FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA
MINISTRY OF WATER & ENERGY

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

ANNEX XI- DEVELOPING GROUNDWATER POTENTIAL MAP OF BUGNA WEREDA (FINAL)

January, 2022
ADDIS ABABA

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

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

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

ANNEX XI– DEVELOPING GROUNDWATER POTENTIAL MAP OF BUGNA WEREDA

January, 2022

Issues and Revision Records

Rev	Date	Originator (s)	Checked by	Approved by	Document Description
	January, 2022	Ashebir G. Abenezer M. Seife N. Simegnew T DestaYoseph Taddese A. Iyasu Ch. FikirteAbebe YelekalYetayew	Ashebir G. EwnetuB.	Ephrem T.	Final Report

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

ANNEX XI– DEVELOPING GROUNDWATER POTENTIAL MAP OF BUGNA 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 Bugna wereda by using integrated remote sensing and GIS-based multi-criteria evaluation to identify promising areas for groundwater exploration.

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 Bugna wereda GWP zones generally match with the conceptual understanding of the Bugna 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 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
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
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
SRTM	-	Advanced Spaceborne Thermal Emission and Transmission
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 the Bugna Wereda of Ethiopia.

It is the initiation of the client to conduct a groundwater study to make groundwater potential maps and to identify drilling target sites for boreholes and alternatives drilling site in the Bugna Wereda.

The Project areas cover Bugna water-scarce wereda 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 Bugna 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 to 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 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, Bugna wereda of Amhara regional state groundwater potential map is presented.

1.2 Location of Bugna

The proposed study area is located in Amhara Regional state. The project area is accessible by a network of dry weather roads and the asphalt road that runs from Addis Ababa –- Bahir Dar-Debere Tabor Lalibela Ayena and/or Addis Ababa-Awash-Woledia- Gashena Lalibela Ayena major asphalt roads. The whole of the project area is confined between the geographic coordinates of UTME 439196-499811 and UTMN 1328346-160825 (Figure 1).

In general, Bugna wereda seem to be easily accessible from all directions by a number of asphalt, all-weather roads, dry season roads and foot paths.

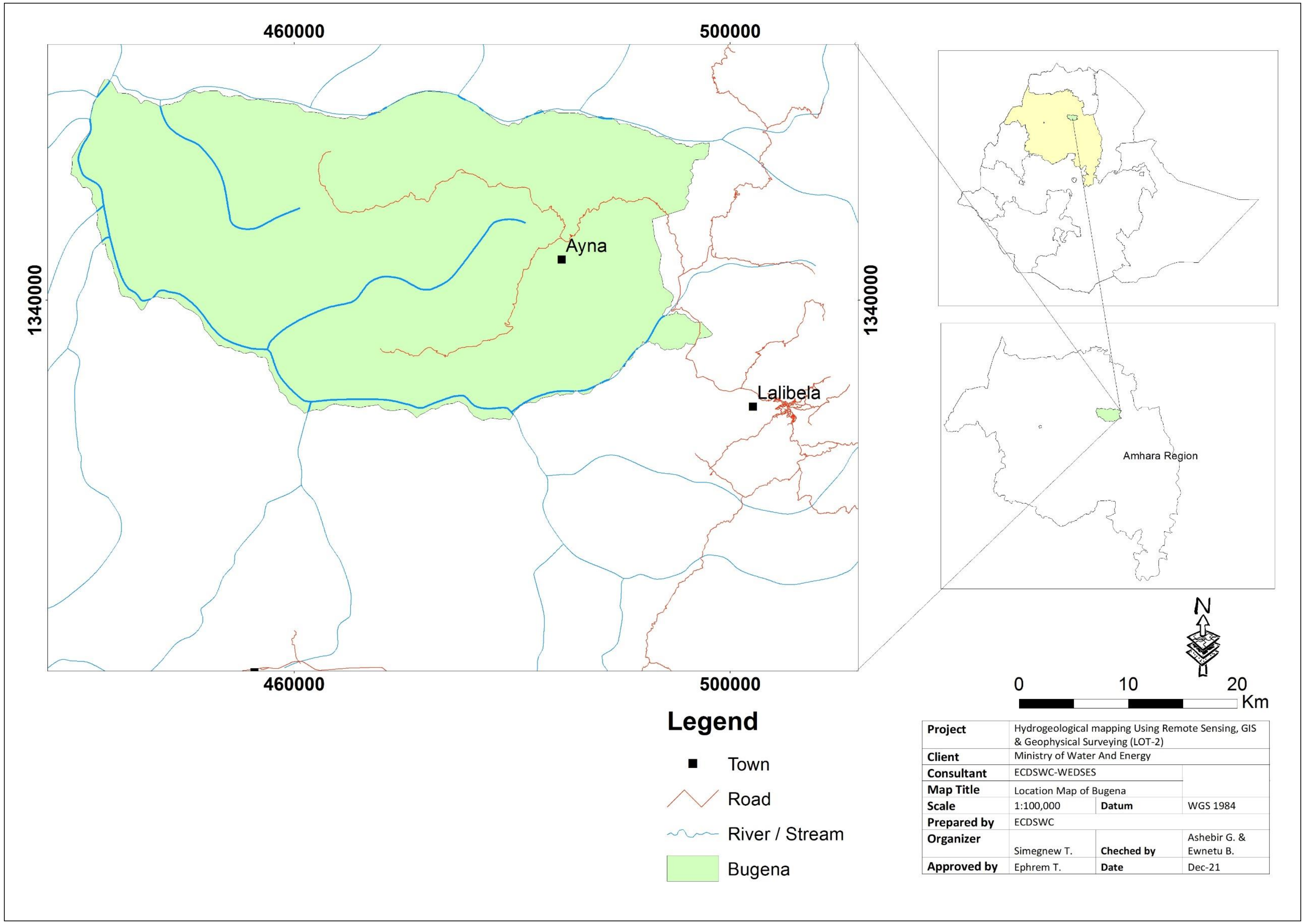


Figure 1: Location of Project area Bugna wereda

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 site for groundwater abstraction and 1 alternative (optional) drilling site for the Bugna Wereda in (LOT-2). Generally, the ultimate goal of the climate-resilient WASH project in Ethiopia is to increase access to safe and sustainable water.

The following specific objectives are also associated with the project:

- Carry out National Groundwater Risk Mitigation Strategy and make recommendations.
- Create detailed groundwater potential maps for target sites
- Identify one optimal drilling site and one alternative (optional) drilling site Bugna 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.

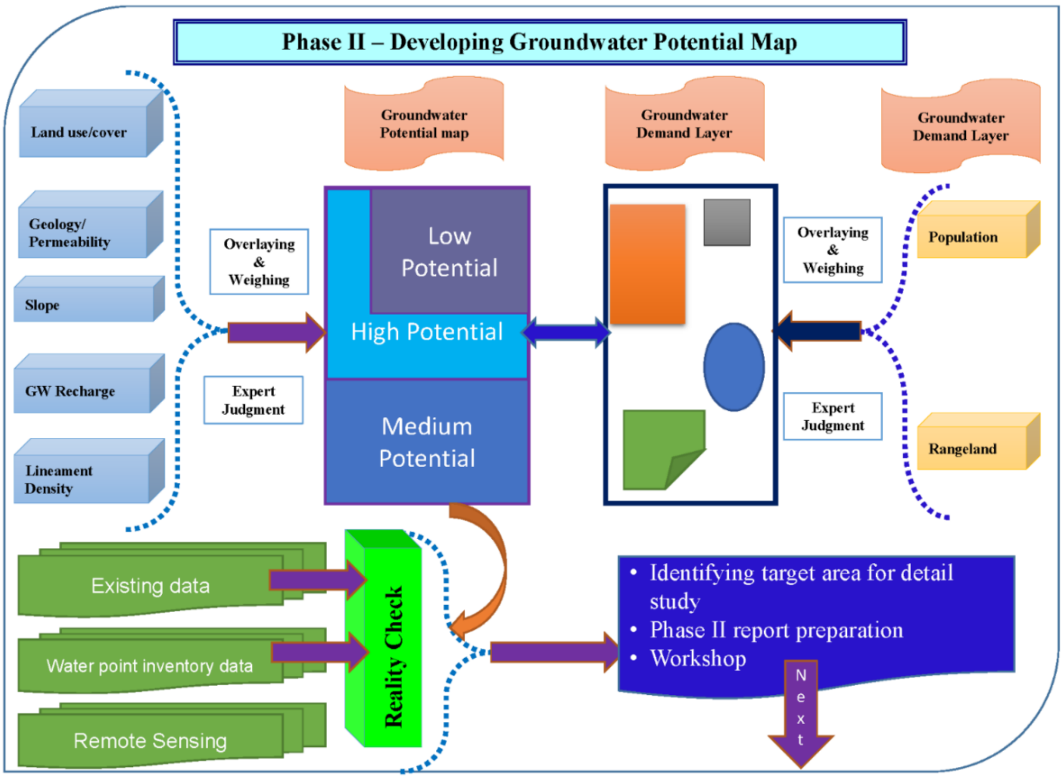
1.4 Scope of Works

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 Bugna Wereda of LOT-2 and identification of target sites for borehole drilling with enhanced drilling success rates and optional drilling sites for the Bugna 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:



