FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA
MINISTRY OF WATER & ENERGY

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

ANNEX XIII- DEVELOPING GROUNDWATER POTENTIAL MAP OF MISRAK BELESA WEREDA (FINAL)

January, 2022
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CONSULTANCY SERVICES FOR HYDROGEOLOGICAL MAPPING USING REMOTE SENSING, GIS, & GEOPHYSICAL SURVEYING

ANNEX XIII– DEVELOPING GROUNDWATER POTENTIAL MAP OF MISRAK BELESA WEREDA FINAL REPORT

	STRUCTURE OF THE REPORT
PHASE - I	INCEPTION REPORT
PHASE - II	DEVELOPING GROUNDWATER POTENTIAL MAP
Annex I	BURE MODAYITU WEREDA GROUNDWATER POTENTIAL MAP
Annex II	ARGOBALIYU 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 XIV	TSELEMET 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 Misrak Belesa 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 Misrak Belesa wereda for satisfying human needs.

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 the Saaty's Analytical Hierarchy Process (AHP). Based on the rank assigned by a conceptual understanding of the specific wereda 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 examine or to compute effective weights.

The spatial distribution of the Misrak Belesa GWP zones generally match with the conceptual understanding of the Misrak Belesa 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, one most appropriate and one optional sites will be selected for drilling.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ANNEXES

ABREVIATIONS ANDACRONYMS

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 MoWE	-	Millimeter Ministry of Water and Energy
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
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
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 Basins Development Authority (Client) and Water &Energy Design and Supervision Works Sector In association with AFX OASIS Water Resources & Hydropower Engineering Construction P.L.C(Consultant) on May14, 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 the Misrak Belesa.

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 Misrak Belesa.

The Project area cover water-scarce 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 Misrak Belesa 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.

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 the Saaty's Analytical Hierarchy Process (AHP). Based on the rank assigned by a conceptual understanding of the specific wereda 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 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

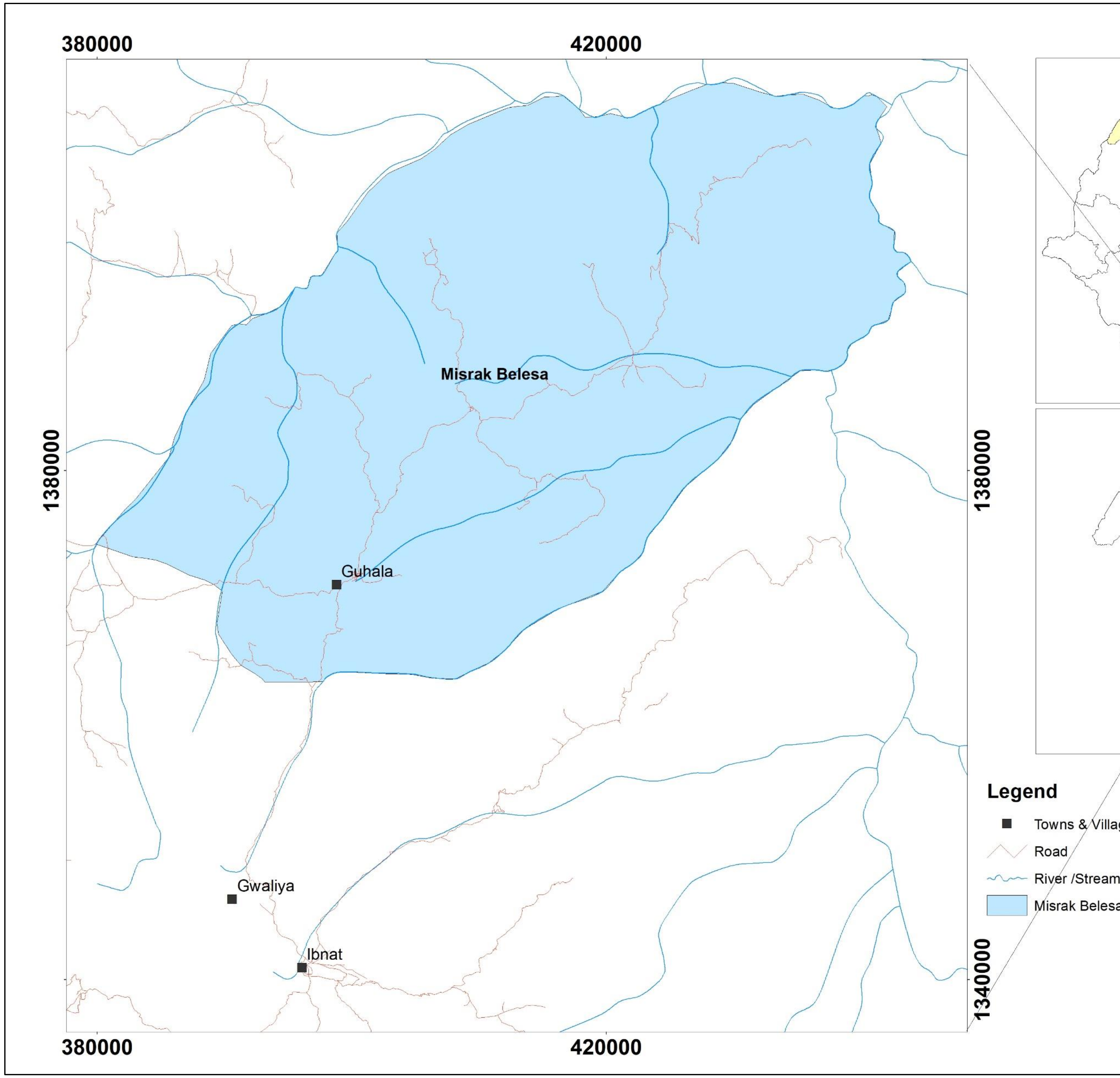
Chapter-6: Conclusion and Recommendation,

Chapter-7: References

In this report, Misrak Belesa wereda of Amhara regional state groundwater potential map is presented.

1.2 Location of Misrak Belesa

Misrak Belesa wereda is located in Amhara Regional state, the study area is accessible by a network of dry weather roads and the asphalt road that runs from Addis Ababa –Bahir Dar-Addis Zemen major asphalt roads.The weather roads from Addis Zemen, Ebenat to Guhala town and from Gondar to Guhala town. In general, Misrak Belesa wereda is easily accessible from all directions by asphalt and all-weather roads, dry season roads and foot paths.The whole of the project area is confined between the geographic coordinates of UTME 378000-443656 and UTMN 1359765-1412134 (Figure 1).



Project	Hydrogeological mapping Using Remote Sensing, GIS & Geophysical Surveying (LOT-2)		
Client	Ministry of Water And Energy		
Consultant	ECDSWC-WEDSES		
Map Title	Location Map of East Belesa		
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 1: Location of the project area (Misrak Belesa wereda)

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 extra geophysical field surveys, the project team will propose 1 most promising drilling sites for groundwater abstraction and 1 alternatives (optional) drilling sites for wereda in (IOT-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.
- Create 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.

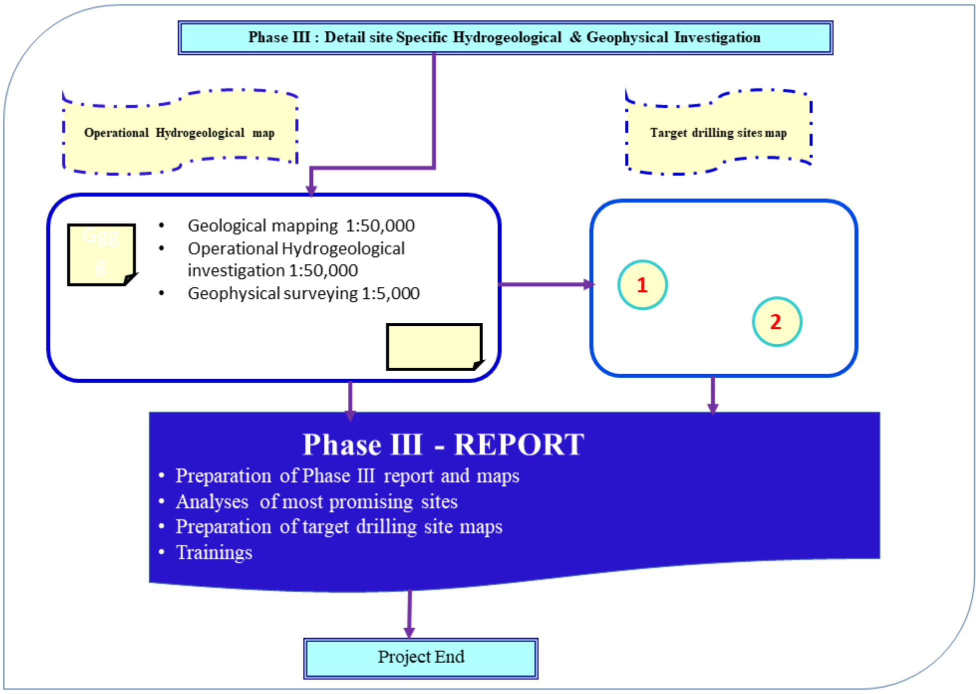
1.4 Scope of Works

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 will be focused on the preparation of Operational hydrogeological maps of the Misrak Belesa of LOT-2 and identification of target sites for borehole drilling with enhanced drilling success rates and optional drilling sites for the Misrak Belesa.

