



FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA
MINISTRY OF WATER AND ENERGY

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

Annex VIII – DEVELOPING GROUNDWATER POTENTIAL MAP ENEBISE SAR MIDIR WEREDA (FINAL)

January, 2022
ADDIS ABABA



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

Annex VIII – DEVELOPING GROUNDWATER POTENTIAL MAP ENEBISE SAR
MIDIR WEREDA
FINAL REPORT

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Executive Summary

The current study aimed at delineating groundwater potential zones of this wereda 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 this wereda of Amhara region for satisfying the community's needs.

In the study, RS (Remote Sensing) and GIS (geographic information system) were utilized to generate five thematic layers. These are 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 the Saaty's Analytical Hierarchy Process (AHP). Based on the rank assigned by a conceptual understanding of this wereda and weights aggregating the thematic maps is done using a weighted overlay method to obtain a groundwater potential (GWP) map. The GWP map is verified by overlay analysis with observed borehole yield data. Single – Parameter sensitivity analyses are used to examine or to compute effective weights.

This wereda GWP zones generally match with the conceptual understanding of this wereda 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 layers show some deviation from empirical weights. The GWP map 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, 1 most appropriate and 1 optional sites will be selected for drilling.

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ABBREVIATIONS AND ACRONYMS

AOI	-	Area of Interest
CSA	-	Central Statistical Agency
CTI	-	Compound Topographic Index
DEM	-	Digital elevation model
EGS	-	Ethiopian Geological Survey
ENVI	-	Environment for Visualizing Images
ESRI	-	Environmental Systems Research Institute
ETV	-	Evapotranspiration
GIS	-	Geographic information system
GSE	-	Geological Surveys of Ethiopia
GWP	-	Groundwater potential
GWPZ	-	Groundwater Potential zone
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
MOWIE	-	Ministry of Water ,Irrigation and Energy
NDVI	-	Normalized Difference Vegetation Index
NMA	-	National Meteorological Agency
pH	-	Hydrogen - Ion Activity
QGIS	-	Quantum Geographic Information System
RS	-	Remote sensing
SNAP	-	Sentinel Application Platform
SWL	-	Static water level
ToR	-	Terms of References
TWI	-	Topographic Wetness Index
UTM	-	Universal Transverse Mercator
WDC	-	Water Development Commission
WetSpaas	-	Water & Energy transfer between soil, plants & atmosphere

1. INTRODUCTION

1.1 General

The consultancy contract agreement was signed between 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 one of the communities in Enebise Sar Midir Wereda of Amhara Region of Ethiopia.

It is the initiation of the client to conduct a groundwater study to make groundwater potential maps and to identify drilling target site for borehole and alternative drilling site in Enebise Sar Midir Wereda.

The Project area cover water-scarce localities known to have complex hydrogeology. The complexity of the hydrogeology is manifested by low and indirect recharge, high salinity groundwater, rugged topography (mountainous), low yielding shallow groundwater, and very low past drilling success rates.

The current study aimed at delineating groundwater potential zones of the wereda 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 threat in this wereda of Amhara region.

In the study, RS (Remote Sensing) and GIS (geographic information system) were utilized to generate five thematic layers. These are 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 the Saaty's Analytical Hierarchy Process (AHP). Based on the rank assigned by a conceptual understanding of this wereda and weights aggregating the thematic maps is done using a weighted overlay method to obtain a groundwater potential (GWP) map. The GWP map is verified by overlay analysis with observed borehole yield data. Single – Parameter sensitivity analyses are used to examine or to compute effective weights.

The Phase – II report has been prepared based upon Field inventory data, Remotes sensing data, Climatological data, and GIS weighted overlay and is presented in seven chapters.

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

1.2 Location of the project LOT-2

The proposed study area is located in Amhara National Regional States of Enbise Sar Midir wereda in the east Gojam zone. The project area is accessible by a network of dry weather roads and the asphalt road that runs from Addis Ababa – Debre Markos major asphalt roads around 320km far from Addis Ababa. The whole of the project area is bounded between the geographic coordinates of UTME 410000-460000 and UTMN 1170000-1230000 and topographically the study area is rugged land surface. The elevation of the area ranges between 1143 and 3544m.a.s.l.

In general, all parts of the project areas are accessible from all directions by several all-weather roads, dry season roads, and footpaths. The location of the study area is depicted in figure 1 below.

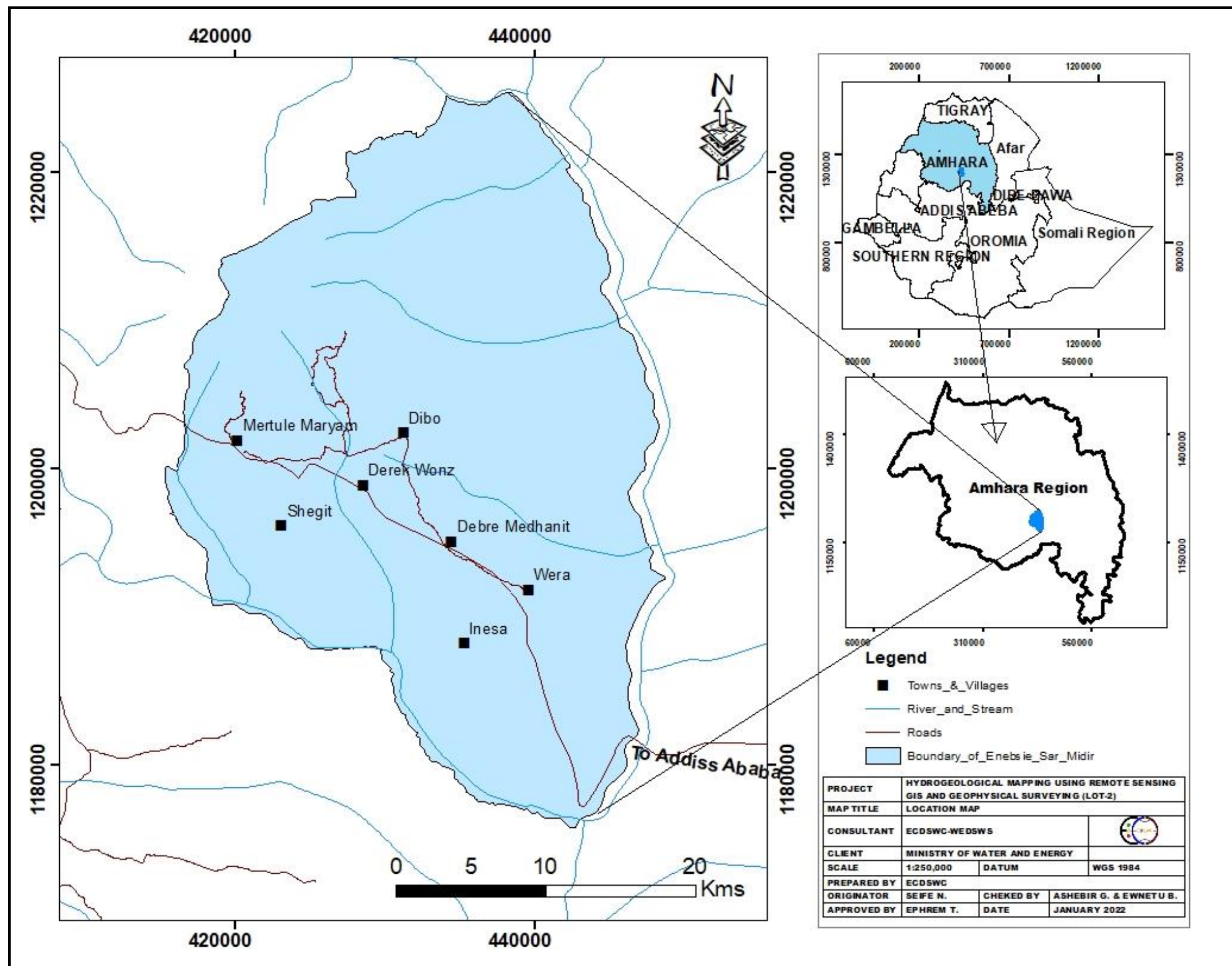


Figure 1: Location Map of Enebise Sar Midir Wereda

1.3 Objectives of the Study

The main objective of this project is to produce operational hydrogeological maps and recommend drilling sites and pinpoint locations with high water demand in combination with high groundwater potential. With the compiled information, associated overlay analyses, and extra geophysical field surveys, therefore, in this wereda the team will propose 1 most promising drilling sites for groundwater abstraction and 1 alternatives (optional) drilling sites. 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.
- Create detailed groundwater potential maps for target sites
- Identify one optimal drilling site and one alternative (optional) drilling site in this Wereda, using these maps and geophysical field investigation, and recommend the type of drilling methodology to be employed.
- Build the capacity of WDC, 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 will be focused on the preparation of Operational hydrogeological maps of this Wereda and identification of target site for borehole drilling with enhanced drilling success rates and optional drilling site for the 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 site maps. The technical route is depicted in figure 2 below