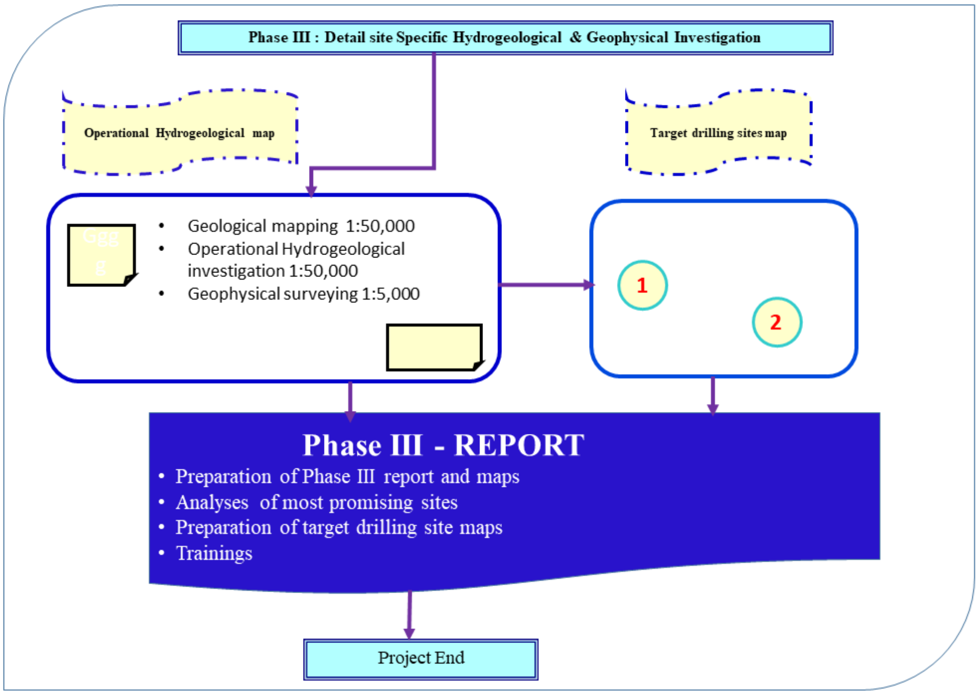


Figure 2: The project phases and the main deliverables

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:-

- For this wereda Field inventory and basic groundwater data such as SWL, PH, and EC were measured on-site, a water sample for laboratory analysis was not carried out due to security problems, available secondary reports were collected from different, government, and private organizations,.
- Climatological data was collected from NMA and Satellite data and detailed analysis was carried out.
- Hydrological data was collected from MoWE and detailed analysis was 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 Bugna 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 was prepared for input for Groundwater recharge estimation.
- Groundwater recharge was estimated by using the WetSpass model for Tekeze basin, and then the Groundwater recharge map was extracted by the respective boundary of the Bugna Wereda.
- Geological Map 1:100,000 was prepared for each wereda from existing 1:50,000 scale base maps and Satellite images.
- Lineament was extracted from SRTM DEM 30m resolution and Sentinel 1A image radar by using PCI Geomatica software initially, and then the lineament extracted was manually filtered by overlaying road, boundary, and drainage density of Bugna Wereda.
- Lineament density map and Lineament proximity map was prepared from lineament map.
- Topographic Wetness index was generated for the Bugna Wereda.
- Hydrogeological Sections was prepared for the Bugna Wereda.
- Overlay Analysis has been carried out for the Bugna Wereda
- Sensitivity analysis was carried out for the Bugna Wereda.
- Validation of groundwater potential for the Bugna Wereda tested by using observed data collected during the groundwater inventory program on progress.
- The groundwater demand layer was prepared based on projected project CSA data
- Groundwater potential maps was prepared for each Bugna 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:

- Due to Security issues around the boundary of Bugna wereda field inventory was not carried out and the model is calibrated by using existing data collected from different organizations.
- Lack and incompleteness of Groundwater data and reports in the Bugna Wereda are observed. The model is validated by using representative 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 of Bugna Wereda Groundwater potential maps.
- The data scarcity was filled by collecting existing available hydrogeological information from Wereda and the zone water bureau.
- The capacity building or Knowledge transfer for wereda Hydrogeologist was given and they participated in the groundwater inventory program together with our senior Hydrogeologists.

2. DATA AND METHODOLOGY OF THE STUDY

The study methodology includes various tasks such as preparations for base maps, map updating according to field observations, digitization, and processing of image using software like WetSpass model M1.3,Arc GIS 10.8,Saaty's AHP (K.D.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.

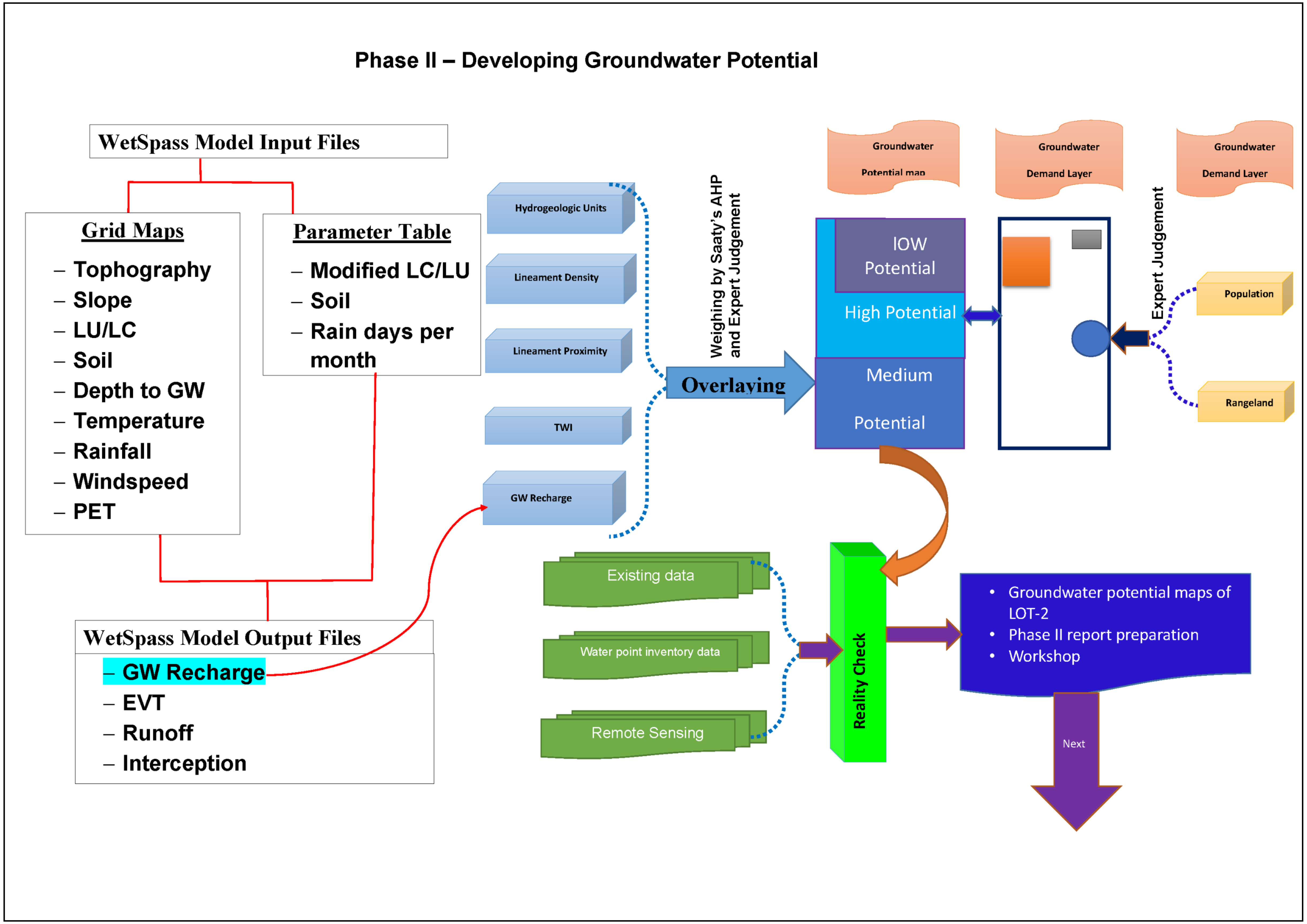


Figure 3: Phase II methods and deliverables

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 (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 the Bugna Wereda, 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.

Secondary data

In addition to the remote sensing data, Secondary 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 and available Groundwater data and reports are collected analyzed.

The Transmissivity and well discharge data was used for validation of Groundwater potential maps of the Bugna Wereda. The summarized existing data are presented in table 2 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
Bugna						3		

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 Bugna 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 Bugna Wereda, the maps were converted into SRTM 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 Bugna 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 Bugna Wereda at a scale of 1:100.000. The Geology map of the Bugna 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.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 (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 Advanced Space borne Thermal Emission and Reflection Radiometer (SRTM). The study area covers 12 DEM Tiles in total and all the tiles were mosaic in the ArcGIS software environment.

Lineament extraction process from SRTM DEM 30m resolution

The lineament extraction process was carried over the overlayed shaded relief images with multi-illumination directions of (0°, 45°, 90°, and 135° azimuth and sun angle of 30°,). PCI Geomatica software was 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 Bugna Wereda.

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 Bugna Wereda. 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 Bugna Wereda.