1.5General 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 routs is depicted in figure 2 below:



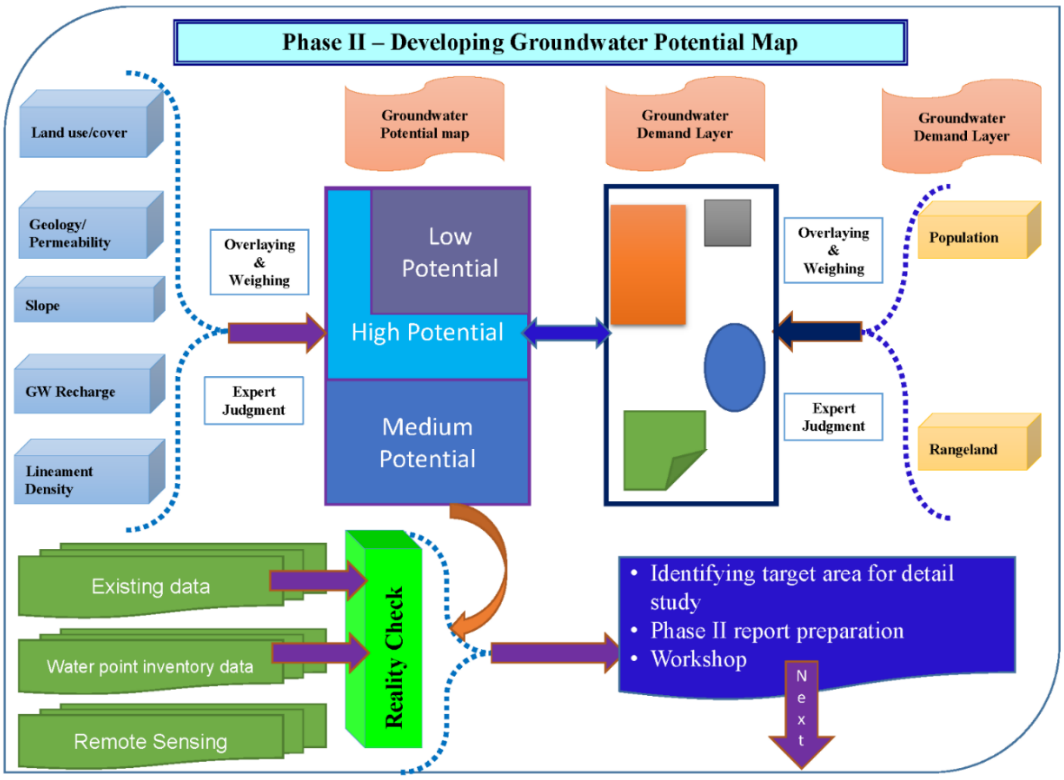


Figure 2: The project phases and the main deliverables

Phase II activities and deliverables

The 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 wascarried out.
- Hydrological data was collected from MoWE and detailed analysis wascarried 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 Misrak Belesa.
- 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 wasprepared for input for Groundwater recharge estimation.
- Groundwater recharge was estimated by using the WetSpass model for Tekeze basin, and then the Groundwater recharge map wasextracted by the respective boundary of the Misrak Belesa.
- Geological Map 1:100,000 wasprepared for each wereda from existing 1:50,000 scale base maps and Satellite images.
- Lineament was extracted from Aster 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 Misrak Belesa.
- Lineament density map and Lineament proximity map wasprepared from lineament map.
- Topographic Wetness index was generated for the Misrak Belesa
- Hydrogeological Sections wasprepared for the Misrak Belesa
- Overlay Analysis has been carried out for the Misrak Belesa
- Sensitivity analysis was carried out for the Misrak Belesa
- Validation of groundwater potential for the Misrak Belesas tested by using observed data collected during the groundwater inventory program on progress.
- The groundwater demand layer wasprepared based on projected project CSA data
- Groundwater potential maps wasprepared for Misrak Belesa
- 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 Misrak Belesa was 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 wereda 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 for groundwater potential maps.
- The data scarcity wasfilled 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.Version15.09.2018),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) 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 wereda 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.

