FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA
MINISTRY OF WATER AND ENERGY

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

ANNEX-VII: DEVELOPING GROUNDWATER POTENTIAL MAP OF DERA WEREDA (FINAL)

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

PHASE II– DEVELOPING GROUNDWATER POTENTIAL MAP

ANNEX-VII: DEVELOPING GROUNDWATER POTENTIAL MAP OF DERA WEREDA

FINAL REPORT

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Executive Summary

The current study aimed at delineating groundwater potential zones of Dera 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 Dera wereda Wereda for satisfying human needs.

In the study, RS (Remote Sensing) and GIS (geographic information system) were utilized to generate five thematic layers, Hydrogeological units, Groundwater recharge, Lineament density, Lineament proximity, and TWI as factors influencing the groundwater potential. All the thematic layers were then assigned weights according to their relative importance in groundwater occurrence and corresponding normalized weights were obtained based on 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 map 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 Dera Wereda GWP zones generally matches with the conceptual understanding of the Dera 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 layer show some deviation from empirical weights. The GWP map produced will be used to quickly identify the prospective GWP zones for conducting site-specific investigations.

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

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ABREVIATIONS AND ACRONYMS

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

SAR	-	Synthetic Aperture Radar
SCP	-	Semi-automatic Classification Plugin
SNAP	-	Sentinel Application Platform
SWL	-	Static water level
TDS	-	Total Dissolved Solids
ToR	-	Terms of References
TWI	-	Topographic Wetness Index
UTM	-	Universal Transverse Mercator
VES	-	Vertical Electrical Sounding
W.E.D.S.W.S	-	Water & Energy Design and Supervision Works Sector
WetSpass	-	Water & Energy transfer between soil, plants & atmosphere
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 Dera Wereda.

It is the initiation of the client to conduct a groundwater study to make a groundwater potential map and to identify a promising drilling target site for borehole and alternative drilling site in the Dera wereda.

The current study aimed at delineating groundwater potential zones of Dera 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 for satisfying human needs.

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

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

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

Chapter-2: Data and Methodology of the study

Chapter-3: Conceptual Hydrogeological model of the study area

Chapter-4: Result and discussion

Chapter-5: Revised work plan for Phase – III

Chapter-6: Conclusion and Recommendation,

Chapter-7: References

1.2 Location of Dera wereda

Dera wereda is located in the North Shewa Zone of Oromia National Regional State. The study area is accessible by all-weather roads that connect Addis Ababa–Fiche– Gundo Meskel town. The main asphalt road from Addis Ababa to Gundo Meskel town is about 231.1 kilometers. The whole of the project area is confined between the geographic coordinates of UTME 427003 - 482219 and UTMN 1110111 - 1148551 and topographically the study area is the northern part is plain land and the southern part rugged and deep gorge (Figure 1).

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

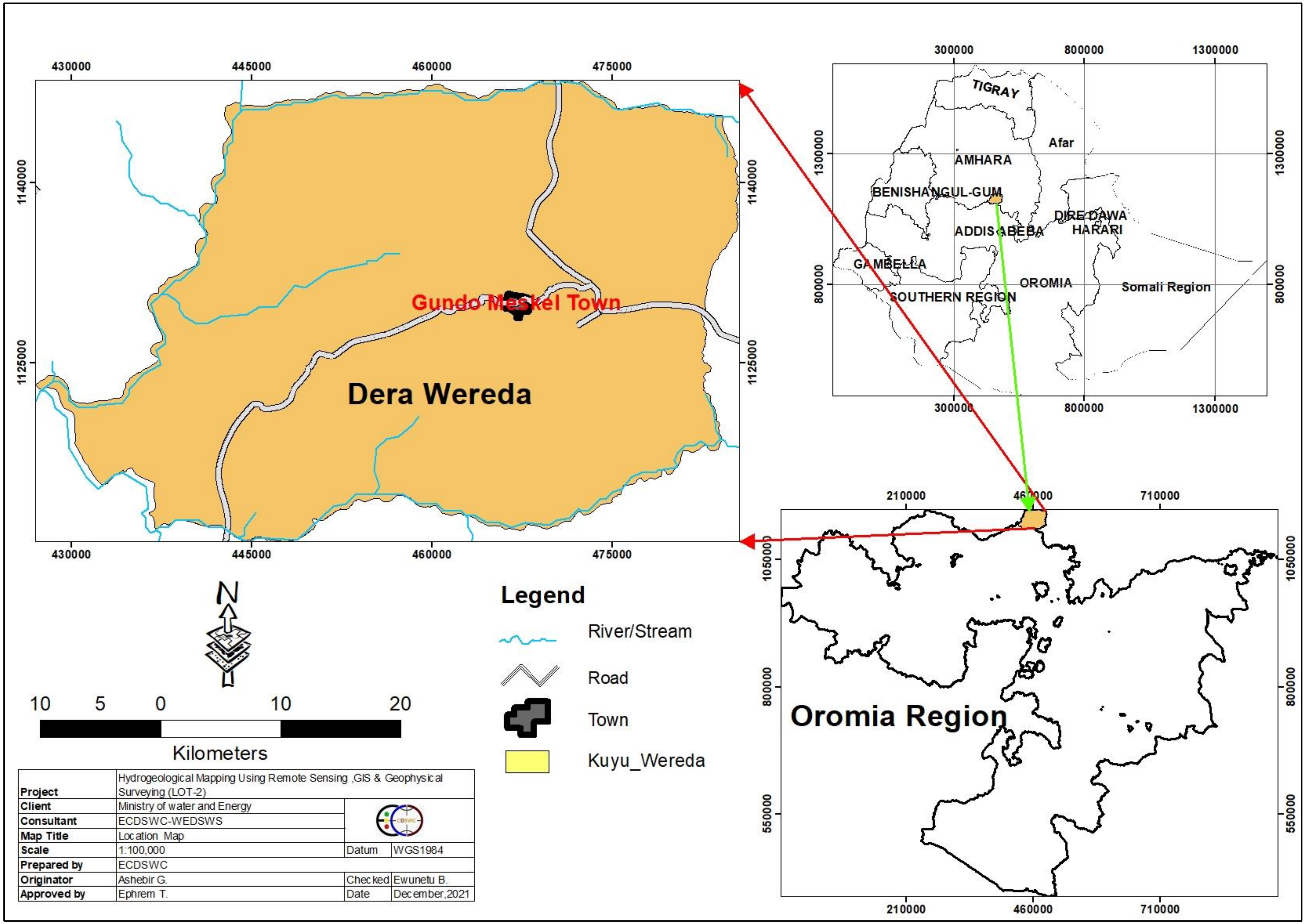


Figure 1: Location of Project area (LOT-2)

1.3 Objectives of the Study

The main objective of this project is to produce operational hydrogeological maps and recommend drilling sites for Dera Wereda 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 one most promising drilling site for groundwater abstraction and one alternative (optional) drilling site for Dera Wereda. 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 map for target sites
- Identify one optimal drilling site and one alternative (optional) drilling site per Wereda, using these maps and geophysical field investigation, and recommend the type of drilling methodology to be employed.
- Build the capacity of MOWE, Regional governments, and NGOs to use overlay analysis techniques for groundwater potential mapping in Ethiopia.

1.4 Scope of Works

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

The ultimate goal of the project will be to produce operational Hydrogeological maps and to identify the most suitable site for drilling. Therefore, this project will be focused on the preparation of Operational hydrogeological maps of Dera Wereda of LOT- 2 projects and identification of target sites for borehole drilling with enhanced drilling success rates and optional drilling sites for Dera 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 select target drilling site maps. The technical route is depicted in figure 2 below