2.2.3 Groundwater recharge estimation methods

In this study, the Hydrological study was conducted by considering the overall hydrological connectivity of the basin; hence it was important to consider all part of the Bugna Wereda upstream hydrological characteristics, particularly for the Bugna Wereda where Main River crosses its boundary by considering the recharging source could be the cumulative effect both the drainage within Bugna wereda or rivers crossing the Bugna Wereda. As the result, all upstream portions of the selected wereda was 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. 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'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 ESRTMn-Africa regions indicates a potential to be used for various applications (Fenta. A, et. al., 2012; Ayehu, G, et.al. 2018; Maidment. R,et. al., 2013)
2	Temperature	JRA-55	0.56° x 0.56°	1958-2019	Japanese global atmospheric reanalysis project, where The Japan Meteorological Agency (JMA) conducted the second Japanese global atmospheric reanalysis, called the Japanese 55-year Reanalysis or JRA-55. Kobayashi et al. ,2015)
3	Wind speed	ECWF-ERA5		1979-2019	
4	Potential evapotranspiration	Calculated	30 km x 30km		penman-monteith and modified penman-monteith (for open water) used for calculation of PET
5	Groundwater depth	Historic GW data by ECDSWC			
6	Slope	SRTM	30m X 30m	--	SRTM (Shuttle Radar Topography Mission) DEM is a unique product that was produced by NASA and NGA in cooperation with the German and Italian space agencies. The slope of the study area is derived from this high-resolution digital elevation model.
7	Land use/ land cover	Esri	10mx 10m	2020	The recent land use-land cover (2020G.C) was used for the analysis. This layer displays a global map of land use/land cover (LULC). The map is derived from ESA Sentinel-2 imagery at 10m resolution. It is a composite of LULC predictions for 10 classes throughout the year in order to generate a representative snapshot of 2020
8	Soil	FAO			Harmonized World Soil Database v 1.2 and supervised in the Ethiopian context

Groundwater Recharge Estimation Method

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

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

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

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

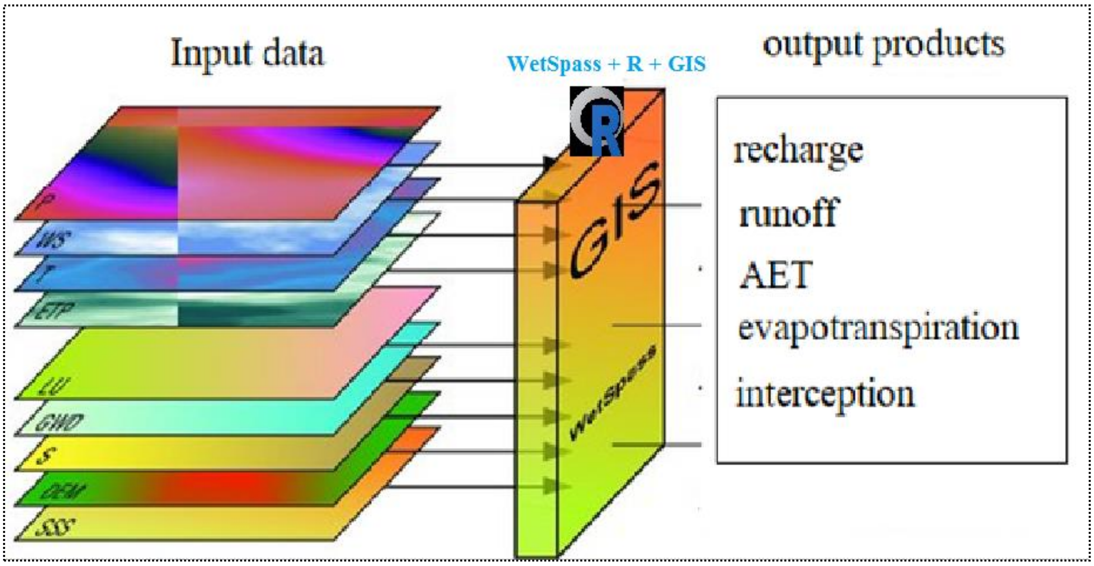


Figure 4: Schematic representation of model used for the study

Land cover data Extraction method

Downloading and processing SRTM 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 SRTM
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 Bugna Wereda.

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 Bugna 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 SRTM 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 Bugna Wereda 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

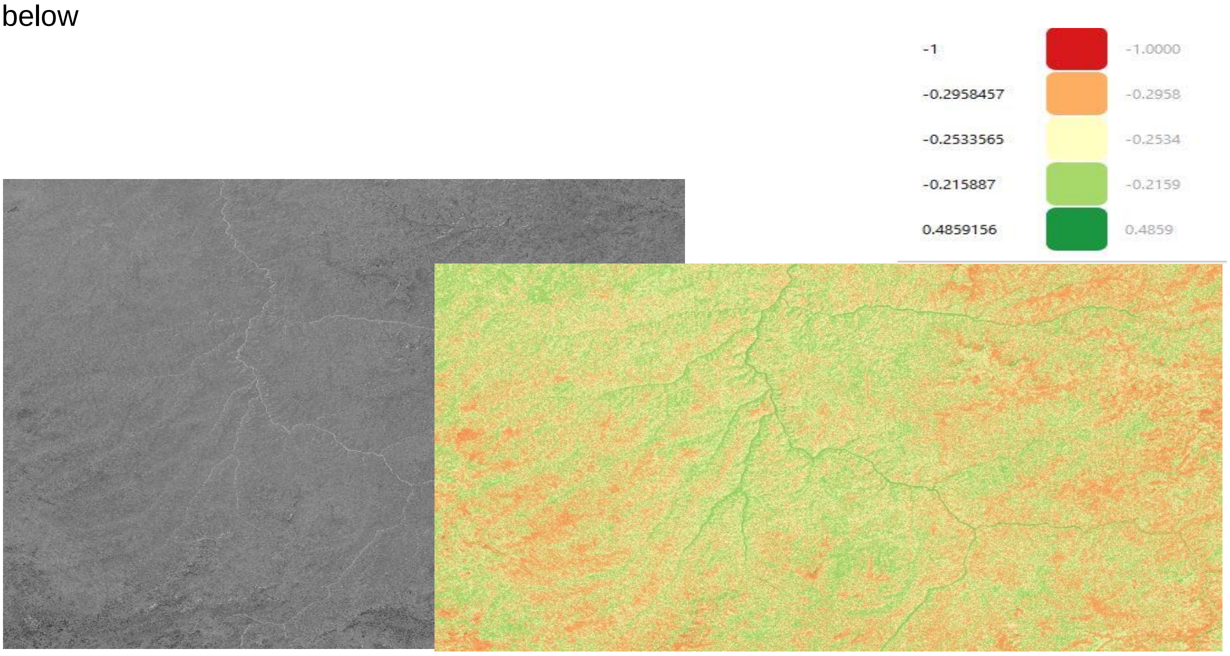


Figure 5: calculated NDVI using QGIS

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 pounding 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 pounding due to sewer overflow or basement back-ups

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

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

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 Bugna 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=PoerΔt

When: Pt = Population at t year

Po= Population at current (initial) year

e=ln10=2.718

Δt= the difference between t year and initial year

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

Table 5: Population size of Bugna wereda, July 2021to 2035

Year	Δt	Growth Rate	Bugna wereda
			Rural
2021	0		89985
2025	4	2.68%	90068
2030	5	2.45%	90134
2035	5	2.31%	90190

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

Woreda	Cattle	Goats	Sheep	Horses	Mules	Donkey	Poultry
Bugna	74524	49018	28715	11	665	12450	117827

3. Conceptual Hydrogeological model of the study area

3.1 Hydrogeological condition

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 basic volcanic rocks covered by thin soil, pyroclastic, trachyte, and basalt are the main volcanic rocks of the study area. They are jointed, fractured, and affected by dense weathering.

The geomorphological setup of the study area is characterized by a series of raged topography.According to previous studies and hydrogeological set up of the area shows, the major sources of recharge for the study area (Wereda) are:

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

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

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

Conceptual Hydrogeological model

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

In shallow groundwater, the movement and flow direction are dependent on the inclination, steepness, or slope of the topography in the area. The direction of flow of springs controlled by topographic breaks is an indicator of the possible groundwater flow. As shown on the hydrogeological map and on cross-section constructed along the groundwater flow path to conceptualize groundwater flow and storage in these wereda on (Figure 7) and also stated in previous works, the Tertiary volcanic units are recharged directly from precipitation, perennial rivers, and runoff. The groundwater flows from the eastern and southern mountain chain to the north and northwest. Existing data generally show groundwater flow to the northwest.