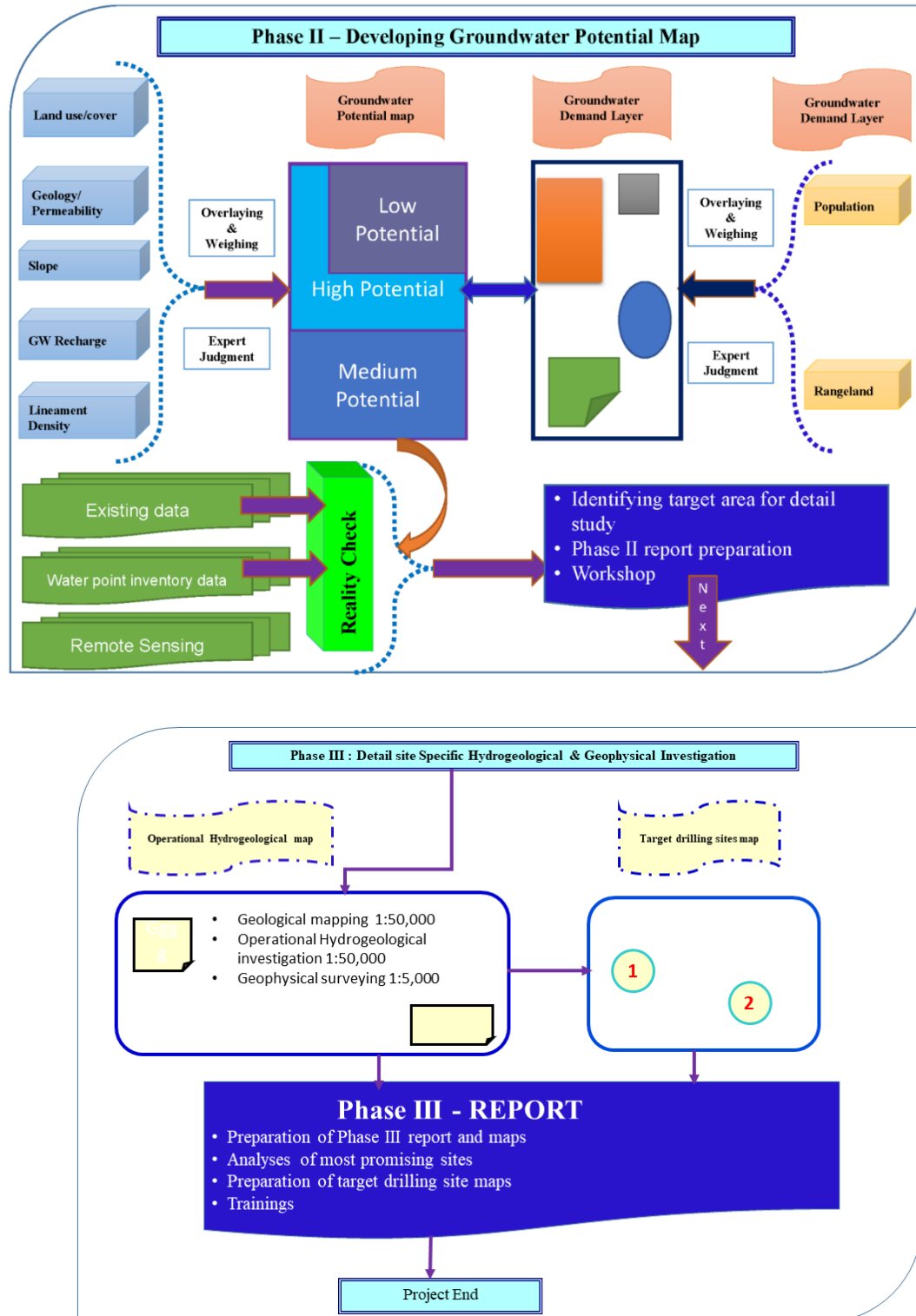


Figure 2: The project phases and the main deliverables

Phase II activities and deliverables

The subject project was launched on the 24th of May 2021. Since validation and acceptance of Phase I Inception report the following activities listed below 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.
- Climatological data was collected from NMA and Satellite data and detailed analysis had been carried out.
- Hydrological data was collected from MoWE and detailed analysis had been carried out
- Kebele with Groundwater scarcity was identified by communicating with the Wereda water office and target population
- Satellite imagery and maps were acquired and interpreted for land cover mapping, Geological mapping, and lineament preparation of the wereda.
- 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 had been prepared for input for Groundwater recharge estimation.
- Groundwater recharge was estimated by using the WetSpss model for the Abay basin, and then the Groundwater recharge map had been extracted by the respective boundary of the wereda.
- Geological Map 1:100,000 had been prepared for the 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 the wereda.
- Lineament density map and Lineament proximity map had been prepared from lineament map
- Topographic Wetness index had been generated for the wereda
- Hydrogeological Sections had been prepared for the wereda
- Overlay Analysis has been carried out for the wereda
- Sensitivity analysis had been carried out for the wereda
- Validation of groundwater potential for the wereda tested by using observed data collected during the groundwater inventory program on progress.
- The groundwater demand layer had been prepared based on projected project CSA data

- Groundwater potential maps had been prepared for the wereda
- 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:

- Lack and incompleteness of Groundwater data and reports in the wereda are observed. The model is validated by using representative and data collected during field inventory and existing data collected from different organizations.
- Lack of expert in the wereda and Gap in the data handling, storing, and report preparation was observed.

The proposed mitigation measures are depicted as follows: -

- The data scarcity had been 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 Geomatica (2017), 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) were utilized to generate five thematic layers of 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 the 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.

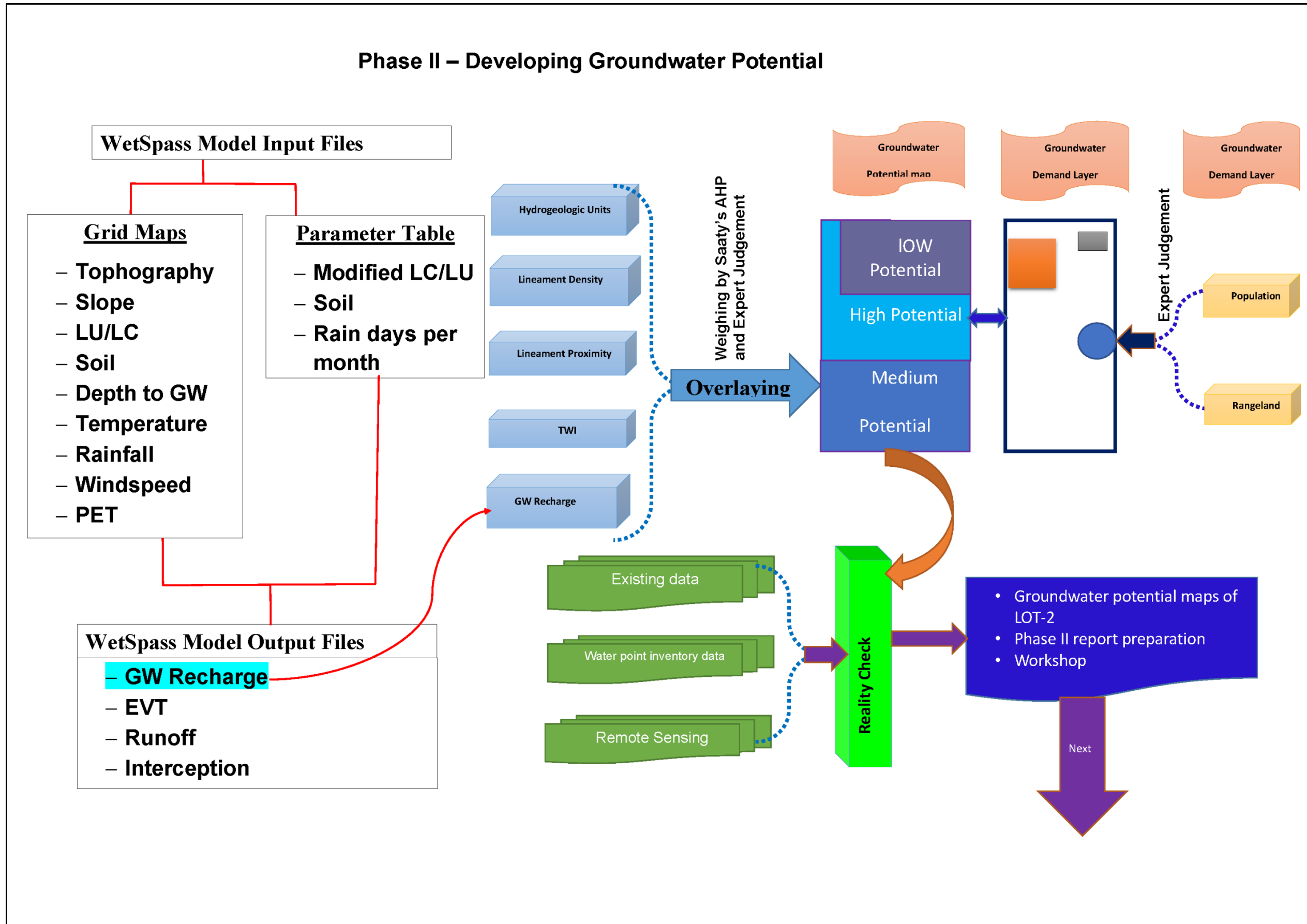


Figure 3: Phase II methods and deliverables

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 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 Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) with the 30-m resolution are used to extract 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, SRTM DEM 30m resolution, Landsat-7 ETM + data 30m spatial resolution and Google Earth image @ 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 existing 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 had been used for validation of Groundwater potential maps of the project weredas. The summarized inventory and existing data are presented in table 1 and the raw data is annexed (2).

