FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA
MINISTRY OF WATER AND ENERGY

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

ANNEX-VI: DEVELOPING GROUNDWATER POTENTIAL MAP OF KUYU 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-VI: DEVELOPING GROUNDWATER POTENTIAL MAP OF KUYU WEREDA

FINAL REPORT

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Executive Summary

The current study aimed at delineating groundwater potential zones of Kuyu 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 Kuyu 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 is 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 Study area GWP zones generally matches with the conceptual understanding of the Study area 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

ADSWE	-	Amhara Design and Supervision Works Enterprise
a.m.s.l	-	above mean sea level
AOI	-	Area of Interest
ASTER	-	Advanced Spaceborne Thermal Emission and Transmission
BGL	-	Below ground level
CSA	-	Central Statistical Agency
CTI	-	Compound Topographic Index
DD	-	Draw down
DEM	-	Digital elevation model
DFID	-	The UK department for international development fund
E.C.D.S.W.Co	-	Ethiopia Construction Design & Supervision Works Corporation
EC	-	Electrical Conductivity
EGS	-	Ethiopian Geological Survey
EMA	-	Ethiopian Mapping Agency
ENVI	-	Environment for Visualizing Images
ESA	-	European Space Agency
ESRI	-	Environmental Systems Research Institute
ETV	-	Evapotranspiration
FA	-	Flow Accumulation
FD	-	Flow Direction
FDRE	-	Federal Democratic Republic of Ethiopia
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
WWDE	-	Water Well Drilling Enterprise
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 Kuyu Wereda.

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

The current study aimed at delineating groundwater potential zones of Kuyu 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 maps is done using a weighted overlay method to obtain a groundwater potential (GWP) map. The GWP map is verified by overlay analysis with observed borehole yield data. Single –Parameter sensitivity analyses are used to examine or to compute effective weights.

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

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

Chapter-2: Data and Methodology of the study

Chapter-3: Conceptual Hydrogeological model of the study area

Chapter-4: Result and discussion

Chapter-5: Revised work plan for Phase – III

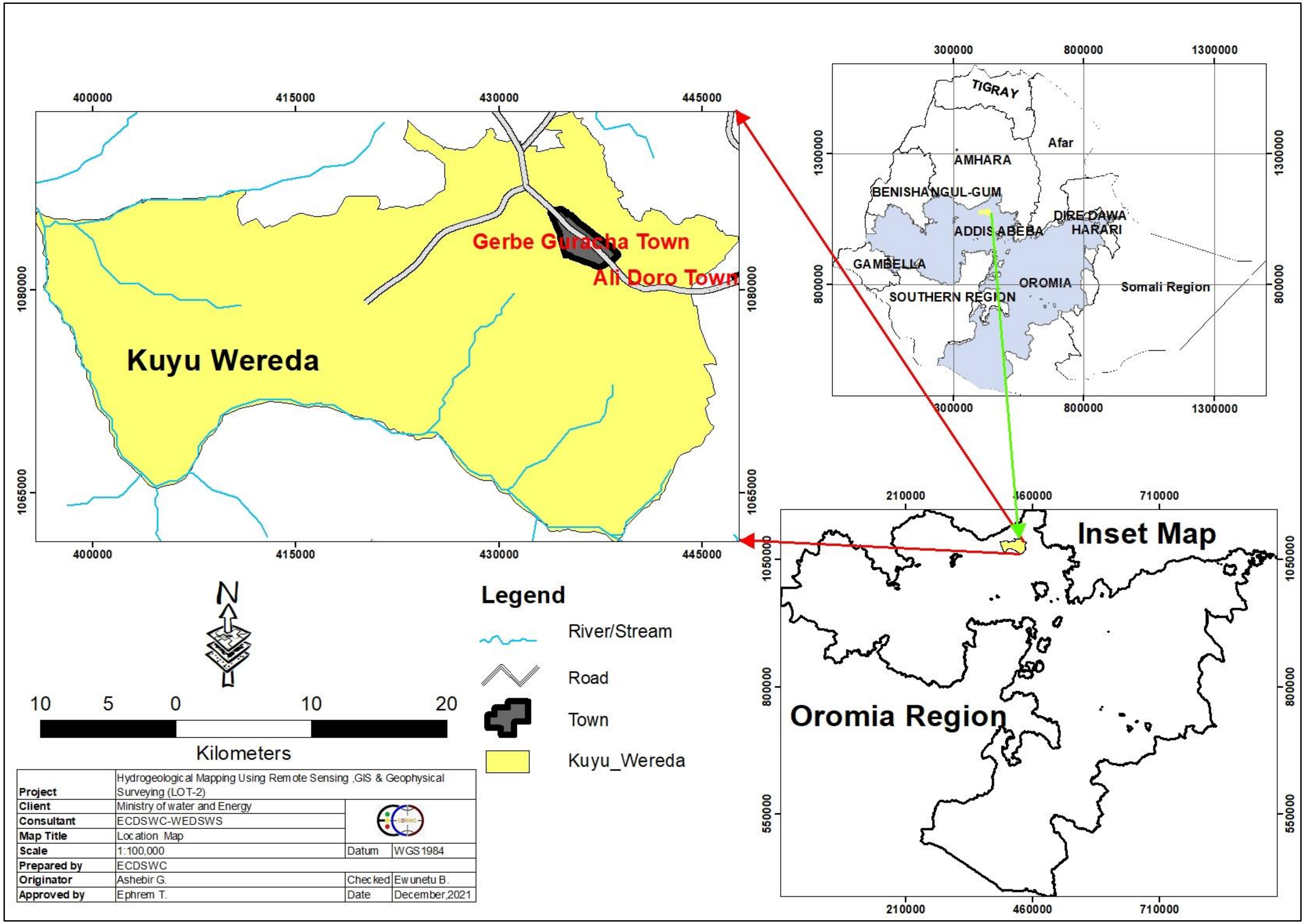
Chapter-6: Conclusion and Recommendation,

Chapter-7: References

1.2 Location of Kuyu wereda

Kuyu wereda is located in North Shewa zone of Oromia National Regional State. The study area is accessible by all-weather roads that connect Addis Ababa– Gerba Gurcha town. The main asphalt road from Addis Ababa to Gerba Gurcha town is about 161.8 kilometers. The whole of the project area is confined between the geographic coordinates of UTME 395768 - 447717 and UTMN 1061408 - 1093170 and topographically the study area is the northern part is plain land and the southern part rugged and deep gorge (Figure 1).