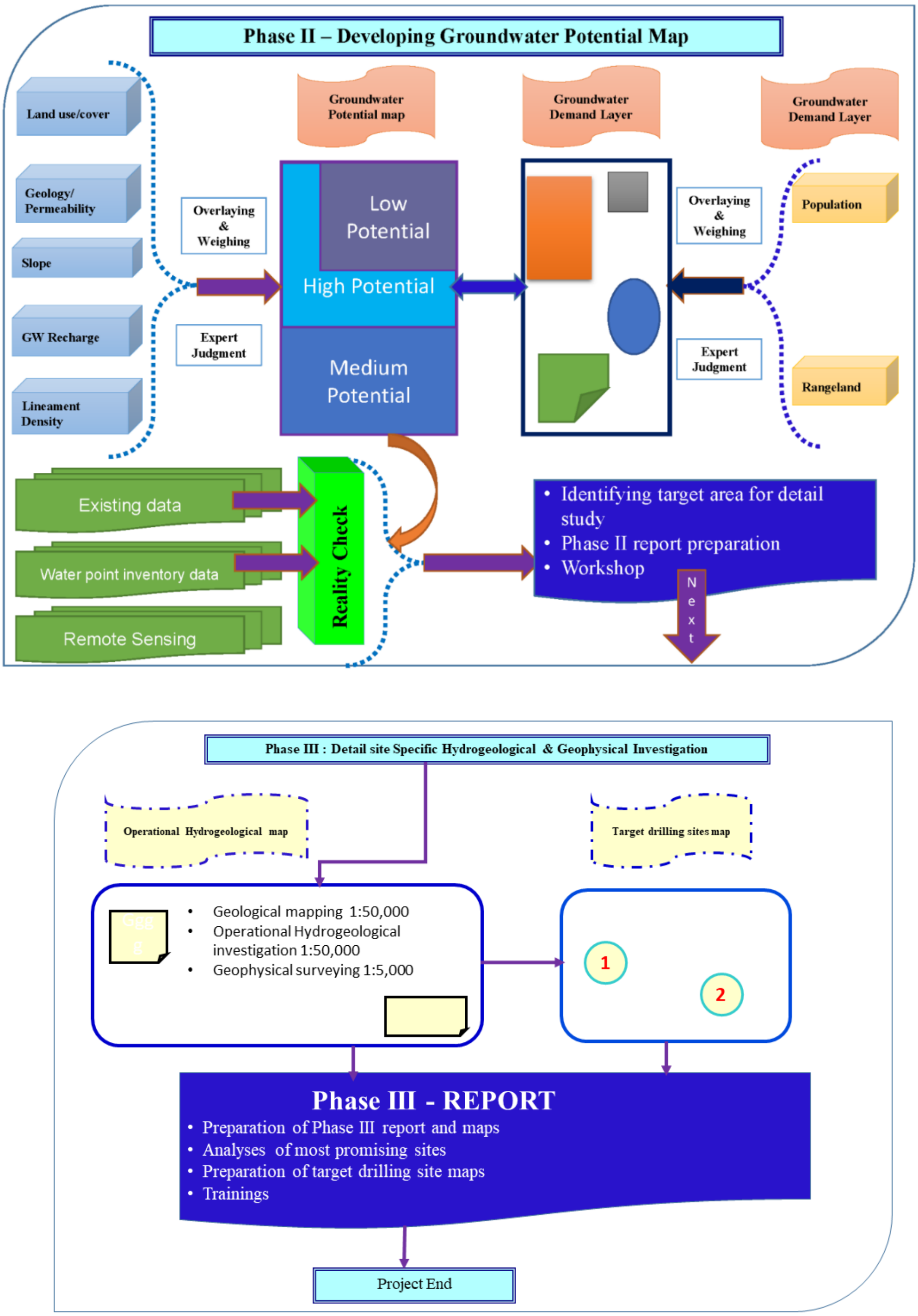


Figure 2: The project phases and the main deliverables

Phase II activities and deliverables of Dera Wereda

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

- Field inventory was carried out and basic groundwater data such as SWL, PH, and EC were measured on-site, a water sample was collected for laboratory analysis, available reports were collected from different, government, and private organizations.
- Climatological data was collected from NMA and Satellite data and detailed analysis 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 Dera Wereda.
- Land cover, Soil, Depth to groundwater, Temperature, Rainfall, Wind speed, PET, Elevation map was 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 the Abay basin and then the Groundwater recharge map was extracted by the Dera wereda boundary.
- Geological Map 1:100,000 was prepared for Dera wereda from existing 1:50,000 scale base map 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 Dera Wereda.
- Lineament density map and Lineament proximity map was prepared from lineament map
- Topographic Wetness index was generated for the Dera Wereda
- Hydrogeological Sections was prepared for the Dera Wereda
- Overlay Analysis has been carried out for the Dera Wereda
- Sensitivity analysis was carried out for the Dera Wereda
- Validation of groundwater potential was carried out for the Dera Wereda
- The groundwater demand layer was prepared based on projected project CSA data.
- Groundwater potential map was prepared for Dera wereda
- Phase II report writing and submission

1.6 Risks and mitigation measures

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

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

The proposed mitigation measures are depicted as follows:-

- 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 Hydrogeologists 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 map, map updating according to field observations, digitization, and processing of image using software like WetSpass model M1.3, Arc GIS 10.8,Saaty's AHP (K.D.Version 15.09.2018), PCI Geomatrica, ESA-SNAP, ERDAS Imagine and ENVI classic software's and interpretation (See figure 3). In this study, RS (remote sensing) and GIS (geographic information system) 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 Saaty's Analytical Hierarchy Process (AHP). Based on the rank assigned by the conceptual understanding of the Dera Wereda and weights aggregating the thematic maps is done using a weighted overlay method to obtain a groundwater potential (GWP) map. The GWP map is verified by overlay analysis with observed borehole yield data. Single – Parameter sensitivity analyses are used to compute effective weights.

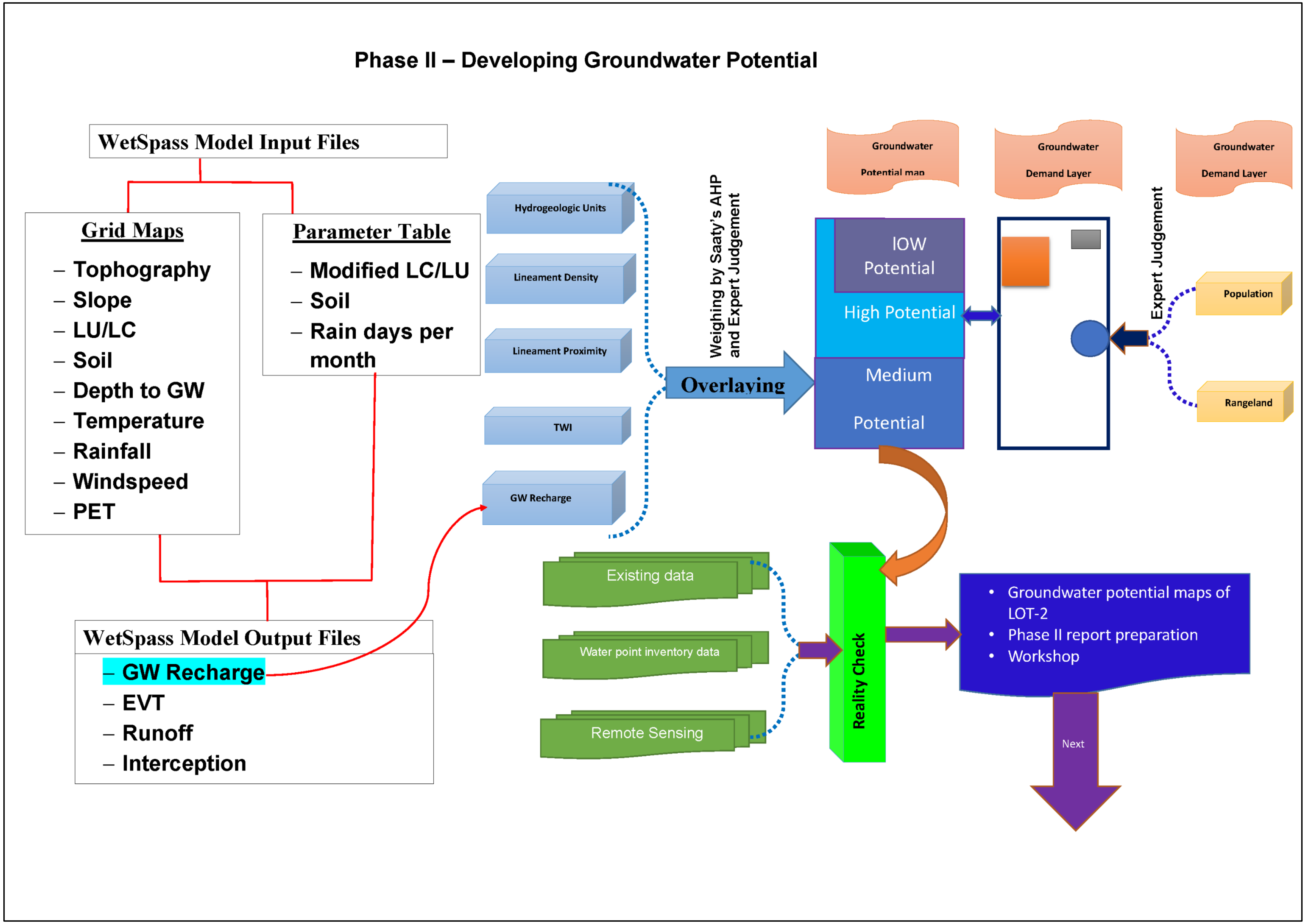


Figure 3: Phase II methods and deliverables

2.1 Remote Sensing data, Field Inventory, and Secondary data

Remote Sensing data

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

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

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

Field Inventory and Secondary data

In addition to the remote sensing data, Secondary and primary data such as 30 years of climatological data, river discharge data, Demographic data from CSA 2007, FAO soil data, existing groundwater data, water point inventory data, and available Groundwater data and reports are collected analyzed. The Transmissivity and well discharge data were used for validation of the Groundwater potential map of the Dera 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
Dera	2	-	67	2	-	-	2	1
Grand Total	2	-	67	2	-	-	2	1

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 Dera 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 map the rank is assigned to each thematic layers attribute based on the conceptual understanding of the Dera Wereda, the map was converted into raster format and then weighted overlay analyses were carried out according to assigned suitable weights in the order of their hierarchy process (AHP) (Saaty 1980, 1992) to each thematic layers. Thematic maps for each parameter are prepared as follows.

2.2.1 Geological mapping method of the study area

The present work is intended to produce a Geologic map of Dera 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 map and review the available geological map in order to get a general overview of the geology of the area and to identify the gaps and fill these gaps by a 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 the geological map,
(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 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 software (ArcGIS, ERDAS Imagine, ENVI, Global Mapper, GeoMatica) together with the existing geologic map were used to prepare the geological map of the Dera Wereda at a scale of 1:100.000. The Geology map of the Dera Weredais 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) 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°, 135°220°, and 345° azimuth and sun angle of 30°,). PCI Geomatica software was used for the automatic lineament extraction. These steps were carried out under the different thresholds, and then lineament extracted was manually filtered by overlaying hill shade, drainage density, and road map of the Dera 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 Dera Wereda. 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 Dera 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 weredas upstream hydrological characteristics, particularly for all wereda where Main River crosses its boundary by considering the recharging source could be the cumulative effect both the drainage within wereda or rivers crossing this wereda. As the result, all upstream portions of the Dera 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 Abay River Basin (Ampe et.al. 2012). A list of data that was used as input after resampled into 100m by 100m is presented in table 3. The spatial representation of land use, soil, Rainfall, Temperature, wind speed, PET and Elevation map, 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 Dera wereda and eventually to understand long term mean annual recharge of the chosen weredas.

