FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA
MINISTRY OF WATER AND ENERGY

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

ANNEX-I: BURI MUDAITU WEREDA GROUNDWATER POTENTIAL MAP (FINAL)

January, 2022
ADDIS ABABA

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

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

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

ANNEX-I: BURI MUDAITU WEREDA GROUNDWATER POTENTIAL MAP

January, 2022

Issues and Revision Records

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

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

PHASE II

ANNEX-I: BURI MUDAITU WEREDA GROUNDWATER POTENTIAL MAP

	STRUCTURE OF THE REPORT
PHASE - I	INCEPTION REPORT
PHASE - II	DEVELOPING GROUNDWATER POTENTIAL MAP
Annex I	BURI MUDAITU WEREDA GROUNDWATER POTENTIAL MAP
Annex II	ARGOBA 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	SAYINT 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 14 weredas by using integrated remote sensing and GIS-based multi-criteria evaluation in order to identify promising areas for groundwater exploration. The scarcity of water is a major menace in these 14 Weredas spread over 3 regions of Ethiopia.

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

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

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

TABLE OF CONTENTS

1. INTRODUCTION 1
1.1 GENERAL 1
1.2 LOCATION OF BURI MUDAITU WEREDA 2
1.3 OBJECTIVES OF THE STUDY 4
1.4 SCOPE OF WORKS 4
1.5 GENERAL APPROACH, DELIVERABLES AND PLANNING 5
1.6 RISKS AND MITIGATION MEASURES 7
2. DATA AND METHODOLOGY OF THE STUDY 8
2.1 REMOTE SENSING DATA, FIELD INVENTORY, AND SECONDARY DATA 10
PREPARATION OF THEMATIC LAYERS 11
2.2.1 Geological mapping method 11
2.2.2 Lineament Extraction method 12
2.2.3 Groundwater recharge estimation method 13
2.2.4 Topographic Wetness Index (TWI) generation 19
2.2.5 Demography data of the project area 19
3. CONCEPTUAL HYDROGEOLOGICAL MODEL OF THE STUDY AREA 20
4. RESULT AND DISCUSSION 23
4.1 MULTI-CRITERIA DECISION ANALYSIS (MCDA) WEIGHT ASSIGNMENT USING AHP 23
4.2 RECLASSIFICATION OF THEMATIC LAYERS 26
4.2.1 HYDROLITHOLOGIC UNITS 26
4.2.2 GROUNDWATER RECHARGE 28
4.2.3 TWI 30
4.2.4 LINEAMENT DENSITY 32
4.2.5 LINEAMENT PROXIMITY 34
4.3 OVERLAY ANALYSIS 36
4.4 SENSITIVITY ANALYSIS 36
4.4.3 SINGLE PARAMETER SENSITIVITY ANALYSIS OF BURI MUDAITU 36
4.5 VALIDATION USING WELL DATA 37
4. 6. SOCIO - ECONOMY AND WATER DEMAND OF BURI MUDAITU WEREDA 39
4.6.1 WATER DEMAND OF BURI MUDAITU WEREDA 39
4.7 GROUNDWATER POTENTIAL MAP OF BURI MUDAITU WEREDA 40
5. REVISED WORK PLAN FOR THE PHASE – III 41

6. CONCLUSION AND RECOMMENDATION 42
7. REFERENCE 43

LIST OF TABLES

TABLE 1 INVENTORIED AND EXISTING WATER POINTS 11
TABLE 2: EXISTING GEOLOGICAL MAP AND REMOTE SENSING DATA SOURCES 11
TABLE 3 DATASET USED FOR THE EVALUATION OF GROUNDWATER RECHARGE 14
TABLE 4 CONFUSION MATRIX OVER TRUE VALUES IN THE PROJECT WEREDA 17
TABLE 5 POPULATION SIZE OF BURI MUDAITU WEREDA, JULY 2021 TO 2035 19
TABLE 6 RANDOM INDEX 23
TABLE 7: PAIR-WISE COMPARISON MATRIX BY USING AHP FOR BURI MUDAITU WEREDA 24
TABLE 8 : ASSIGNED RANK FOR VARIOUS CLASSES OF ALL THEMATIC LAYERS OF BURI MUDAITU WEREDA 25
TABLE 9: EFFECTIVE WEIGHT OF SINGLE PARAMETER SENSITIVITY ANALYSES OF BURI MUDAITU WEREDA 36

LIST OF FIGURES

FIGURE 1 LOCATION OF BURI MUDAITU WEREDA 3
FIGURE 2: PROJECT PHASES AND THE MAIN DELIVERABLES 5
FIGURE 3: PHASE II METHODS AND DELIVERABLES 9
FIGURE 4 SCHEMATIC REPRESENTATION OF MODEL USED FOR THE STUDY 16
FIGURE 5: CALCULATED NDVI USING QGIS 18
FIGURE 6 HYDROGEOLOGICAL MAP OF BURI MUDAITU WEREDA 21
FIGURE 7 HYDROGEOLOGICAL CROSS- SECTION ALONG B-B' DIRECTION 22
FIGURE 8 HYDROLITHOLOGIC UNITS OF BURI MUDAITU WEREDA 27
FIGURE 9 GROUNDWATER RECHARGE MAP OF BURI MUDAITU WEREDA 29
FIGURE 10 TWI OF BURI MUDAITU WEREDA 31
FIGURE 11 LINEAMENT DENSITY MAP OF BURI MUDAITU WEREDA 33
FIGURE 12 LINEAMENT PROXIMITY MAP OF BURI MUDAITU WEREDA 35
FIGURE 13 GROUNDWATER POTENTIAL TRUTHING OF BURI MUDAITU WEREDA 38
FIGURE 14 GROUNDWATER POTENTIAL MAP OF BURI MUDAITU WEREDA 40
FIGURE 15: REVISED WORK PROGRAM FOR PHASE III WORK ACTIVITIES 41

LIST OF ANNEXES

ANNEX 1: GROUNDWATER TRUTHING AND VALIDATION 46

ANNEX 2: WATER POINT INVENTORY DATA 47

ANNEX 3: GEOLOGIC MAP OF BURI MUDAITU WEREDA 48

ABREVIATIONS AND ACRONYMS

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	-	Millimeter
MOWIE	-	Ministry of Water ,Irrigation and Energy
NDVI	-	Normalized Difference Vegetation Index
NMA	-	National Meteorological Agency
pH	-	Hydrogen - Ion Activity
QGIS	-	Quantum Geographic Information System
RS	-	Remote sensing

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
TWI	-	Topographic Wetness Index
UTM	-	Universal Transverse Mercator
VES	-	Vertical Electrical Sounding
W.E.D.S.W.S	-	Water & Energy Design and Supervision Works Sector
WDC	-	Water Development Commission
WetSpass	-	Water & Energy transfer between soil, plants & atmosphere
WWDSE	-	Water Works Design and Supervision Enterprise