In general, Kuyu wereda seems 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 & Geophysical Surveying (LOT-2)		
Client	Ministry of water and Energy		
Consultant	ECDSWC-WEDSWS		
Map Title	Location Map		
Scale	1:100,000	Datum	WGS1984
Prepared by	ECDSWC		
Originator	Ashebir G.	Checked	Ewunetu B.
Approved by	Ephrem T.	Date	December,2021

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 of Kuyu 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 Kuyu Wereda in (lOT-2). Generally, the ultimate goal of the climate-resilient WASH project in Ethiopia is to increase access to safe and sustainable water.

The following specific objectives are also associated with the project:

- Carry out National Groundwater Risk Mitigation Strategy and make recommendations.
- Create detailed groundwater potential maps for target sites
- Identify one optimal drilling site and one alternative (optional) drilling site per Wereda, using these maps and geophysical field investigation, and recommend the type of drilling methodology to be employed.
- Build the capacity of MOWE, 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 Kuyu Wereda of LOT- 2 and the identification of promising target site for borehole drilling with enhanced drilling success rate and optional drilling site for Kuyu Wereda.

1.5 General approach, Deliverables and Planning

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

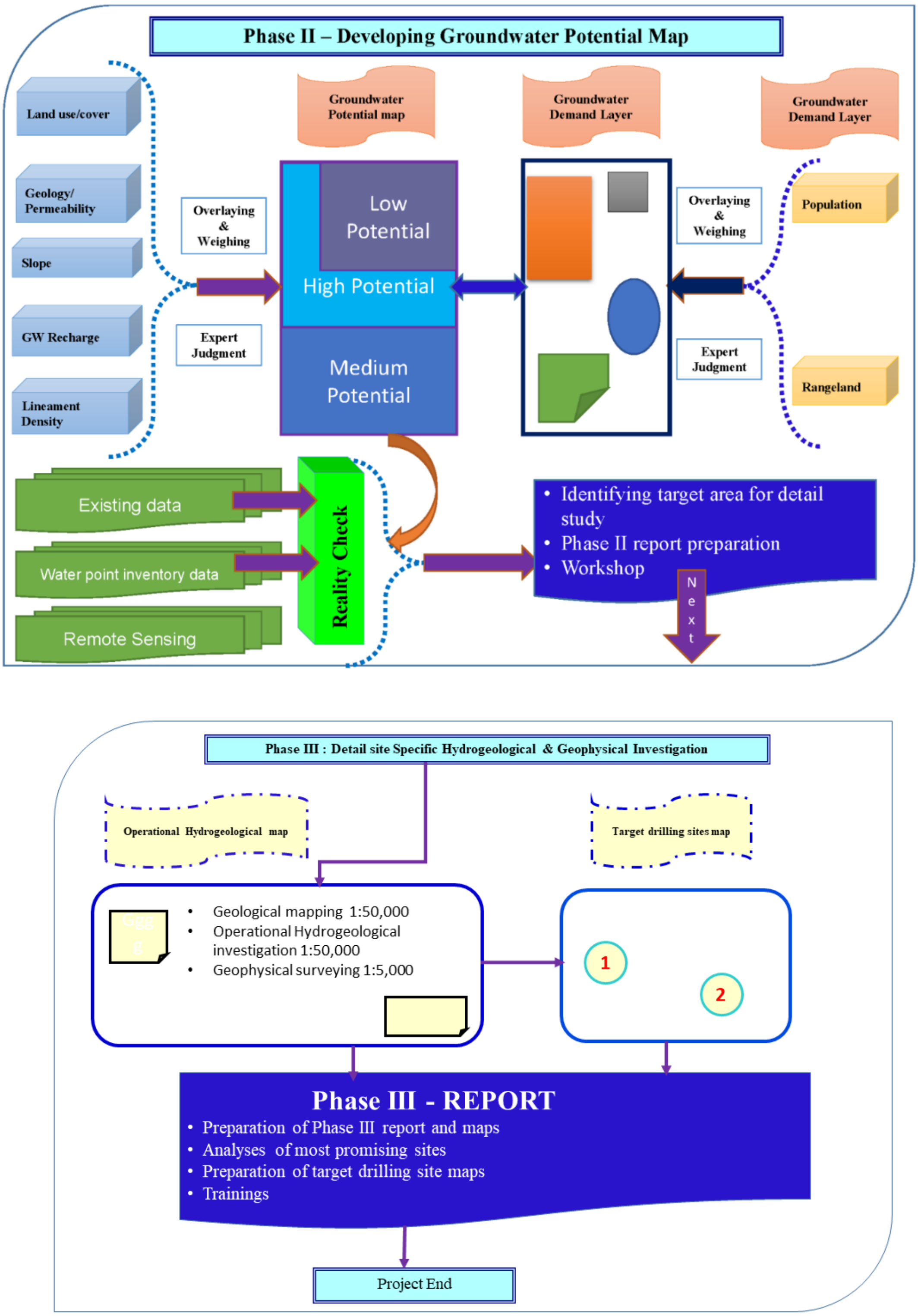


Figure 2: The project phases and the main deliverables

Phase II activities and deliverables of kuyu 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 Study area.
- Land cover, Soil, Depth to groundwater, Temperature, Rainfall, Wind speed, PET, Elevation maps were prepared.
- Rain days per month, modifying land cover parameter table based on the land cover map was prepared for input for Groundwater recharge estimation.
- Groundwater recharge was estimated by using the WetSpass model for the Abay basin and then the Groundwater recharge map was extracted by the Kuyu wereda boundary.
- Geological Map 1:100,000 was prepared for Kuyu wereda from existing 1:50,000 scale base maps and Satellite images.
