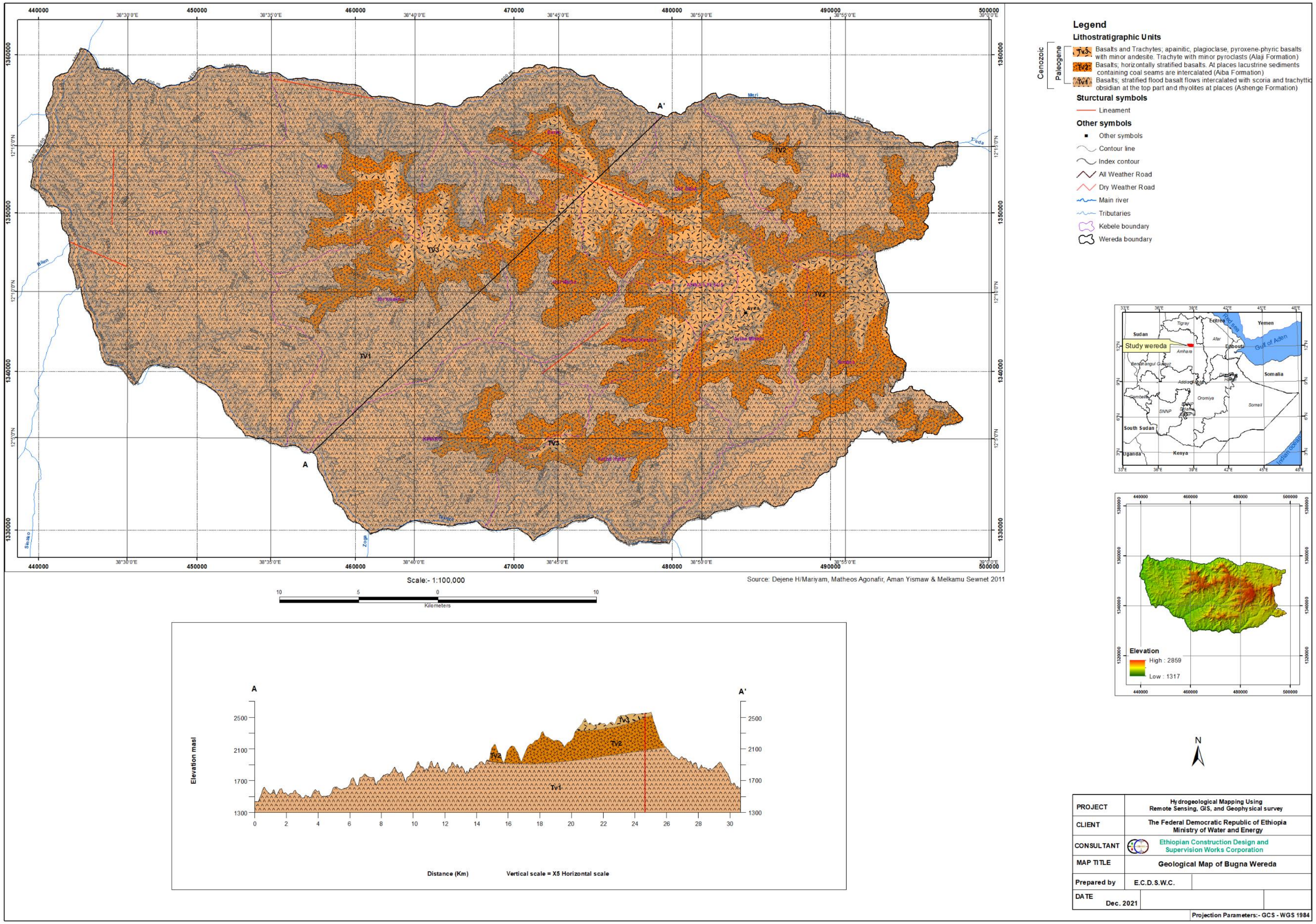
Geologic map and cross section of Wuchale Wereda.