Table 1: Inventoried and existing water points

Wereda	Inventoried water point				Existing water point			
	BH	Shallow wells	HDW	Spring	BH	Shallow Wells	HDW	Spring
Enebsie Sar Midir	5	8	1	1	2			
Grand Total	5	8	1	1	2			

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 map of the wereda, the thematic layers of lithological units, Groundwater recharge, lineament density, lineament proximity, and TWI were prepared on a scale of 1:100,000 with a spatial resolution of 100m pixel size in a GIS environment. After the preparation of the thematic maps the rank is assigned to each thematic layers attribute based on the conceptual understanding of the wereda, 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

The present work is intended to produce a Geologic map of the wereda at a scale of 1:100,000 by combining remote sensing and GIS. The methodologies adopted in this work are divided into; (i) Literature survey and (ii) Remote sensing and GIS studies.

A literature survey 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 area has previously been geologically mapped by GSE at a scale of 1:50,000 and 1:250,000. These maps were provided better information to understand the geological evolution of the project area. However, a review of these geological maps has identified the gaps listed below which are considered during the present investigations by RS and GIS studies. The gaps identified were: -

- (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 of the geological process are 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 below. 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 wereda at a scale of 1:100.000. The Geology map of the project wereda is presented in annex (3).

Table 2: 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.glcg.umd.edu:8080/esdi
5	SRTM 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) http://glcfapp.glcg.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 DEM sources were used to generate lineaments of the study area. The first one is Shuttle Radar Topography Mission (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 Shuttle Radar Topography Mission (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 overlaid shaded relief images with multi-illumination directions of (0°, 45°, 90°, and 135° azimuth and sun angle of 30°). PCI Geomatica software was used for the automatic lineament extraction. These steps were carried out under the different threshold, 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 methods

In this study, the Hydrological study had been 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 3. The spatial representation of land use, soil, Rainfall, Temperature, wind speed, PET and Elevation maps, and modified land use, soil, and rain days per month parameter tables used as an input for the model is presented in phase III water balance reports.

Table 3: Dataset used for the evaluation of groundwater recharge

S. N	Input data	Data name	Resolution	Period	Description
1	Rainfall	CHIRIPS	0.25°x 0.25°	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 softwares 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: -

$$E_{\text{raster}} = a_v E T_v + a_s E_s + a_o E_o + a_i E_i \text{-----Eq.1}$$

$$S_{\text{raster}} = a_v S_v + a_s S_s + a_o S_o + a_i S_i \text{-----Eq.2}$$

$$R_{\text{raster}} = a_v R_v + a_s R_s + a_o R_o + a_i R_i \text{-----Eq.3}$$

Where the index raster refers to raster cell, with $E T_{\text{raster}}$, S_{raster} and R_{raster} respectively, the total evapotranspiration, surface runoff and recharge in a raster cell and a_v , a_s , a_o and a_i 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:

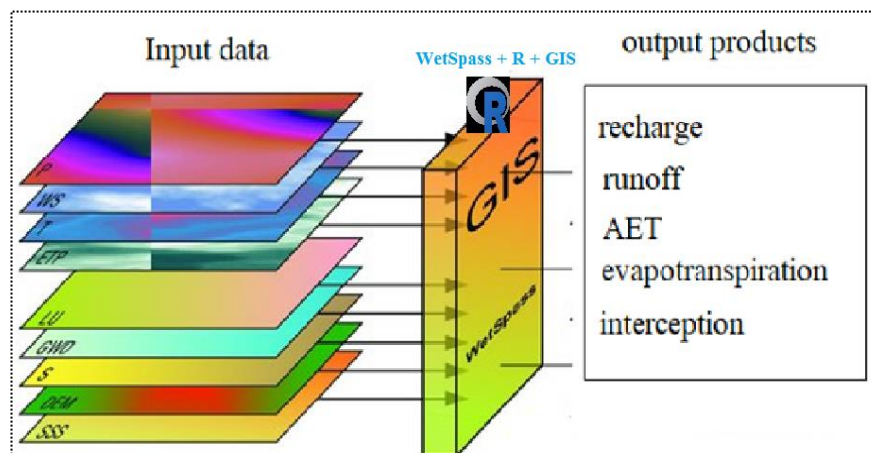


Figure 4: Schematic representation of model used for the study

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 4). 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 4: confusion matrix over true values in the Enebise Sar Midir 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. $NDVI = \frac{NIR-RED}{NIR + RED}$

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

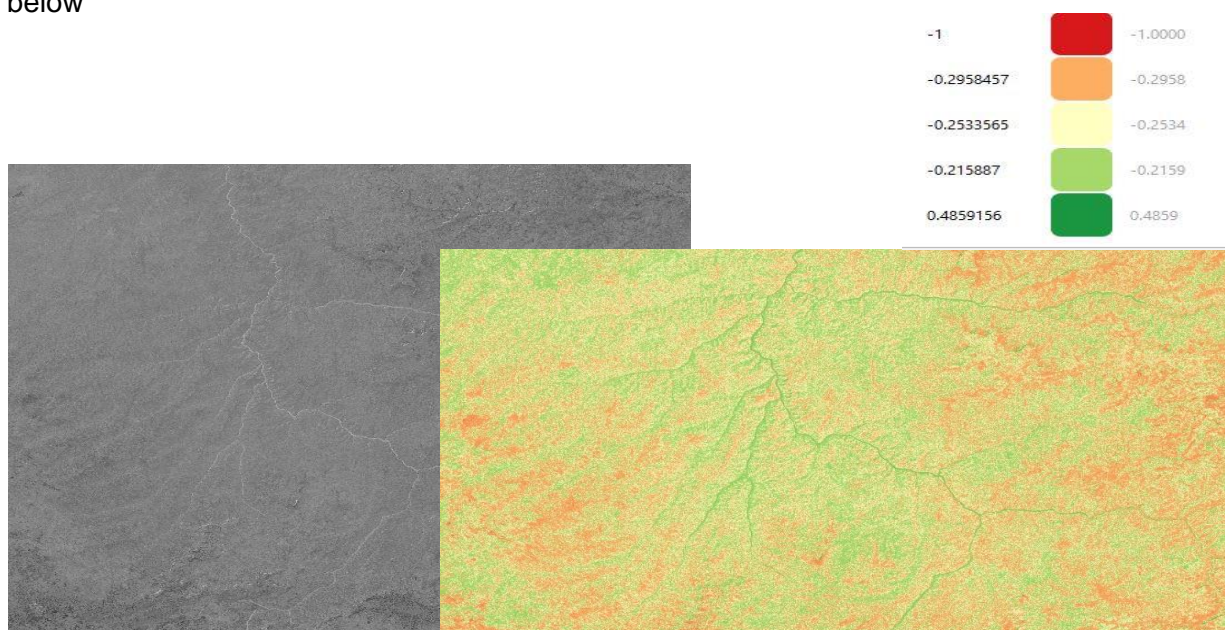


Figure 5: calculated NDVI using QGIS

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.

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

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 population growth rate is very important .Accordingly, the population of Enebise Sar Midir wereda is estimated to grow at the rate of 2.68%, 2.45% & 2.31% annually in accordance with 2025, 2030 & 2035 CSA estimates of population growth rate for Amhara region respectively. The projection is based on exponential growth rate model which goes, $P_t = P_o e^{r\Delta t}$

Where: P_t = Population at t year

P_o = Population at current (initial) year

$e = \ln 10 = 2.718$

Δt = the difference between t year and initial year

Therefore, based on the above exponential population projection formula, the current population size of Enebise Sar Midir wereda is projected for the planning period 2035 and the summarized population size is presented in the following tables.

Table 5: Population size of Enebise Sar Midir wereda, July 2021 to 2035

Year	Δt	Growth Rate	Enebise Sar Midir Wereda	
			Rural	Mertule Maryiam Twon
2021	0		144,964	26,264
2025	4	2.68%	161,366	29,236
2030	5	2.45%	182,393	33,045
2035	5	2.31%	204,721	37,091

Table 6: Number of livestock and Livestock and poultry (for private holdings), July 2020

Wereda	Cattle	Goats	Sheep	Horses	Mules	Donkey	Poultry
Enebise Sar Midir	174,565	41,868	16,950	152	297	25,582	56,030

3. Conceptual Hydrogeological model of the study area

3.1 Hydrogeological condition of Enebise Sar Midir Wereda

The study area falls in the Abay River 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 alluvial, elluvium, limestone, sandstone and basaltic rocks are the main formation of the study area. They are jointed, fractured, and affected by dense weathering.

The study area is part of central Ethiopian plateau. Part of the study area is deeply dissected by Abay River and its tributaries. From ground observation and satellite image interpretation, the study area separated into: plateau with small hills and small ridges, mountains, escarpments/or cliffs and deep gorges and slopping topography.

According to previous studies and hydrogeological set up of the areas shows, the major sources of recharge for the study area are:

- Subsurface inflow from north-western fractured volcanic rocks,
- precipitation induced within the study area
- Infiltration from surface rivers and overland flows (river banks infiltration)

In addition, geomorphological setup, water level observed, geologic structures, groundwater contour, and conceptual model developed based on previous studies shows that groundwater recharged at north-western and north highland areas flow toward the Abay river (Enebise Sar Midir wereda) and mixed up with groundwater recharge from surface rivers and rainfall-induced in the area.