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

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

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

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

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

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

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

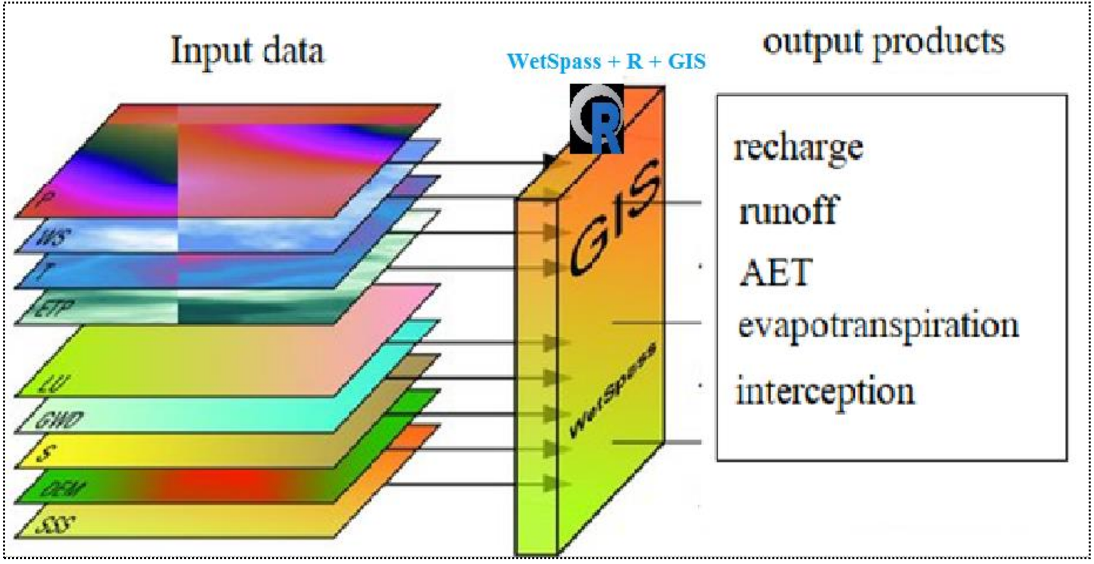


Figure 4: Schematic representation of model used for the study

Land cover data Extraction method

Downloading and processing raster data for land cover classification

Cloud-free Sentinel 2 imagery that has a higher spatial resolution (10 m) is used for LULC image classification. In this stage over 18 sentinels - 2b images were downloaded and pre-processed (geometrically and radiometrically 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 (subsetting, 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 Dera wereda over the project area.

The accuracy assessment aims to provide an index of how closely the derived class allocations depicted in the thematic land cover map represent reality. In essence, the summary metrics of accuracy provide a measure of the degree of correctness in the class allocations in the map. Attention is, therefore, focused on thematic accuracy. The confusion matrix is well suited to this task (Table 4). The cases that lie on the main diagonal of the matrix represent those correctly allocated, while those in the off-diagonal elements represent errors. Two types of thematic error, omission, and commission, are possible and both may be readily derived from a confusion matrix (Congalton and Green, 1999). An error of omission occurs when a case belonging to a class is not allocated to that class by the classification. Such a case has been erroneously allocated to another class, which suffers an error of commission.

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

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

Table 4: confusion matrix over true values in the Dera 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 Dera 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

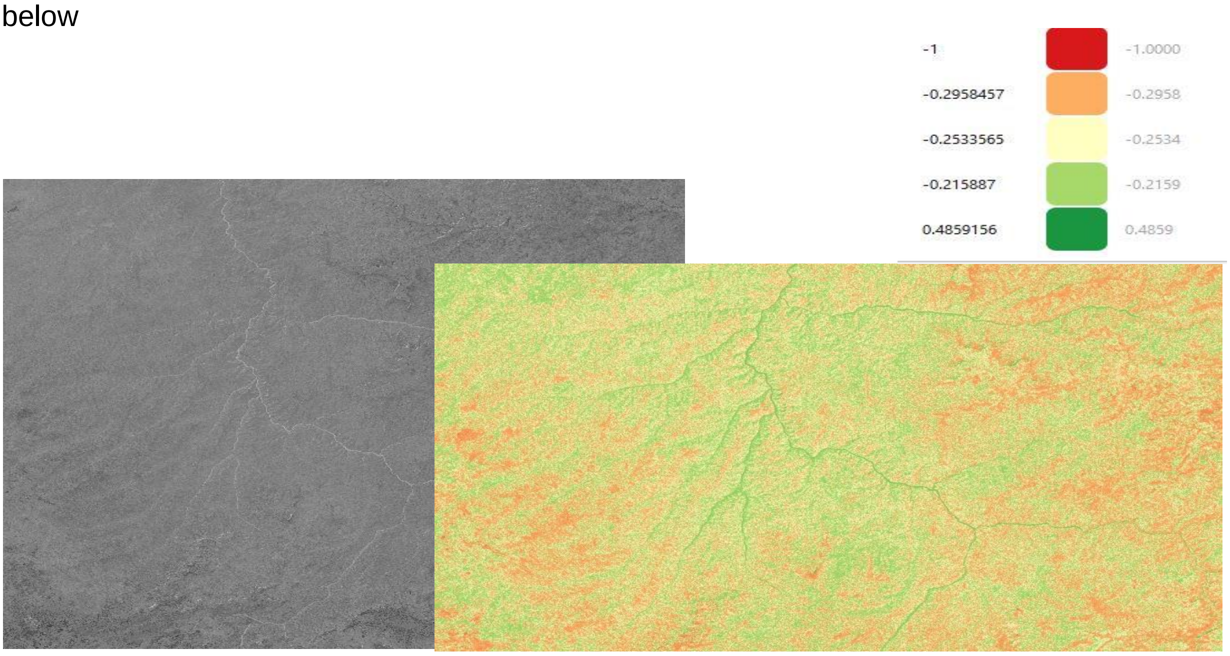


Figure 5: calculated NDVI using QGIS

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 Dera Wereda

In order to estimate water demand knowing the 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 Dera wereda, July 2021to 2035

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

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

Wereda	Cattle	Goats	Sheep	Horses	Mules	Donkey	Poultry
Dera	173551	40568	17350	132	397	27583	60000

3. Conceptual Hydrogeological model of the study area

3.1 Hydrogeological condition of Dera Wereda

Based on hydraulic characteristics of rock units, spring discharge, depth to the groundwater, mode of recharge, and groundwater intake to their system, the Hydrogeological condition of Dera wereda is conceptualized and discussed as follows:

Conceptual Hydrogeological model of Dera wereda

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

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

As depicted on the hydrogeological map and also cross-section constructed along the groundwater flow path to conceptualize groundwater flow and storage in this wereda (Figure 6 and 7), the local geomorphic setup and subsurface configuration of permeable and impermeable rock units control the depth and pattern of groundwater circulation in the area.