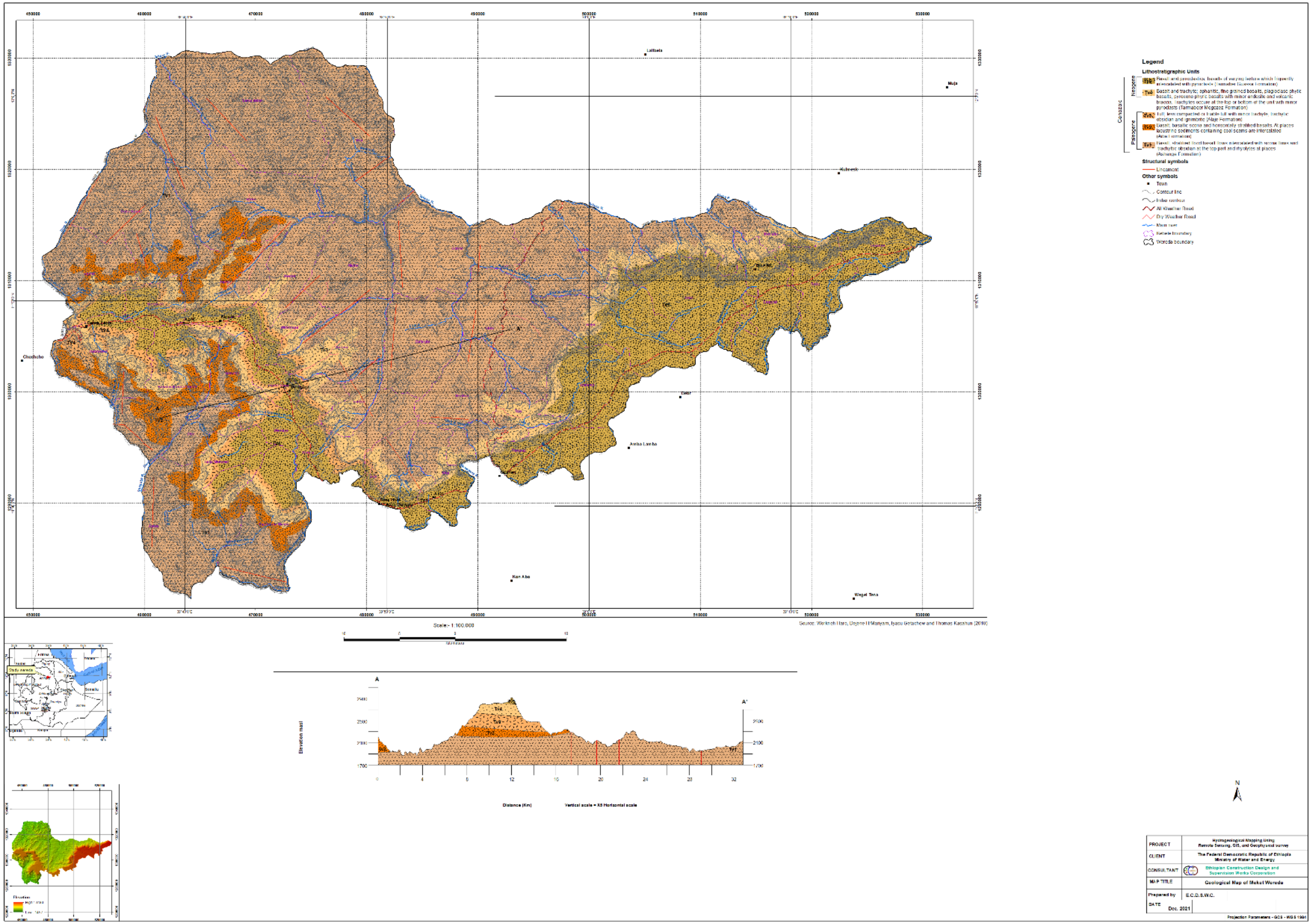
Geological map and cross section of Sayint Wereda.