- Lineament was extracted from SRTM DEM 30m resolution and Sentinel 1A image radar by using PCI Geomatica software initially, and then the lineament extracted was manually filtered by overlaying road, boundary, and drainage density of Study area.
- Lineament density map and Lineament proximity map was prepared from lineament map
- Topographic Wetness index was generated for the Kuyu Wereda
- Hydrogeological Sections was prepared for the Study area
- Overlay Analysis has been carried out for the Study area
- Sensitivity analysis was carried out for the Study area

- Validation of groundwater potential was carried out for the Study area The groundwater demand layer was prepared based on projected project CSA data
- Groundwater potential map was prepared for Kuyu 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 Study area 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 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 (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 specific weredas 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.

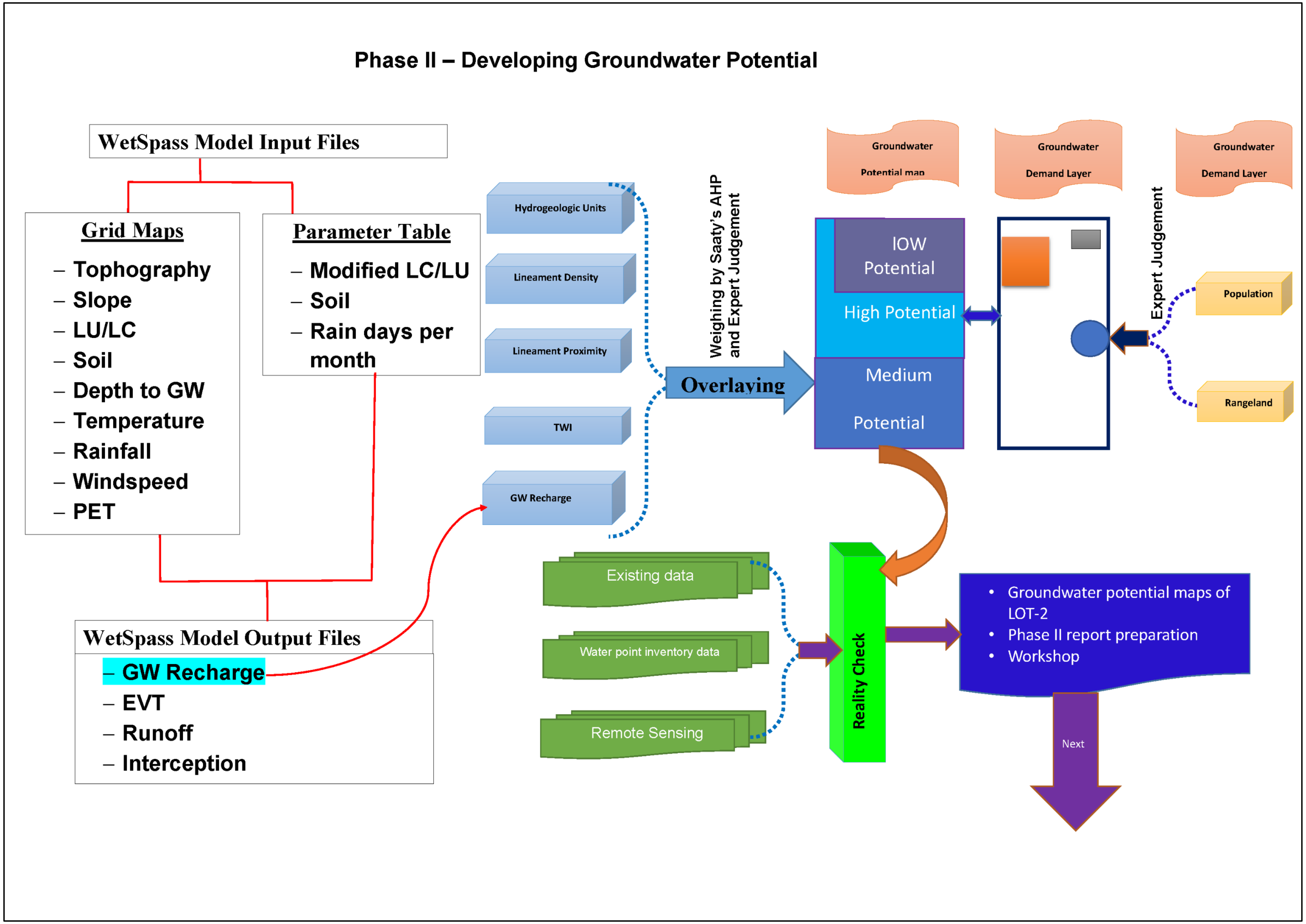


Figure 3: Phase II methods and deliverables

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 Study area, 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 Study area. 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
Kuyu	10	-	-	4	-	28	402	39
Grand Total	10	-	-	4	-	28	402	39

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 Kuyu Wereda , the thematic layers of lithological units, Groundwater recharge, lineament density, lineament proximity, and TWI were prepared on a scale of 1:100,000 with a spatial resolution of 100m pixel size in a GIS environment. After the preparation of the thematic maps, the rank is assigned to each thematic layers attribute based on the conceptual understanding of the Kuyu Wereda , the maps were converted into raster format, and then weighted overlay analyses were carried out according to assigned suitable weights in the order of their hierarchy process (AHP) (Saaty 1980, 1992) to each thematic layers. Thematic maps for each parameter are prepared as follows.