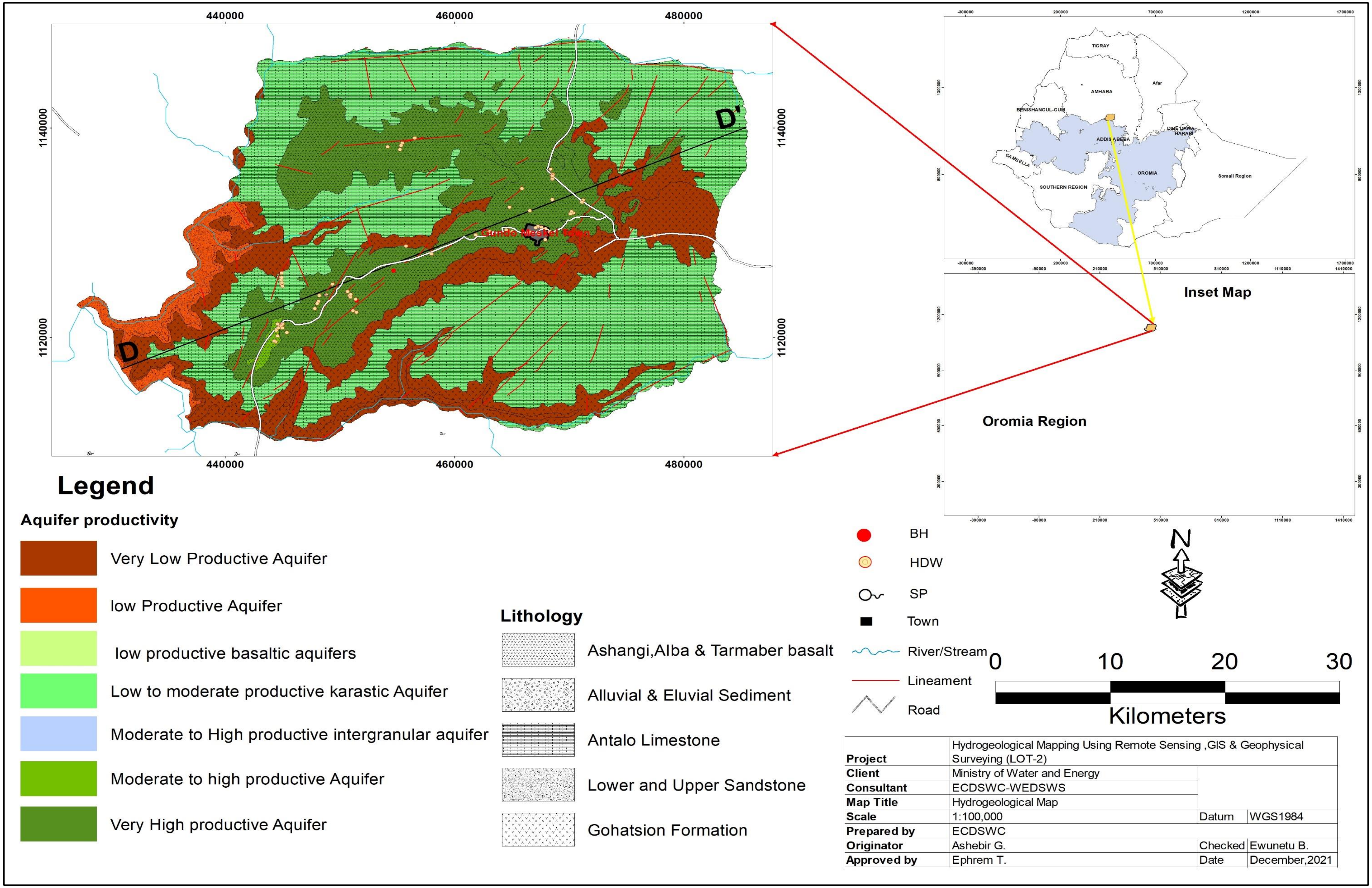


Figure 6 : Hydrogeological map of Dera wereda

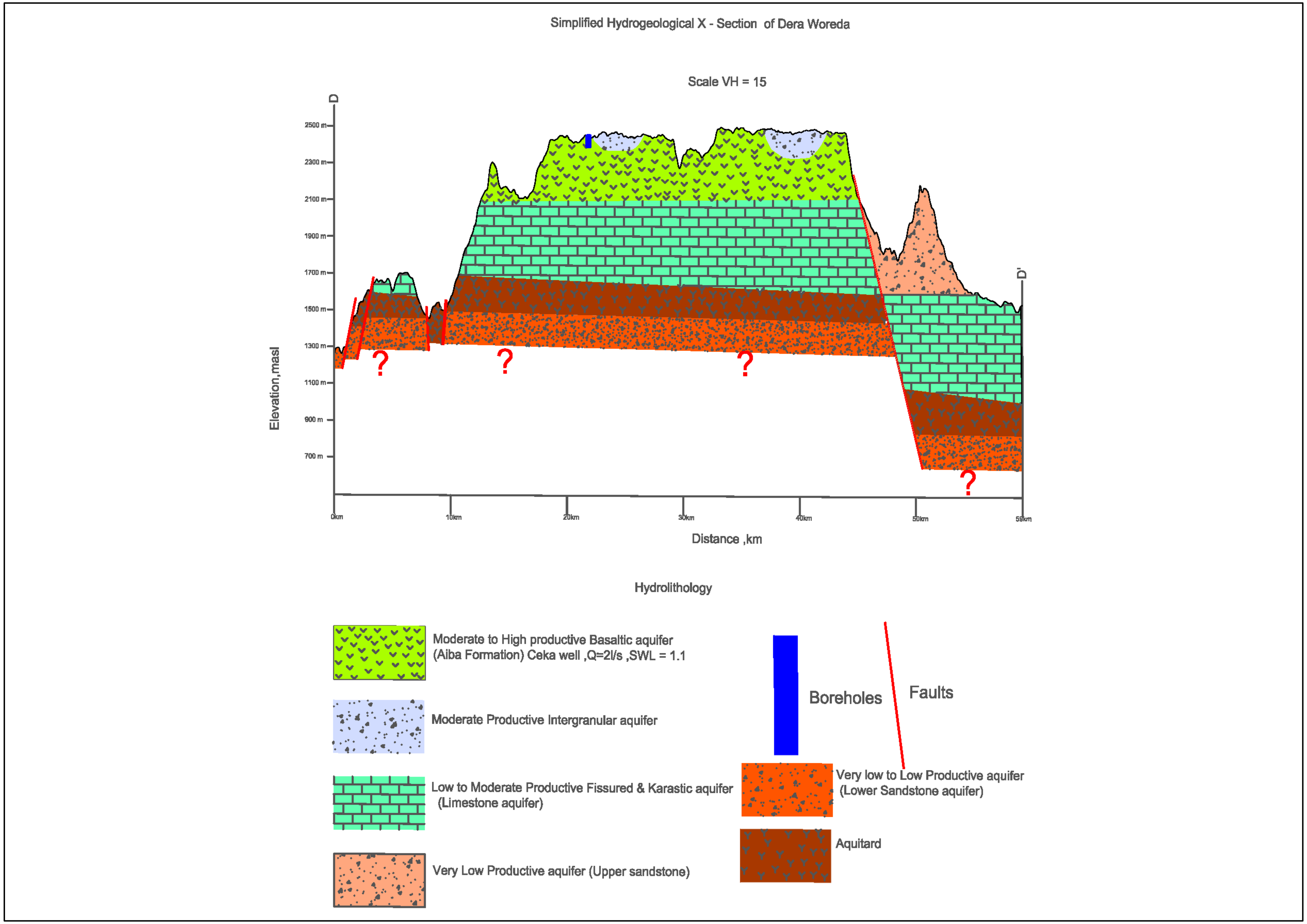


Figure 7 : Hydrogeological section of Dera weredas

4. RESULT AND DISCUSSION

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

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

The waiting criteria are prepared by AHP (Analytic Hierarch process) (EVM multiple inputs) (K.D. Version 15.09.2018) based on the conceptual model and thematic layers proposed to use. As the hydrogeological conditions vary greatly across the projects, weights were determined for this Wereda separately. The result is shown in the tables below. The minimum and maximum values are included as well, which will be taken as the basis for sensitivity analyses on the mapped groundwater potential zones.

Analytic Hierarchy Process

The first step of the AHP method is to assign the level of importance of this 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 Dera wereda.

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

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

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

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

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

4.2 Reclassification of Thematic layers

4.2.1 Hydro - lithologic units

Hydrogeological units play a fundamental role in governing the spatial distribution and occurrence of groundwater. The porosity, size of pore space, and the ease at which the pore spaces are interconnected control storage and permeability of geologic medium that in turn affect the availability of groundwater in the area of interest. The main lithologic units found in the study area consist of Elluvium& alluvial sediments, Aiba basalt, Tarmaber-Megezez basalt,Antalo limestone,Muger mudstone,upper Sandstone, and Addigrate sandstone. These lithologic units have been given weights (rates) based on hydraulic properties (hydraulic conductivity, transmissivity, Storativity and yields observed from pumping test, lithologic log (well completion reports) of the area. Based on the conceptual understanding of the Dera Wereda, the Hydrogeological units of the Dera Wereda were classified as very high, high, moderate, low, and very low potential. The reclassified hydrogeological units are presented in see Figure 8 below.

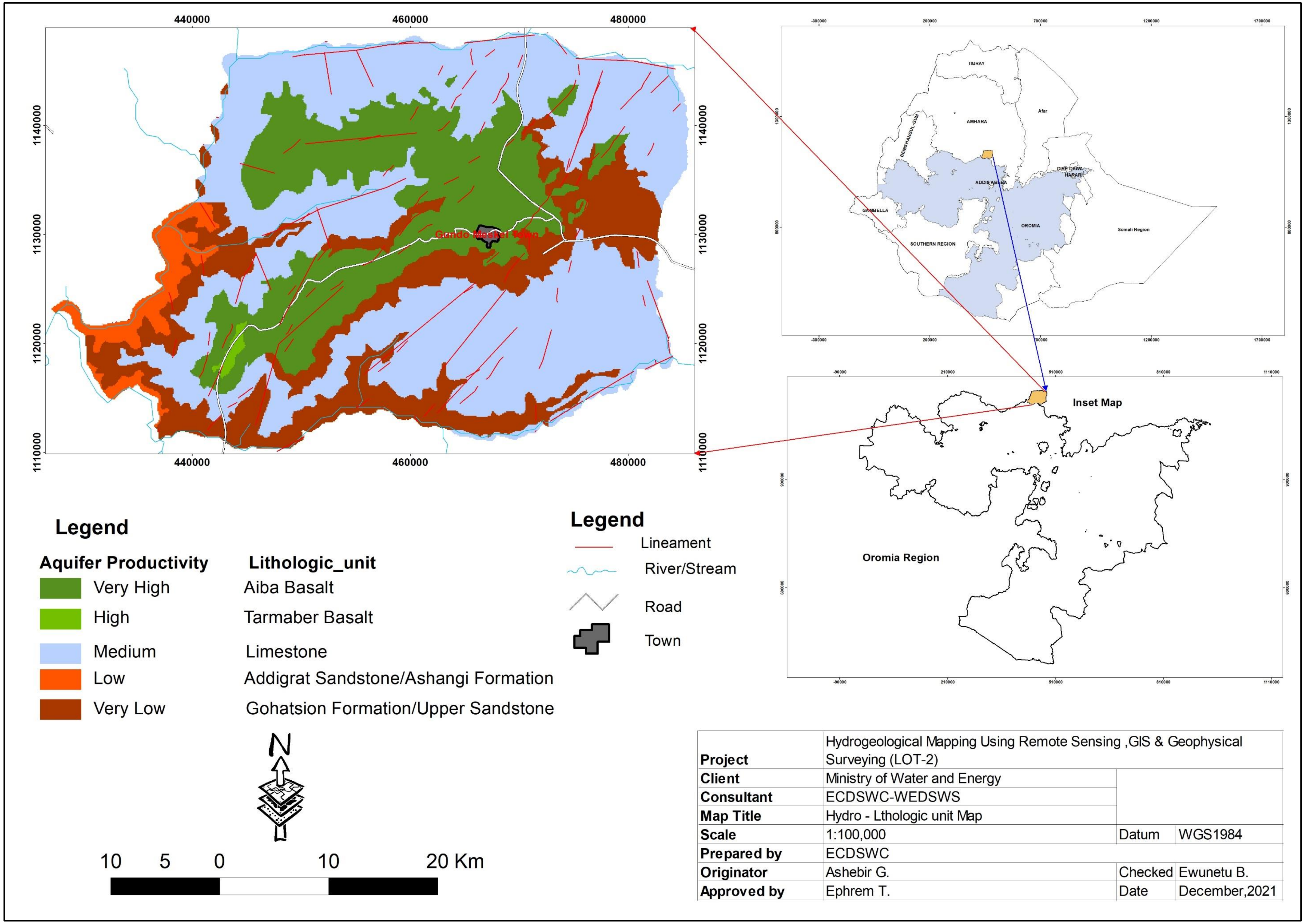


Figure 8: Hydro – Lithologic Unit of Dera Wereda

4.2.2 Groundwater Recharge

In this study, Groundwater recharge of Abay basin (upstream of Weredas in Lot – 2) was calculated by using the WetSpass model, and then groundwater recharge of the study areas was extracted by respective weredas boundary.

The WetSpass model produces monthly hydrological parameters like grid map 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 Abay 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 show the yearly groundwater recharge estimated with the WetSpass model of Dera wereda. The recharge estimated was used as one thematic layer for groundwater potential mapping of the Dera 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.