1. INTRODUCTION

1.1 General

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

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

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

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

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

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

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

Chapter-2: Data and Methodology of the study

Chapter-3: Conceptual Hydrogeological model of the study area

Chapter-4: Result and discussion

Chapter-5: Revised work plan for Phase – III

Chapter-6: Conclusion and Recommendation,

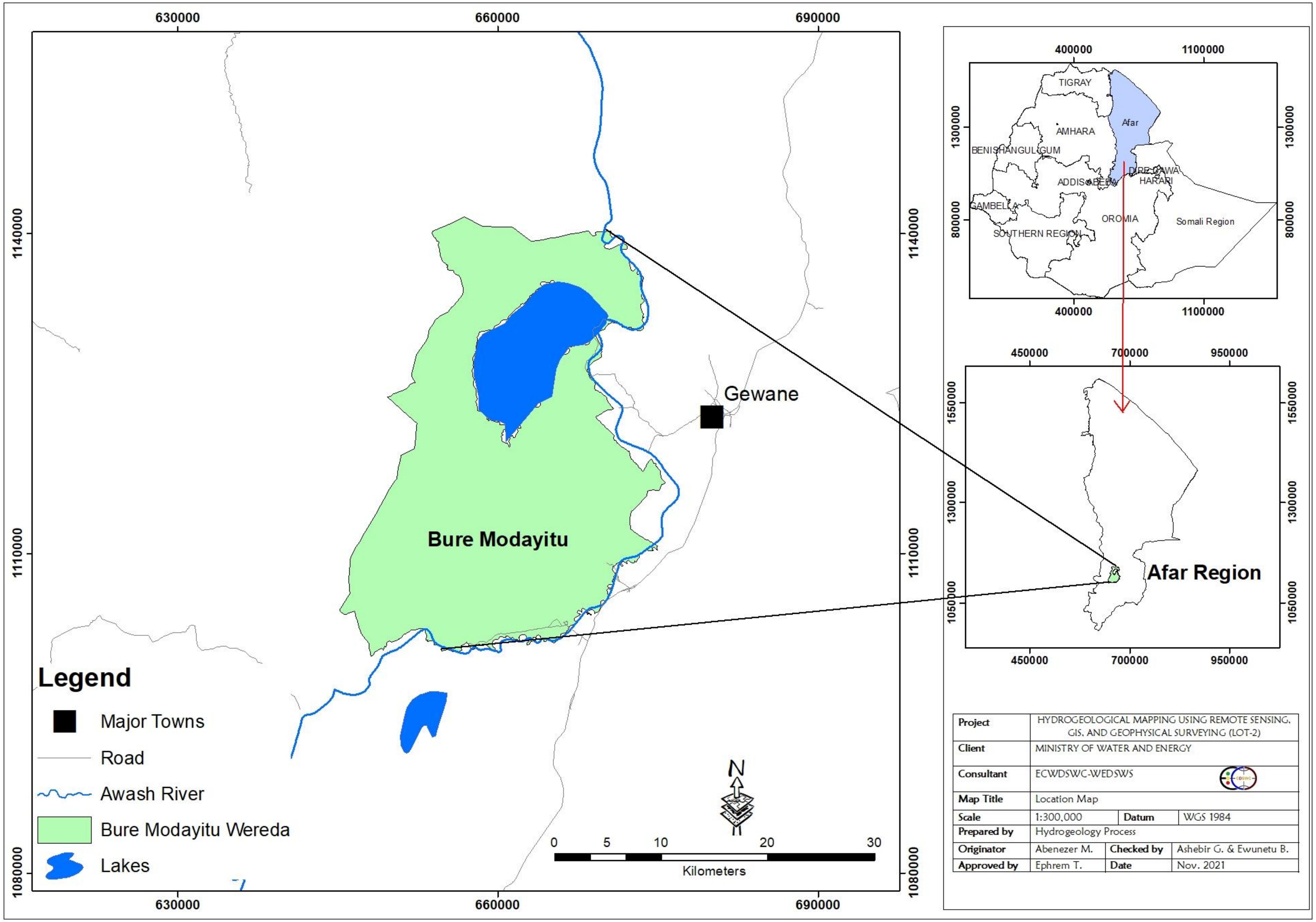
Chapter-7: References

In this report, Buri Mudaitu wereda of Afar regional state groundwater potential map is presented.

1.2 Location of Buri Mudaitu Wereda

Buri Mudaitu wereda is located in Zone three (3) of Afar National Regional State. The study area is accessible by all-weather roads that connects Addis Ababa–Awash-Gewane. The main asphalt road from Addis Ababa to Semera via Awash Sebat-Gewane is about 373 kilometer. The whole of the project area is confined between the geographic coordinates of UTME 645181-675640 and UTMN 1100442-1141757 and topographically the study area is plain land and the plain rises slightly up to an elevation of more than 1000m on the western escarpment (Figure 1).

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



Project	HYDROGEOLOGICAL MAPPING USING REMOTE SENSING, GIS, AND GEOPHYSICAL SURVEYING (LOT-2)		
Client	MINISTRY OF WATER AND ENERGY		
Consultant	ECWDSWC-WEDSWS		
Map Title	Location Map		
Scale	1:300,000	Datum	WGS 1984
Prepared by	Hydrogeology Process		
Originator	Abenezer M.	Checked by	Ashebir G. & Ewunetu B.
Approved by	Ephrem T.	Date	Nov. 2021

Figure 1 Location of Buri Mudaitu 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 geophysical surveys, 14 most promising drilling sites for groundwater abstraction and 14 alternatives (optional) drilling sites will be selected for each weredas of Lot-2. Generally, the ultimate goal of the climate-resilient WASH project in Ethiopia is to increase access to safe and sustainable water.

The following specific objectives are also associated with the project:

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

1.4 Scope of Works

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

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

1.5 General approach, Deliverables and Planning

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

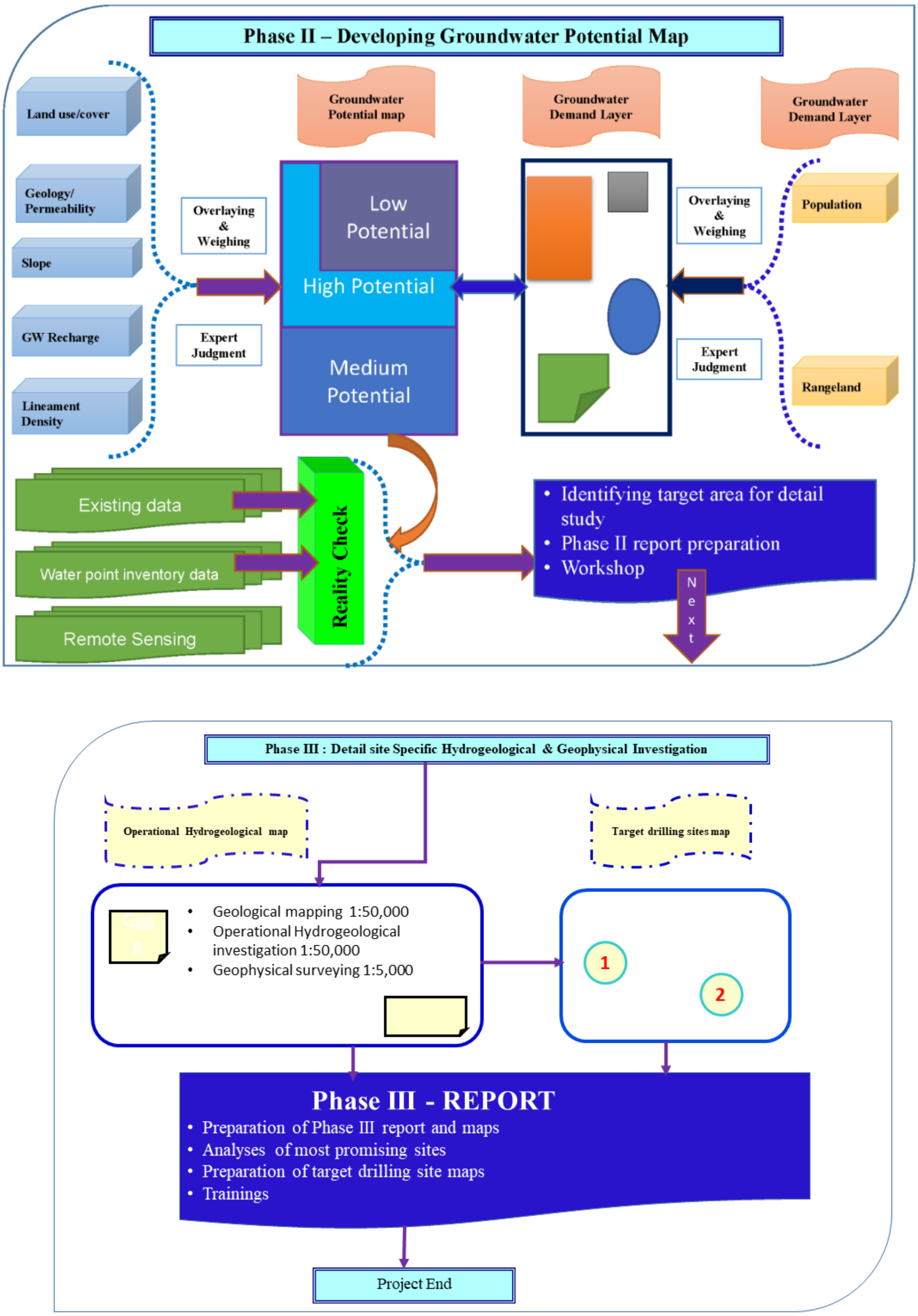


Figure 2: project phases and the main deliverables

Phase II activities and deliverables

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

- Field inventory was carried out and basic groundwater data such as SWL, PH, and EC were measured on-site, a water sample was collected for laboratory analysis, available reports were collected from different, government, and private organizations.
- Climatological datas were collected from NMA and satellite data and also detailed analysis was carried out.
- Hydrological datas were collected from MoWE and detailed analysis was carried out
- Kebeles with Groundwater scarcity were identified by communicating with wereda water office and target population
- Satellite imagery and maps were acquired and interpreted for land cover mapping, Geological mapping, and lineament extraction of the project 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 Groundwater recharge estimation input.
- Groundwater recharge was estimated by using the WetSpass model for Awash basin, and then the Groundwater recharge map was extracted by the respective boundary of wereda.
- Geological map of 1:100,000 was prepared 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.
- Lineament density and Lineament proximity maps were prepared from extracted lineament
- Topographic Wetness Index was generated
- Hydrogeological sections were constructed in order to shows conceptual model.
- Overlay analysis was conducted
- Sensitivity analysis was carried out
- Validation of groundwater potential are tested by data of existing boreholes collected.
- Groundwater potential map is produced
- 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 project wereda is 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:-

- The data scarcity had been filled by collecting existing available hydrogeological information from Wereda and the zone water bureau.
- The capacity building or Knowledge transfer for wereda Hydrogeologist was given and they participated in the groundwater inventory program together with our senior Hydrogeologists.