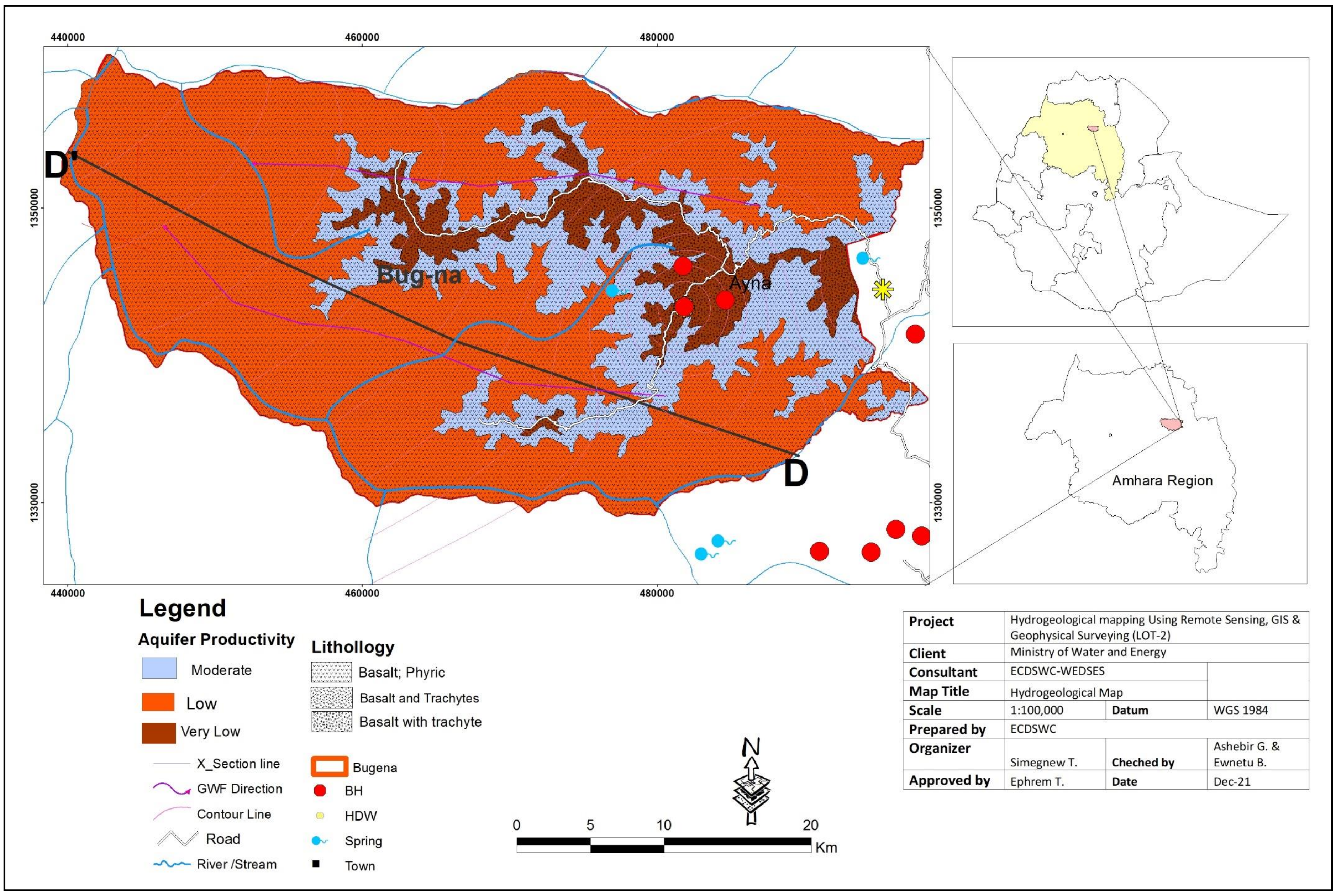


Figure 6: Hydrogeological map of Bugna wereda

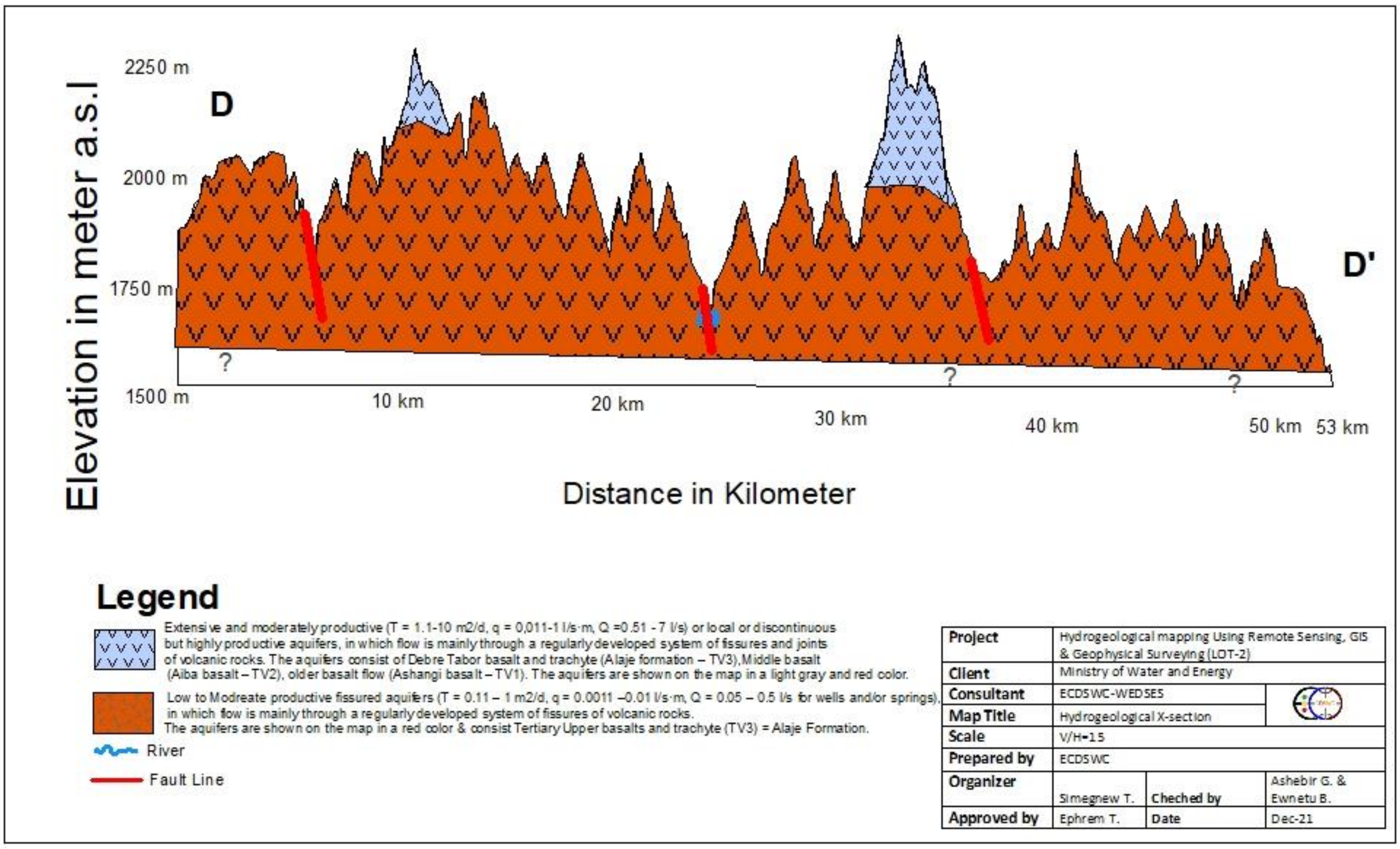


Figure 7: Hydrogeological section of Bugna wereda

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, and weights are determined based on conceptual groundwater system for Bugna 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 project, weights were determined for the Bugna Wereda. 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

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

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 Bugna wereda

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

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

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

Table 9: Assigned rank for various classes of all thematic layers of Bugna wereda

Factors	Weight	Class	Groundwater Storage potential	Assigned Rank
Lithology	35.5	Basalt & Pyroclastic	Moderate	3
		Basalt &Trachyte	low Productive	2
		Basalt with Trachyte	Very low Productive	1
Recharge	31.4	226 -- 355	Very high	5
		179 -- 226	High	4
		141 -- 179	Medium	3
		112 -- 141	low	2
		0 -- 112	Very Low	1
Lineament Density	17.3	1.0 – 1.33	Very high	5
		0.5 – 1.0	High	4
		0.3 – 0.5	Medium	3
		0.1 – 0.3	low	2
		0.0 – 0.1	Very Low	1
Lineament Proximity	10.7	0 - 250	Very high	5
		250 - 750	High	4
		750 - 1250	Medium	3
		1250 - 2000	low	2
		>2000	Very Low	1
TWI	5.1	13 -- 19	Very high	5
		10 -- 13	High	4

		8 -- 10	Medium	3
		6.6 -- 8	low	2
		6.6 – 4.5	Very Low	1

4.2 Reclassification of Thematic layers

4.2.1 Hydro - lithologic units

Hydrogeological units play a fundamental role in governing the spatial distribution and occurrence of groundwater. The porosity, size of pore space, and the ease at which the pore spaces are interconnected control storage and permeability of geologic medium that in turn affect the availability of groundwater in the area of interest. The main lithologic units found in the study area consist of Ashange, Aiba and Alaje formation. 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 Bugna Wereda, the Hydrogeological units of the Bugna Wereda were classified as very high, high, moderate, low, and very low potential. The reclassified hydrogeological units are presented in see figures 8.

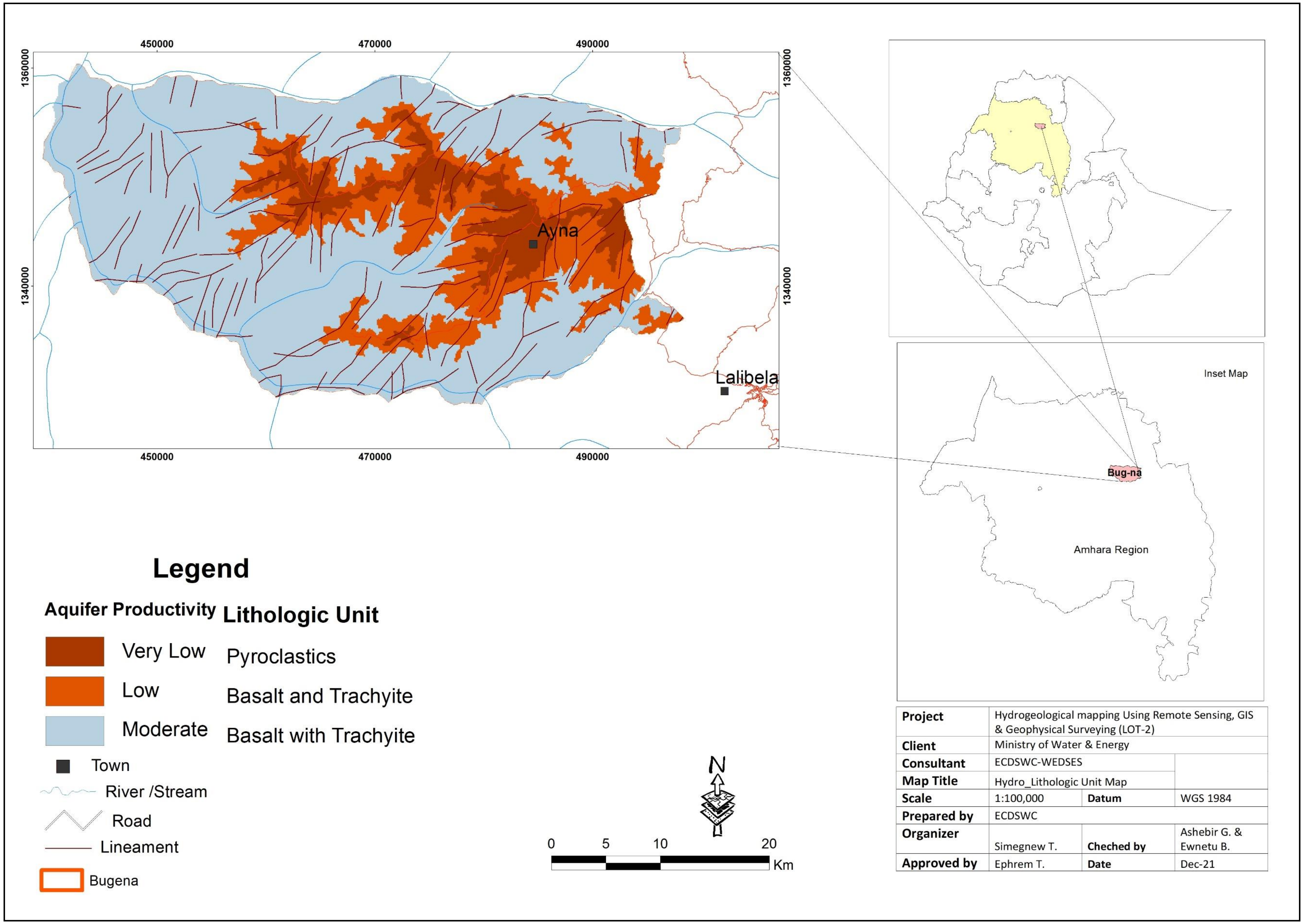


Figure 8: Hydro – Lithologic unit of Bugna

4.2.2 Groundwater Recharge

In this study, Groundwater recharge of Tekeze basin were calculated by using the WetSpass model, and then groundwater recharge of the study areas was extracted 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 SRTM 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 the Bugna Wereda. The recharge estimated was used as one thematic layer for groundwater potential mapping of the Bugna Wereda. 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.