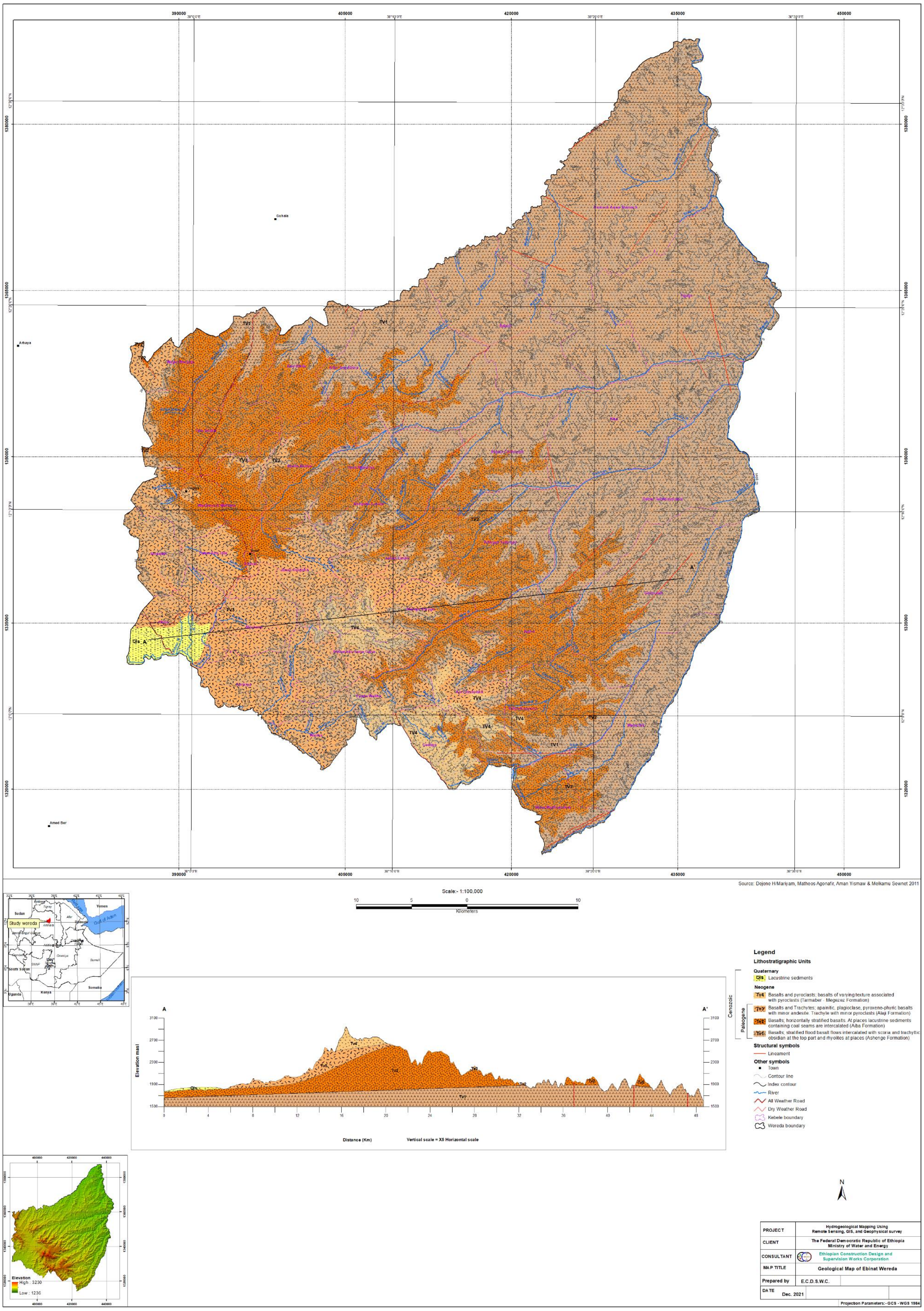
Geological map and cross section of Enebise Sar Midir Wereda.