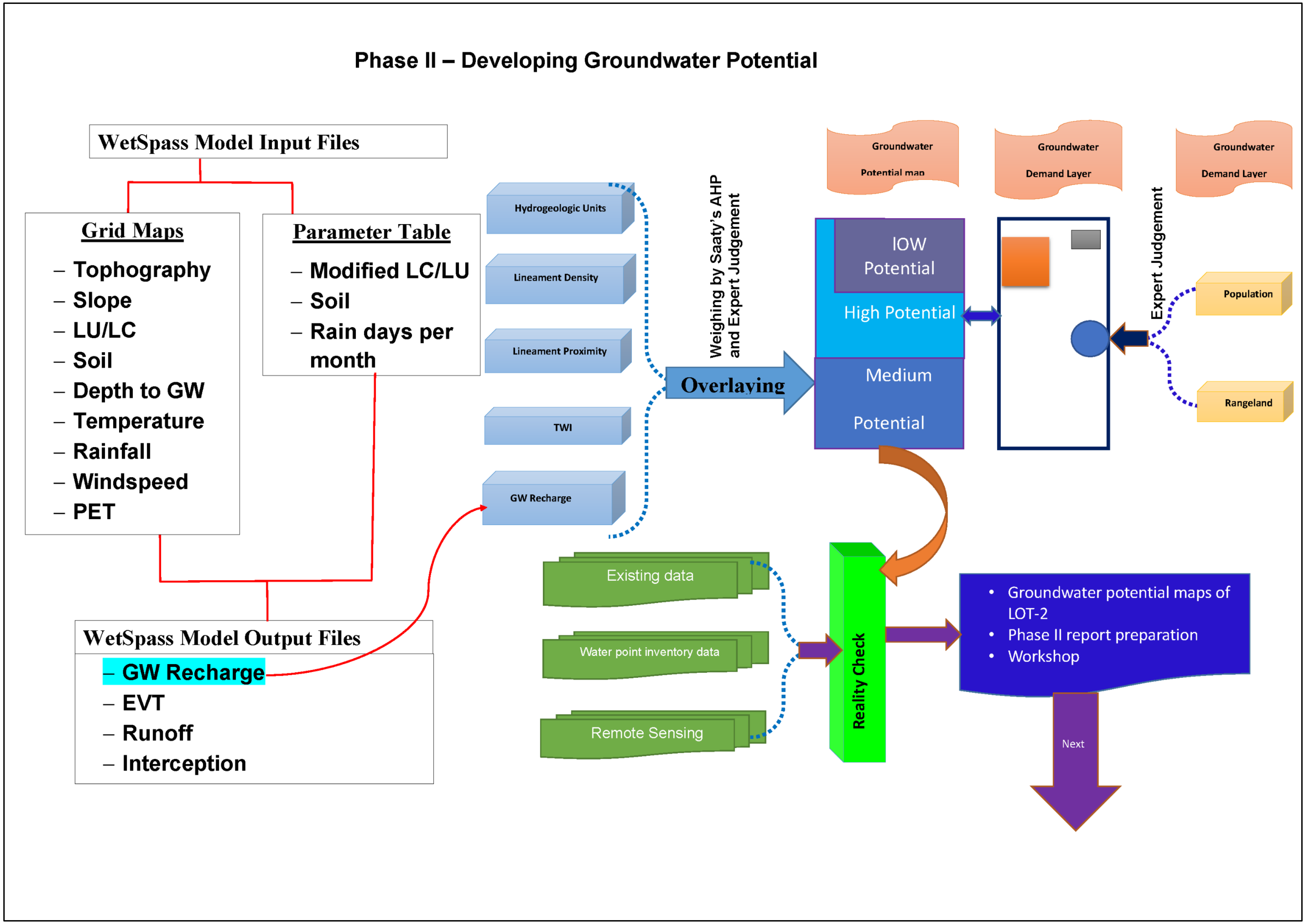


Figure 3: Phase II methods and deliverables

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 Advanced Space-borne Thermal Emission and Reflection Radiometer Digital Elevation Model (ASTERDEM) 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, ASTER DEM 30m resolution and Sentinel 1 imager using the interferometry approach and ESA-SNAP environment is used to extract lineament for the Misrak Belesa, SRTM DEM 30m resolution, ASTER 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 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 wasused for validation of Groundwater potential maps of the Misrak Belesa. The summarized inventory and existing data are presented in table1and 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
Misrak Belesa	3	68		1	2	35		

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 Misrak Belesa, 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 Misrak Belesa, 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 Misrak Belesa 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 Misrak Belesas at a scale of 1:100.000. The Geology map of the Misrak Belesa 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.glcf.umd.edu:8080/esdi
5	ASTR 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.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 DEM sources were used to generate lineaments of the study area. The first one is Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) 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 Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER). The study area covers 12 DEM Tiles in total and all the tiles were mosaic in the ArcGIS software environment.

Lineament extraction process from ASTER 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 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 Misrak Belesa.

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 Misrak Belesa. Generally, the lineament extracted by using SRTMDEM 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 Misrak Belesa.

2.2.3 Groundwater recharge estimation methods

In this study, the Hydrological study wasconducted by considering the overall hydrological connectivity of the basin; hence it was important to consider the Misrak Belesa upstream hydrological characteristics, particularly for the Misrak Belesa 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 Tekeze River Basins (Ampeet.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 map, and modified land use, soil, and rain days per month's 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	0.25^0x 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 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 wereda.

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: -

$E_{raster} = a_v ET_v + a_s E_s + a_o E_o + a_i E_i$ --Eq.1

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

$R_{raster} = a_v R_v + a_s R_s + a_o R_o + a_i R_i$ --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, baresoil, 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:

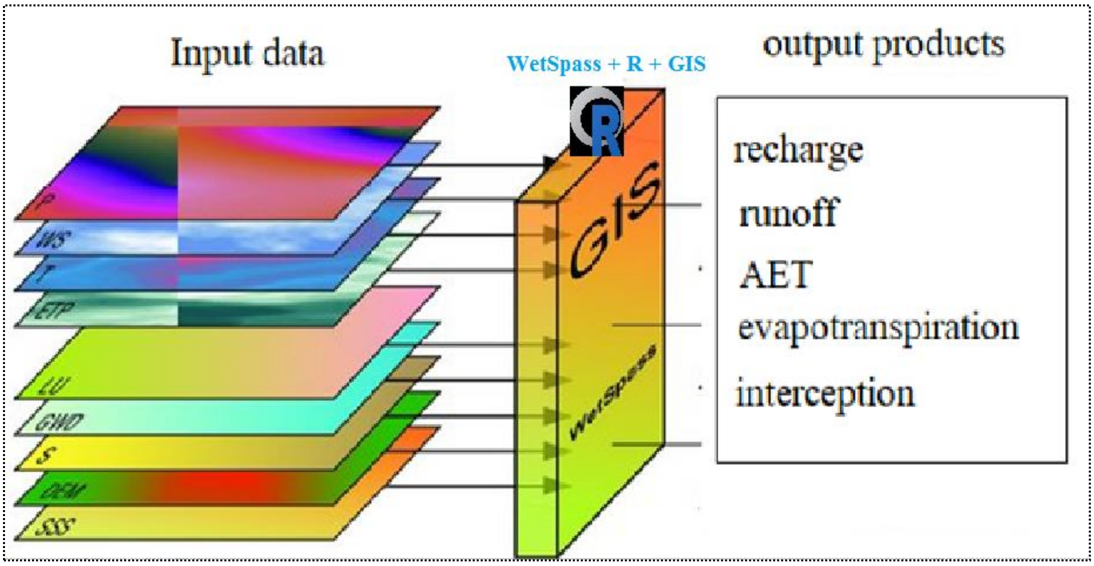


Figure 4: Schematic representation of model used for the study

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 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 (Table4). 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 Misrak Belesa.

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 Misrak Belesa 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

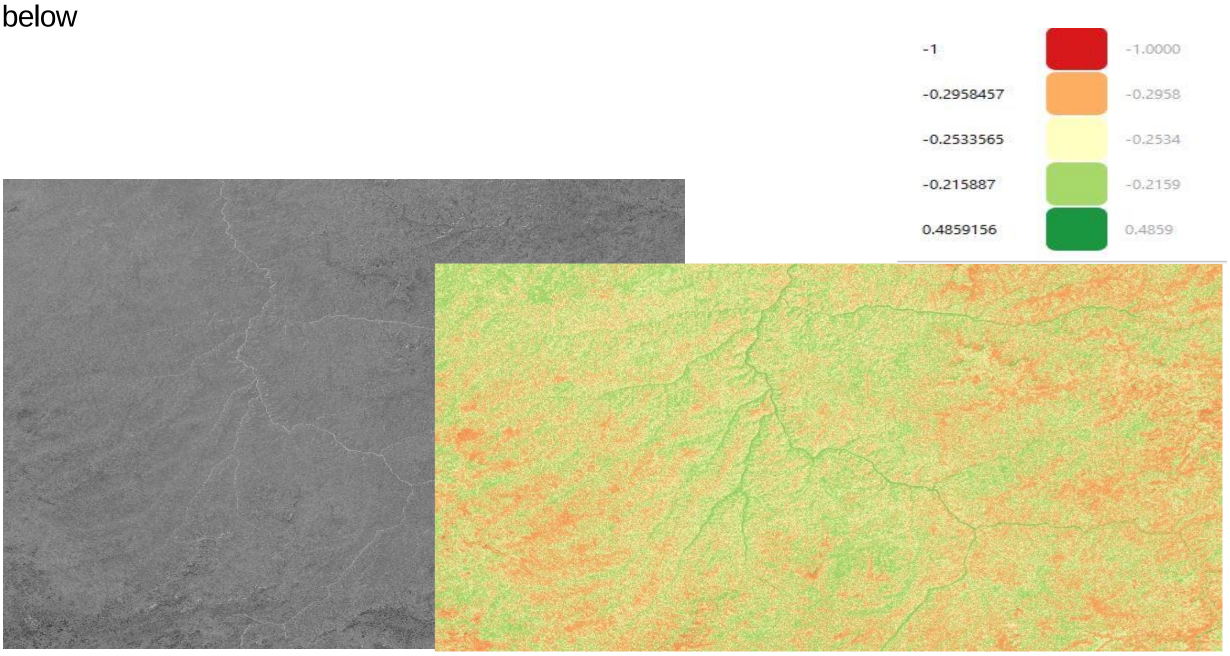


Figure 5: calculated NDVI using QGIS

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.

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

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 Misrak Belesa 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,

$Pt=Poer\Delta t$

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 Misrak Belesa wereda is projected for the planning period 2035 and the summarized population size is presented in the following tables.

Table 5: Population size of Misrak Belesa wereda July 2021 to 2035

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

Table 6: Number of livestock and Livestock and poultry (for private holdings), July 2021

Woreda	Cattle	Goats	Sheep	Horses	Mules	Donkey	Poultry
Misark Belesa	172470	98476	76463	5	2329	29613	122748

3. Conceptual Hydrogeological model of the study area

3.1 Hydrogeological condition of Misrak Belesa

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. The hydrogeological setup of the area is discussed preliminary as follows:

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.

The boreholes are shallow. Generally, groundwater flow in the area can be indicated from the southern highlands to the central Tekeze gorge.