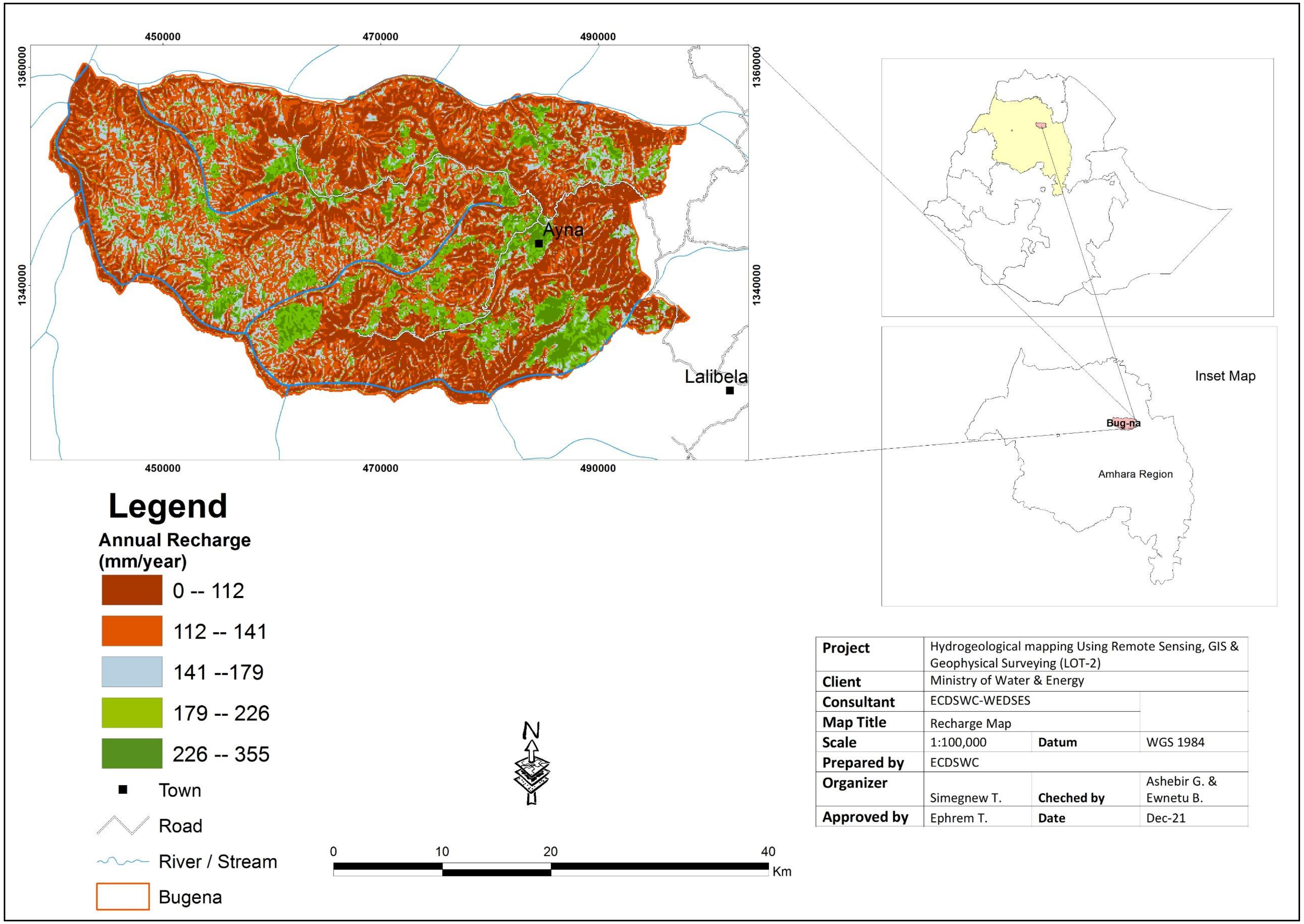
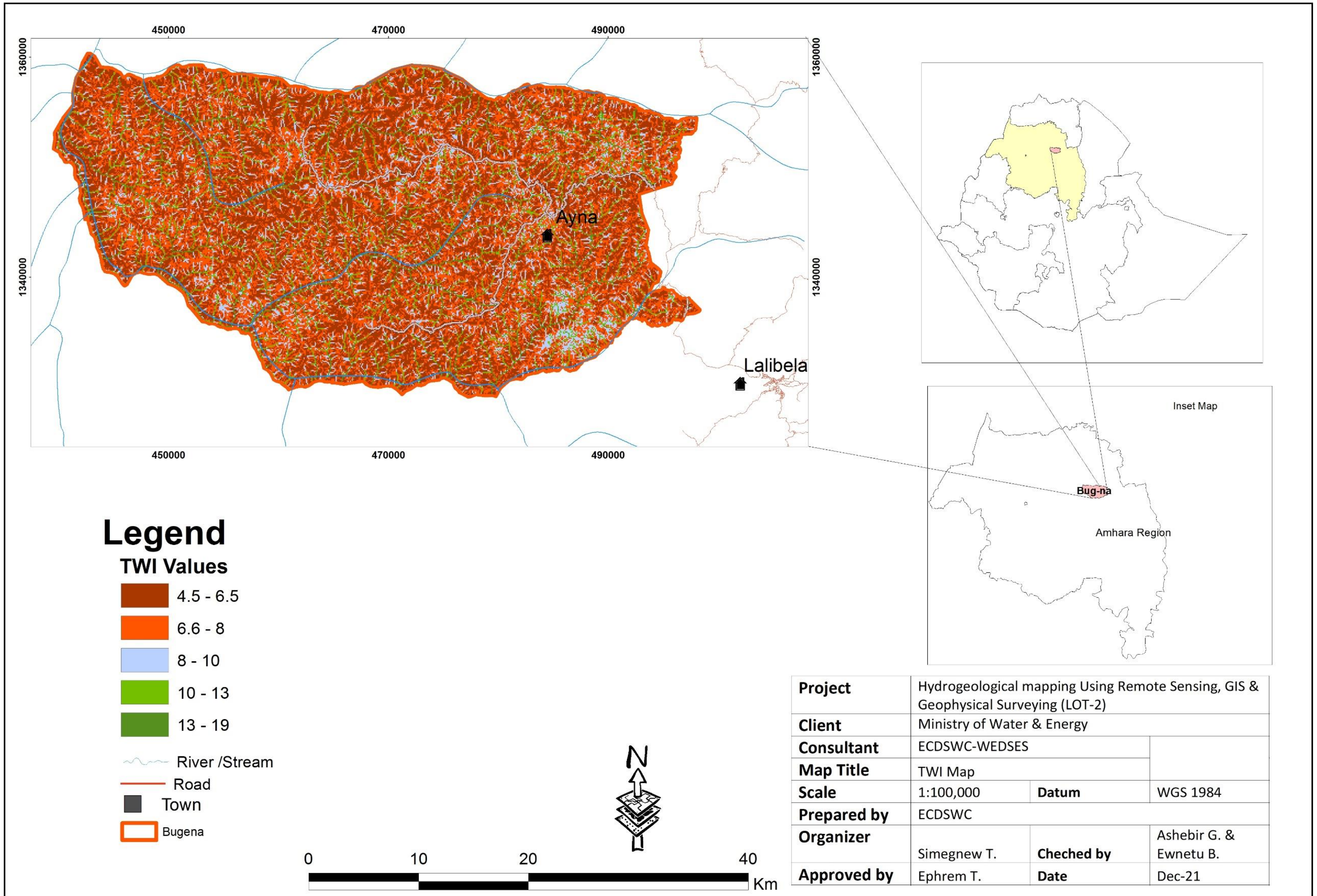


Figure 9: Groundwater Recharge of Bugna wereda

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. Figure 10 shows the TWI map of the Bugna Wereda.