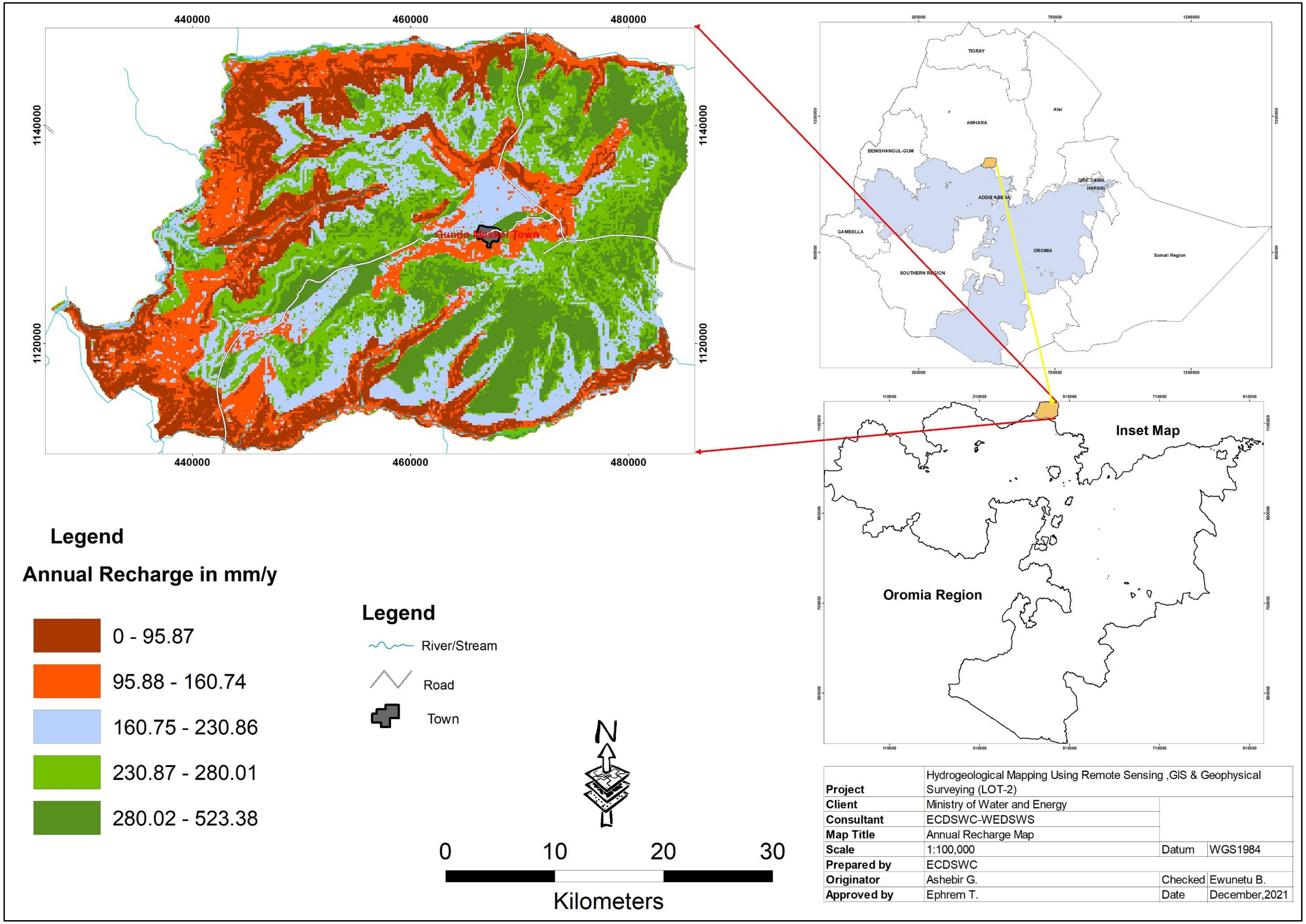


Figure 9 : Groundwater recharge of Dera Wereda

4.2.3 TWI Thematic layers

Topographic Wetness Index (TWI) is usually used to compute topographic control on the hydrological process and reflects the potential groundwater infiltration caused by the effect of topography. The values were reclassified into five categories such as very low, low, moderate, high, and very high. The high weights have been assigned for high TWI and vice versa. Figure 10 shows the TWI map of the Dera wereda.

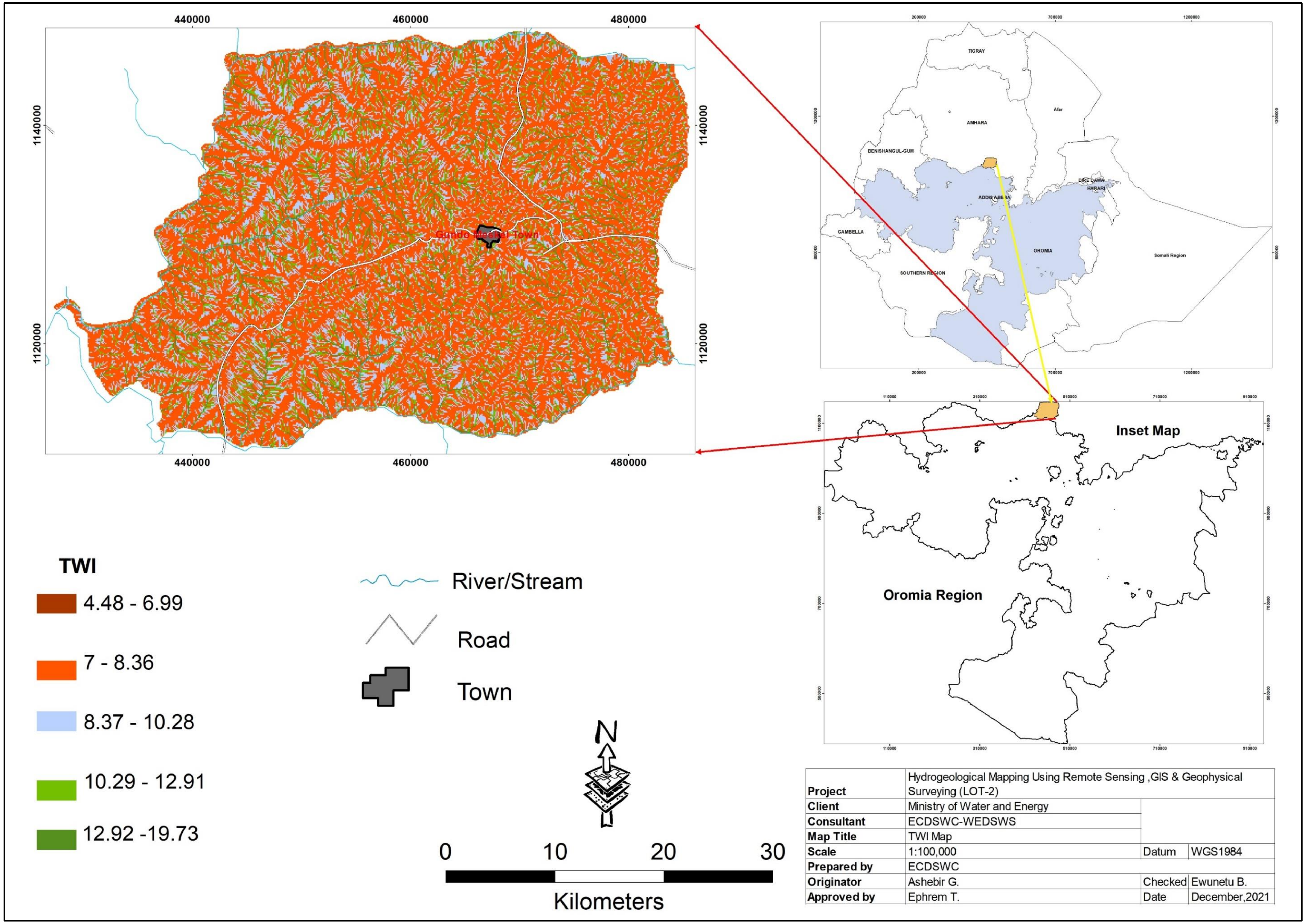


Figure 10 : TWI of Dera Wereda

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 Dera 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 (figure11)