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

3.2 Hydrogeological setup & Conceptual model of Enebise Sar Midir

Conceptual model of Enebise Sar Midir

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 showing that on the top part (0 - 20) meters depth soft formations, in the middle part up to 74m acidic formation 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 x-section, the groundwater flow system is from the northwest to southeast direction.

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 5 and 7 below.

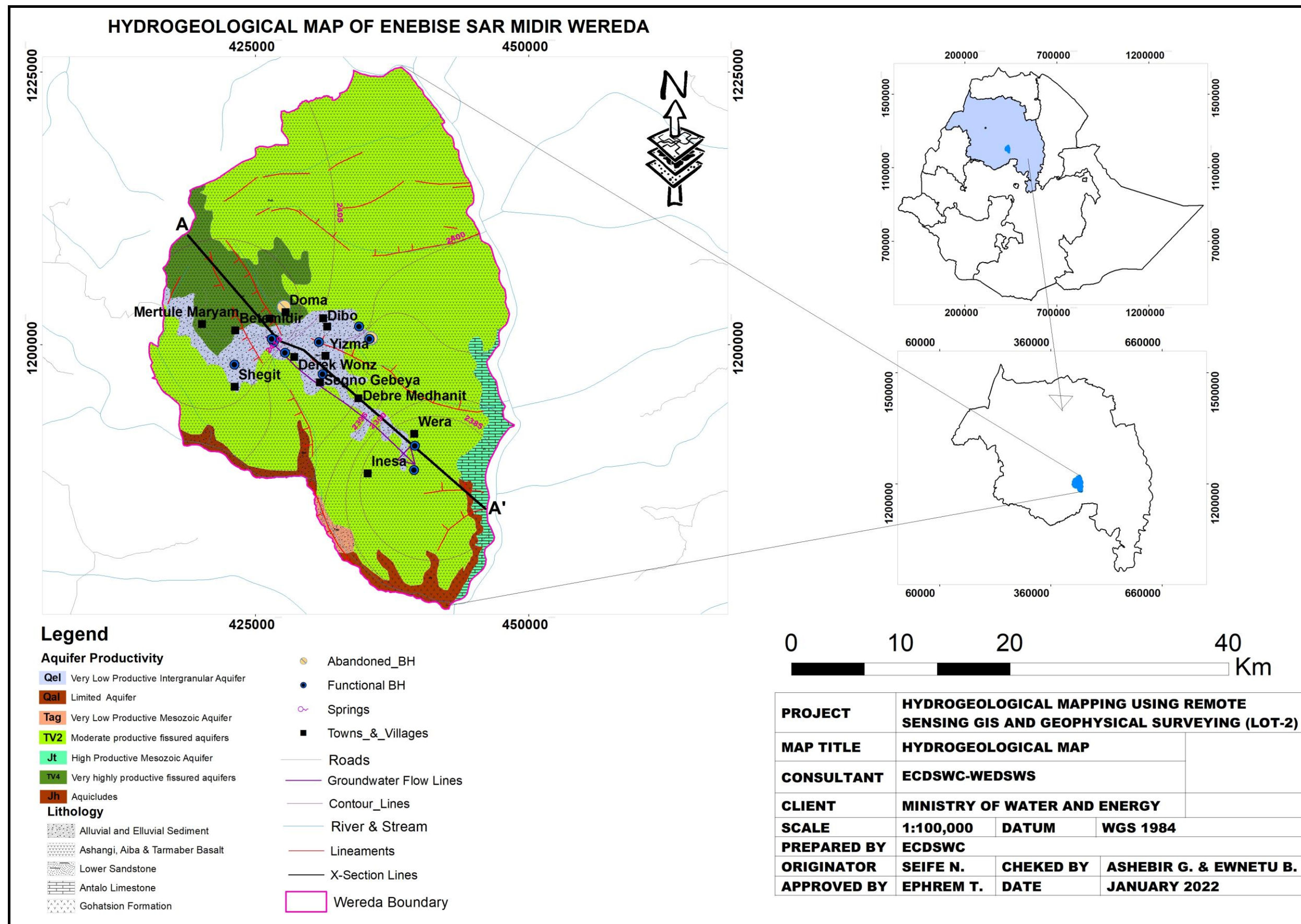


Figure 6: Hydrogeological map of Enebise Sar Midir Wereda

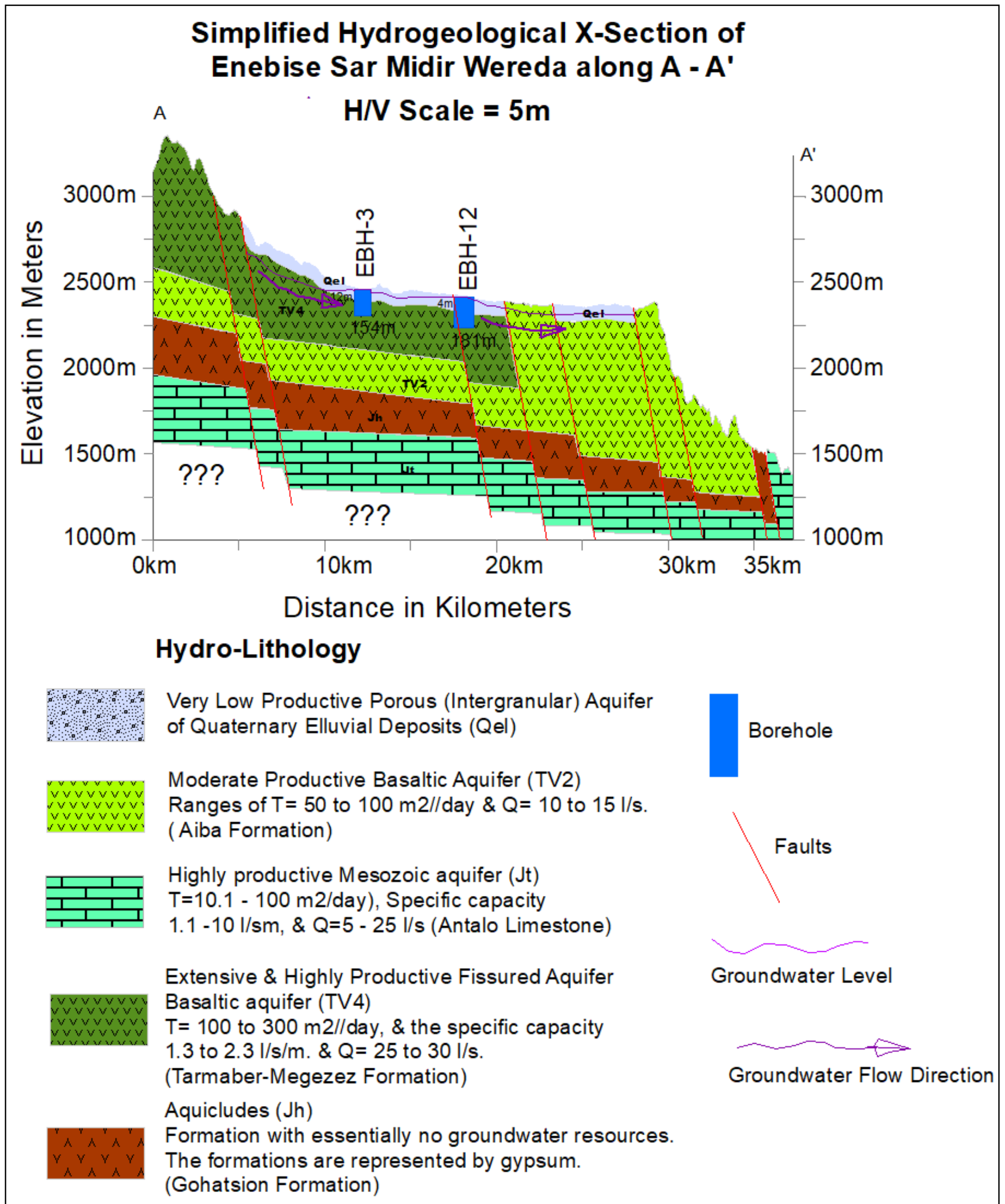


Figure 7: Hydrogeological section of Enebise Sar Midir wereda along A – A'

4. RESULT AND DISCUSSION

4.1 Multi-criteria decision analysis (MCDA) Weight assignment using AHP of Enebise Sar Midir 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 wereda separately.

The waiting criteria 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. The result is shown in the tables below. 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 (λ_{max}). 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

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

Table 7: 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 8: 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 9: 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 Thematic Layers

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 this wereda, the Hydrogeological units of this wereda is classified as very high, high, moderate, low, and very low potential. The reclassified hydrogeological units are presented in figure 8 below.