2. DATA AND METHODOLOGY OF THE STUDY

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

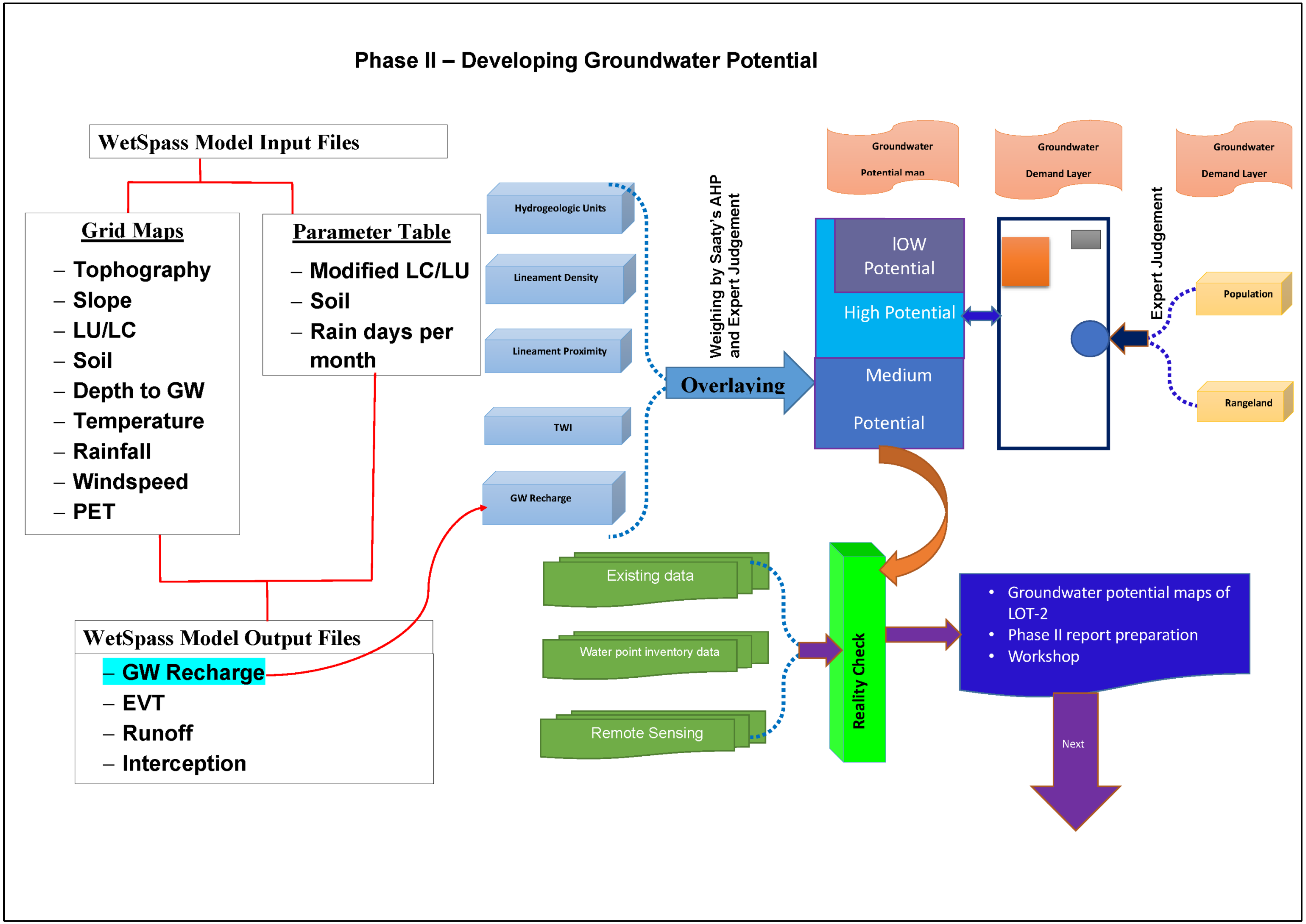


Figure 3: Phase II methods and deliverables

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

Field Inventory and Secondary data

In addition to the remote sensing data, secondary and primary data such as climatological data (Data of 30 years), river discharge data, Demographic data from CSA 2007, FAO soil data, existing groundwater data, water point inventory data, and available groundwater data and reports are collected analyzed. Discharge datas of existing wells is used for validation of Groundwater potential map of the project wereda. The summarized inventory and existing data are presented in table 1 and the raw data is annexed (2).

Table 1 Inventoried and existing water points

Wereda	Inventoried water point				Existing water point			
	BH	Shallow wells	HDW	Spring	BH	Shallow wells	HDW	Spring
Buri Mudaitu	7				2			

Preparation of thematic layers

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

2.2.1 Geological mapping method

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

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

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

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

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

Table 2: Existing geological map and Remote sensing data sources

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

2.2.2 Lineament Extraction method

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

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

Lineament extraction process from SRTM 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 project 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 project weredas. Generally, the lineament extracted by using SRTM 30m and Lineament extracted from Sentinel 1A image were validated by ground-truthing and by comparing with the existing 1:250,000 geological map of the project wereda.

2.2.3 Groundwater recharge estimation method

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

Data used for Groundwater Recharge estimation

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

Table 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, 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.

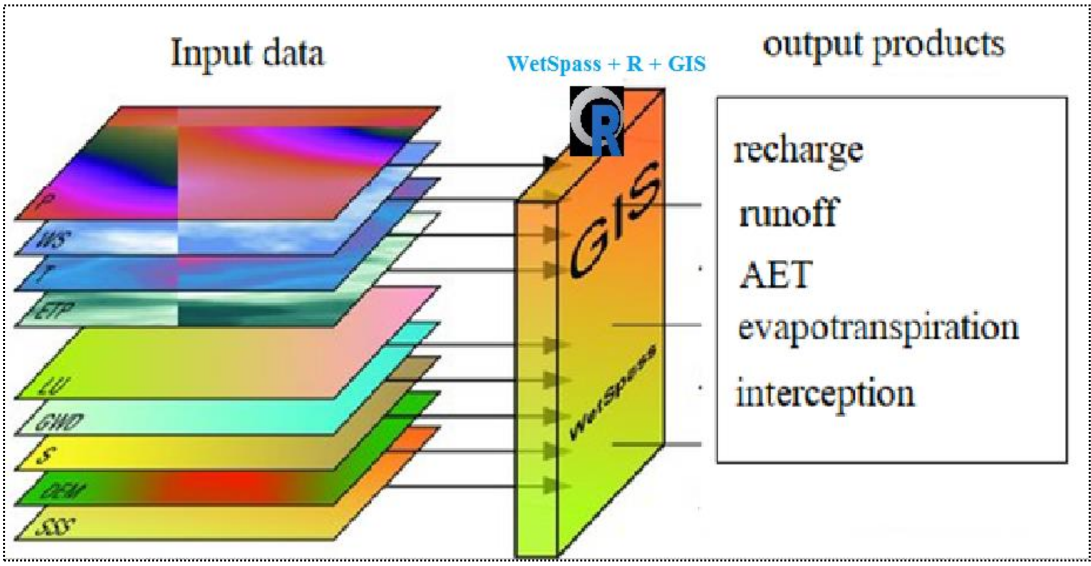


Figure 4 Schematic representation of model used for the study

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 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 (Table 4). The cases that lie on the main diagonal of the matrix represent those correctly allocated, while those in the off-diagonal elements represent errors. Two types of thematic error, omission, and commission, are possible and both may be readily derived from a confusion matrix (Congalton and Green, 1999). An error of omission occurs when a case belonging to a class is not allocated to that class by the classification. Such a case has been erroneously allocated to another class, which suffers an error of commission.

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

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

Table 4 Confusion matrix over true values in the project wereda

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

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

Normalized difference vegetation index (NDVI)

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

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

One of the input spatial layers for the hydrogeology study is NDVI. To calculate NDVI the inputs are availing appropriate imagery and a program that allows interaction with the image data. QGIS is a great, free option for a GIS program that provides the tools to display, analyze and present remotely sensed data. The following steps below are followed in QGIS and its toolbox environment to calculate NDVI for the project 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

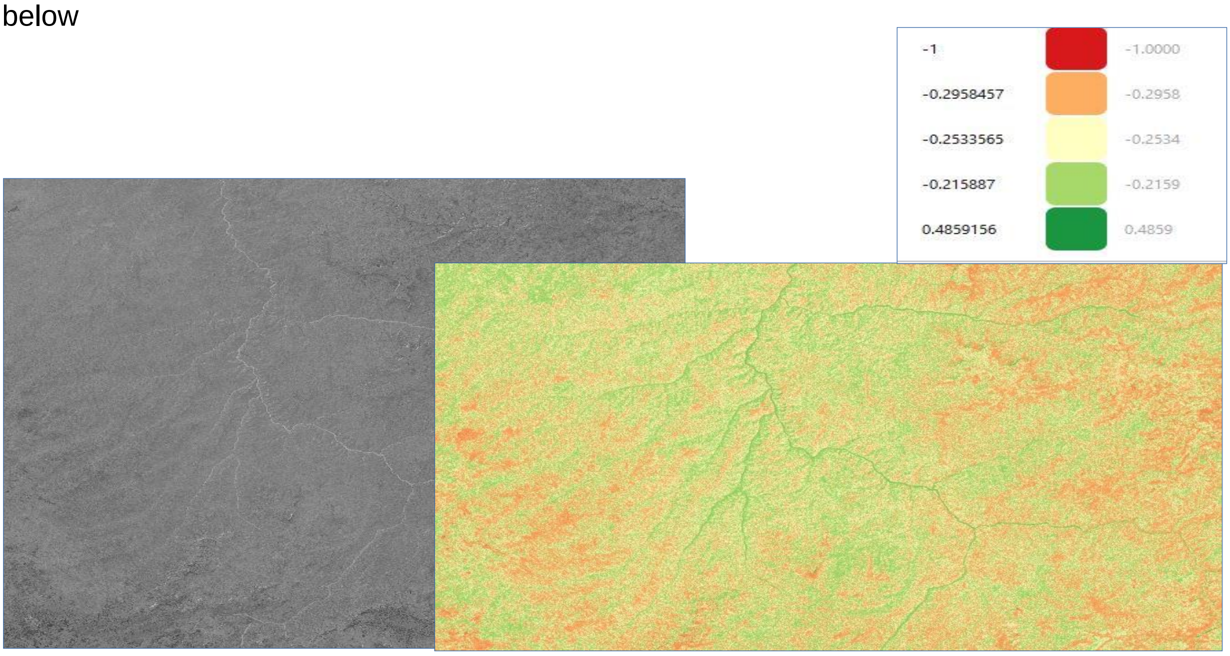


Figure 5: Calculated NDVI using QGIS

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

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

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

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 Dera wereda is estimated to grow at the rate of 3.46%, 2.99% & 2.65% annually in accordance with 2025, 2030 & 2035 CSA estimates of population growth rate for Oromia 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 Dera wereda is projected for the planning period 2035 and the summarized population size is presented in the following tables.