Project	Hydrogeological mapping Using Remote Sensing, GIS & Geophysical Surveying (LOT-2)		
Client	Ministry of Water & Energy		
Consultant	ECDSWC-WEDSES		
Map Title	TWI 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 10: TWI of Bugna 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 Bugna Wereda 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)

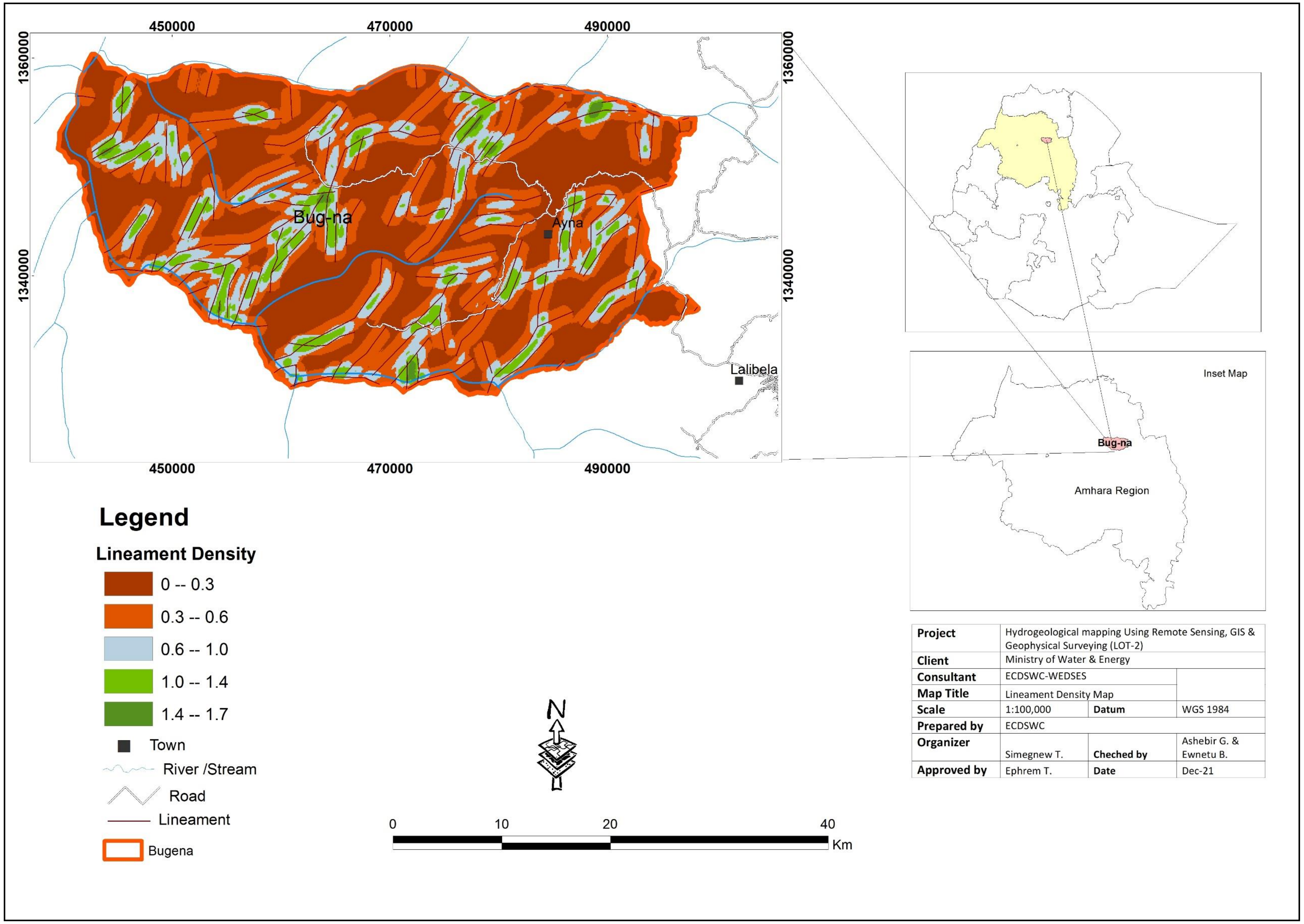


Figure 11: Lineament Density map of Bugna wereda

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 Bugna 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 figures (12).

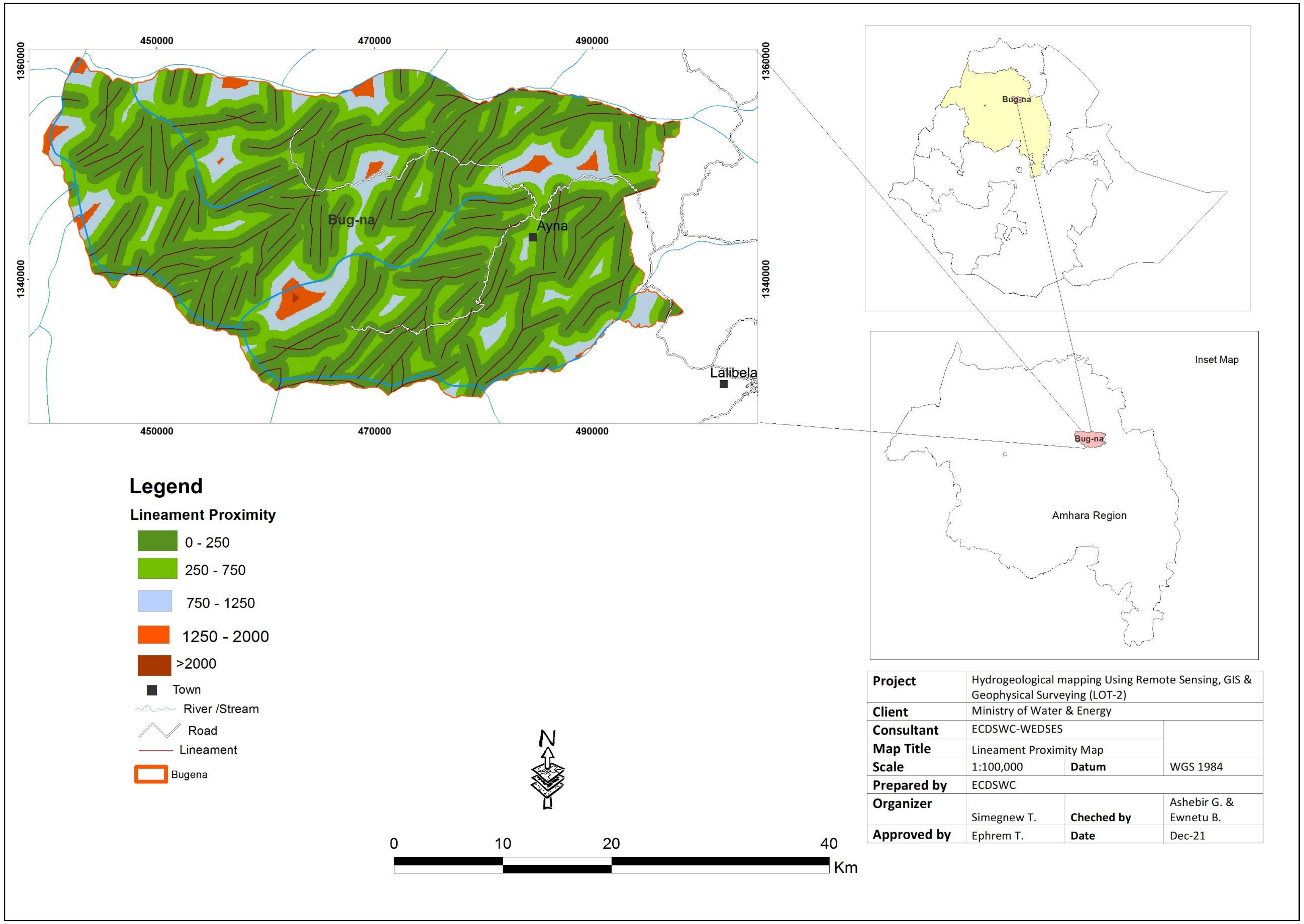


Figure 12: Lineament proximity of Bugna wereda

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 Bugna Wereda. The following formula was used to estimate the groundwater potential maps of the Bugna Wereda.

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

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

4.4 Sensitivity analysis

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

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

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

Where W is the effective weight of each thematic layer

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

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

4.4.1 Single parameter Sensitivity analysis of Bugna

The statistics of the single-parameter sensitivity analysis of Bugna wereda shown in Table 9.There is some deviation in the effective weights when compared to the empirical weights. The single–parameter analysis of Bugna wereda shows Lithologic units and groundwater recharge as the most effective layer in GWP mapping with mean effective weights of 42.0% and 26.3% respectively. The next higher effective weight of 14.0% and 13.6% was recorded in the Lineament proximity layer and lineament density respectively. In addition, the TWI tends to be almost effective thematic layers with mean effective weightings of 3.3% when compared with its empirical weights of 5.1%.

Table 10: Effective weight of single parameter sensitivity analyses of Bugna wereda