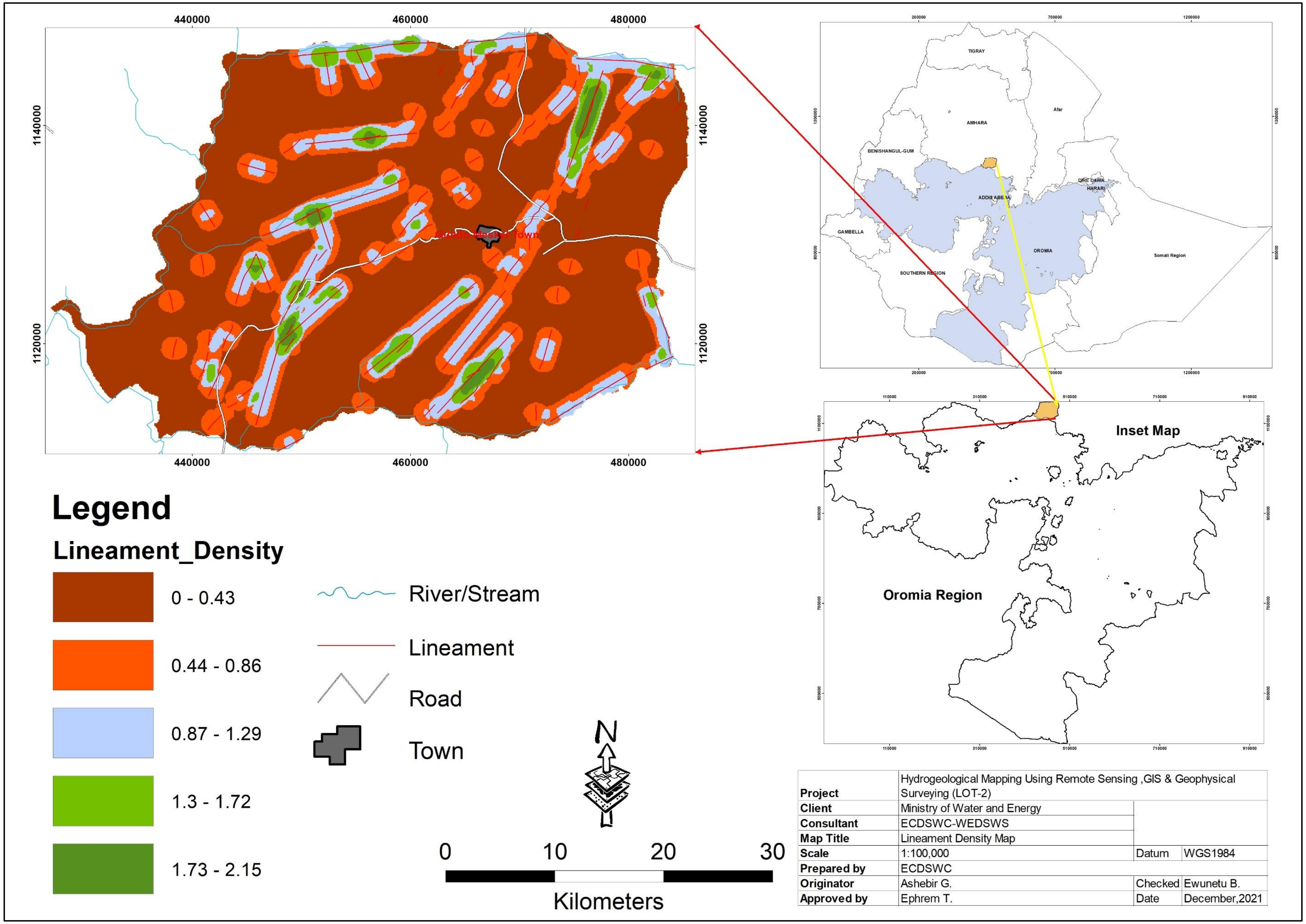


Figure 11: Lineament Density map of Dera wereda

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 Dera Wereda. High weights are assigned to the areas nearby the lineament and low weights to distance locations. The proximity from lineament map is shown in figure 12.

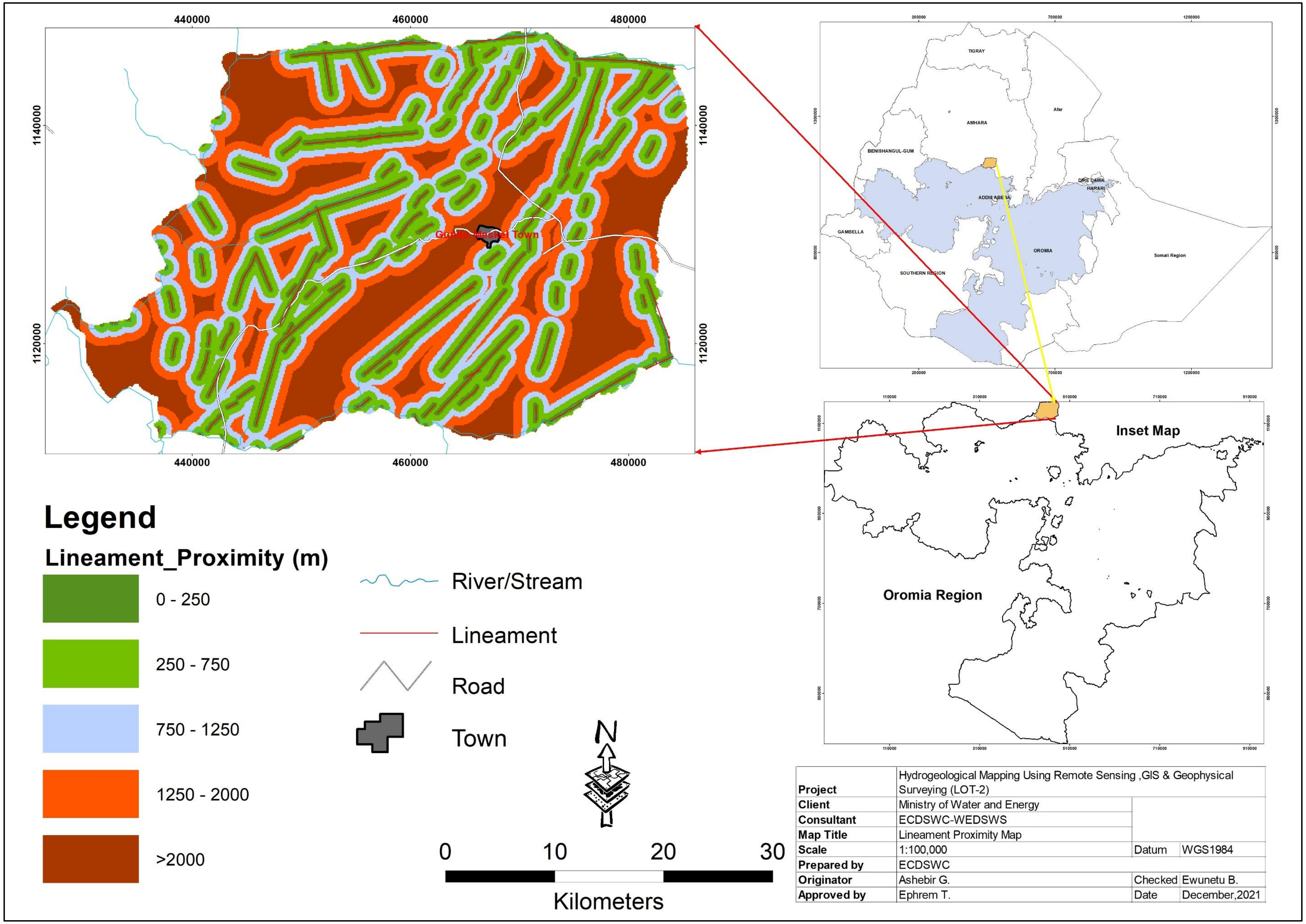


Figure 12 : Lineament Proximity Map of Dera wereda

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

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

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

4.4 Sensitivity analysis

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

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

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

Where W is the effective weight of each thematic layer

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

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

4.4.1 Single parameter Sensitivity analysis of Dera Wereda

The statistics of the single-parameter sensitivity analysis of Dera Wereda are shown in Table 10. There are some deviations in the effective weights when compared to the empirical weights. The single–parameter analysis of Dera Wereda shows Lithologic units as the most effective layer in GWP mapping with mean effective weights of 48.2%.The next higher effective weighs of 25 % and 10.4% were recorded in groundwater recharge and Lineament density layers. The TWI and Lineament proximity tend to be less effective thematic layers with mean effective weightings of 9.6% and 6.3% respectively compared with their empirical weights of 11.7% and 7.1%.

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

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

4.5 Validation using well data

Introduction

Overlay analysis techniques based on GIS methods have been applied to evaluate the groundwater potential of Dera 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 setup of this wereda, and analysis of previously conducted works. The final output of the work is the production of a groundwater potential map for this 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 (GWP map), ground-truthing work has been conducted for Dera 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

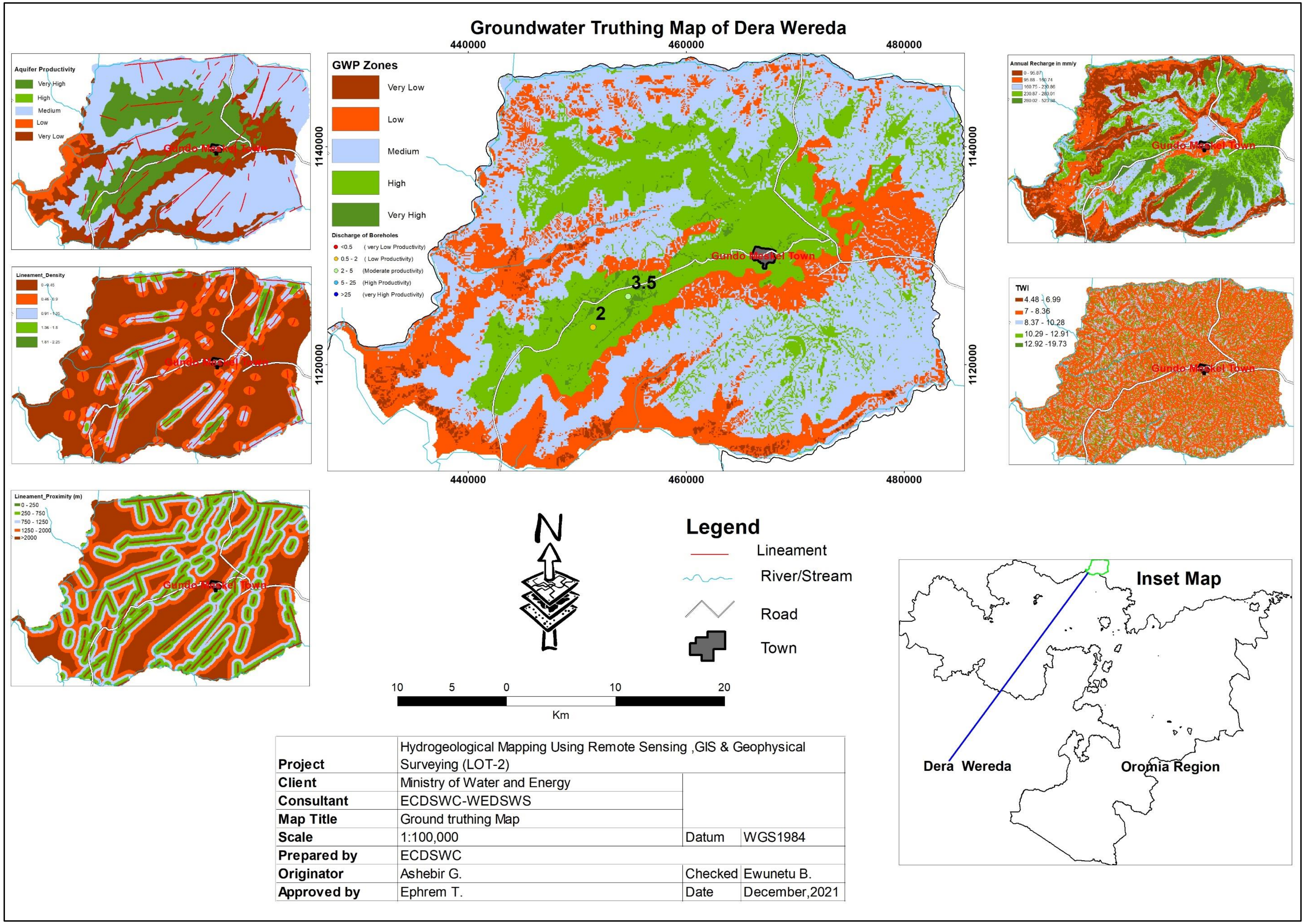
- Regional and local geomorphological settings observation
- Verifications of groundwater potential map with series of ground control
- Waterpoint inventory and comparison of inventoried boreholes characteristics with groundwater potential map
- Checking groundwater potential map produced with general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