Table 5 Population size of Buri Mudaitu wereda, July 2021 to 2035

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

Table 6 Number of livestock and Livestock and poultry (for private holdings)

Wereda	Cattle	Goats	Sheep	Horses	Mules	Donkey	Poultry	Camel
Buri Mudaitu	88811	113352	48948	4535			48000	60164

3. Conceptual Hydrogeological model of the study area

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

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

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

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

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

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

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

According to an inventory conducted, boreholes drilled on plain areas of this wereda are either dry or saline due to the existence of lacustrine deposits. This fact is supported by a number of one-dimensional VES conducted by ECDSWC (2019) for water supply well sittings that show the existence of geo-electric units that exhibit very low apparent resistivity response. According to the developed conceptual model (Figure 9), Bure Mudayitu wereda and its vicinity groundwater is recharge mainly from subsurface flow from west highland including subsurface inflow from the intermountain valley of eastern Amhara region area through Jewaha outlet, subsurface inflow from southern areas, and surface rivers (mainly Awash River) and flow towards the northeast direction (Figure 6 & 7).

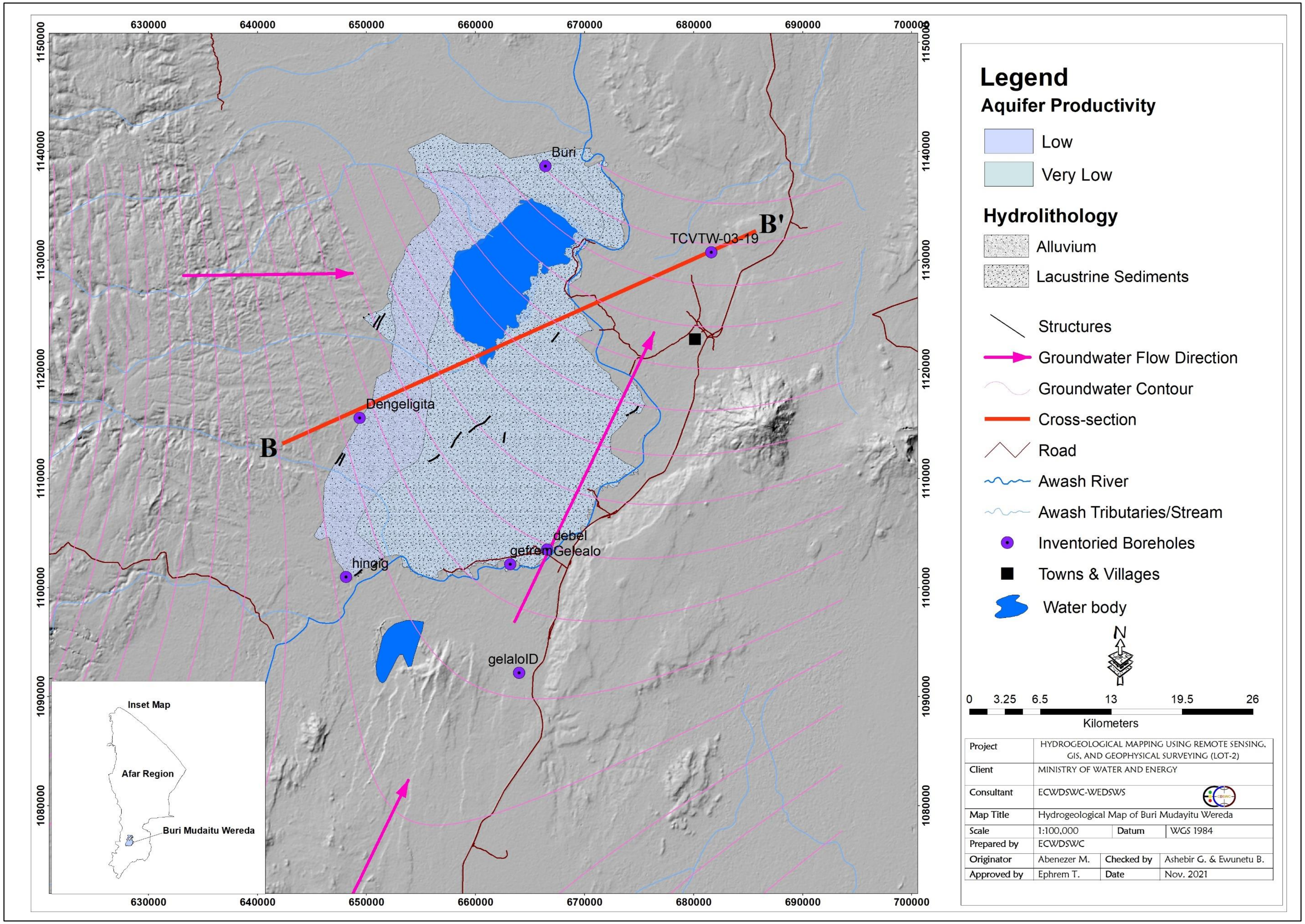


Figure 6 Hydrogeological map of Buri Mudaitu wereda

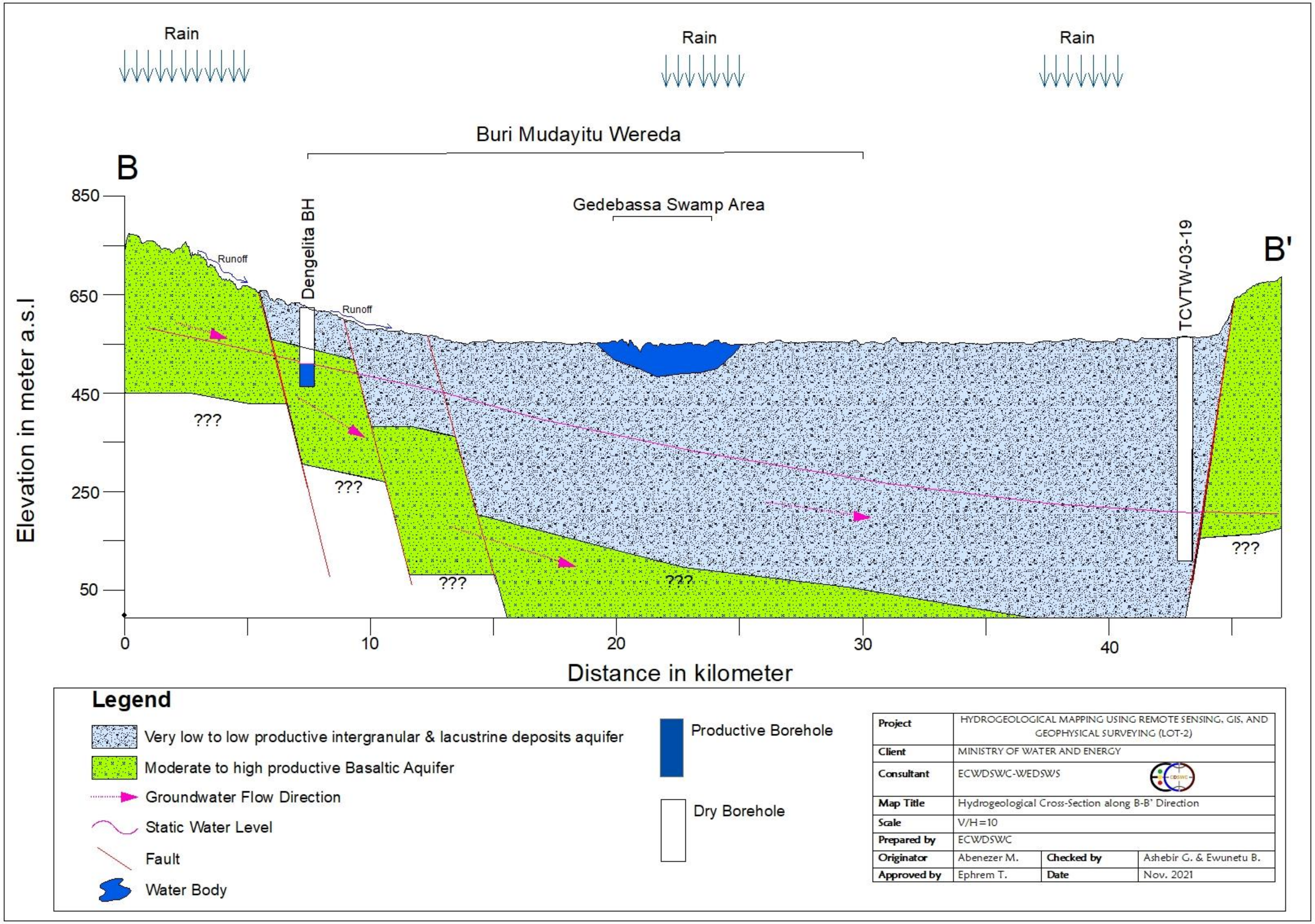


Figure 7 Hydrogeological cross- section along B-B' Direction

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 wereda and weights are determined based on conceptual groundwater system for Buri Mudaitu 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. 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 Buri Mudaitu Wereda

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

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

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

Table 9 : Assigned rank for various classes of all thematic layers of Buri Mudaitu Wereda

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

4.2 Reclassification of Thematic layers

4.2.1 Hydrolithologic 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 Alluvium, basalt and Ignimbrite. 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 study area, hydrogeological units of the Buri Mudaitu wereda were classified as very low and low potential. The reclassified hydrogeological units are presented in figure 8.