2.2.1 Geological mapping method of the study area

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

A literature survey was carried out to survey the availability of the geological maps and review the available geological maps in order to get a general overview of the geology of the area and to identify the gaps and fill these gaps by Remote sensing study. The project area has previously been geologically mapped by GSE at a scale of 1:50,000 and 1:250,000. These maps were provided better information to understand the geological evolution of the project area. However, a review of these geological maps has identified the gaps listed below which are considered during the present investigations by RS and GIS studies. The gaps identified were: -

(i) Lack of exhaustive Imagery interpretation,
(ii) Lack of consistency in lithological naming on geological maps,
(iii) Lack of systematic mapping of litho-stratigraphy, and

(iv) The significance of the lithology and structural data in establishing and understanding 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 maps were used to prepare the geological map of the Study area at a scale of 1:100.000. The Geology map of the Kuyu 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) 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 Study area.

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

$E_{raster} = a_vET_v + a_sE_s + a_oE_o + a_iE_i$ --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:

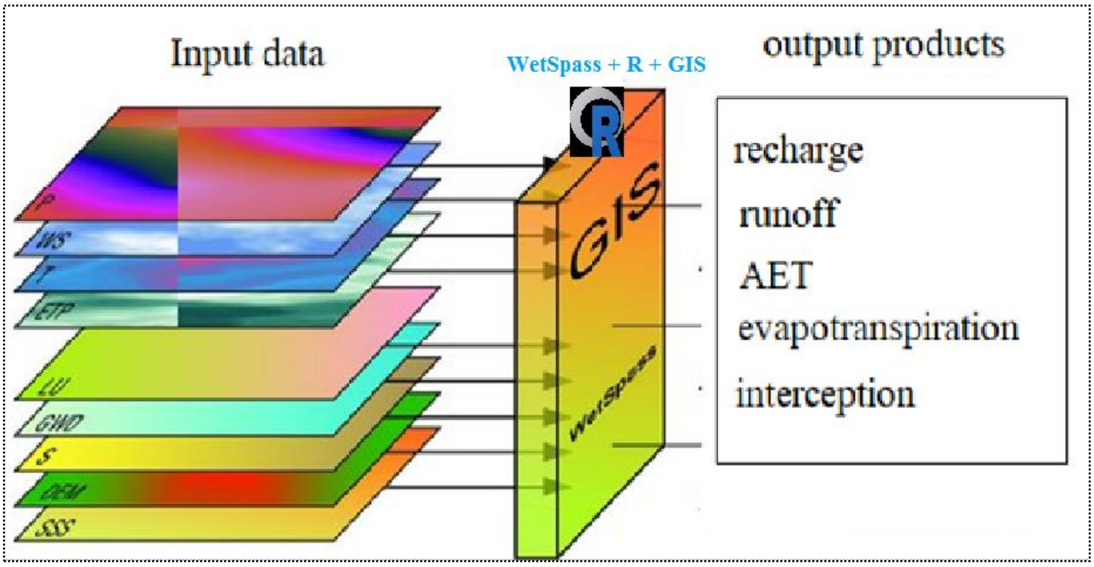


Figure 4: Schematic representation of model used for the study

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 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 Kuyu 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 Kuyu 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 Study area 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

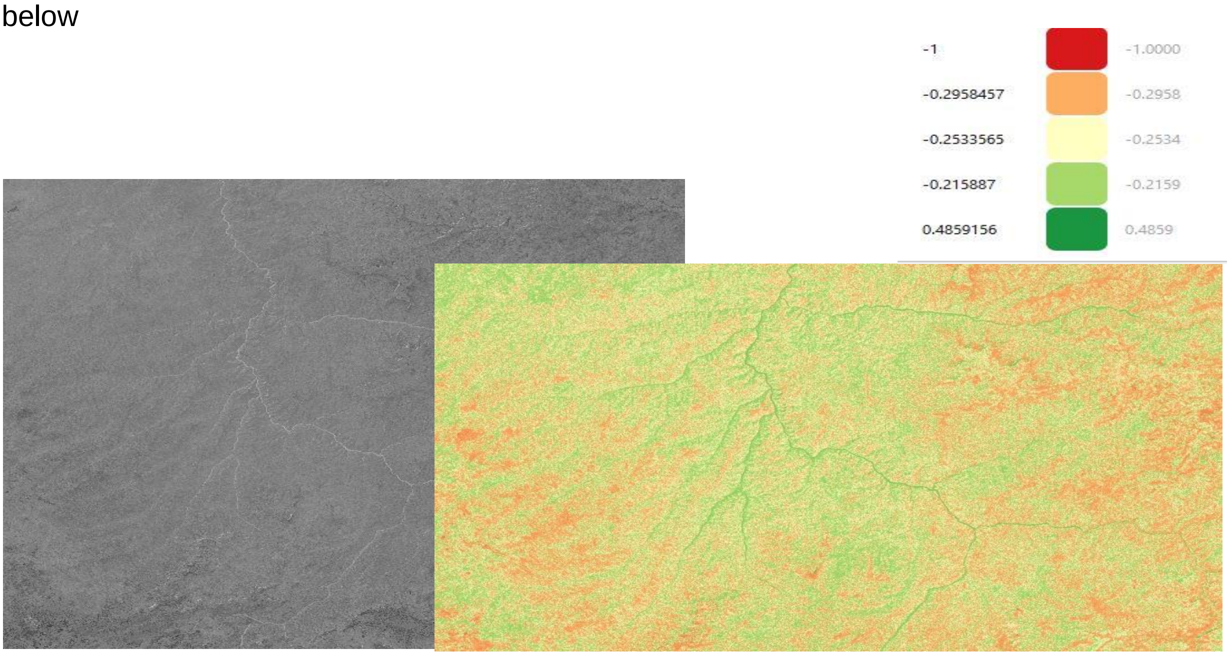


Figure 5: calculated NDVI using QGIS

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.