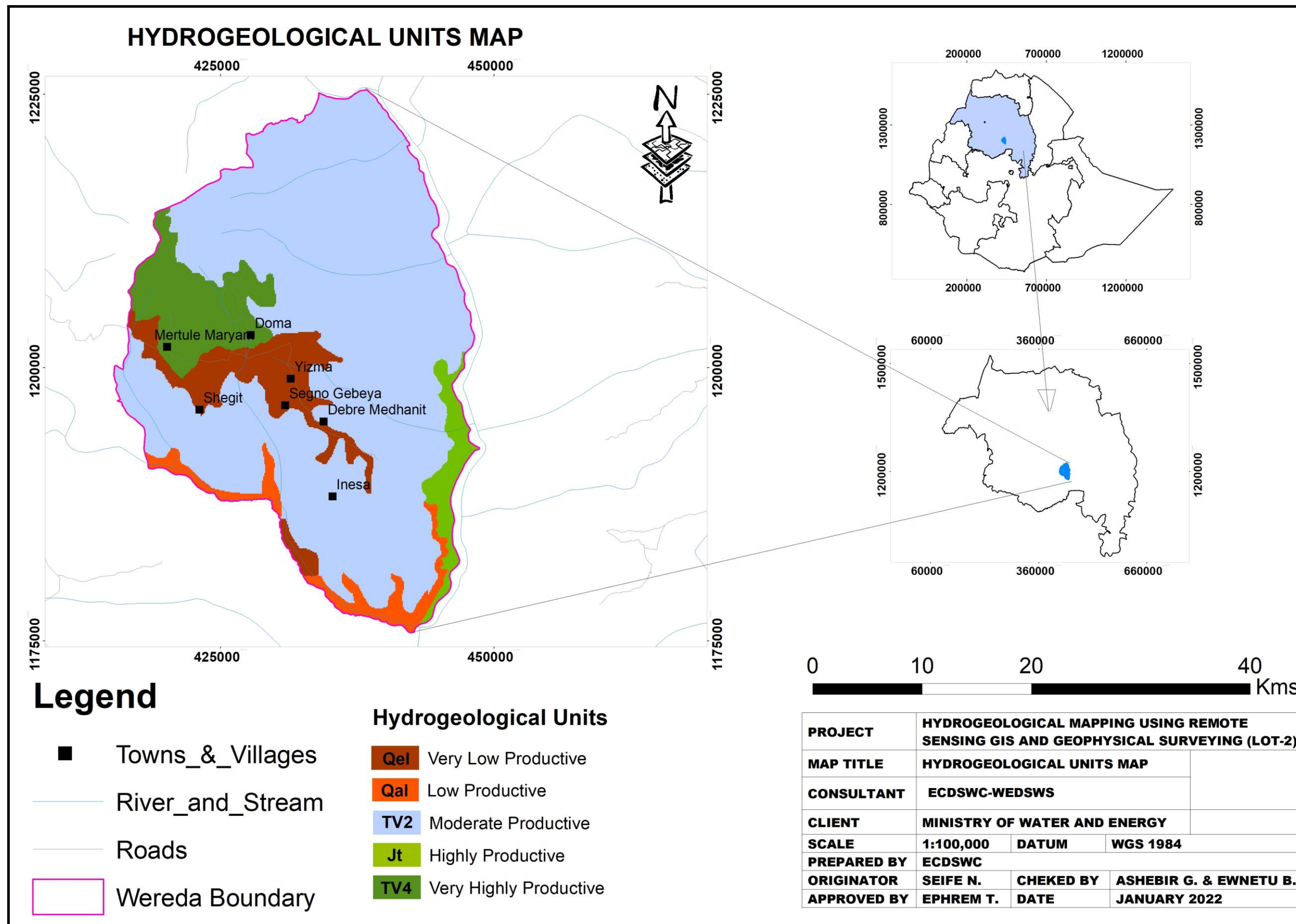


Figure 8: Hydro – Lithologic units of Enebise Sar Midir

4.2.2 Groundwater Recharge Thematic Layers

In this study, Groundwater recharge of Abay basin, (Enebise Sar Midir Wereda) was calculated by using the WetSpass model, and then groundwater recharge of the study areas had been 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.

Figure 9 show the annually 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.

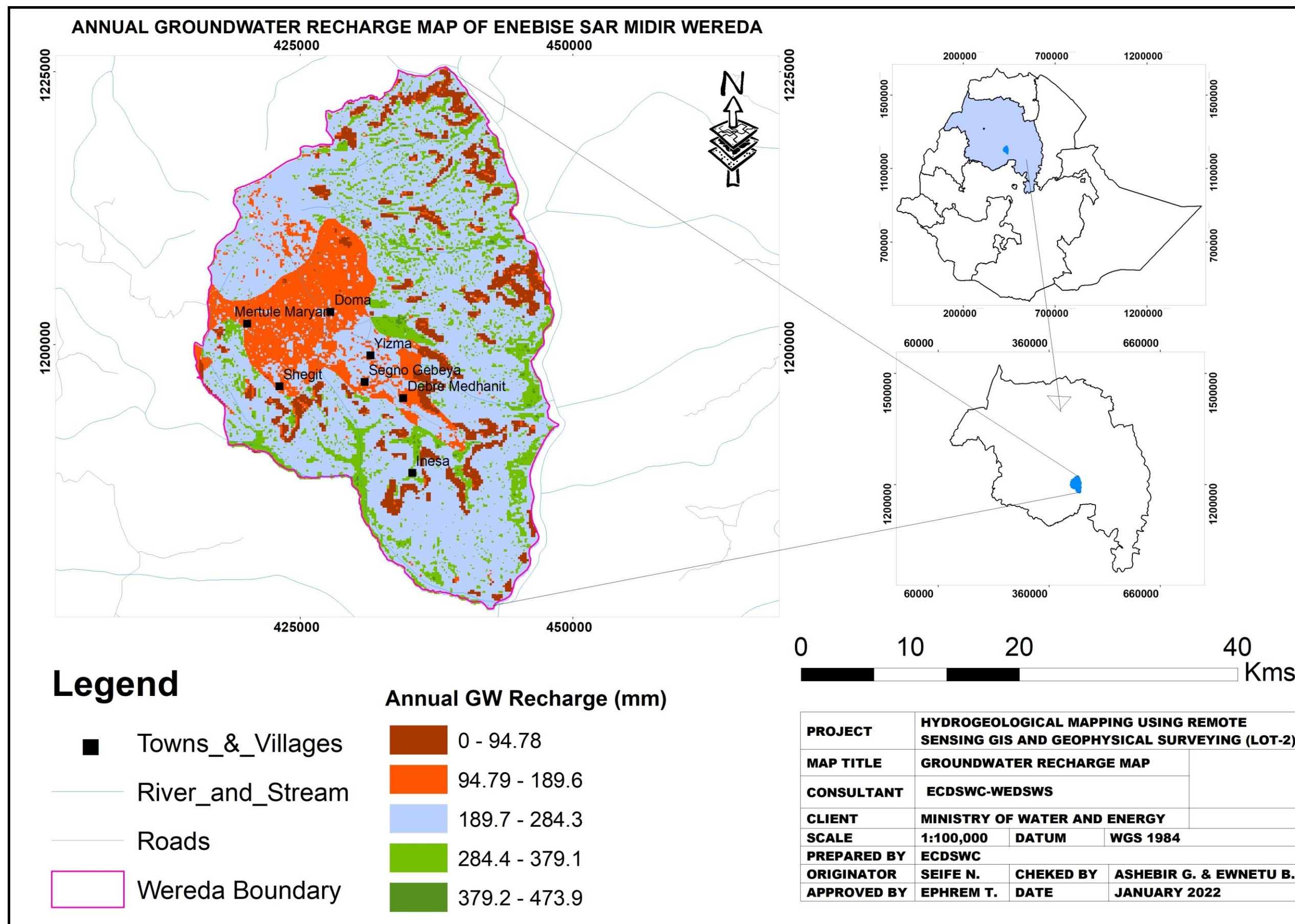


Figure 9: Groundwater recharge of Enebise Sar Midir

4.2.3 TWI Thematic layers

Topographic Wetness Index (TWI) is usually 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 10 shows the TWI maps of this wereda.