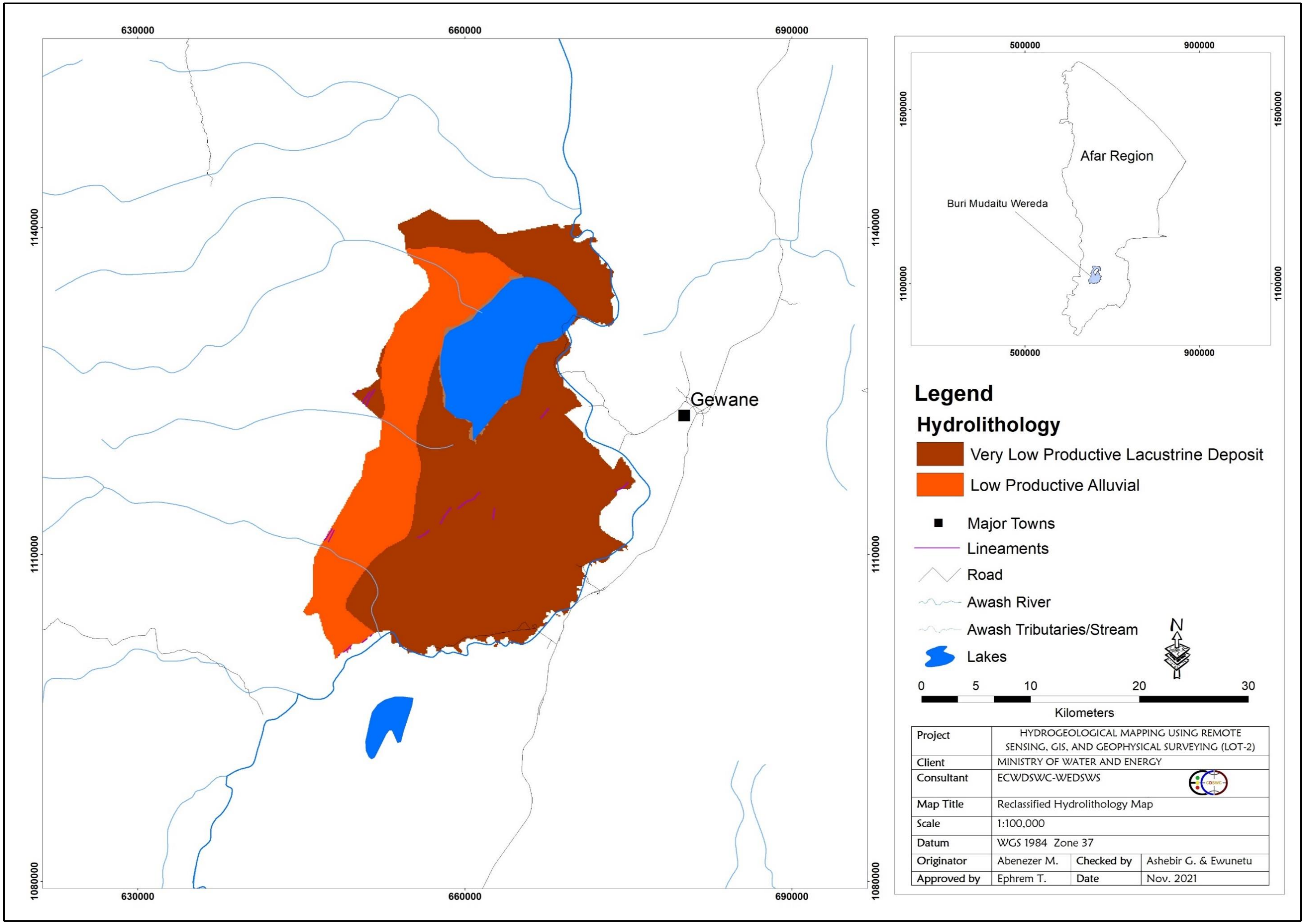


Figure 8 Hydrolithologic units of Buri Mudaitu wereda

4.2.2 Groundwater Recharge

In this study, Groundwater recharge of Awash basin, was calculated by using the WetSpass model, and then groundwater recharge of the study areas had been 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 raster calculator of ARC GIS 10.8 respectively. A brief description of this output will be presented as a separate document in the phase III water balance study report.

There are different models to estimate recharge in a given area depending on actual areal conditions. In this case, the WetSpass model estimates monthly long-term spatial distribution amounts of groundwater recharge of Awash basin 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 shows the yearly groundwater recharge estimated with the WetSpass model of each project wereda. The recharge estimated was used as one thematic layer for groundwater potential mapping of the project 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.

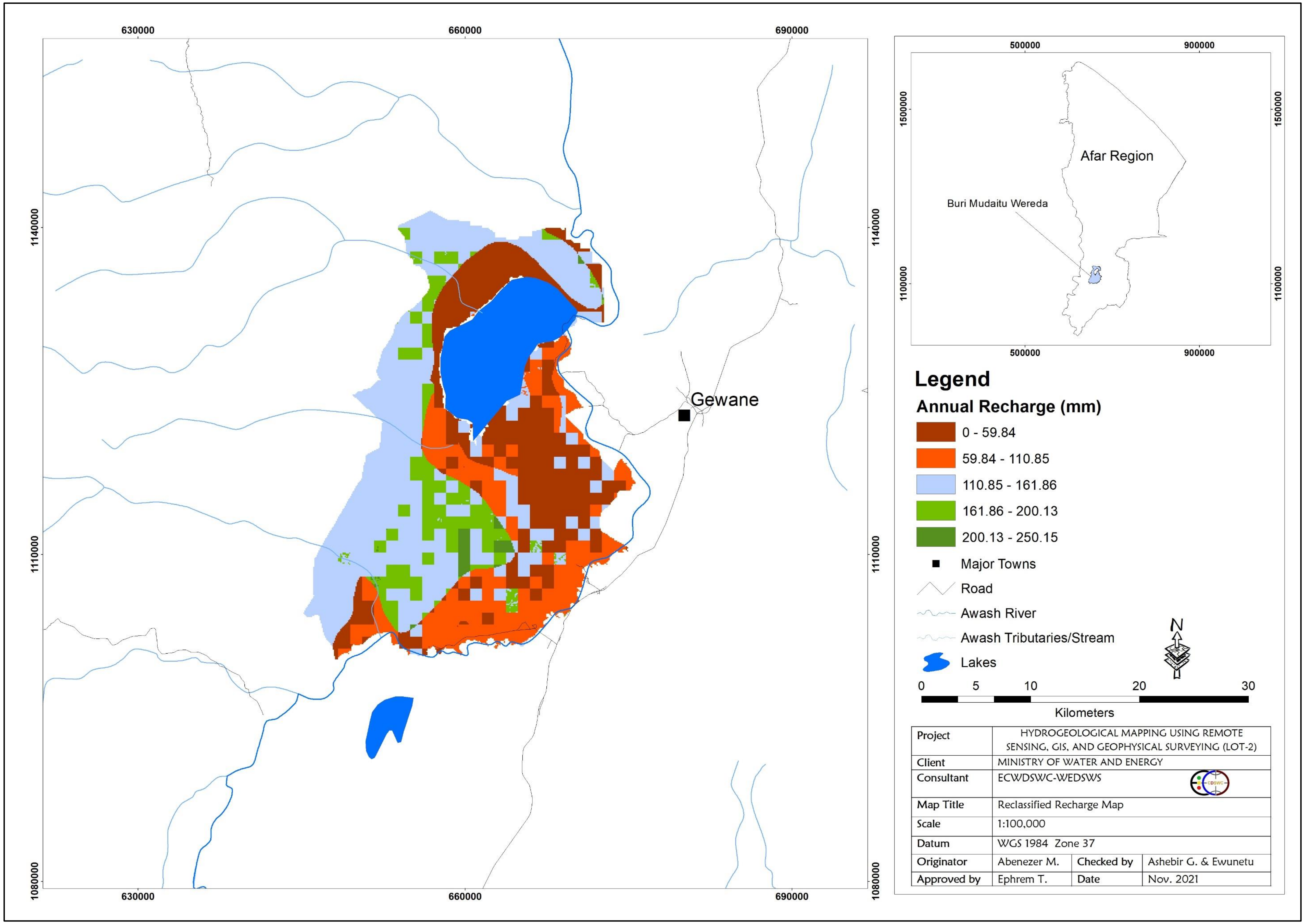


Figure 9 Groundwater recharge map of Buri Mudaitu wereda

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 maps of the Buri Mudaitu wereda.