Most of the rivers are also 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.

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.

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 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 this wereda exposures are favorable for groundwater recharge, storage, and movement due to the existence of primary and secondary porosities. However, groundwater recharged in the area flows toward the lowland/rift floor through main fractures due to high head differences.

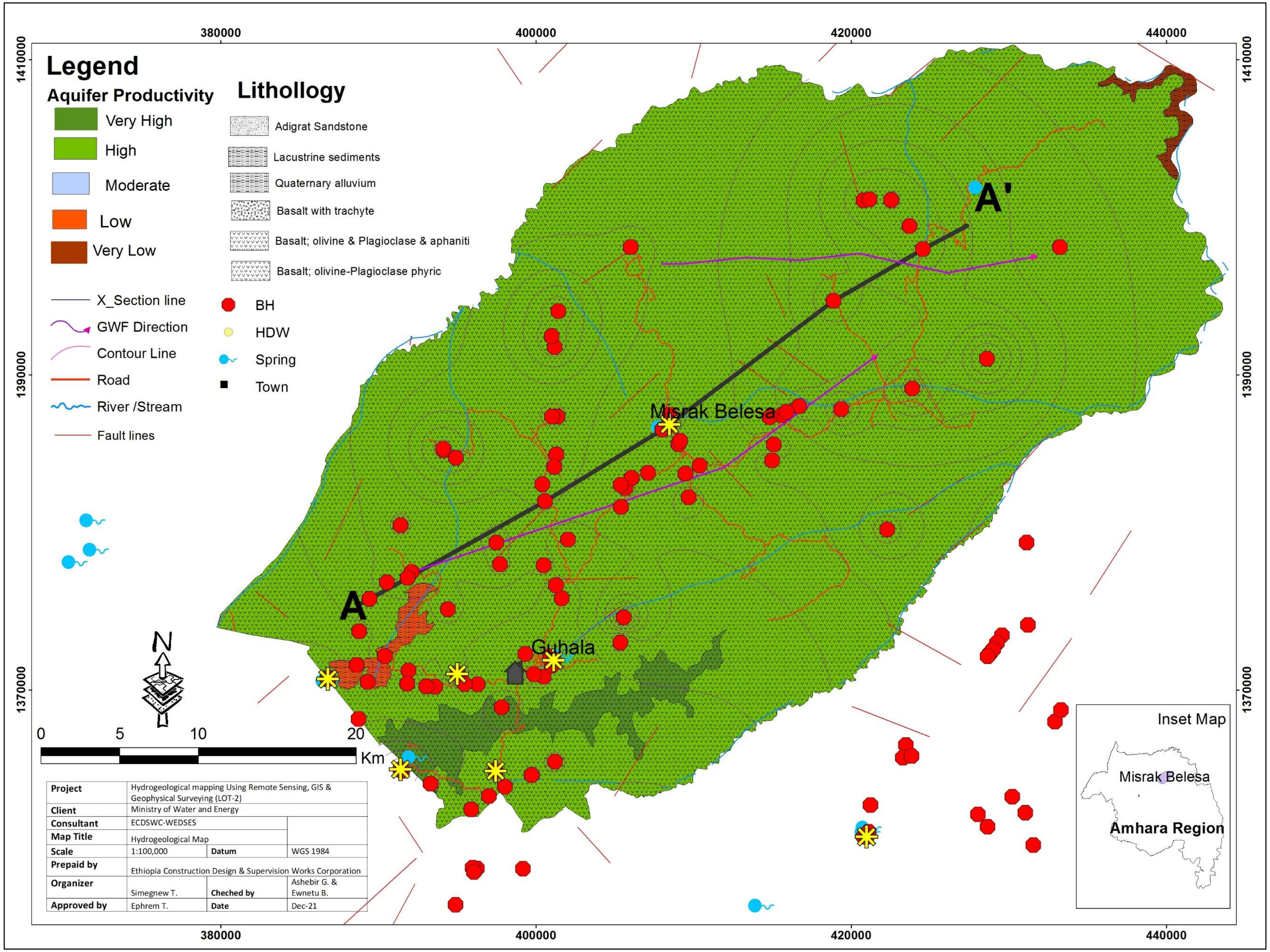


Figure 6: Hydrogeological map of Misrak Belesa

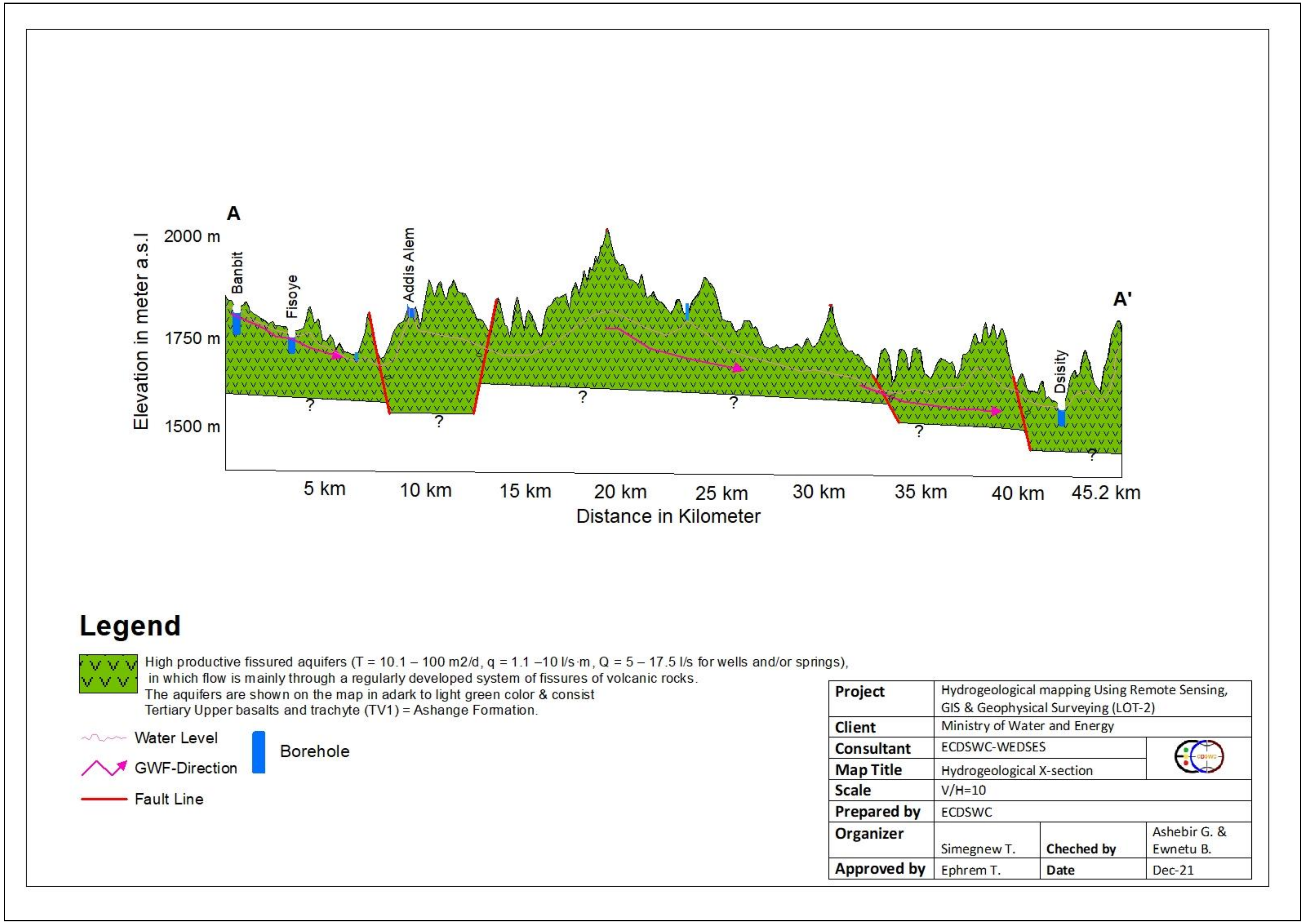


Figure 7: Hydrogeological Section Misrak Belesa wereda

4. RESULT AND DISCUSSION

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

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

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 the Misrak Belesa. 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 (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.