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

4.5 Validation using well data

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

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

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

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

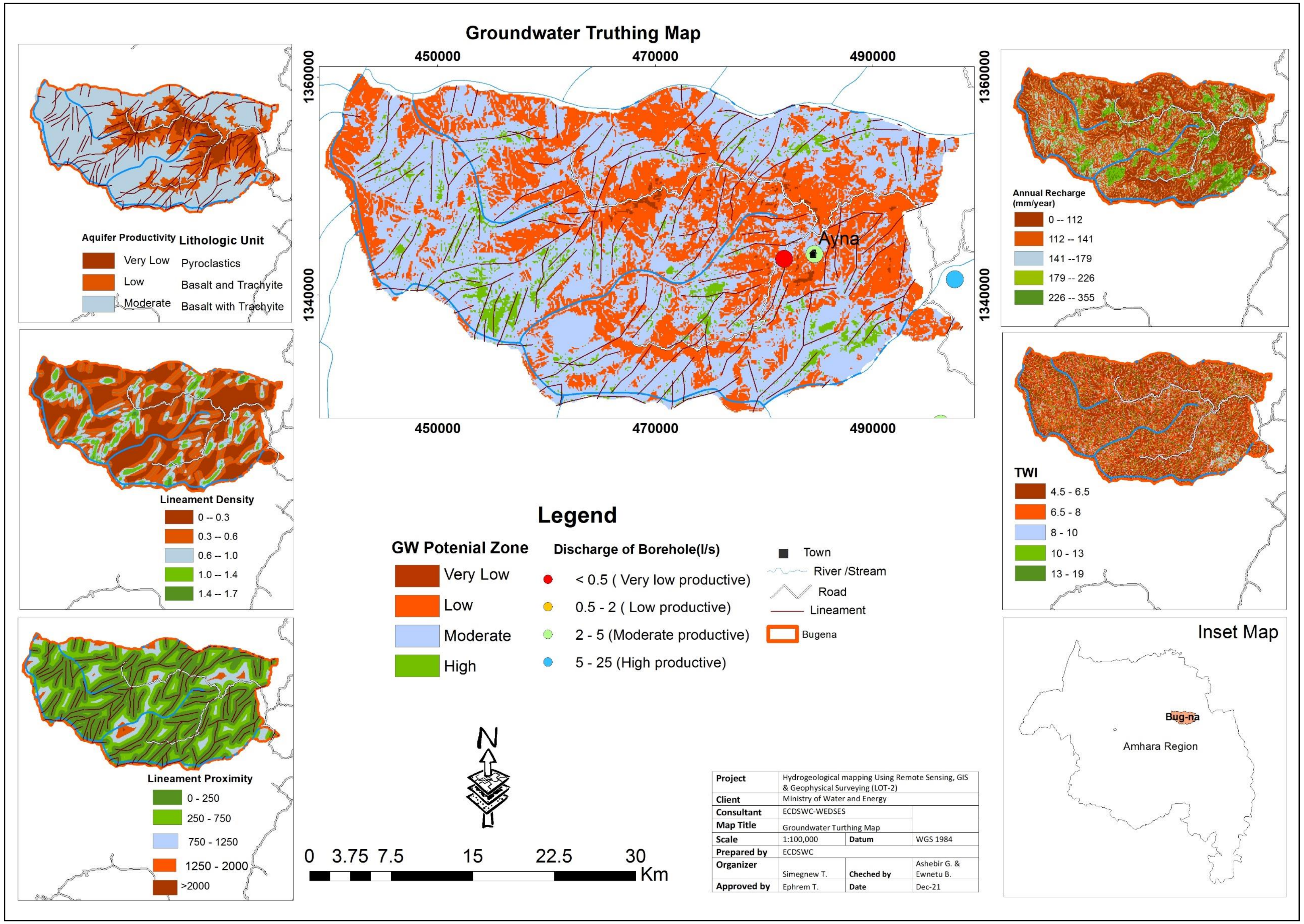


Figure 13: Groundwater truthing map of Bugna wereda

4. 6. Socio - Economy and water demand of Bugna wereda

To estimate the water demand of the Bugna Wereda CSA projected population data of July 2021 is used. According to MoWE (2011), the Government of Ethiopia produced a Universal Access plan to achieve 98% for rural and 100% urban access for water supply and sanitation by 2012, the first phases until 2012 setting per capita consumption rural 15 L/c/d in 1.5km service radius. The target year 2021 was moved to 2016 which would be improved in the second phase and a subsequent phase would be adopted. In estimating domestic water demand general design standards were adopted: 30 to 50 L/c/d for urban centers, 15 to 25 L/c/d for rural areas. Accordingly, the maximum 50L/c/d for the urban center and 25 L/c/d for rural are used to estimate the water demand of the Bugna Wereda.The water demand of the Bugna Wereda for water supply of small-town, livestock & rural water supplies water demand are summarized in the following table below

Table 11: Water demand of Bugna Wereda

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

Wereda	Livestock Category									Water Demand in m3/day
	Shoats	0.01	Cattle	0.7	Donkey	0.6	Chicken	0.001	TLU	
Bugna	77733	777.33	74524	52166.8	13126	7875.6	117827	117.827	60819.73	1520.49325

4.7 Groundwater potential zone (GWPZ)

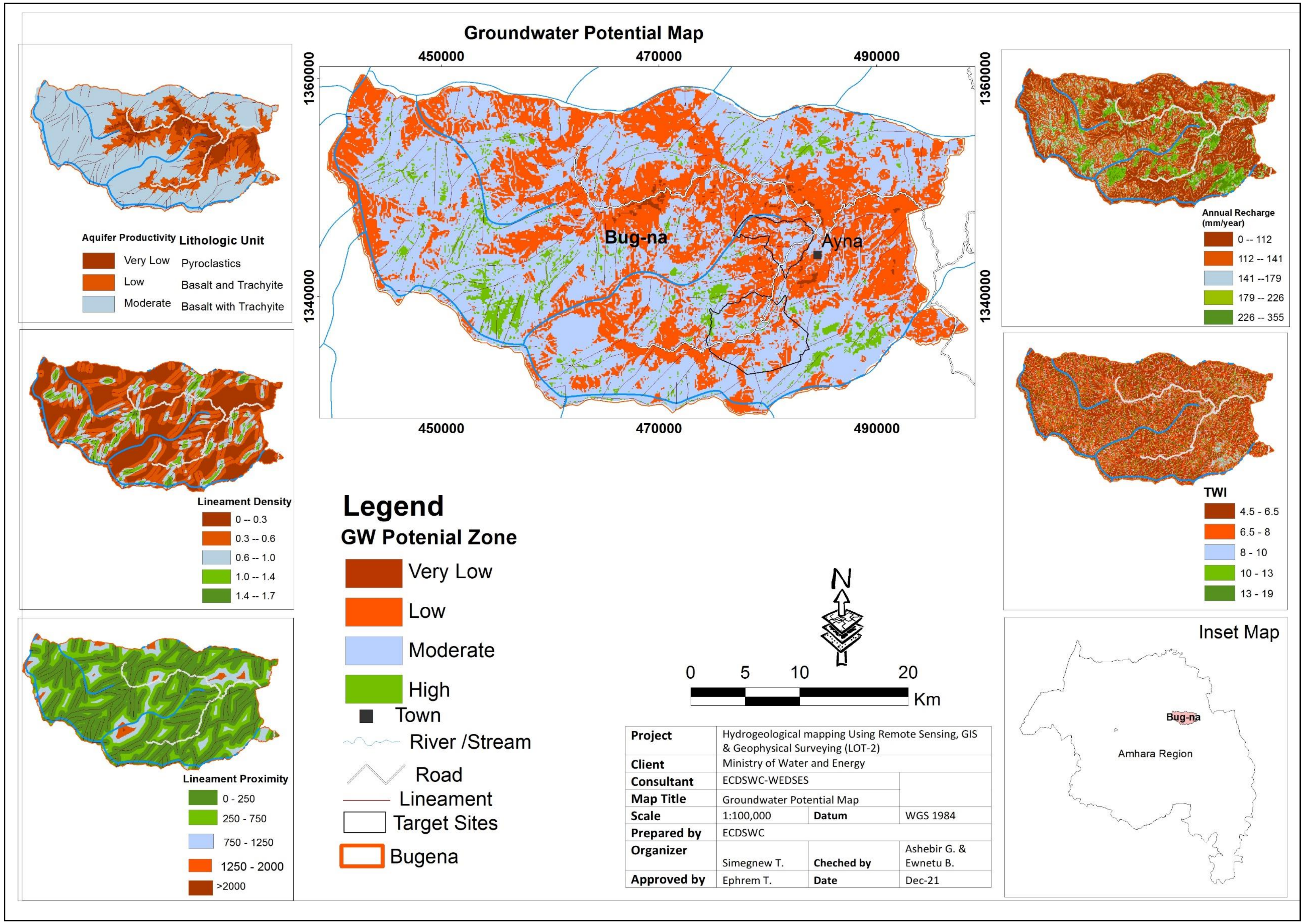


Figure 14: Groundwater Potential map of Bugna wereda

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 Bugna 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 the Bugna Wereda.

The spatial distribution of the Bugna Wereda GWP zones generally match with the conceptual understanding of the Bugna 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 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.

7. REFERENCE

- Abdelsalam, M.G., Stern, R.J., 1996. Sutures and shear zones in the Arabian-Nubian Shield. Journal African Earth Sciences 23, 289-310.
- Agostini, A., Bonini, M., Corti, G., Sani, F., Mazzarini, F., 2011. Fault architecture in the Main Ethiopian Rift and comparison with experimental models: Implications for rift evolution and Nubia–Somalia kinematics. Earth and Planetary Science Letters 301, 479–492.
- Amhara Design and Supervision Works Enterprise (ADSWE), 2013; Groundwater Potential Assessment of ESRTMnAmhara Development Corridor of Awash basin (Kobo-Robit-Minjar) Detail Reconnaissance Report.
- Ampe, E.M.; Vanhamel, I.; Salvadore, E.; Dams, J.; Bashir, I.; Demarchi, L.; Batelaan, O. Impact of urban land-cover classification on groundwater recharge uncertainty. IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens. 2012, 5, 1859–1867.
- Assefa, G., 1991. Lithostratigraphy and environment of deposition of Late Triassic to Early Cretaceous sequences of the central part of Northwestern Plateau, Ethiopia. N. Jb. Geol. Palaont. Abb. 182, (3): 255-284.
- Ayehu, G.T.; Tadesse, T.; Gessesse, B.; Dinku, T. Validation of new satellite rainfall products over the Upper Blue Nile Basin, Ethiopia. Atmos. Meas. Tech. 2018, 11, 1921–1936.
- AyeleAlmawFenta& Addis Kifle&TesfamichaelGebreyohannes&GebrerufaelHailu (2015), Spatial analysis of groundwater potential using remote sensing and GIS-based multi-criteria evaluation in Raya Valley, northern Ethiopia
- B. Fentaw, M. Manayeand, and A. Tadese, GSE (2017), Hydrogeological and Hydrochemical Maps of Debre Tabor NC 37 – 2 Sheet
- B. Fentaw, M. Manayeand, and A. Tadese, GSE (2017), Hydrogeological and Hydrochemical Maps of Debre Tabor NC 37 – 2 Sheet
- BereketFentaw, MihretManaye and AlemayehuTadese (2017). Hydrogeological and Hydrochemical Maps of Debre Tabor NC 37-2 and Dessie NC 37-3 Sheet.
- Beyth, M., 1972. Paleozoic–Mesozoic sedimentary basin of Mekele Outlier, Northern Ethiopia. The American Association of Petroleum Geologists Bulletin 56, 2426–2439.
- Bonini, M., Corti, G., Innocenti, F., Manetti, P., Mazzarini, F., Abebe, T., Pecskay, Z., 2005.
- Central Statistical Agency (2013), Population Projection of Ethiopia for all Regions at wereda Level from 2014 – 2017.
- Central Statistical Agency (2013), Population Projection of Ethiopia for all Regions at wereda Level from 2014 – 2017.
- Charlotte MacAlister, Paul Pavelic, CallistTindimugaya, TenalemAyenew, Mohamed Elhassan Ibrahim and Mohamed Abdel Meguid, (2012), Overview of groundwater in the Nile River Basin.
- Corti, G., 2009. Continental rift evolution: from rift initiation to incipient break-up in the Main Ethiopian Rift, East Africa. Earth Sci. Rev. 96, 1–53.
- EngidaZemedagegnehu, YelmaSileshi, Albert Tuinhof (2007), Groundwater Resources in Lake Tana Sub Basin and Adjacent Areas rapid Assessment and Terms of Reference of Further Study; Federal Republic of Ethiopia/ World bank.