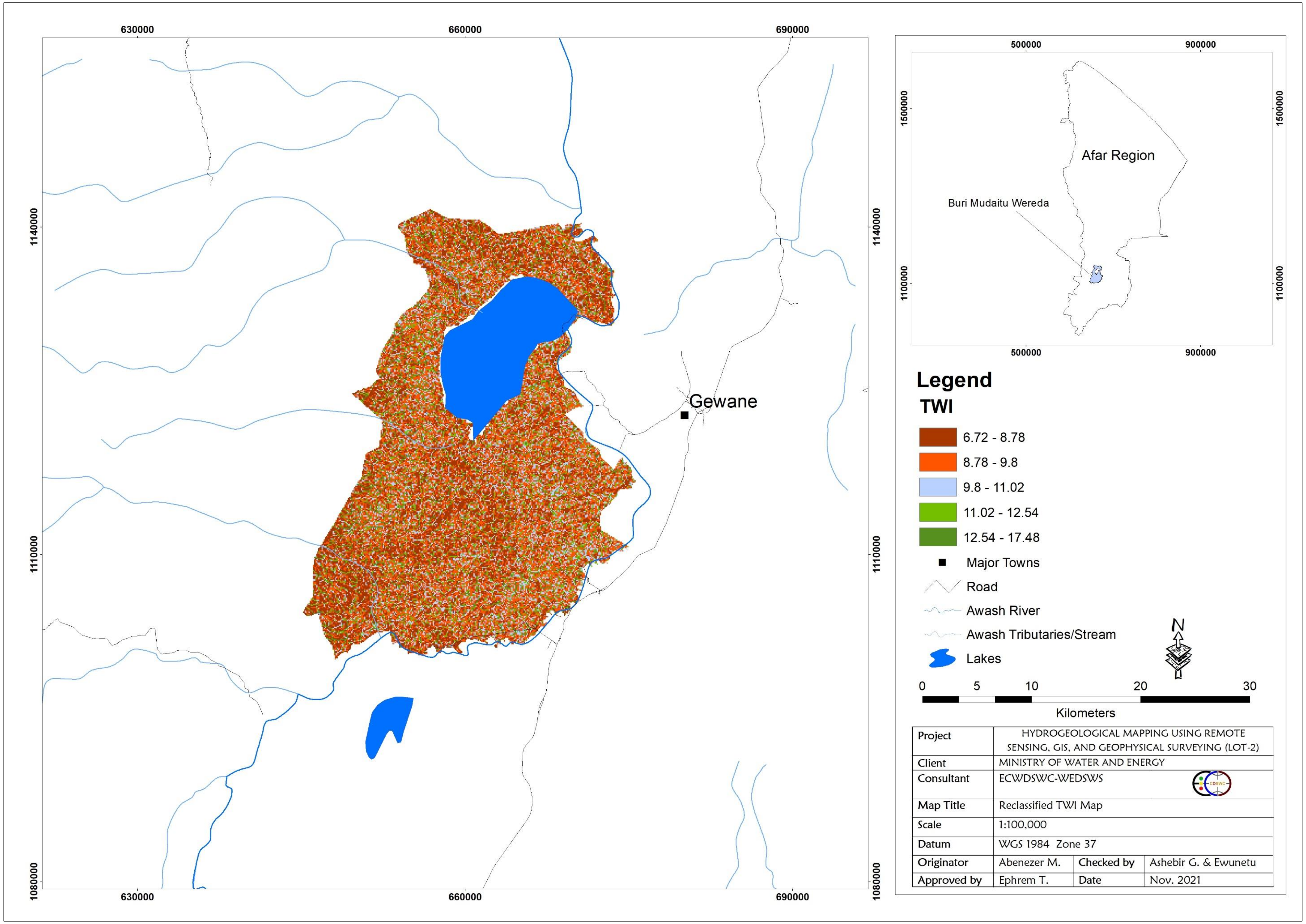


Figure 10 TWI of Buri Mudaitu wereda

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 Buri Mudaitu wereda is classified into five classes, in decreasing order of their relative infiltration capability. These classes were: 5, 4, 3, 2, and 1, representing very high, high, medium, low, and very low density, respectively (Figure 11)

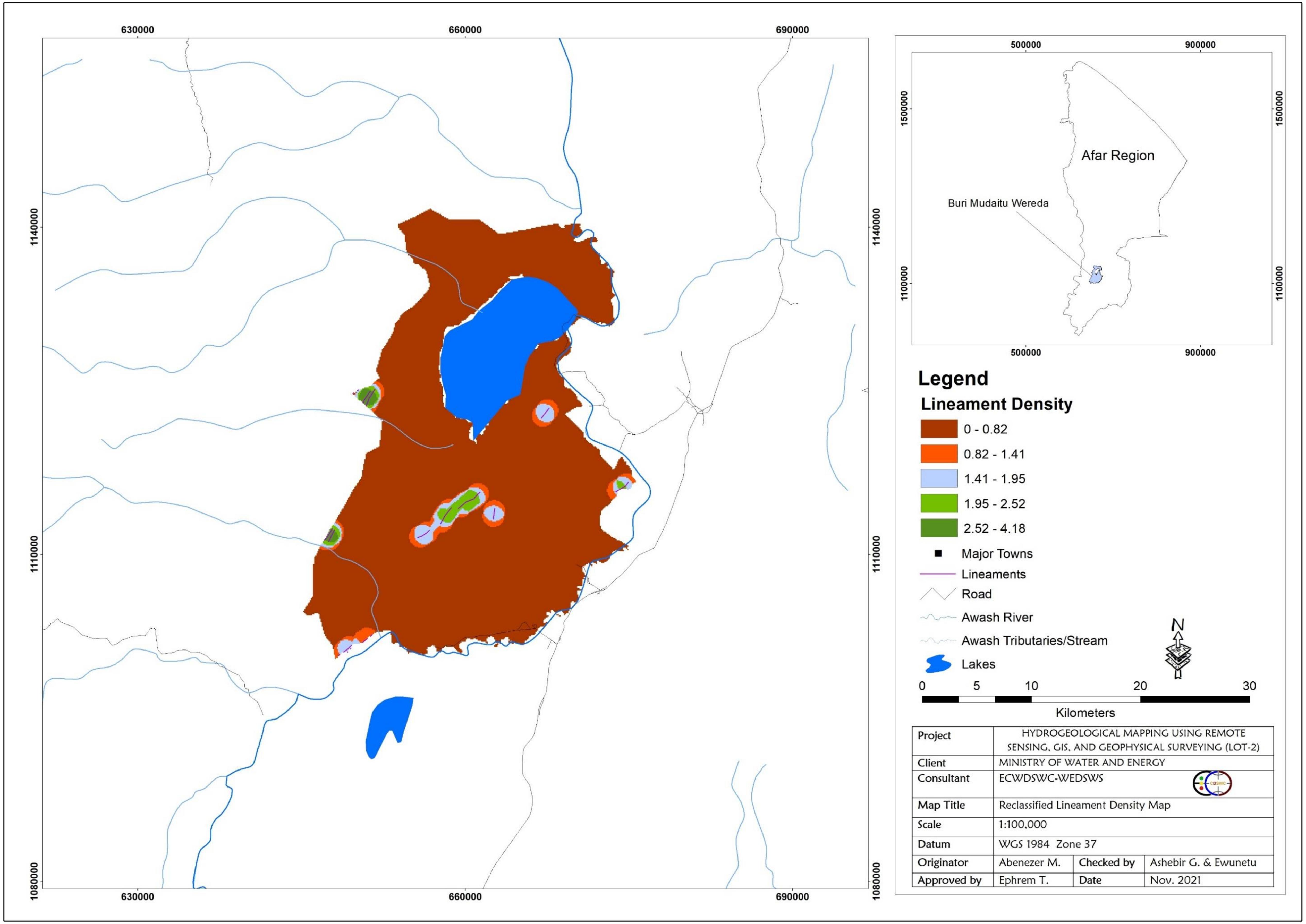


Figure 11 Lineament Density map of Buri Mudaitu wereda

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 project wereda. High weights are assigned to the areas nearby the lineament and low weights to distance locations (Figure 12).