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

Consistency Ratio = Consistency Index /Random Index

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

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 Misrak Belesa

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 9: Pair-wise Comparison Matrix by using AHP for Misrak Belesa

Factors	Weight	Class	Groundwater Storage potential	Assigned Rank
Lithology	41.3	Basalt, olivine plagioclase, phyric	Very high productive	5
		Basalt, olivine plagioclase, aphi	High productive	4
		Basalt with trachyte	Moderate	3
		Quaternary Alluvium	low Productive	2
		Adigrat Sandstone	Very low Productive	1
Recharge	21.5	303 - 456	Very high	5
		222 – 303	High	4
		164 - 222	Medium	3

		122 - 164	low	2
		0 - 122	Very Low	1
Lineament Density	21.5	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 – 0.3	Very Low	1
Lineament Proximity	11.2	0 - 250	Very high	5
		250 -750	High	4
		750 - 1250	Medium	3
		1250 - 2000	low	2
		>2000	Very Low	1
TWI	4.4	14 - 22	Very high	5
		10 - 14	High	4
		8.0 - 10	Medium	3
		6.6 – 8.0	low	2
		4.6 – 6.6	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 wereda consist of alluvial sediments, Aiba basalt, Tarmaber-Guassa basalt, Ignimbrite, Adigrat sandstone. 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 Misrak Belesa, the Hydrogeological units of the Misrak Belesa was classified as very high, high, moderate, low, and very low potential. The reclassified hydrogeological units are presented in Figures 8.

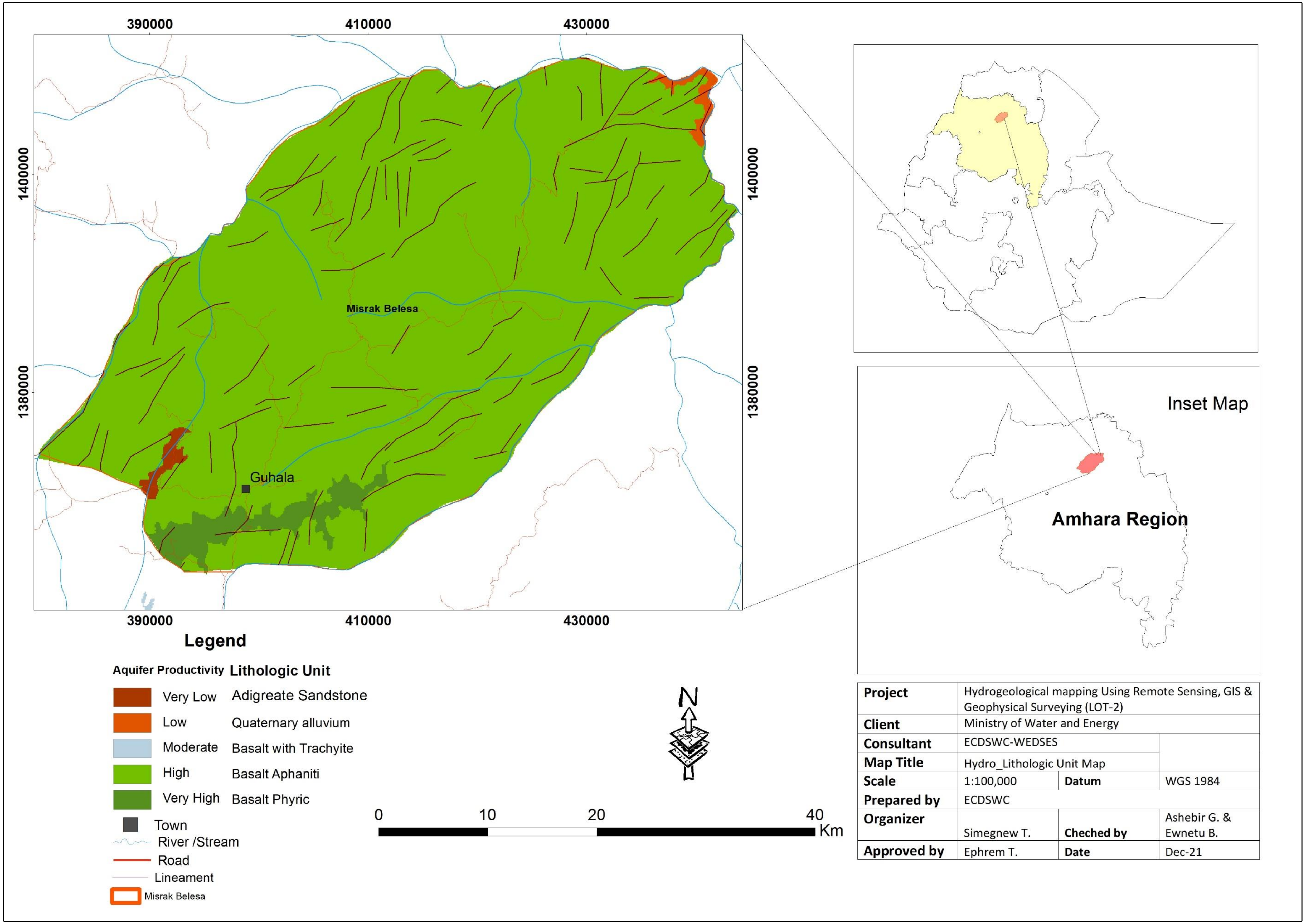


Figure 8: Hydro-lithologic units of Misrak Belesa wereda

4.2.2 Groundwater Recharge

In this study, Groundwater recharge of Tekeze basin was calculated by using the WetSpass model, and then groundwater recharge of the study areas wasextracted by respective wereda 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 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 9 show the yearly groundwater recharge estimated with the WetSpass model of each Misrak Belesa. The recharge estimated was used as one thematic layer for groundwater potential mapping of the Misrak Belesa. 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.