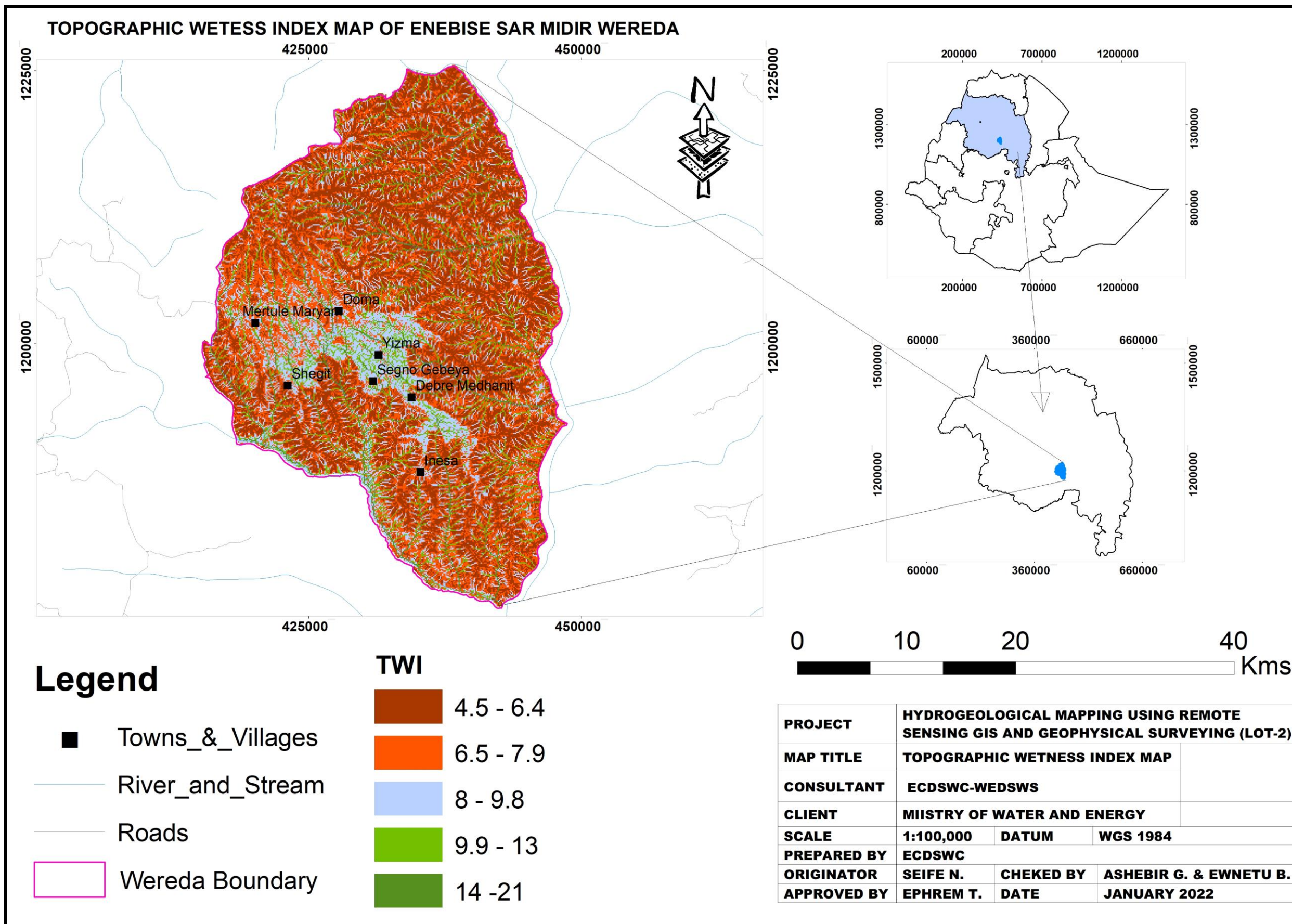


Figure 10: Topographic Wetness Index of Enebise Sar Midir

4.2.4 Lineament Density thematic layers

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 this wereda is 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 11).

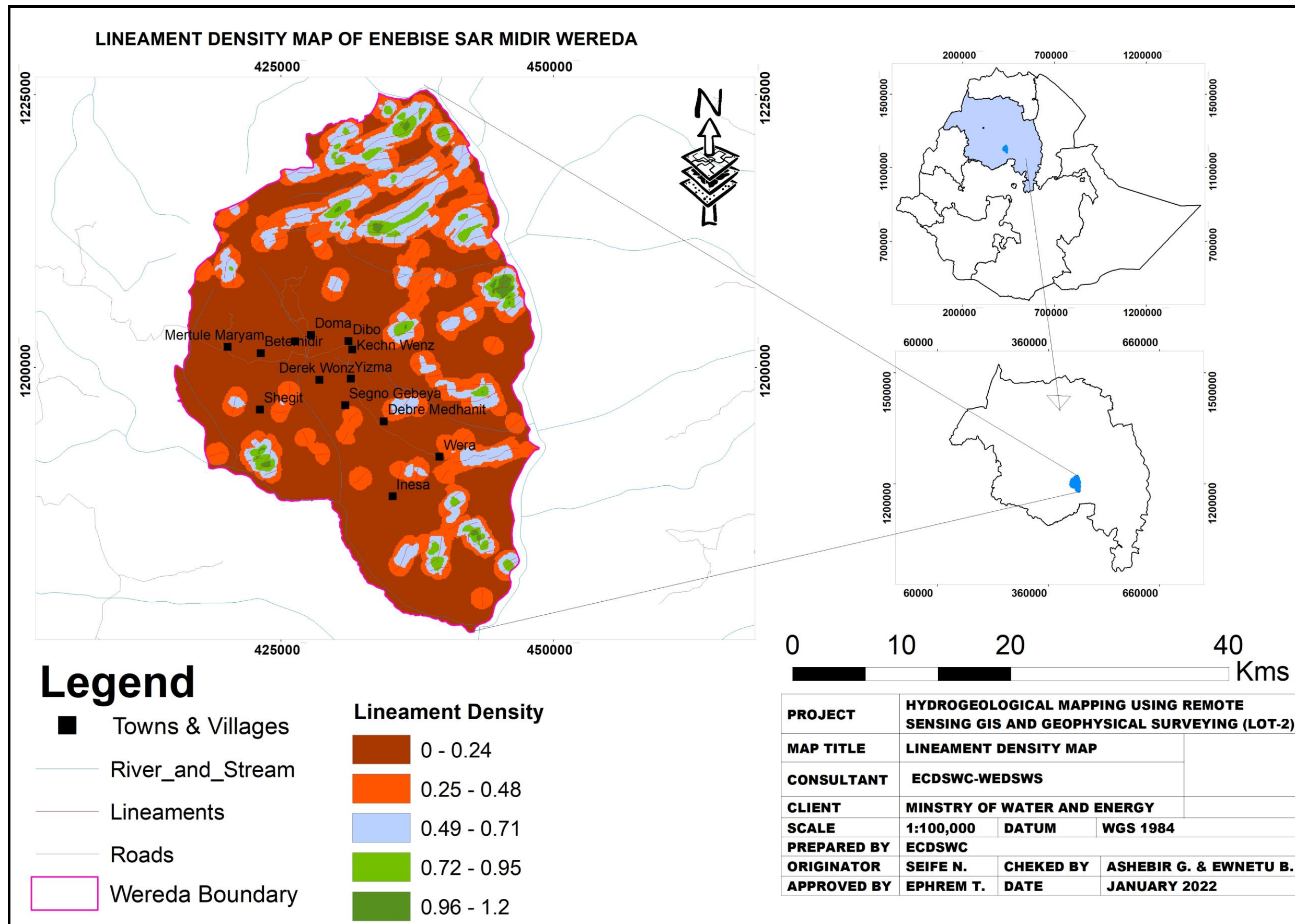


Figure 11: Lineament Density of Enebise Sar Midir

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 wereda. High weights are assigned to the areas nearby the lineament and low weights to distance locations. The proximity from lineament maps is shown in Figure 12.

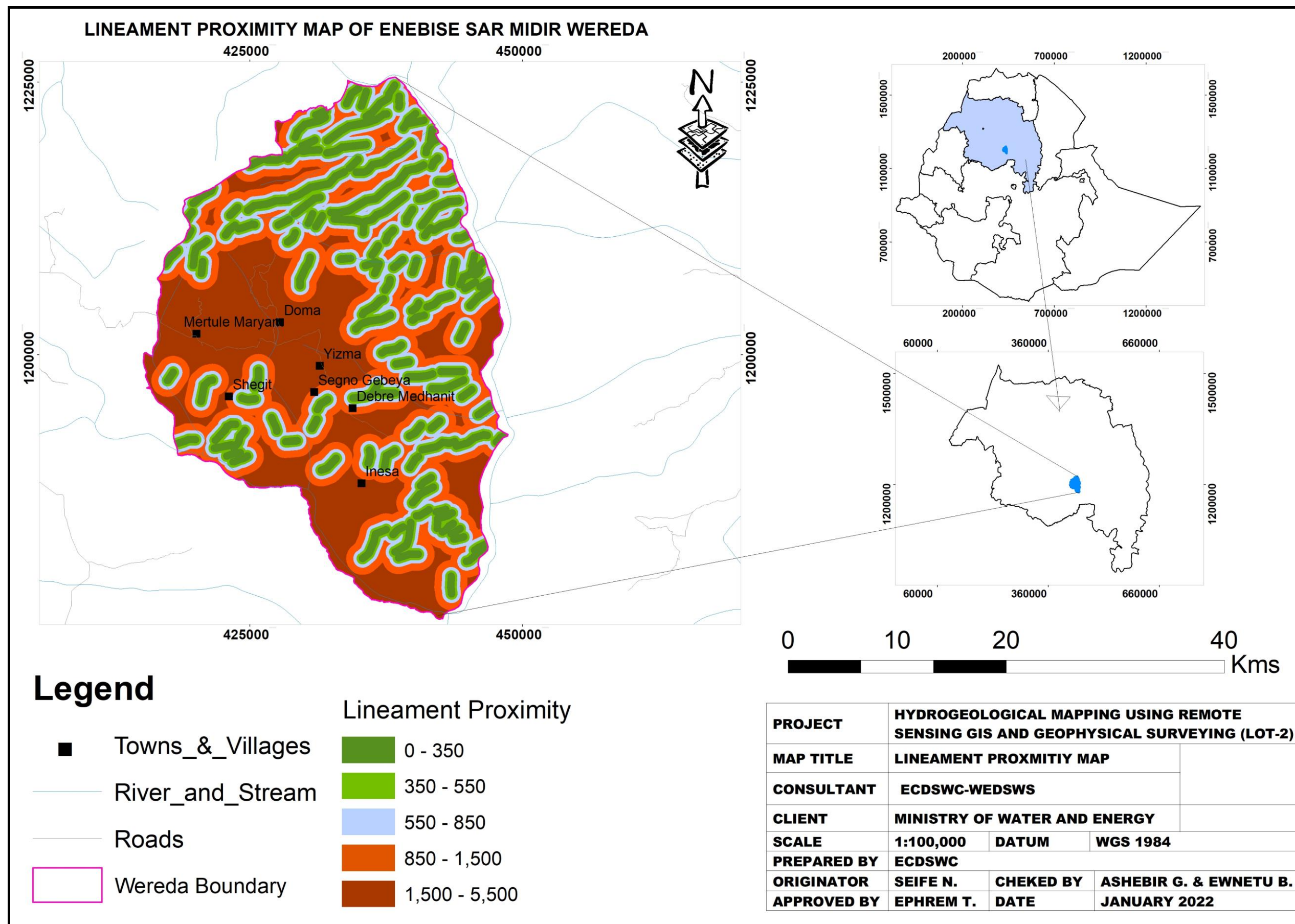


Figure 12: Lineament proximity of Enebise Sar Midir

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 wereda. The following formula was used to estimate the groundwater potential map of the wereda.

$$GWP = \sum_{i=1}^n w_i x_i \quad \text{-----Eq.7}$$

Where, GWP = groundwater potential, W_i = weight for each thematic layer, and X_i = 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 1996) 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):

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

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 Enebsie Sar Midir

The statistics of the single-parameter sensitivity analysis of Enebise Sar Midir Wereda are shown in Table 10. 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 10: 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

4.5 Validation using well data

Introduction

Overlay analysis techniques based on GIS methods have been applied to evaluate the groundwater potential of project Enebise Sar Midir wereda. 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 this wereda, and analysis of previously conducted works. The final output of the work is the production of a groundwater potential map for Enebise Sar Midir 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 for Enebise Sar Midir 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

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.