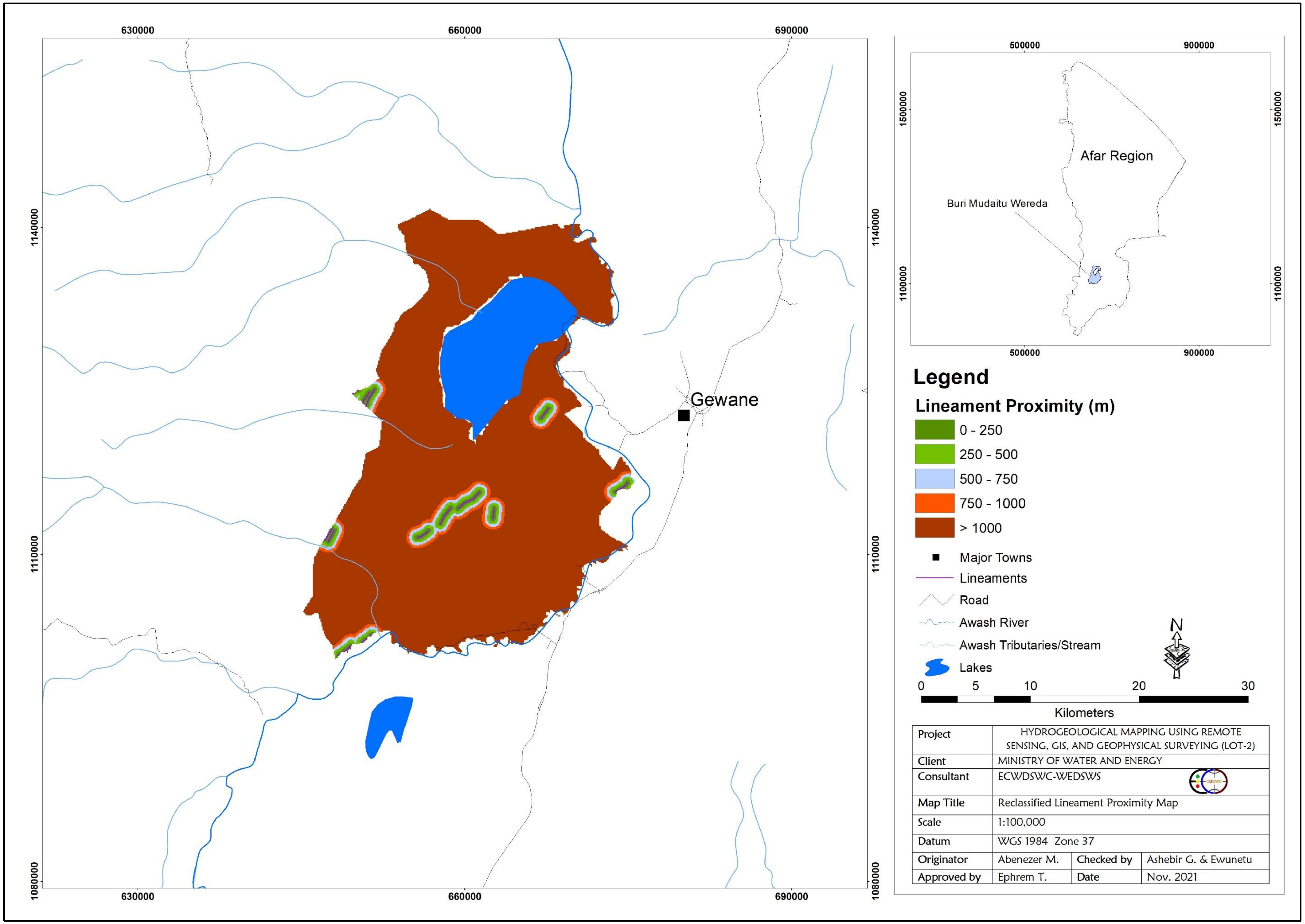


Figure 12 Lineament Proximity map of Buri Mudaitu wereda

4.3 Overlay analysis

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

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

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

4.4 Sensitivity analysis

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

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

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

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.

4.4.3 Single parameter Sensitivity analysis of Buri Mudaitu

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

Table 10: Effective weight of single parameter sensitivity analyses of Buri Mudaitu wereda

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

4.5 Validation using well data

Overlay analysis techniques based on GIS methods have been applied to evaluate the groundwater potential of Buri Mudayitu 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 the wereda, and analysis of previously conducted works. The final output of the work is the production of a groundwater potential map 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.

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

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

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

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

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

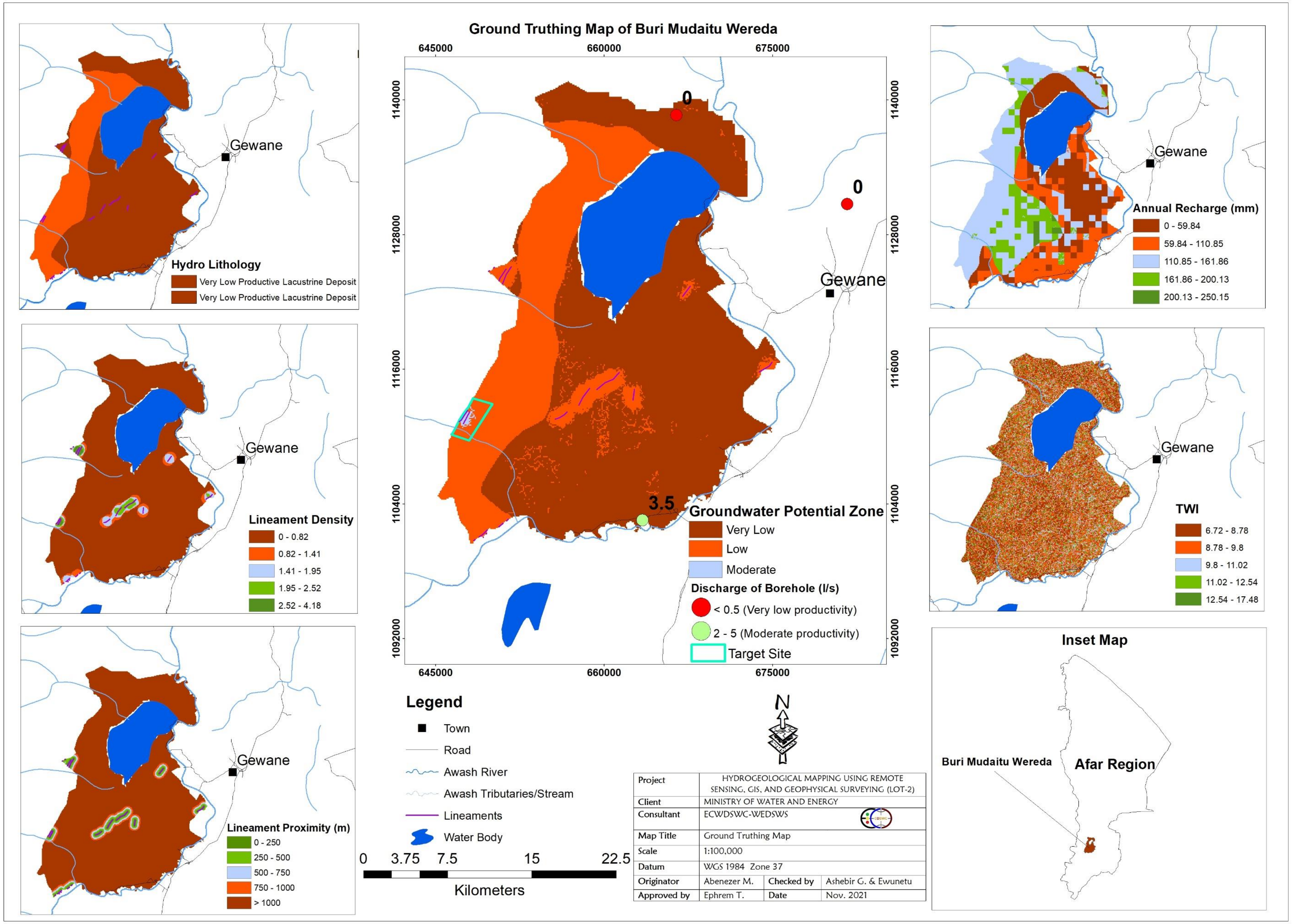


Figure 13 Groundwater potential truthing of Buri Mudaitu wereda

4. 6. Socio - Economy and water demand of Buri Mudaitu wereda

To estimate the water demand of the project weredas CSA projected population data of July 2021 is used.As per the GTP-2 (2016-2020) water supply service level standard, it is required to provide safe water in 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 Dera wereda for water supply of small-town, livestock & rural water supplies water demand are summarized in the table below.

4.6.1 Water demand of Buri Mudaitu wereda

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

Livestock Category											
Shoats	**0.01**	**Cattle**	**0.7**	**Camel**	**1**	**Donkey**	**0.6**	**Chicken**	**0.001**	**TLU**	**Water Demand in m3/day**
162300	579	88811	77710	60164	75206	4535	3401	48000	60	126,676.77	3,167