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

α = upslope contributing area; β = Topographic gradient (Slope)

2.2.5 Demography data of the Kuyu Wereda

In order to estimate water demand knowing the population growth rate is very important. Accordingly, the population of Kuyu 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 Kuyu wereda is projected for the planning period 2035 and the summarized population size is presented in the following tables.

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

Year	Δt	Growth Rate	Kuyu Wereda	
			Kuyu Rural	Gerba Guracha Twon
2021	0		138979	39272
2025	4	3.46%	159606	45101
2030	5	2.99%	185340	52373
2035	5	2.65%	211596	59792

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

Wereda	Cattle	Goats	Sheep	Horses	Mules	Donkey	Poultry
Kuyu	135333	27290	43210	7698	351	25778	122443

3. Conceptual Hydrogeological model of the study area

3.1 Hydrogeological condition of Kuyu 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 Kuyu wereda is conceptualized and discussed as follows:

Conceptual Hydrogeological model of Kuyu wereda

Kuyu wereda is located in the Mugger sub-basin. Topographically, the Northern part of Kuyu wereda is plain land and the southern part is a rugged and sloppy topographic setup. Most part of the wereda is covered by volcanic rocks, mainly Aiba and Tarmaber basalts and sedimentary rocks such as Upper sandstone, Mugger mudstone, Limestone, and Lower sandstone.

The yield and transmissivity of boreholes drilled in this wereda revealed that the intergranular alluvial aquifer and the basaltic aquifer have moderate to high groundwater potential due to primary and secondary permeability of the lithological units exposed in the area. Besides in the southern part of the wereda at the contact between Antalo limestone and Muger mudstone springs with the moderate discharge of 2 and 4 l/s.

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. The E-W oriented horst of the impermeable mudstone underlying the Tertiary volcanic control aquifer distribution into Mugger and Upper Awash groundwater sub-basin where surface water and groundwater divides do not coincide.