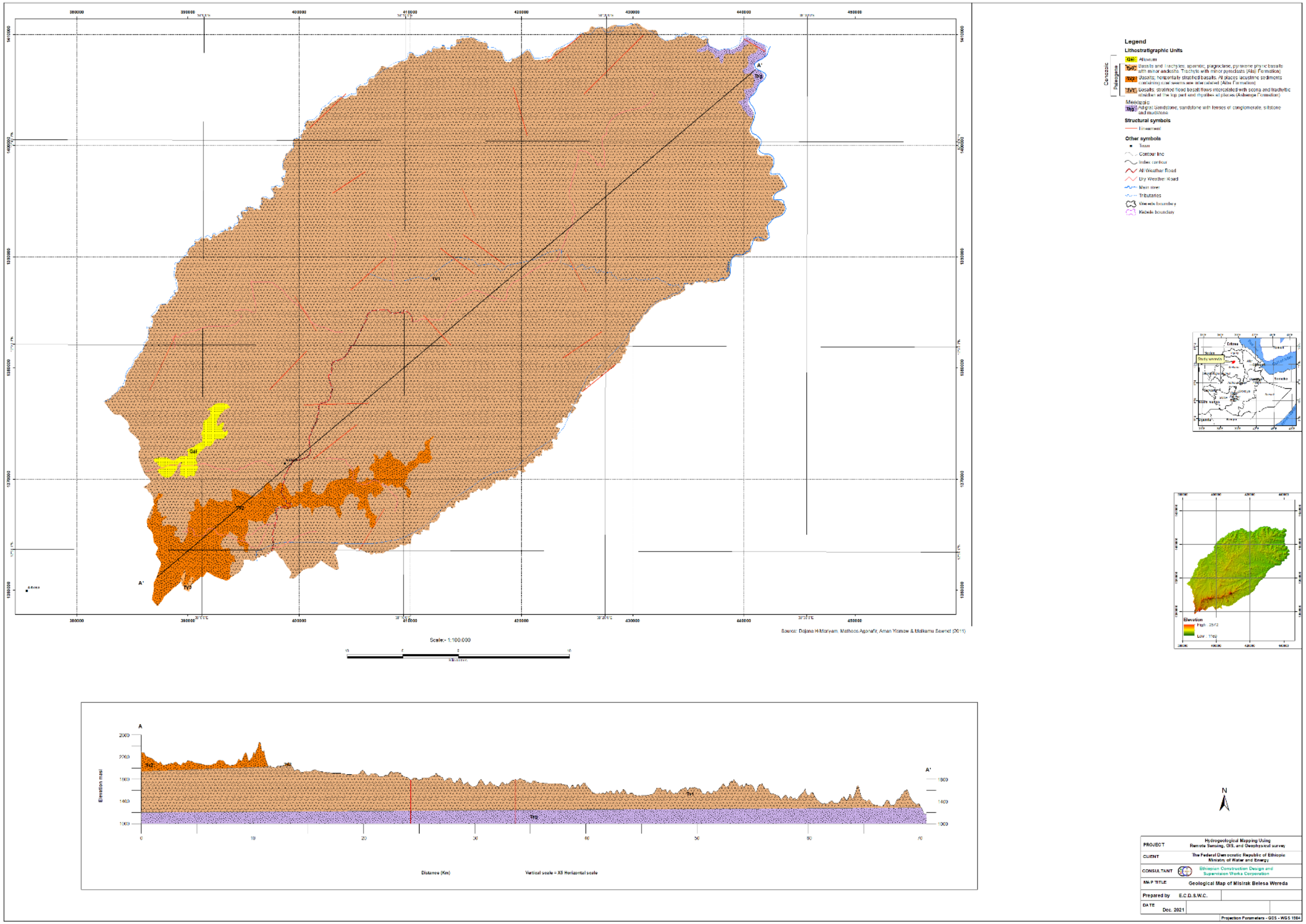
Geological map and cross section of Bugna Wereda



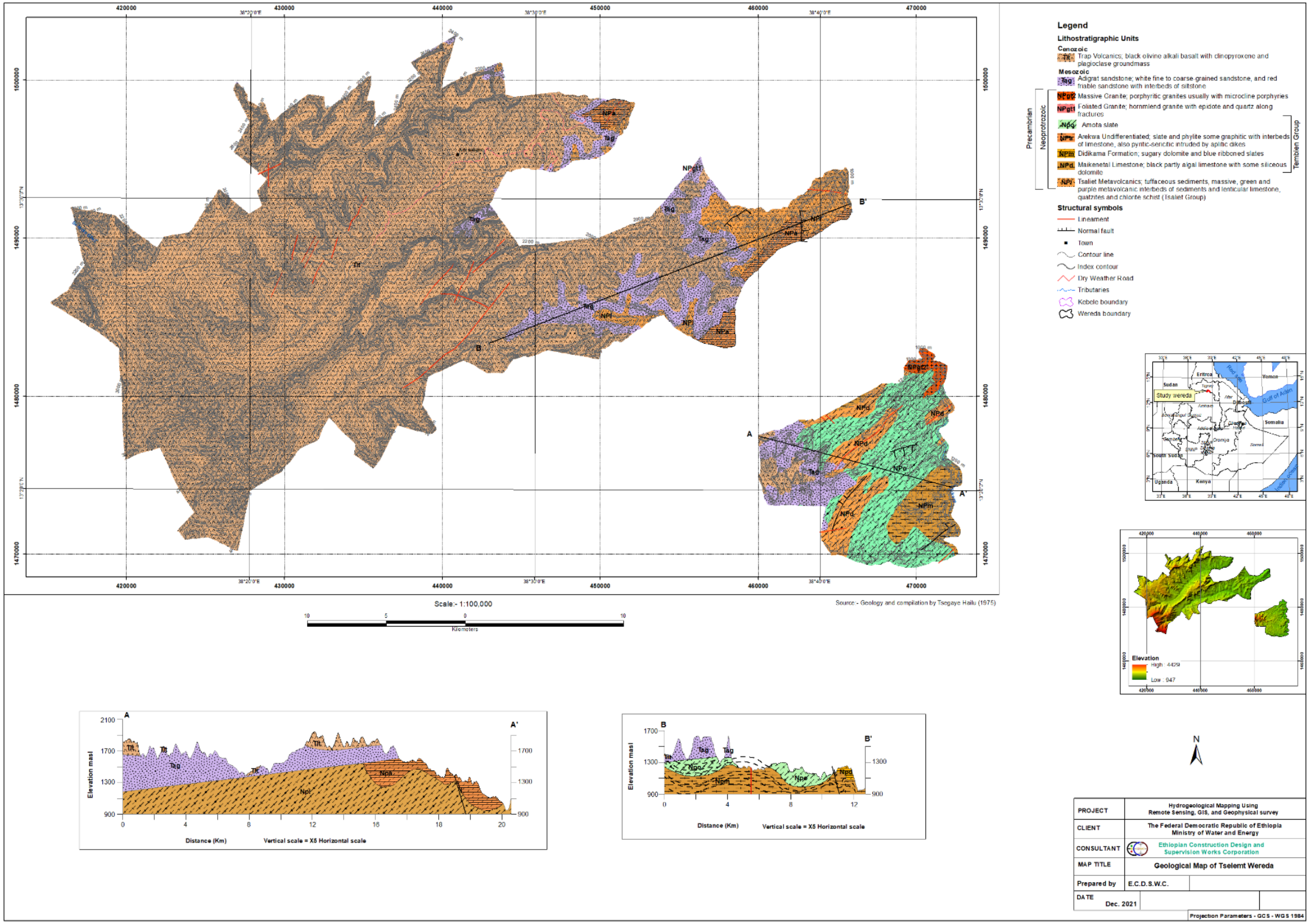
Geological map and cross section of Meket Wereda.



Geological map and cross section of Ebinat Wereda.



Geological map and cross section of Misrak Belesa Wereda.



Geologic map and cross section of Tselemit Wereda