Dera wereda

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

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

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



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

Figure 13 : Groundwater potential truthing of Dera wereda

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

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

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

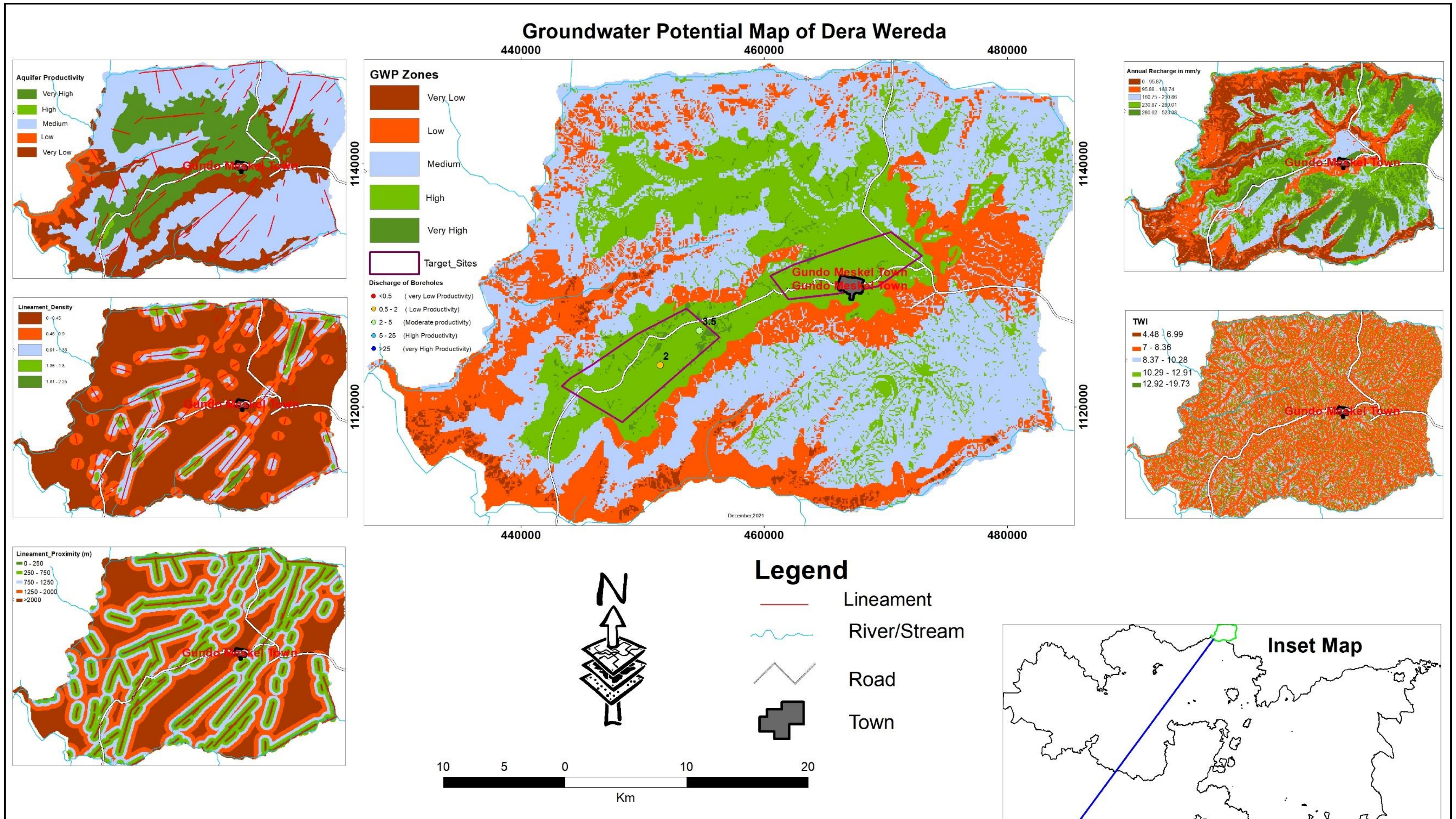
4.6.1water demand of Dera Wereda

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

Wereda	**Livestock Category**											**Water Demand in m3/day**
	Shoats	0.01	Cattle	0.7	Camel	1	Donkey	0.6	Chicken	0.001	TLU	
Dera	57,918	579	173551	121486	0	0	28112	16867	60000	60	138,932.08	3,473

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

4.7 Groundwater potential zone (GWPZ)



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

Figure 14: GWP map of Dera 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 promising sites					
3.8	Select optimal site for drilling borehole and corresponding climatic Sensitivities resilience measures					
3.9	Validation of target sites					
3.10	Preparation of target dirilling site maps					
3.11	Produce well design, specification and select appropriate drilling technology and BOQ preparation for CR-boreholes					
3.12	Organize validation workshop of draft report					
3.13	Preparation and submission of final report and maps					
3.14	**Training and Capacity builiding activities**					
3.15	**Training 1 :** Groundwater resource mapping methodology					
3.16	**Training 2:** workshop to Ethiopia federal and regional 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 Dera wereda, which are located in Oromia regional states. A total of five thematic layers such as Lithologic units, Lineament density, Lineament proximity, TWI, and Recharge were used in this study to delineate the groundwater potential zones. Different steps chosen for the study include the development of the thematic layers followed by GIS-based Multi-Criteria evaluation based on saaty's analytical hierarchy process (AHP) is used to compute weights for the thematic layers, the ranks from 1 to 5 allocated for each thematic layer which indicates very low, low, medium, high and very high in ascending order, associated with each class, were selected based on the influence of each factor on the groundwater potential, weighted overlay analyses for the demarcation of GWP zones, sensitivity analyses to understand effect weight of each thematic layer and validation of GWP zone by using well data and conceptual understanding of Dera Wereda.

The spatial distribution of the Dera Wereda GWP zones generally matches with the conceptual understanding of the Dera 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 layer show some deviation from empirical weights. The GWP map produced will be used to quickly identify the prospective GWP zones for conducting site-specific investigations.

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

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

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.
- Abebe, T., Mazzarini, F., Innocentti, F., and Manetti, P. 1998. The Yerer-Tullu Wollel Volcano-tectonic Lineament: a transtensional structure in central Ethiopia and the associated magmatic activity. Journal of African Earth Sciences, 26, 135-150.
- Ampe, E.M.; Vanhamel, I.; Salvadore, E.; Dams, J.; Bashir, I.; Demarchi, L.; Batelaan, O. Impact of urban land-cover classification on groundwater recharge uncertainty. IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens. 2012, 5, 1859–1867.
- Assefa, G., 1991. Lithostratigraphy and environment of deposition of Late Triassic to Early Cretaceous sequences of the central part of Northwestern Plateau, Ethiopia. N. Jb. Geol. Palaont. Abb. 182, (3): 255-284.
- Ayehu, G.T.; Tadesse, T.; Gessesse, B.; Dinku, T. Validation of new satellite rainfall products over the Upper Blue Nile Basin, Ethiopia. Atmos. Meas. Tech. 2018, 11, 1921–1936.
- Ayele Almaw Fenta & Addis Kifle & Tesfamichael Gebreyohannes & Gebrerufael Hailu (2015), Spatial analysis of groundwater potential using remote sensing and GIS-based multi-criteria evaluation in Raya Valley, northern Ethiopia
- 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
- Bereket Fentaw and Leta Alemayehu, GSE (2017), Hydrogeological and Hydrochemical Maps of Addis Ababa sheet NC 37-10 Sheet
- Beyth, M., 1972. Paleozoic–Mesozoic sedimentary basin of Mekele Outlier, Northern Ethiopia. The American Association of Petroleum Geologists Bulletin 56, 2426–2439.
- Bonini, M., Corti, G., Innocenti, F., Manetti, P., Mazzarini, F., Abebe, T., Pecskay, Z., 2005.
- Central Statistical Agency (2013), Population Projection of Ethiopia for all Regions at wereda Level from 2014 – 2017.
- Central Statistical Agency (2013), Population Projection of Ethiopia for all Regions at wereda Level from 2014 – 2017.
- Charlotte MacAlister, Paul Pavelic, Callist Tindimugaya, Tenalem Ayenew, Mohamed Elhassan Ibrahim and Mohamed Abdel Meguid, (2012), Overview of groundwater in the Nile River Basin.
- Charlotte MacAlister, Paul Pavelic, Callist Tindimugaya, Tenalem Ayenew, Mohamed Elhassan Ibrahim and Mohamed Abdel Meguid, (2012), Overview of groundwater in the Nile River Basin.
- Corti, G., 2009. Continental rift evolution: from rift initiation to incipient break-up in the Main Ethiopian Rift, East Africa. Earth Sci. Rev. 96, 1–53.
- Ebinger, C., 2005. Continental breakup: the East African perspective. Astron. Geophys. 46, 2.16–2.21. Ebinger, C., Casey, M., 2001 Continental breakup in magmatic provinces: an Ethiopian example, Geology 29, 527– 530.
- Engida Zemedagegnehu, Yelma Sileshi, Albert Tuinhof (2007), Groundwater Resources in Lake Tana Sub Basin and Adjacent Areas rapid Assessment and Terms of Reference of Further Study; Federal Republic of Ethiopia/ World bank.