- EngidaZemedagegnehu, YelmaSileshi, Albert Tuinhof (2007), Groundwater Resources in Lake Tana Sub Basin and Adjacent Areas rapid Assessment and Terms of Reference of Further Study; Federal Republic of Ethiopia/ World bank.
- ErmiasHagos, TenalemAyenew,SeifuKedede and MulugetaAlene, (2015). Review of hydrogeology Tekeze River Basin: Implication for rural and urban water supply in the region.
- FAO. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements- Irrigation and drainage paper 56. Rome, Italy.
- Fenta, A.A.; Yasuda, H.; Shimizu, K.; Ibaraki, Y.; Haregeweyn, N.; Kawai, T.; Belay, A.S.; Sultan, D.; Ebabu, K. Evaluation of satellite rainfall estimates over the Lake Tana basin at the source region of the Blue Nile River. Atmos. Res. 2018, 212, 43–53.
- Gamachu, D. (1977). The aspect of Climate Change and Water Budget in Ethiopia. A Technical Monograph for Addis Ababa University. Addis Ababa, Ethiopia: Addis Ababa University Press.
- Gani, N.D.S., Gani, M., Abdelsalam, M.G., 2008. Blue Nile incision on the Ethiopian Plateau: pulsed plateau growth, Pliocene uplift, and hominin evolution. GSA Today 17, 4–11.
- GSE (2010), Geology, Geochemistry and Gravity Survey of the Debre Tabor area.
- GSE (2010), Geology, Geochemistry, and Gravity Survey of the Debre Tabor area.
- H, B.Coye ,Kennedy.R and Donkin, 1998. Tekeze Medium Hydropower Project, Feasibility Study MoWR.
- Hydrogeological and Hydrochemical Maps of Yifag ND 37-14 Sheet by Jiri Sima and YonasMulugeta (2017)
- Hydro-geological Map of AyeluTerara Sheet NC37-8; compiled by BawokeBirhan, RobelAsamnew, and Marta Wegu (GSE, 2007)
- Hydro-geological Map of Debrebirhan Map Sheet NC37-11; compiled by Tsehay Amare, Thomas Agzew, HabtamuYaze (GSE, 2016)
- Hydrogeological Investigation of Domestic water supply source in East EastBelesaWereda for nine kebeles Residents, ADSWE September 5, 2016
- Hydrogeological survey and investigation in Gelealo/ Burimodaituwereda, Drought Resilience, and Sustainable Livelihoods Program Phase I (DRSLP- I), ECDSWEC-WEDSWS, October 2018
- Jiri Sima and MuhuddinAbdella (2018). Hydrogeological and Hydrochemical Maps of Maychew ND 37-15 Sheet
- Khalid Benjmel, FouadAmraoui, Said Boutaleb, Mohammed Ouchchen, Amine Tahiri and Amine Touab, Mapping of Groundwater Potential Zones in Crystalline Terrain Using Remote Sensing, GIS Techniques, and Multicriteria Data Analysis (Case of the Ighrem Region, Western Anti-Atlas, Morocco).
- MahamatOuchar Al-Djazouli . Karim Elmorabiti. AbdelmejidRahimiOmaymaAmellah. Omer Abdelrahim Mohammed Fadil (2020), Delineating of groundwater potential zones based on remote sensing, GIS and analytical hierarchical process: a case of Waddai, eSRTMn Chad
- Maidment, R.I.; Grimes, D.I.F.; Allan, R.P.; Greatrex, H.; Rojas, O.; Leo, O. Evaluation of satellite-based and model re-analysis rainfall estimates for Uganda. Meteorol. Appl. 2013, 20, 308–317
- Mutreja, K.N. (1995) Applied Hydrology. Tata Mcgraw-Hill Publishing Company Limited, New Delhi.

- R. H. McCuen, 1998, Hydrologic Analysis and design, Department of Civil engineering University of Maryland, USA.
- R.K Linsley, L.H, (1983), PAULHUS, Hydrology for Engineers, McGraw-HILL
- Shaw E.M. (1994). Hydrology in Practice. Second Edition, Chapman and Hall, New York, USA
- Sima, Jiri et al. (2009): Water Resources Management and Environmental Protection Studies of the Jemma River Basin for Improved Food Security. ISBN 978-80-254-5021-5. AQUATEST a.s., Prague, Czech Rep.
- Sir Alexander GIBB & Partners (1988). Gelana Irrigation Project Feasibility Study Final Report, volume 2.
- T. Alemayehu, 2006, Groundwater Occurrence in Ethiopia, Addis Ababa University, Ethiopia.
- T. Grabs, J. Seibert, K. Bishop, H. Laudon, (2009) Modeling spatial patterns of saturated areas: A comparison of the tophographic wetness index and a dynamic distributed model.
- T.Azagegn et al, A.Asrat et al,T.Ayenew et al ,S.Kebede et al : Litho-structural control on interbasin groundwater transfer in central Ethiopia.Journal of African Earth Science, Volume 101, January 2015, pages 383-395
- Tadesse Dagnew, (2020). Delineate the groundwater potential zones of Nile river catchment in Tekeze river basin using the application of integrated Geographical Information System and Remote Sensing techniques.
- Tesfaye, Chernet (1993): Hydrogeology of Ethiopia and Water Resources Development–MSEIGS, Ministry of Mines and energy, Addis Ababa (Library880-051-17).
- The evolution of the Main Ethiopian Rift in the frame of Afar and Kenya rifts propagation. Tectonics 24, TC1007. doi:10.1029/2004TC001680.
- Thomas Agezew and Tsehay Amare, GSE (2018), Hydrogeological and Hydrochemical Maps of Debre Birhan sheet NC 37-11 Sheet
- Tis IsatWater Works PLC (TIWWPLC), (2016).7 (Seven) shallow wells completion report in Ebinat wereda (Emergency wells).
- VenTe Chow, David R. Maindment and Larry W. Mays, 1988, Applied Hydrology, McGraw-HILL International Editions for Civil Engineering Series.
- Well completion report of drlp1w-06-18 (Buri abandoned well site), drought resilience and sustainable livelihood program (DRSLP -1 PROJECT), ECDSWEC-WEDSWS, May 2021
- Well completion report of Gewane (TCVTW-03-19) test well, groundwater resources assessment of south Teru-Chifra areas and surroundings, ECDSWEC-WEDSWS May 2021
- WMO-NO 168, Guide to hydrological practice, Data Acquisition and processing, Analysis, Forecasting, and other applications. Fifth edition, 1994.
- WWDE (2008):EvaluationofwaterresourcesofAdaaandBechoplainsgroundwaterresourceforirrigation.AddisAbaba, Ethiopia.
- WWDSE (2006): Evaluation of water resources of the Ada'a and Becho plains groundwater basin for the irrigation development project, April2006, Water Works Design and Supervision Enterprise.

- Yates D. (1994), WatBal- An Integrated Water Balance Model for Climate Impact Assessment of River Basin Runoff IIASA Working Paper WP-94-064,
- Yerer Engineering, 2004. Hydrogeological Condition of Lalibella Area
- Zelalem L, Melkamu M., Getnet T., Alebachew T., Mulugeta Ch., Minyahl T.(2019) Appraising groundwater potential zones using geospatial and multi-criteria decision analysis (MCDA) techniques in Andasa-Tul watershed, Upper Blue Nile basin, Ethiopia

Annex 1: Observation during groundwater truthing and validation Bugna wereda

No.	Wereda	Locality	UTM E	UTM N	Elv.	Characteristic of validation point
1	Bugna	Kobe	462977	1350351	2536	▪ The observation point is mountainous, sloppy. No deep & shallow well, no hand dug well, no spring and basalt and trachyte is the observed outcrop. ▪ The area is mapped as low to moderate groundwater potential zone
2		Ayinan Eyesus	481743	1345948	2495	▪ The observation point topographically the area is steep sloping and rivers that flows in almost NW direction exists. Basalt and Trachyte is observed exposure. One borehole (43 depth & 7 L/sec discharge) is located at this observation point. From hydrogeological point of view and overlay analysis the observed point has moderate groundwater potential due to hydrogeological set up of the area. ▪ The area is mapped as moderate groundwater potential zone

Annex 2: Water point inventory data Bugna Wereda

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	Ayina Mechael	484614	1343643	2495		Amhara	Bugna	SW	46		12	2
2	Sora well	481743	1345948	2495		Amhara	Bugna	SW	43		7	7
3	shenetewuha well	481843	1343187	2494		Amhara	Bugna	SW	67			0
4	CSP17	477348	1344267	2056		Amhara	Bugna	Spring				8.5

Annex 3: Geologic map and cross section of Bugna Wereda