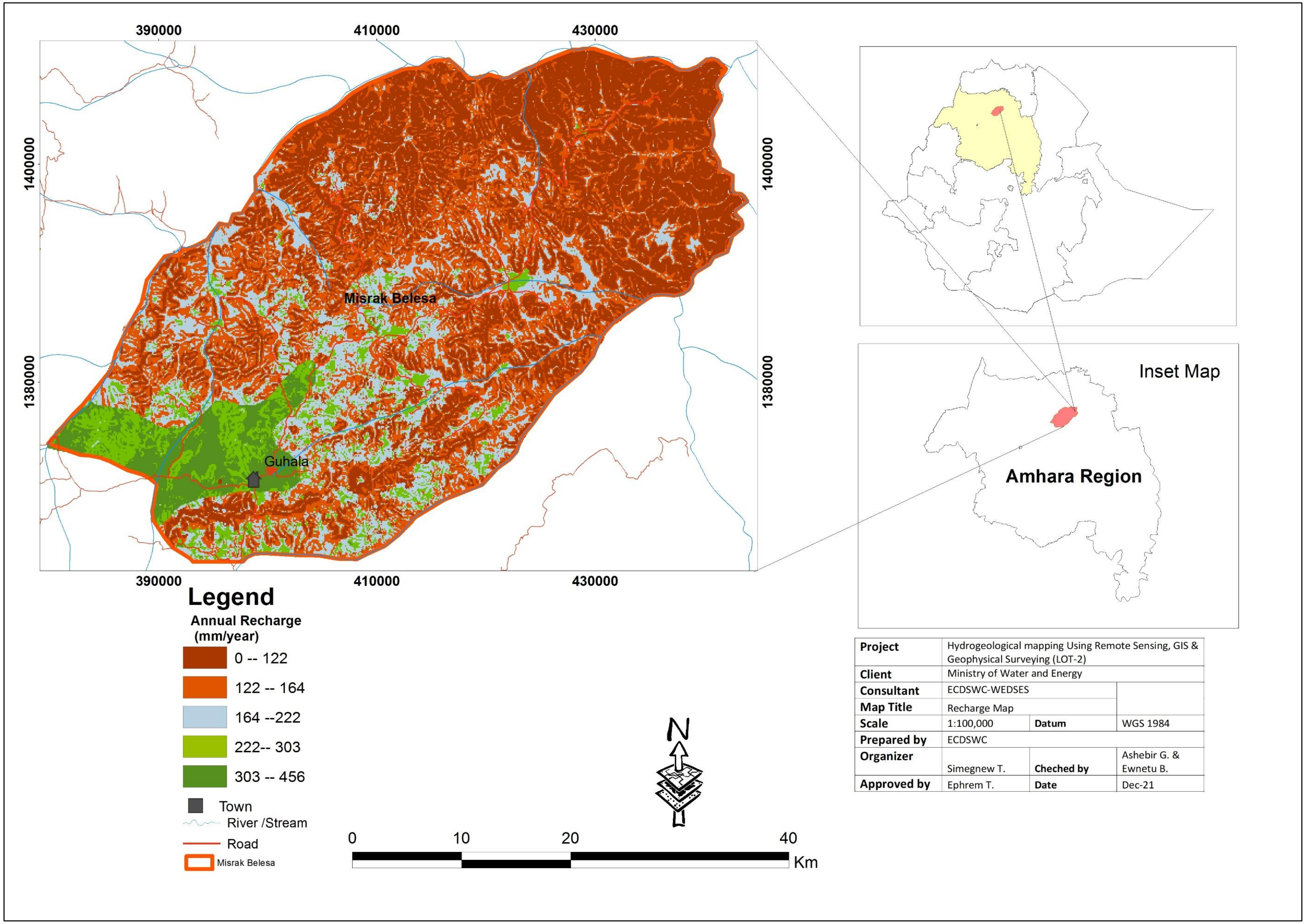


Figure 9: Groundwater recharge map of Misrak Belesa wereda

4.2.3 TWI

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.Figure10 shows the TWI map of the Misrak Belesa.

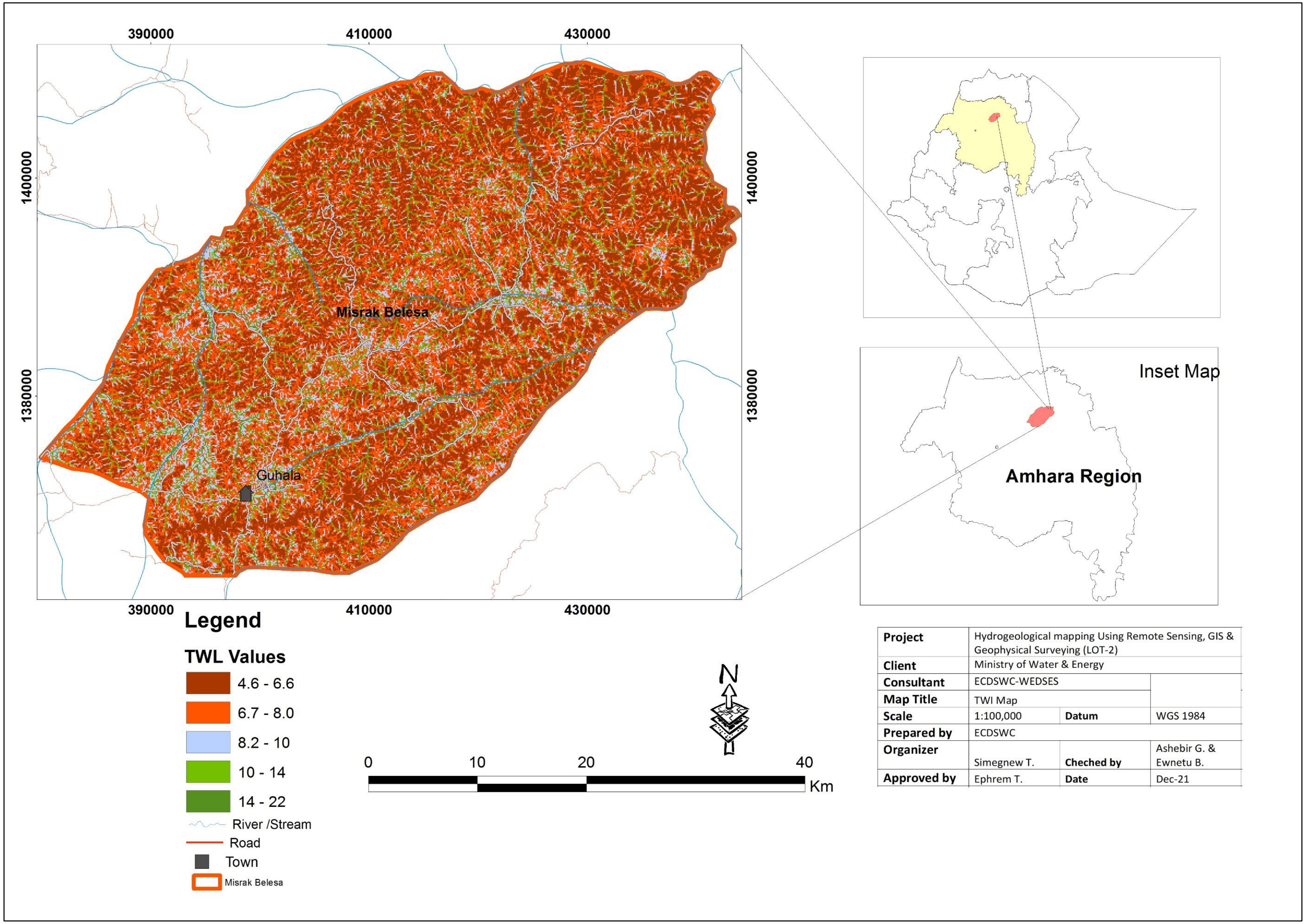


Figure 10: TWI Map of Misrak Belesa wereda

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 Misrak Belesa 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 11)