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

4.7 Groundwater potential Map of Buri Mudaitu Wereda

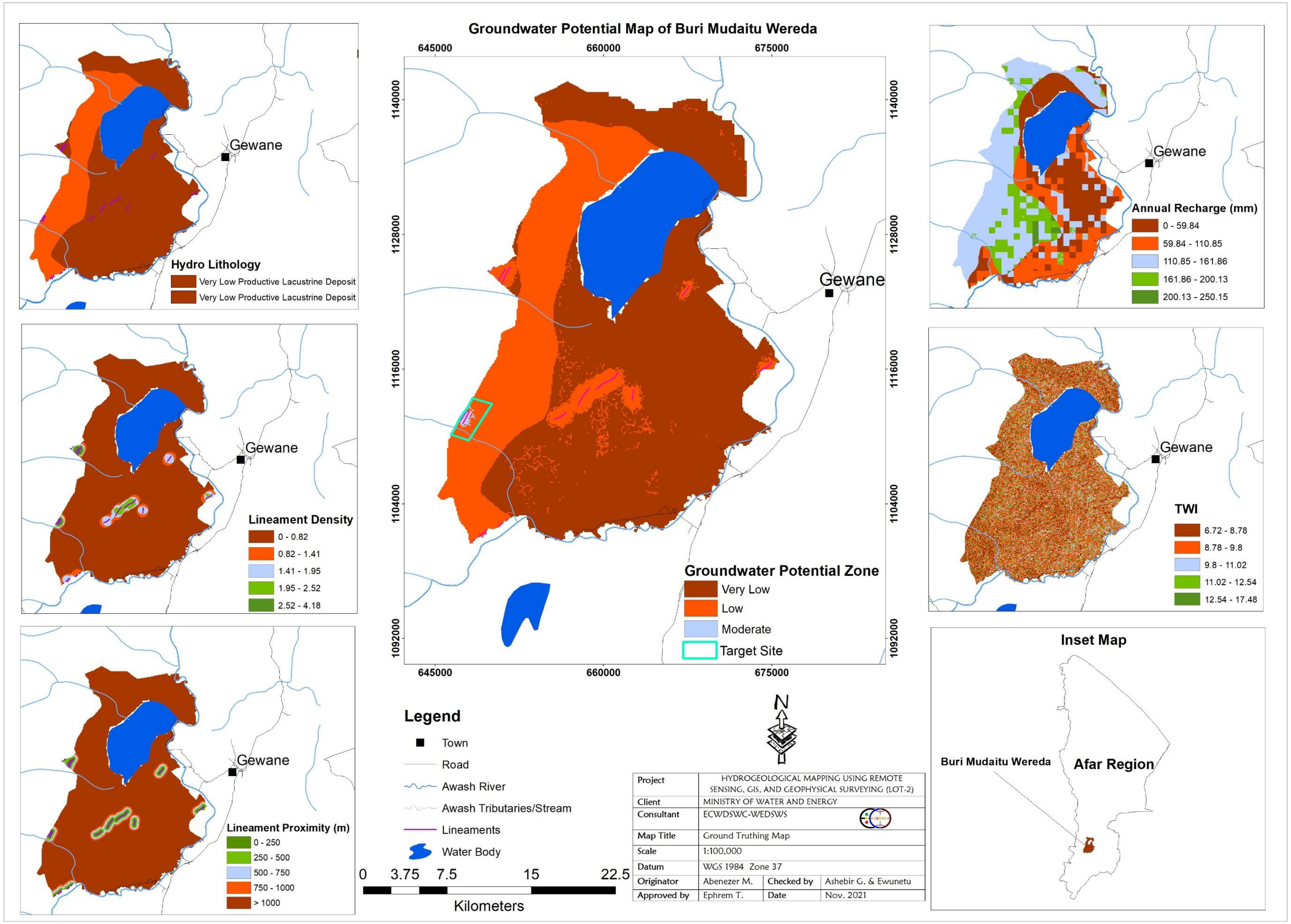


Figure 14 Groundwater potential map of Buri Mudaitu wereda

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 Buri Mudaitu wereda, located in Afar 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 project wereda.

The spatial distribution of the project wereda GWP zones generally match with the conceptual understanding of the project 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

- Ayehu, G.T.; Tadesse, T.; Gessesse, B.; Dinku, T. Validation of new satellite rainfall products over the Upper Blue Nile Basin, Ethiopia. Atmos. Meas. Tech. 2018, 11, 1921–1936.
- Ayele Almaw Fenta & Addis Kifle & Tesfamichael Gebreyohannes & Gebrerufael Hailu (2015), Spatial analysis of groundwater potential using remote sensing and GIS-based multi-criteria evaluation in Raya Valley, northern Ethiopia
- Basavarajappa H.T, Dinakar s and Manjunatha M.C (2016), Validation of derived groundwater potential zones (GWPZ) using geo-informatics and actual yield from well points in parts of upper Cauvery basin of Mysuru and Chamarajanagara districts, Karntaka, India
- Basin water balance modeling, Tendaho Sugarcane Irrigation Expansion Project (WWDSE, 2013)
- 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.
- Corti, G., 2009. Continental rift evolution: from rift initiation to incipient break-up in the Main Ethiopian Rift, East Africa. Earth Sci. Rev. 96, 1–53.
- Ebinger, C., 2005. Continental breakup: the East African perspective. Astron. Geophys. 46, 2.16–2.21. Ebinger, C., Casey, M., 2001 Continental breakup in magmatic provinces: an Ethiopian example, Geology 29, 527– 530.
- FAO. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements- Irrigation and drainage paper 56. Rome, Italy.
- 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.
- Geological investigation of Allaidege plain-volume-II, Allaidege groundwater resources assessment project, WWDSE 2011
- Geophysical investigation of Allaidege plain-volume-III, Allaidege groundwater resources assessment project, WWDSE 2014
- Hallstein lie & Agust Gudmundsson (2002), the importance of hydraulic gradient, lineament trend, proximity to lineaments, and surface drainage pattern for the yield of groundwater wells on Askoy, West Norway.
- Hydrogeological investigation of Allaidege plain-volume-I, Allaidege groundwater resources assessment project, WWDSE 2011
- Hydro-geological Map of Ayelu Terara Sheet NC37-8; compiled by Bawoke Birhan, Robel Asamnew, and Marta Wegu (GSE, 2007)
- Hydro-geological Map of Debrebirhan Map Sheet NC37-11; compiled by Tsehay Amare, Thomas Agzew, Habtamu Yaze (GSE, 2016)
- Hydrogeological survey and investigation in Gelealo/ Burimodaitu wereda, Drought Resilience, and Sustainable Livelihoods Program Phase I (DRSLP- I), ECDSWEC-WEDSWS, October 2018
- Khalid Benjmel, Fouad Amraoui, Said Boutaleb, Mohammed Ouchchen, Amine Tahiri and Amine Touab, Mapping of Groundwater Potential Zones in Crystalline Terrain

Using Remote Sensing, GIS Techniques, and Multicriteria Data Analysis (Case of the Ighrem Region, Western Anti-Atlas, Morocco).

- Kobayashi, S., Ota, Y., Harada, Y., Ebita, A., Moriya, M., Onoda, H., Onogi, K., Kamahori, H., Kobayashi, C., Endo, H., Miyaoka, K., and Takahashi, K., 2015. The jra-55 reanalysis, General specifications and basic characteristics. Journal of the Meteorological Society of Japan. Ser. II, 93(1), 5–48.
- Mahamat Ouchar Al-Djazouli. Karim Elmorabiti. Abdelmejid Rahimi Omayma Amellah. Omer Abdelrahim Mohammed Fadil (2020), Delineating of groundwater potential zones based on remote sensing, GIS and analytical hierarchical process: a case of Waddai, eastern Chad
- Maidment, R.I.; Grimes, D.I.F.; Allan, R.P.; Greatrex, H.; Rojas, O.; Leo, O. Evaluation of satellite-based and model re-analysis rainfall estimates for Uganda. Meteorol. Appl. 2013, 20, 308–317
- Mutreja, K.N. (1995) Applied Hydrology. Tata Mcgraw-Hill Publishing Company Limited, New Delhi.
- R. H. McCuen, 1998, Hydrologic Analysis and design, Department of Civil engineering University of Maryland, USA.
- R.K Linsley, L.H, (1983), PAULHUS, Hydrology for Engineers, McGraw-HILL
- Shaw E.M. (1994). Hydrology in Practice. Second Edition, Chapman and Hall, New York, USA
- Sima, Jiri et al. (2009): Water Resources Management and Environmental Protection Studies of the Jemma River Basin for Improved Food Security. ISBN 978-80-254-5021-5. AQUATEST a.s., Prague, Czech Rep.
- 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.
- 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
- Ven Te Chow, David R. Maindment and Larry W. Mays, 1988, Applied Hydrology, McGraw-HILL International Editions for Civil Engineering Series.
- Well completion report of drlp1w-06-18 (Buri abandoned well site), drought resilience and sustainable livelihood program (DRSLP -1 PROJECT), ECDSWEC-WEDSWS, May 2021
- Well completion report of Gewane (TCVTW-03-19) test well, groundwater resources assessment of south Teru-Chifra areas and surroundings, ECDSWEC-WEDSWS May 2021
- WMO-NO 168, Guide to hydrological practice, Data Acquisition and processing, Analysis, Forecasting, and other applications. Fifth edition, 1994.
- Yates D. (1994), WatBal- An Integrated Water Balance Model for Climate Impact Assessment of River Basin Runoff IIASA Working Paper WP-94-064,
- Zelalem L, Melkamu M., Getnet T., Alebachew T., Mulugeta Ch., Minyahl T.(2019) Appraising groundwater potential zones using geospatial and multi-criteria decision analysis (MCDA) techniques in Andasa-Tul watershed, Upper Blue Nile basin, Ethiopia

- 100 deep production wells drilling supervision project of groundwater resources evaluation of Allaidege plain

Annex 1: Groundwater truthing and validation

No.	Region	Wereda	Locality	UTM E	UTM N	Elv.	Characteristic of validation point
1	Afar	Buri Mudaitu wereda	Dengeligita	649387	1115566	638	▪ The observation point is mountain side, there is one deep well with unknown discharge but currently functional, no shallow well, no hand dug well, no spring and alluvial deposit is the observed formation ▪ The area is mapped as low groundwater potential zone
2			Buri	666420	1138650	562	▪ The observation point is on flat plain sloping up to NE areas. There is one deep (400 meter) and dry well, no shallow well, no hand dug well & no spring. Lacustrine deposit and clay is observed formations of the area. ▪ The area is mapped as very low groundwater potential zone
3			Gefrem	663399	1102584		▪ The observation point is close to Awash river. There is one borehole of unknown depth and 3.5 l/s yield. Lacustrine deposit is observed formations of the area. ▪ The area is mapped as very low groundwater potential zone. However, promising yield (3.5) and shallow static water level (3m) of inventoried borehole shows that bank infiltration of nearby Awash River deemed to recharge the groundwater.

Annex 2: Water point inventory data

ID	Locality	Region	Wereda	UTM E	UTM N	Elv, m.a.s.l	Depth, m	SWL, m	Q, l/s
Gelalo	Gelalo tawon	Afar	Buri Mudayitu	663997	1092186	572	100	29.00	
Debel	Debel	Afar	Buri Mudayitu	666571	1103508	2463			
Buri		Afar	Buri Mudayitu	666420	1138650	562	400		
Gefrem	Gefrem	Afar	Buri Mudayitu	663190	1102147	558		artesian	
Debel	Debel	Afar	Buri Mudayitu	666571	1103508	2463		artesian	
Hingig	Hingig	Afar	Buri Mudayitu	648123	1100973	600		13.60	
Dengeligita		Afar	Buri Mudayitu	649387	1115566	638	161		
Debel	Debel	Afar	Buri Mudayitu	666637	1103684	572	60		
Gefrem	Gefrem	Afar	Buri Mudayitu	663399	1102584			3	3.5
TCVTW-03-19		Afar		681626	1130742		456		

Annex 3: Geologic map of Buri Mudaitu Wereda