Ground Truthing of Enebise Sar Midir Wereda

In order to support the evaluation groundwater conditions of the wereda under investigation, overlay analysis techniques which is based on GIS methods has been applied during the present Phase II work of the project. The technique involves setting of overlay criteria for the five thematic layers applied to this study i.e., Lithology, Groundwater Recharge, TWI, Lineament Density and Lineament Proximity. Layer weights and class weights have been established by expertise of this project. The final output of the work is production of groundwater potential zone maps of this wereda classified as Very High, High, Moderate, Low and Very low to delineate target sites for further detailed hydrogeological and geophysical investigations during subsequent Phase III stage.

In this process, the output of the overlay analysis needs to be validated before application. As part of validation of the overlay analysis results (maps), ground-truthing work has been conducted over this wereda (Figures 13 -14).

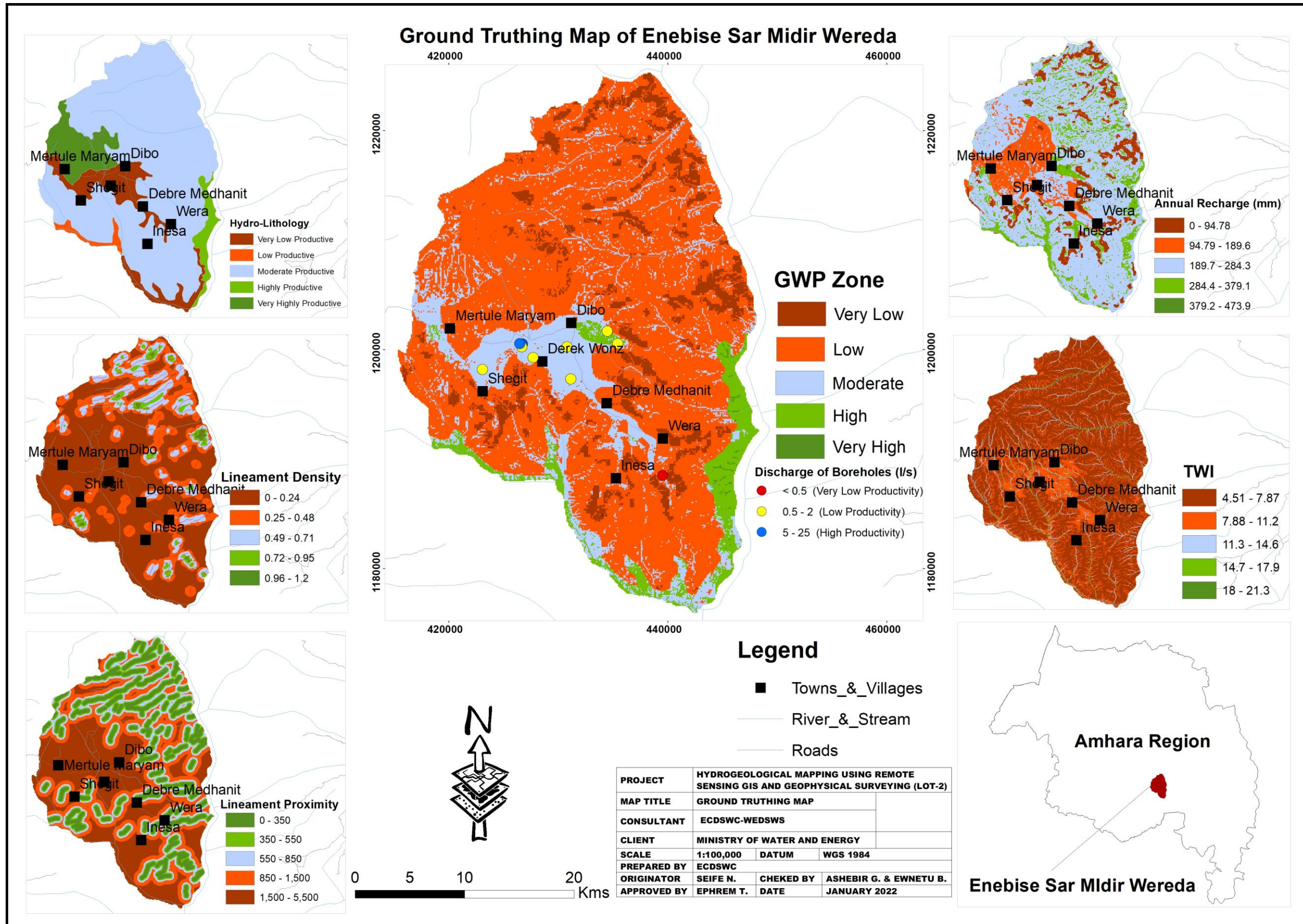


Figure 13: Ground truthing map Enebise Sar Midir Wereda with thematic layers

4. 6. Socio - Economy and water demand of Enebise Sar Midir wereda

To estimate the water demand of the Saint wereda 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 minimum 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 minimum 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 Enebise Sar Midir wereda for water supply of small-town, livestock & rural water supplies water demand are summarized in the table below.

4.6.1 Water demand of Enebise Sar Mldir wereda

year	Enebise Sar Midir Wereda	
	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

Kebele	Livestock Category											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

4.7. Groundwater Potential Zones and Selected Target Sites

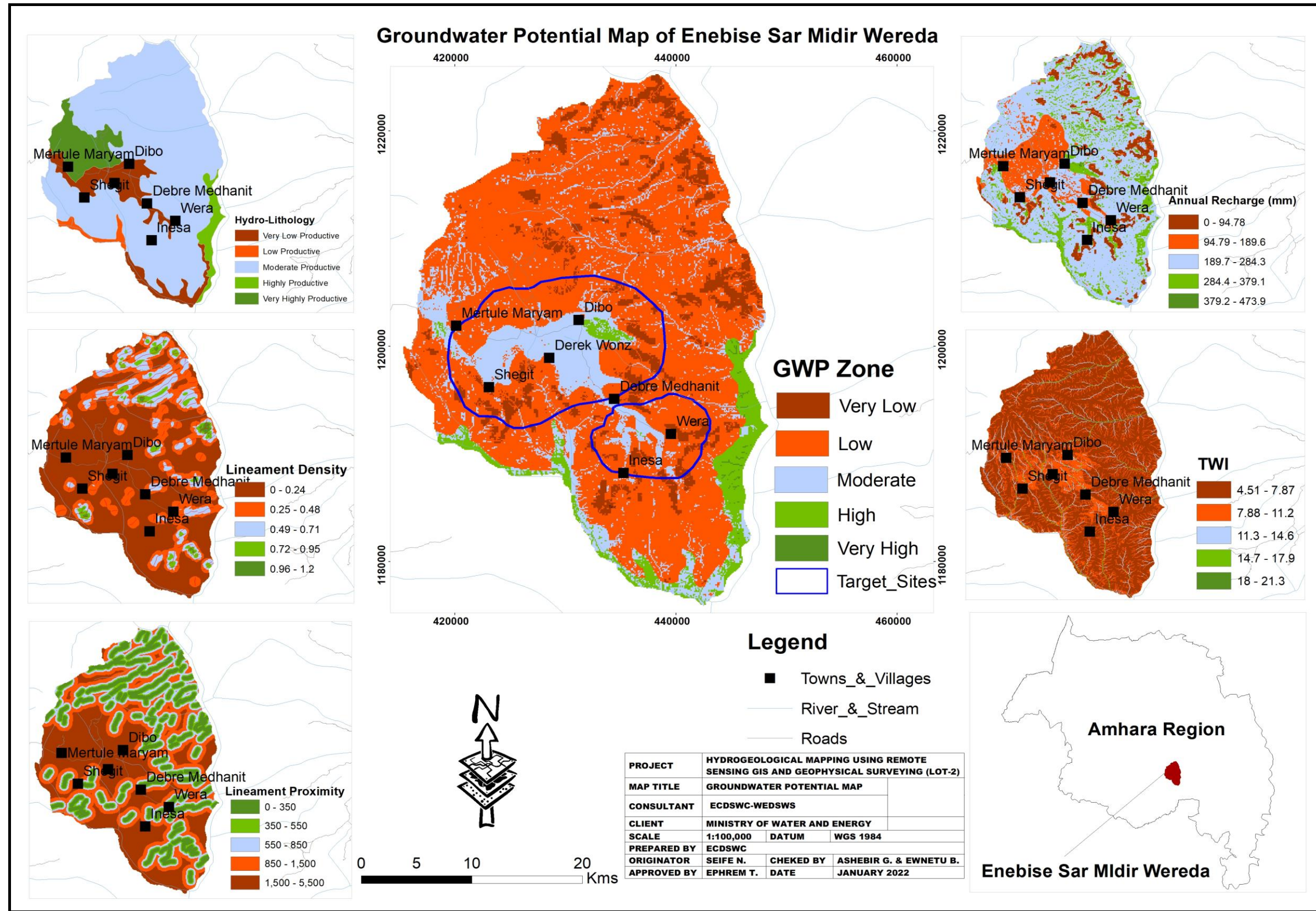


Figure 14. Target Sites of Enebise Sar Midir Wereda

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 17.