- Engida Zemedagegnehu, Yelma Sileshi, Albert Tuinhof (2007), Groundwater Resources in Lake Tana Sub Basin and Adjacent Areas rapid Assessment and Terms of Reference of Further Study; Federal Republic of Ethiopia/ World bank.
- FAO. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements- Irrigation and drainage paper 56. Rome, Italy.
- Fedlu Hassen and Aschalew Gurmu, GSE (2017), Hydrogeological and Hydrochemical Maps of Debre Markos NC 37-6 Sheet
- Fedlu Hassen and Aschalew Gurmu, GSE (2017), Hydrogeological and Hydrochemical Maps of Debre Markos NC 37-6 Sheet
- Fedlu Hassen, Aschalew Gurmu, GSE (2012), Geological Survey of Ethiopia Integrated Groundwater Resource Assessment of Debre-Markos Sheet (NC 37–6)
- Fedlu Hassen, Aschalew Gurmu, GSE (2012), Geological Survey of Ethiopia Integrated Groundwater Resource Assessment of Debre-Markos Sheet (NC 37–6)
- Fedlu Hassen, Aschalew Gurmu, GSE (2012), Integrated Groundwater Resource Assessment of Debre-Markos Sheet (NC 37 – 6)
- Fedlu Hassen, Aschalew Gurmu, GSE (2012), Integrated Groundwater Resource Assessment of Debre-Markos Sheet (NC 37 – 6)
- Fenta, A.A.; Yasuda, H.; Shimizu, K.; Ibaraki, Y.; Haregeweyn, N.; Kawai, T.; Belay, A.S.; Sultan, D.; Ebabu, K. Evaluation of satellite rainfall estimates over the Lake Tana basin at the source region of the Blue Nile River. Atmos. Res. 2018, 212, 43–53.
- Gamachu, D. (1977). The aspect of Climate Change and Water Budget in Ethiopia. A Technical Monograph for Addis Ababa University. Addis Ababa, Ethiopia: Addis Ababa University Press.
- Gani, N.D.S., Gani, M., Abdelsalam, M.G., 2008. Blue Nile incision on the Ethiopian Plateau: pulsed plateau growth, Pliocene uplift, and hominin evolution. GSA Today 17, 4–11.
- 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.
- 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.
- 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
- Tesfaye, Chernet (1993): Hydrogeology of Ethiopia and Water Resources Development – MS EIGS, Ministry of Mines and energy, Addis Ababa (Library 880-051-17).
- Thomas Agezew and Tsehay Amare, GSE (2018), Hydrogeological and Hydrochemical Maps of Debre Birhan sheet NC 37-11 Sheet
- Tilahun, Azagegn, Tafere (2008): Hydrogeochemical Characterization of Aquifer Systems in upper Awash and Adjacent Abay Plateau using Geochemical Modeling and Isotope Hydrology. Addis Ababa University, School of Graduate Studies, Department of Earth Sciences.
- Tilahun, Azagegn, Tafere (2014): Groundwater Dynamics in the Left Bank Catchments of the Middle Blue Nile and the Upper Awash River Basins, Central Ethiopia
- Ven Te Chow, David R. Maindment and Larry W. Mays, 1988, Applied Hydrology, McGraw-HILL International Editions for Civil Engineering Series.
- WMO-NO 168, Guide to hydrological practice, Data Acquisition and processing, Analysis, Forecasting, and other applications. Fifth edition, 1994.
- WWDE (2008): Evaluation of water resources of Adaa and Becho plains groundwater resource for irrigation. Addis Ababa, Ethiopia.
- WWDSE (2006): Evaluation of water resources of the Ada'a and Becho plains groundwater basin for the irrigation development project, April 2006, Water Works Design and Supervision Enterprise.
- 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

Dera Wereda

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

Annex 2: Water point inventory data

Dera Wereda

SN	UTME	UTMN	ELEV, M	Site_Name	Region	Wereda	Well_Type	Depth	SWL	DWL	DD	Q	K	T
1	448787	1123980	2423	ada'a	Oromia	Dera	spring							
2	468311	1129973	2506	ada'a dirre	Oromia	Dera								
3	444969	1124810	2422	adaadi	Oromia	Dera	HDW							
4	450657	1124321	2442	adisu gebaya	Oromia	Dera	HDW							
5	464772	1132370	2466	adisu gebaya 1	Oromia	Dera	HDW							
6	466601	1129970	2478	adisu gebaya 2	Oromia	Dera	HDW							
7	447804	1122678	2406	adoola	Oromia	Dera	HDW							
8	466553	1132035	2457	alaltu	Oromia	Dera	HDW							
9	454162	1138123	2246	ana kure	Oromia	Dera	HDW							
10	444910	1125658	2436	anxuree	Oromia	Dera	HDW							
11	451139	1122485	2415	bisati	Oromia	Dera	HDW							
12	456508	1138976	2222	buritti	Oromia	Dera	HDW		8.00					
13	451368	1123574	2404	burka ako	Oromia	Dera	HDW							
14	464488	1130201	2484	burka basho	Oromia	Dera	HDW							
15	451446	1122326	2419	burka curree	Oromia	Dera	HDW							
16	450899	1123793	2421	burka lemi	Oromia	Dera	HDW		8.00					
17	450937	1124034	2427	burka lemi 2	Oromia	Dera	HDW		0.00					
18	468565	1135476	2486	burkitu	Oromia	Dera	HDW		7.00					
19	468487	1135356	2489	cabare	Oromia	Dera	HDW		5.00					

SN	UTME	UTMN	ELEV, M	Site_Name	Region	Wereda	Well_Type	Depth	SWL	DWL	DD	Q	K	T
20	468530	1135318	2490	cabare 2	Oromia	Dera	HDW		10.00					
21	455775	1128660	2475	caf├⌐	Oromia	Dera	HDW		0.00					
22	468502	1135064	2483	cangee	Oromia	Dera	HDW		9.00					
23	468511	1133094	2488	cangee2	Oromia	Dera	HDW		8.00					
24	451428	1123457	2399	ceka genet	Oromia	Dera	BH		1.10		26.3	2		1.43*10-3
25	462986	1130086	2500	darabbaa	Oromia	Dera	HDW		0.00					
26	465005	1130017	2500	darabbaa2	Oromia	Dera	HDW		7.00					
27	467273	1130549	2493	dire dawa	Oromia	Dera	HDW							
28	471453	1131665	2434	G/Arabuu	Oromia	Dera	spring							
29	470096	1131725	2492	G/qarree	Oromia	Dera	HDW							
30	471099	1132841	2495	G/SH/Useen	Oromia	Dera	HDW							
31	470332	1131805	2496	ganda qarree	Oromia	Dera	HDW		10.00					
32	470192	1131933	2500	ganda qarree2	Oromia	Dera	HDW		0.00					
33	471192	1133048	2499	ganga she useen	Oromia	Dera	HDW		5.00					
34	451140	1122485	2415	golalee	Oromia	Dera	HDW							
35	467559	1130467	2507	gulti	Oromia	Dera	HDW		14.00					
36	455227	1137883	2227	haxe	Oromia	Dera	HDW		0.40					
37	448786	1123979	2423	Indiko	Oromia	Dera	HDW		4.00					
38	448013	1123180	2407	indikoo 1ffaa	Oromia	Dera	HDW							
39	448186	1123921	2420	indikoo 2ffaa	Oromia	Dera	HDW							
40	444977	1121196	2450	jojoke 1	Oromia	Dera	HDW							
41	444894	1121140	2452	jojoke2	Oromia	Dera	HDW							
42	444882	1120984	2447	jojokee	Oromia	Dera	HDW							
43	455432	1138493	2215	karsa	Oromia	Dera	HDW		3.00					
44	448105	1123386	2412	kusaye	Oromia	Dera	HDW							
45	447804	1122678	2417	kusaye	Oromia	Dera	HDW							
46	445375	1120397	2427	laga jiilsii	Oromia	Dera	HDW							
47	444907	1126105	2426	M/gobana	Oromia	Dera	HDW							
48	444971	1120843	2466	masgida	Oromia	Dera	HDW							
49	444902	1121089	2444	membera tsehay 3	Oromia	Dera	HDW							
50	444416	1120617	2470	naannawa beteskaanaa	Oromia	Dera	HDW							
51	466410	1130003	2484	o1	Oromia	Dera	HDW							
52	467071	1130413	2482	o2	Oromia	Dera	HDW							
53	467336	1129855	2492	o3	Oromia	Dera	HDW							
54	458001	1127900	2462	qoro	Oromia	Dera	HDW		3.00					
55	450823	1123926	2424	rako	Oromia	Dera	HDW							
56	455324	1138262	2246	sagno gebaya	Oromia	Dera	HDW							
57	465863	1134138	2249	sagno gebaya	Oromia	Dera	HDW							
58	454656	1126297	2433	salayish	Oromia	Dera	BH		2.4			3.5		
59	467909	1129256	2371	saqa	Oromia	Dera	HDW							
60	455760	1128660	2394	satayii	Oromia	Dera	HDW							
61	467917	1130307	2506	shola bari	Oromia	Dera	HDW		10.00					
62	444565	1121211	2435	suluula	Oromia	Dera	HDW							

SN	UTME	UTMN	ELEV, M	Site_Name	Region	Wereda	Well_Type	Depth	SWL	DWL	DD	Q	K	T
63	444857	1125059	2461	waglo 1ffaa	Oromia	Dera	HDW							
64	444933	1125155	2441	waglo 2ffaa	Oromia	Dera	HDW							
65	444857	1125426	2442	waglo 3ffaaa	Oromia	Dera	HDW							
66	444378	1119502	2453	wallo 1ffaa	Oromia	Dera	HDW							
67	444246	1119601	2471	wallo 2 ffaa	Oromia	Dera	HDW							
68	461831	1129712	2494	wayyuu	Oromia	Dera	HDW		5.00					
69	444623	1120862	2445	xunjitii 1ffaa	Oromia	Dera	HDW							
70	444550	1120072	2470	xunjitii 2ffaa	Oromia	Dera	HDW							
71	468540	1135522	2496	yaya	Oromia	Dera	HDW		7.00					
72	468365	1135998	2491	yaya gama	Oromia	Dera	HDW		7.00					

Annex 3: Geologic map and cross section of Dera Wereda