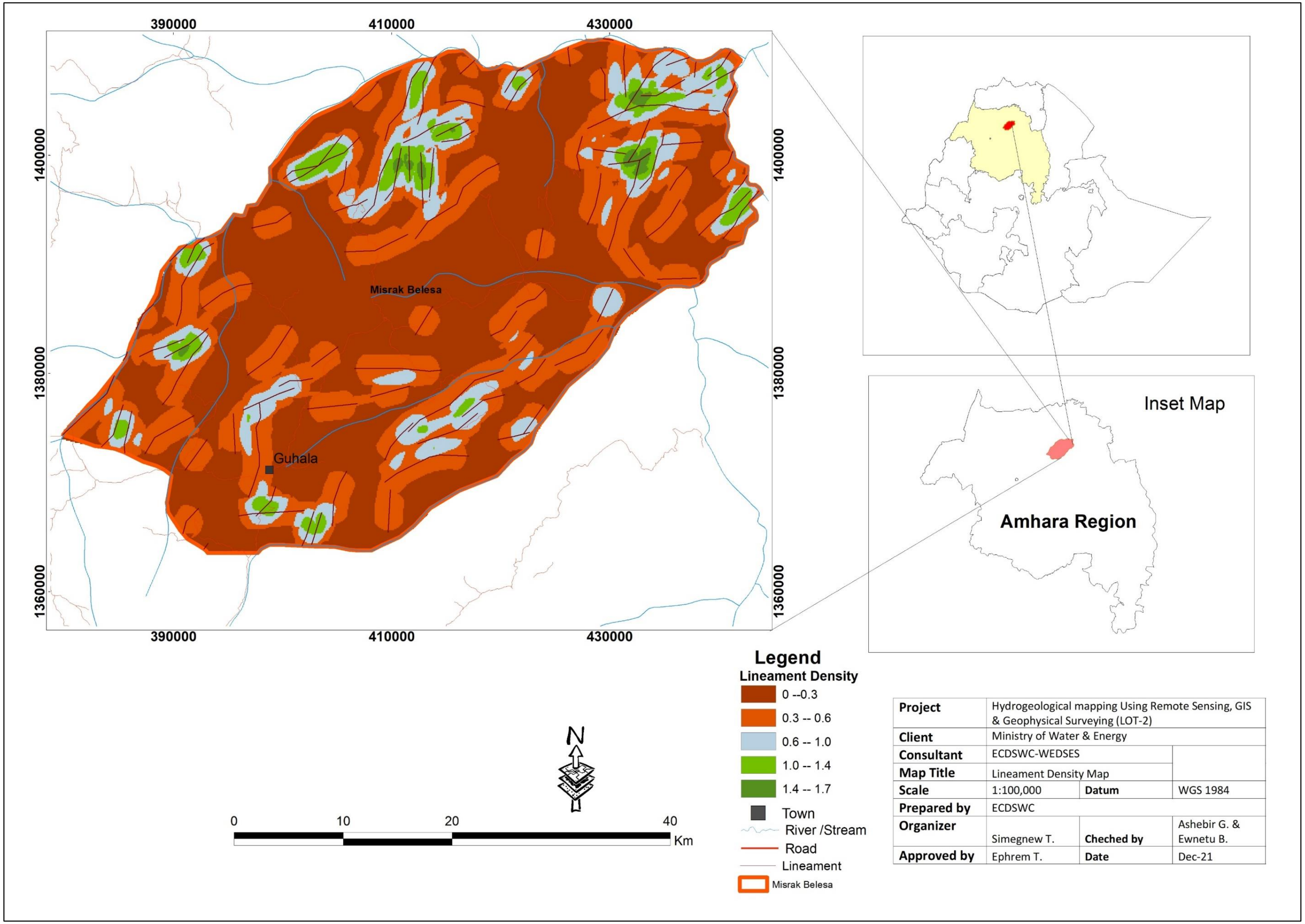
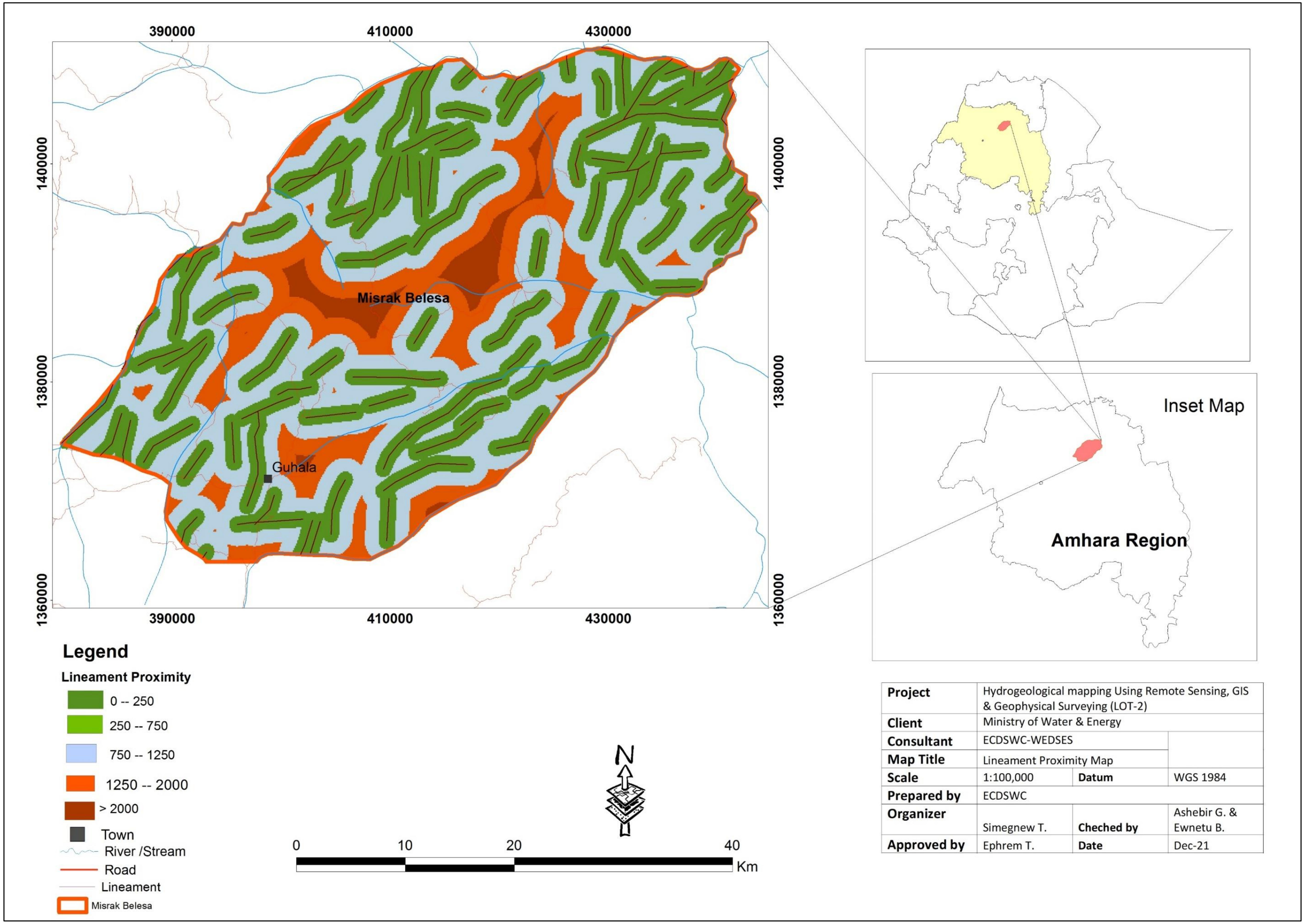


Figure 11: Lineament Density map of Misrak Belesa wereda

4.2.5 Lineament Proximity

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 Misrak Belesa. 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 (12)



Project	Hydrogeological mapping Using Remote Sensing, GIS & Geophysical Surveying (LOT-2)		
Client	Ministry of Water & Energy		
Consultant	ECDSWC-WEDSES		
Map Title	Lineament Proximity 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 12: Lineament Proximity map of Misrak Belesa 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 Misrak Belesa.The following formula was used to estimate the groundwater potential maps of the Misrak Belesa.

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

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):

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

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.

4.4.1Single parameter Sensitivity analysis of Misrak Belesa

The statistics of the single-parameter sensitivity analysis of Misrak Belesa wereda are shown in table 9.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 10: 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

4.5 Validation using well data Misrak Belesa

Overlay analysis techniques based on GIS methods have been applied to evaluate the groundwater potential of Misrak Belesa. 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

The groundwater potential map of Misrak Belesa Wereda has been classified as a very low, low, moderate, and high groundwater potential area except fora small portion of very high groundwater potential delineated in the south-western 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 wereda is productive, and fractured volcanic rocks are encountered at shallow depth.

Most parts of these wereda 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 fora 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.