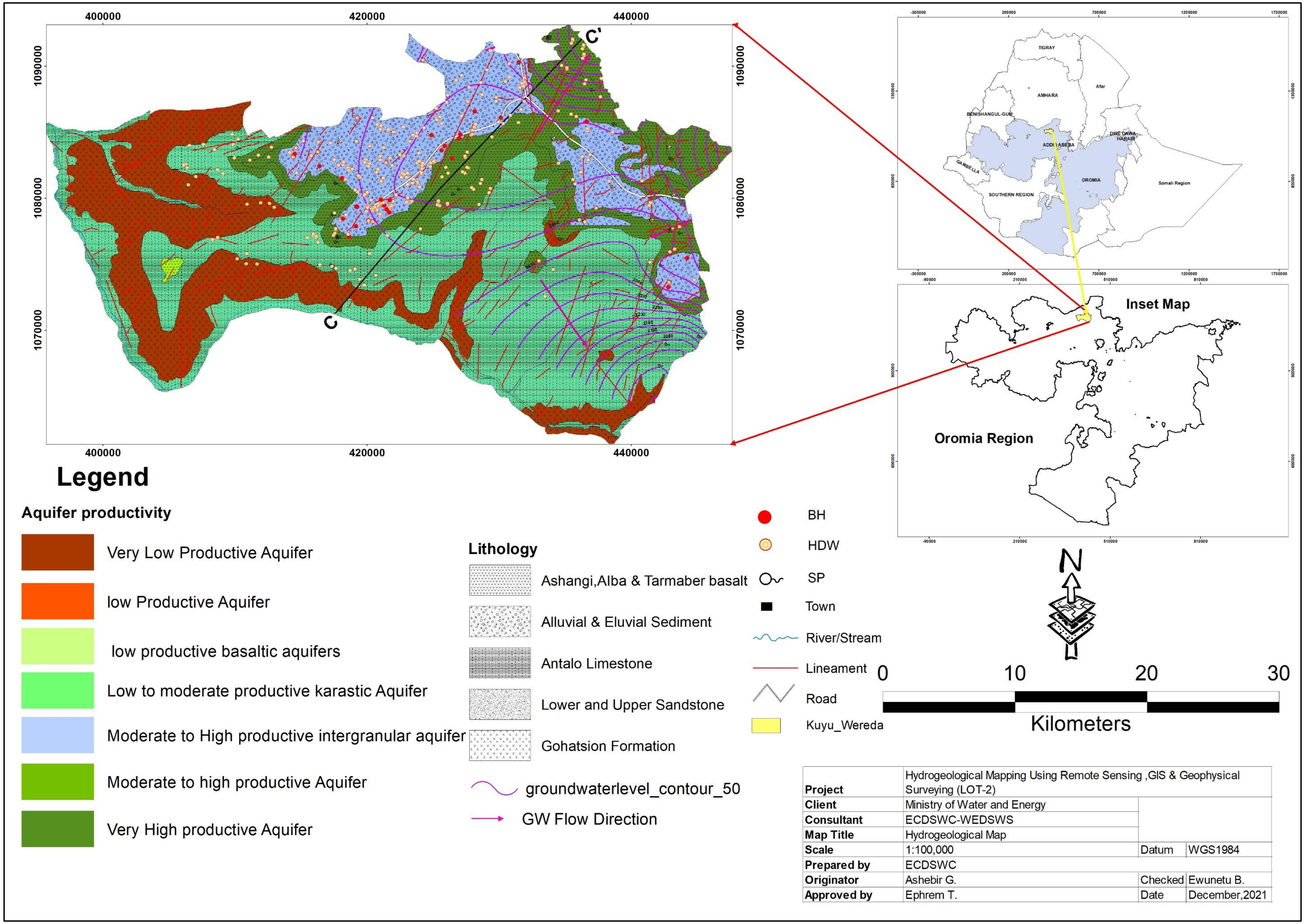


Figure 6 : Hydrogeological map of Kuyu wereda

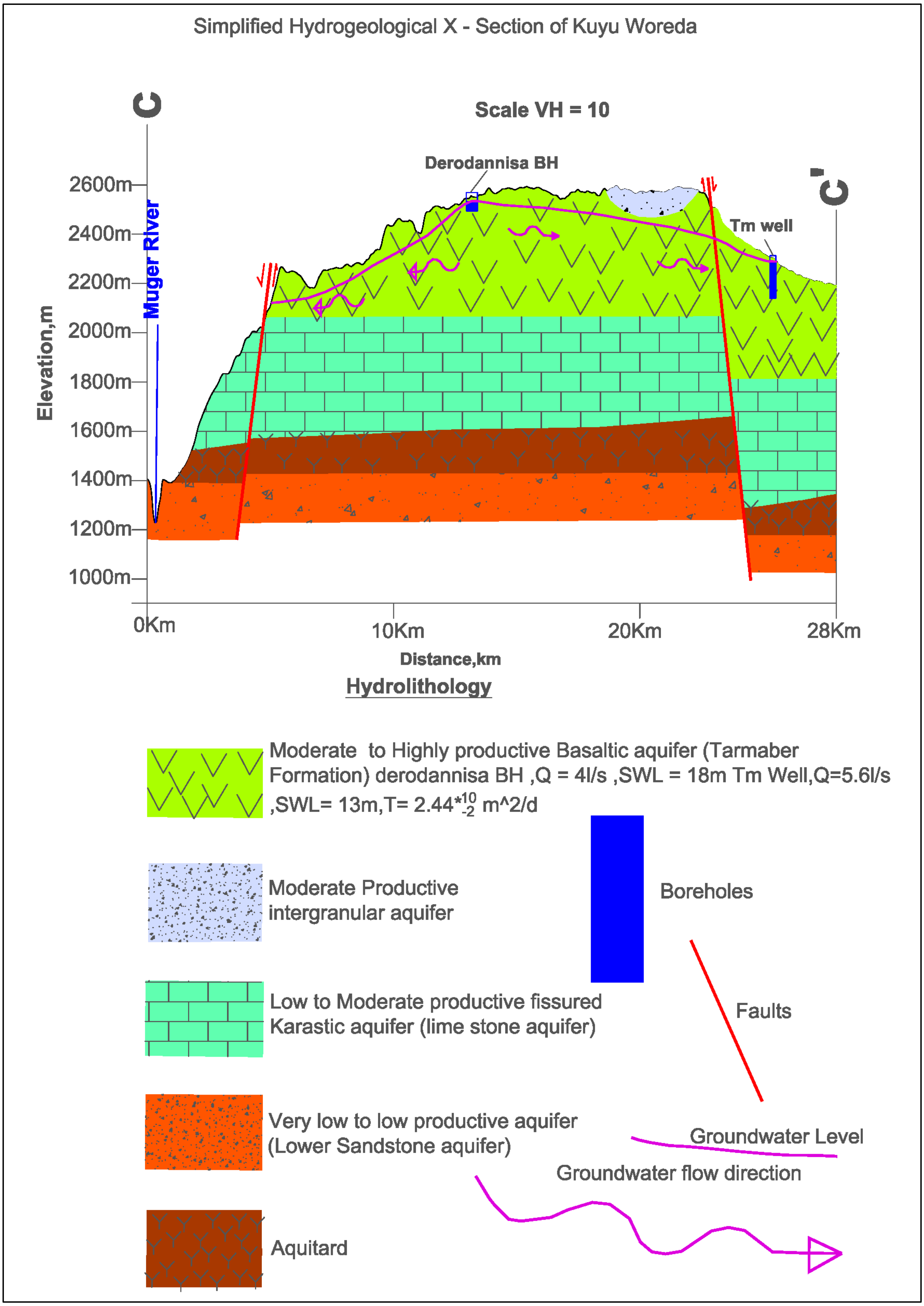


Figure 7 : Hydrogeological section of Kuyu weredas

4. RESULT AND DISCUSSION

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

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

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

Analytic Hierarchy Process

The first step of the AHP method is to assign the level of importance of each factor based on Saaty's (2008) scale values. Consequently, all factors are compared in a pairwise comparison matrix. The weight which was assigned to different thematic layers was normalized using Saaty's AHP techniques. To control and test the Consistency Ratio (CR) is calculated. The first step to calculate CR is to compute the maximum eigenvalue (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 Kuyu 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%		