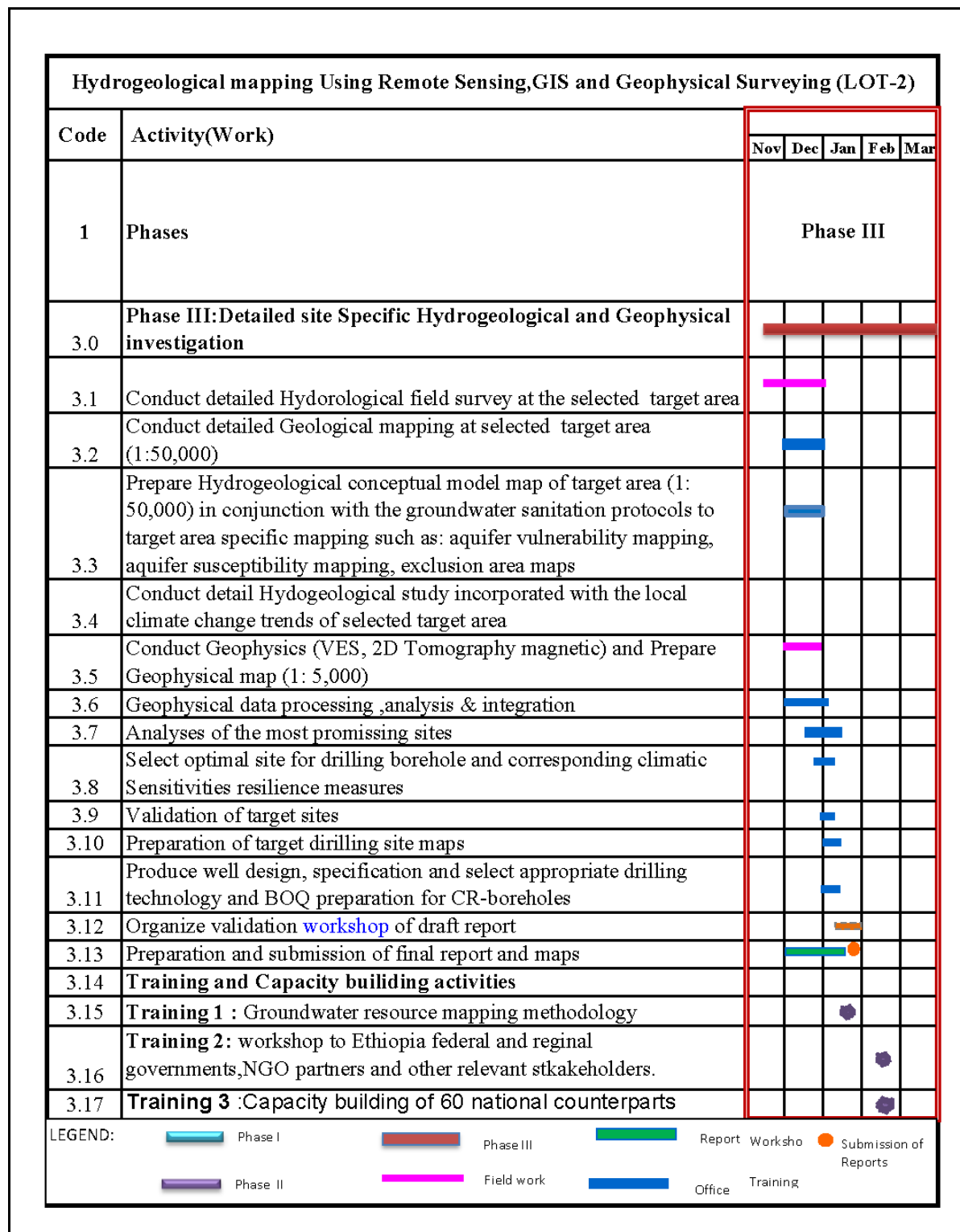


Figure 15: Revised Work Program for phase III work activities

6. Conclusion and Recommendation

The present study is an attempt to delineate the groundwater potential zones using RS, GIS, and MCDM techniques in Enebise Sar Midir wereda, which is located in Amhara 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 layers which indicate 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 match 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 layers 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 before being used by planners and decision-makers.

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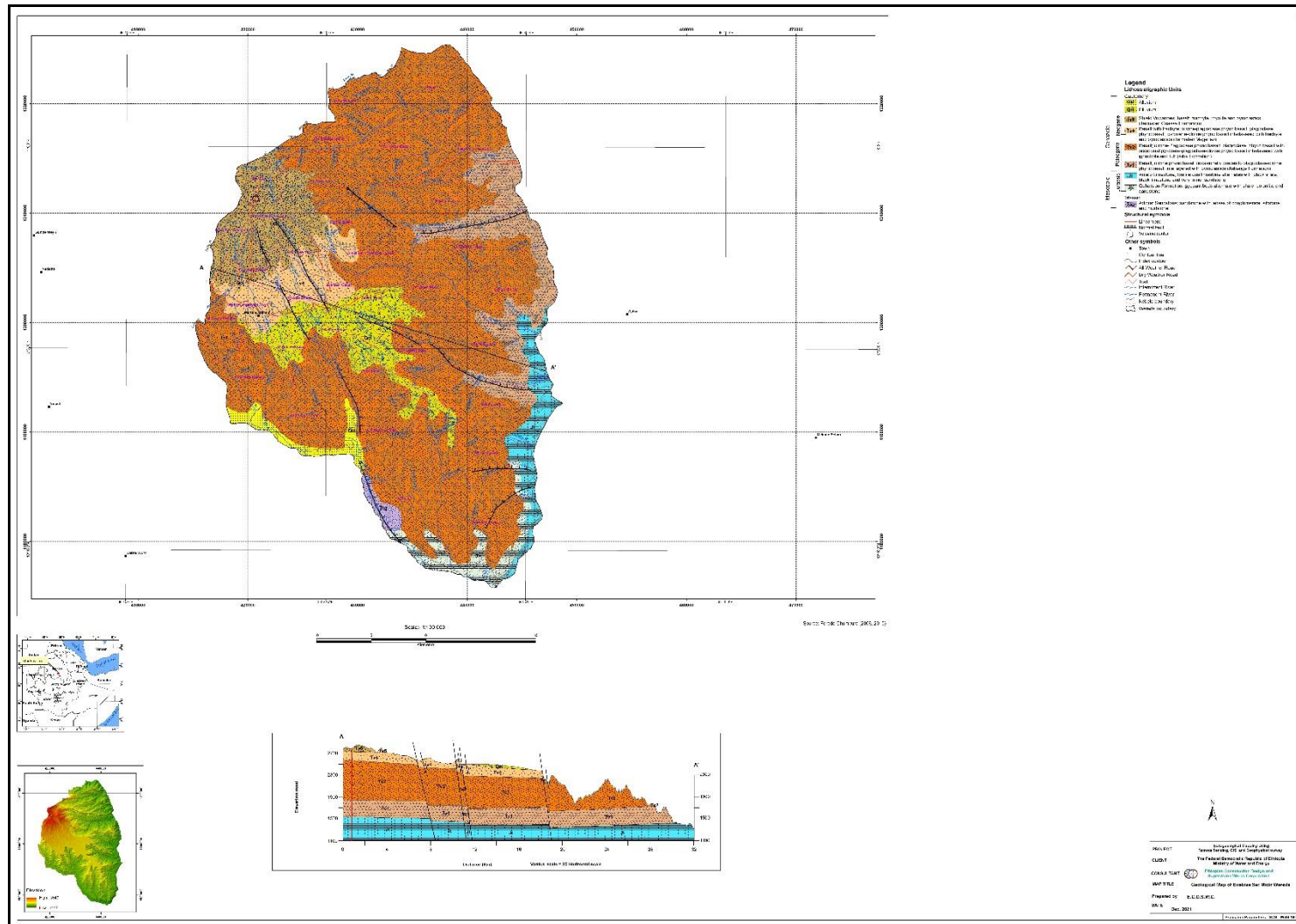
Annex 1: Observation during groundwater truthing and validation

No.	Wereda	Region	Locality	UTM E	UTM N	Elev.	Characteristic of validation point
1	Enebise Sar Midir	Amhara	Mertule maryam well#4	426727	1200526	2440	<ul style="list-style-type: none"> 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	

Annex 2: Field inventoried water points data

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

Annex 3: Geological Map of Enebise Sar Midir Wereda



Geological map and cross section of Enebise Sar Midir Wereda.