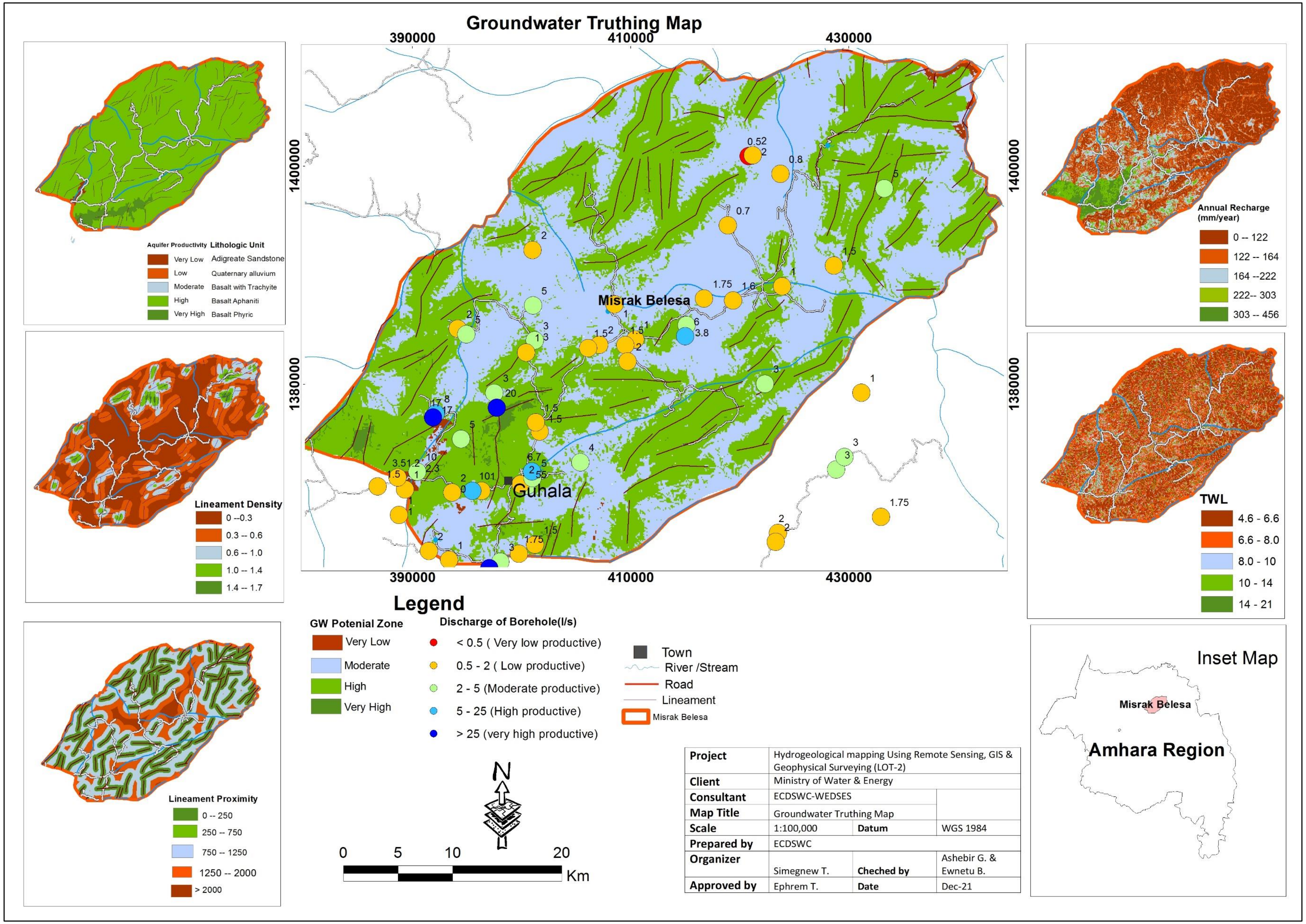


Figure 13: Groundwater truthing map of Misrak Belesa wereda

4. 6. Socio - Economy and water demand of Misrak Belesa wereda

To estimate the water demand of the Misrak Belesa 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.

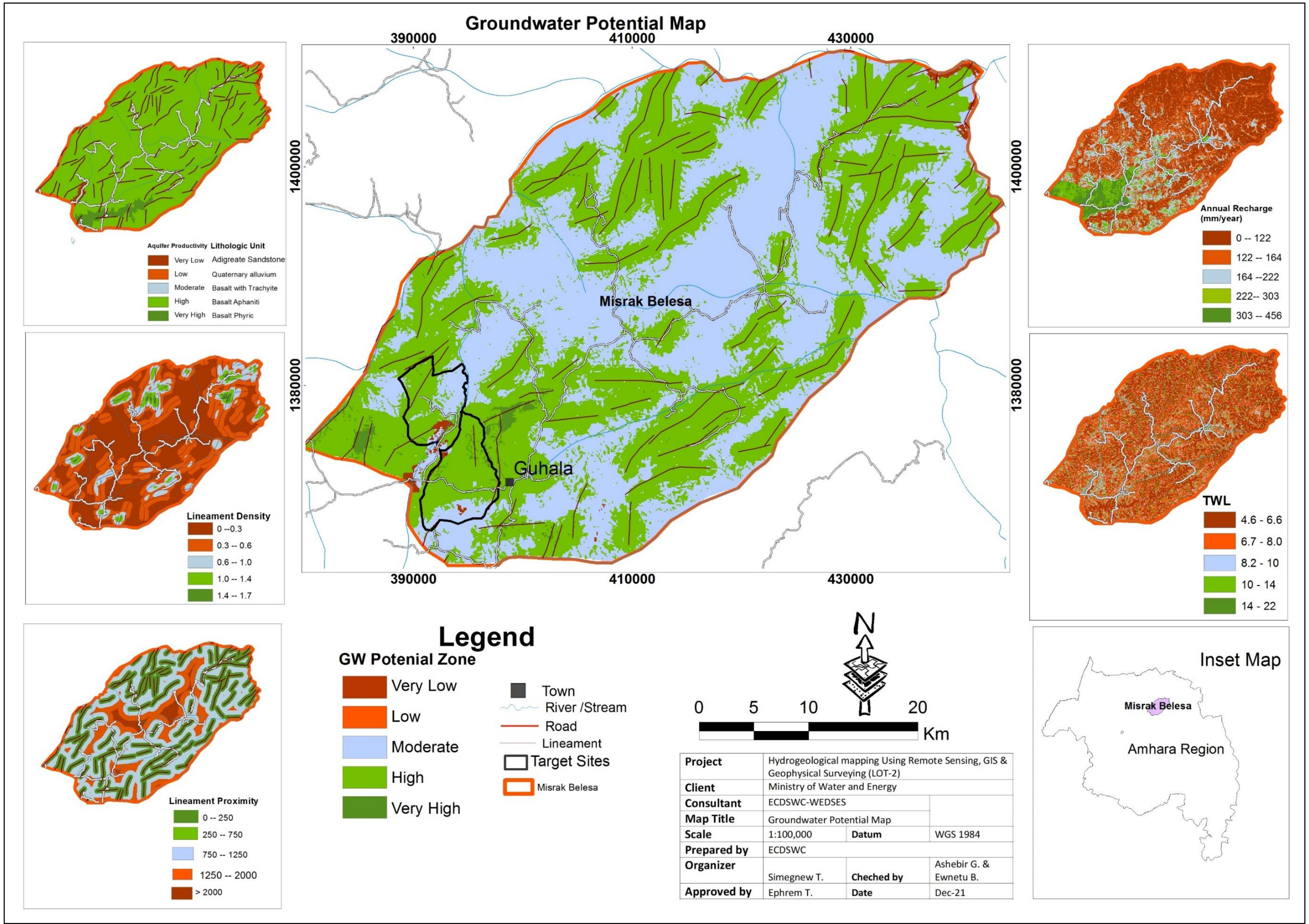
The water demand of the Misrak Belesa wereda for water supply of small-town, livestock & rural water supplies water demand are summarized in the table below.

Table 11: Water demand of Misrak Belesa

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

Wereda	Livestock Category									Water Demand in m3/day
	Shoats	0.01	Cattle	0.7	Donkey	0.6	Chicken	0.001	TLU	
Misark Belesa	174939	1749.39	106506	74554.2	17178	10306.8	122748	122.748	86733.138	2168.32845

4.7 Groundwater potential zone (GWPZ)



Project	Hydrogeological mapping Using Remote Sensing, GIS & Geophysical Surveying (LOT-2)		
Client	Ministry of Water and Energy		
Consultant	ECDSWC-WEDSES		
Map Title	Groundwater Potential 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 14 : Groundwater Potential map of Misrak Belesa 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 15.

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 promissing 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 II; Phase III; Field work; Report; Office; Worksho Training; Submission of Reports

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 Misrak Belesa wereda, which are located in, Amhara regional state. 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 Misrak Belesa.

The spatial distribution of the Misrak Belesa GWP zones generally match with the conceptual understanding of the Misrak Belesa 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 Misrak Belesa

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

Annex 2: Water point inventory data of Misrak Belesa

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
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	YesenibetGebeya	393328	1363924	1982	YesenibetGebeya	Amhara	Misrak Belesa	SW	74		15	1
96	GendaWuha	397831	1368771	1977	GendaWuha	Amhara	Misrak Belesa	SW	52	2012	14	0.5
97	Chelekaina	400400	1382938	1714	Chelekaina	Amhara	Misrak Belesa	SW	60	2012	10	1
98	MaryeWenz	386789	1370644	1921	MaryeWenz	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	TilikuMesik	388797	1373601	1857	TilikuMesik	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	TilkMeda	401297	1384826	1692	TilkMeda	Amhara	Misrak Belesa	SW	40	2012	6	0.7
106	AchekenTebazela	400485	1377786	1789	AchekenTebazela	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	MitishKayina	393607	1370099	1887	MitishKayina	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

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
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
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	SherieAnget	423717	1399313	1546	SherieAnget	Amhara	Misrak Belesa	SW	45	2008	7.5	0.8
134	QunaKayina	409493	1383620	1784	QunaKayina	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	NiguseBahir	400575	1381847	1740	NiguseBahir	Amhara	Misrak Belesa	SW	65	2008		
140	ChichilWiha	409038	1385469	1813	ChichilWiha	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

Annex 3: Geologic map and cross section of Misrak Belesa Wereda