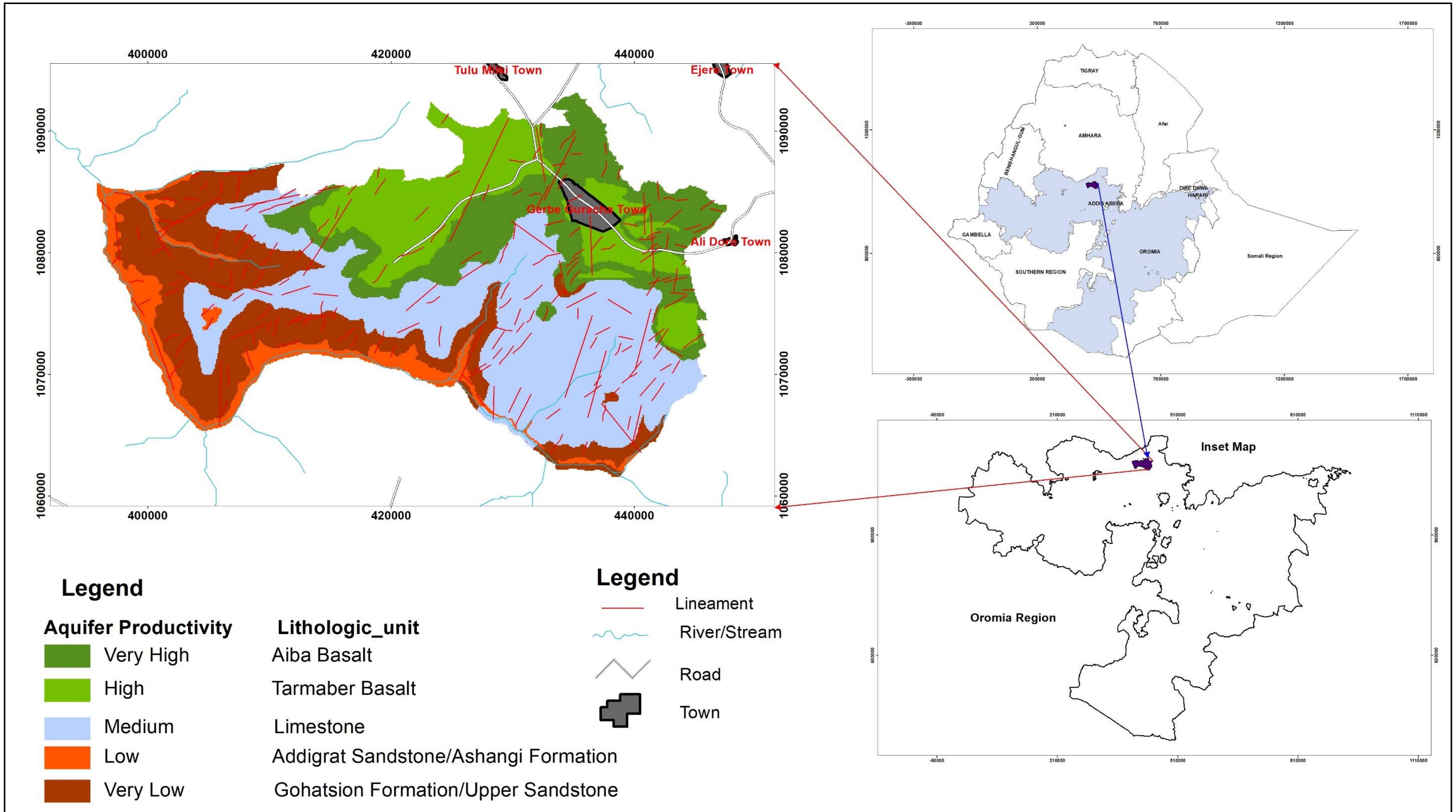
Table 9: Assigned rank for various classes of all thematic layers of Kuyu wereda

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 and Addigrat 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 Study Area, the Hydrogeological units of the Study area were classified as very high, high, moderate, low, and very low potential. The reclassified hydrogeological units are presented in see Figure 8 below.



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

Figure 8: Hydro – Lithologic Unit of Kuyu 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 Kuyu wereda boundary.

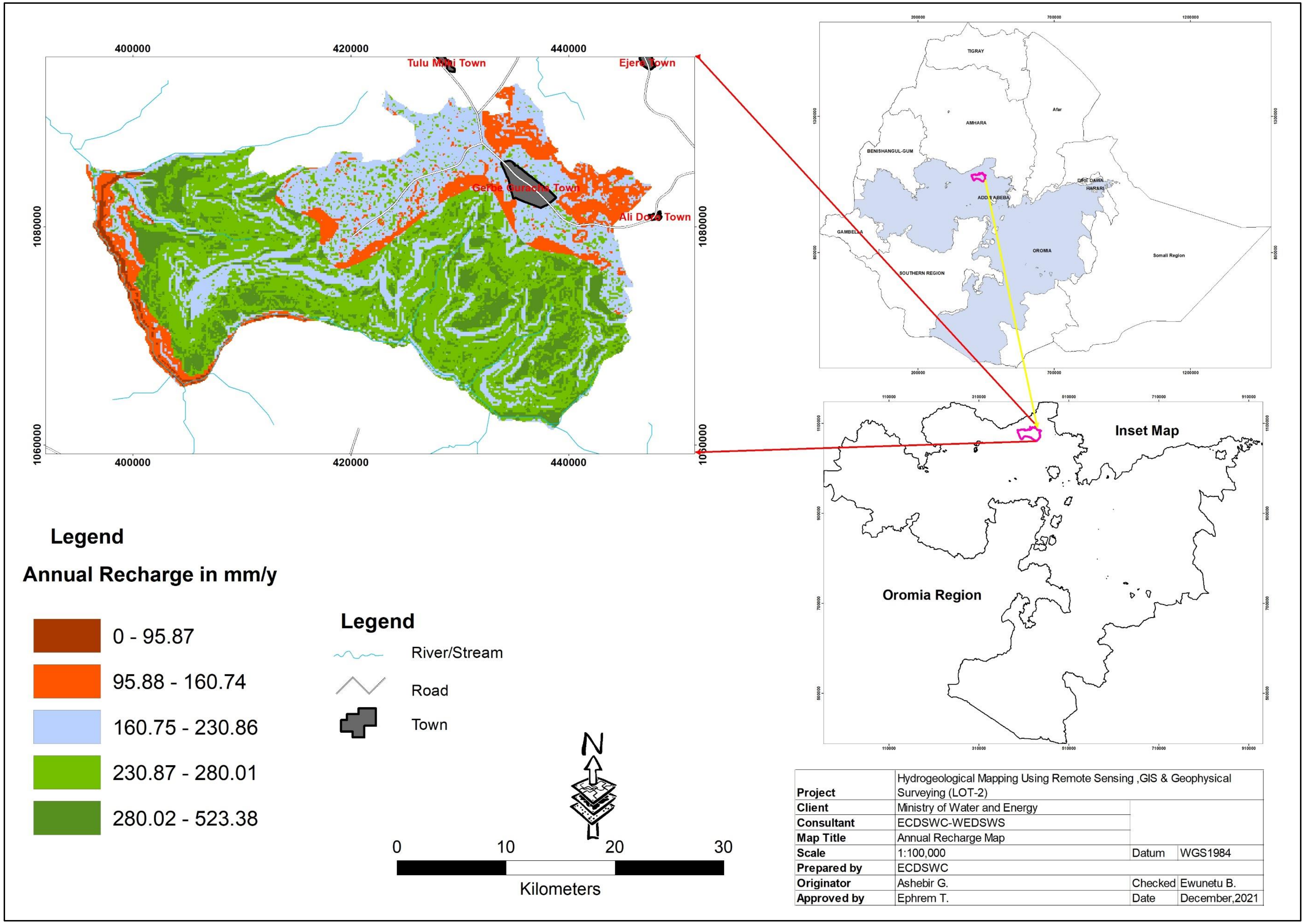
The WetSpass model produces monthly hydrological parameters like grid maps of groundwater recharge, actual evapotranspiration, surface runoff, interception loss, evaporation, etc. In this study, the annual groundwater recharge, annual actual evapotranspiration, and annual surface runoff are calculated 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 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 Kuyu wereda. The recharge estimated was used as one thematic layer for groundwater potential mapping of the Study area. 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.



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

Figure 9 : Groundwater recharge of Kuyu 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 Kuyu wereda.

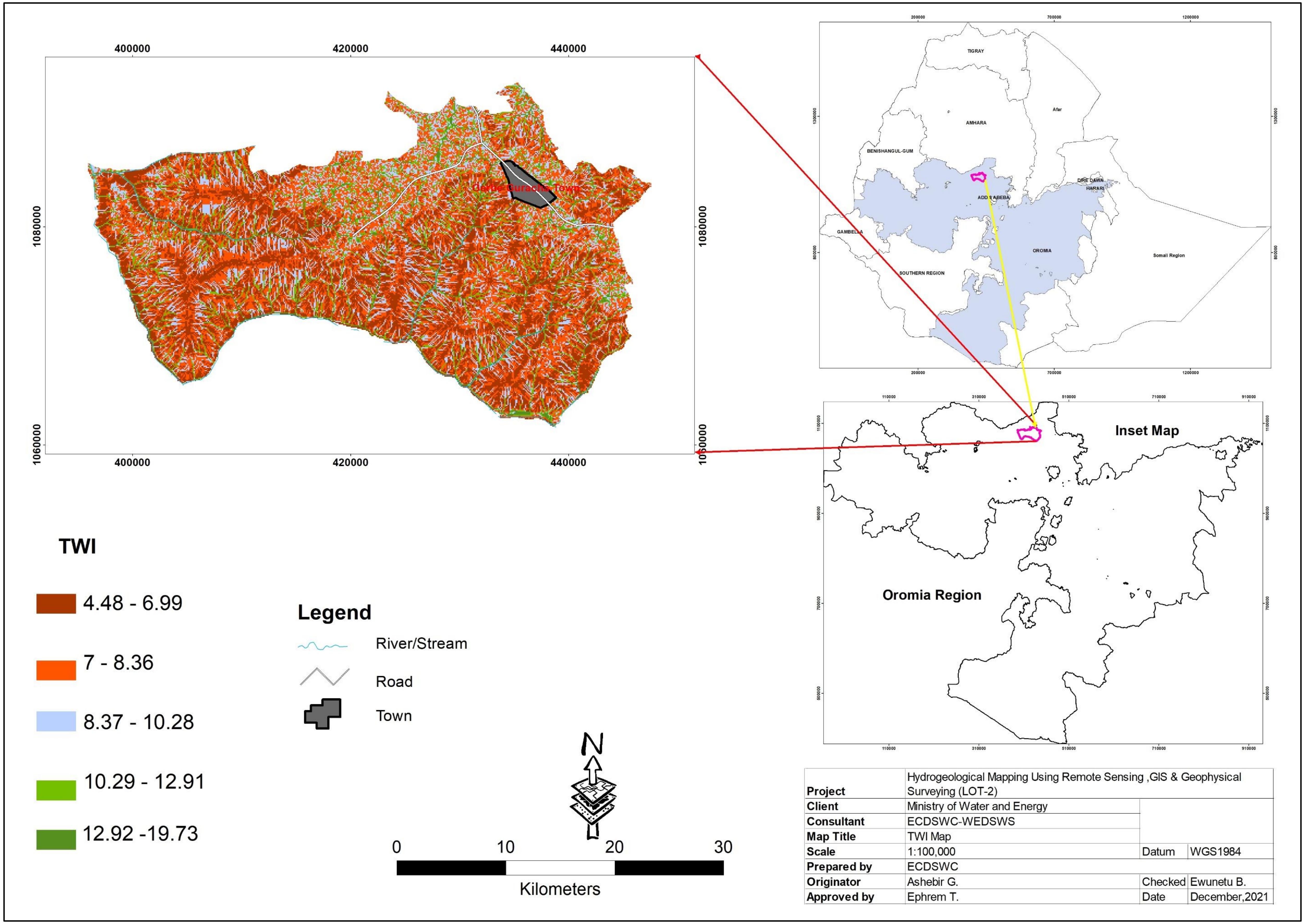


Figure 10 : TWI of Kuyu Wereda

4.2.4 Lineament Density thematic layers

Like primary porosity, secondary porosity is also essential for the determination of hydrogeological conditions. Lineaments represent secondary porosity and are linear features of tectonic origin. Due to their linear, direct, curvilinear form, they can easily be demarcated in satellite imagery. Some other indications like tone, texture, relief, drainage, and vegetation soil tone's linearity also give valuable information for lineament differentiation.

The groundwater potential is expected to increase with increasing lineament density values. Thus, areas that are characterized by high lineament density values are expected to have high groundwater potential. This is because; lineament acts as conduits for groundwater flow and reservoir for groundwater storage .considering lineament map as a baseline, lineament density is defined as the total length of the lineament per unit area.

The lineament density of the Study area 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)

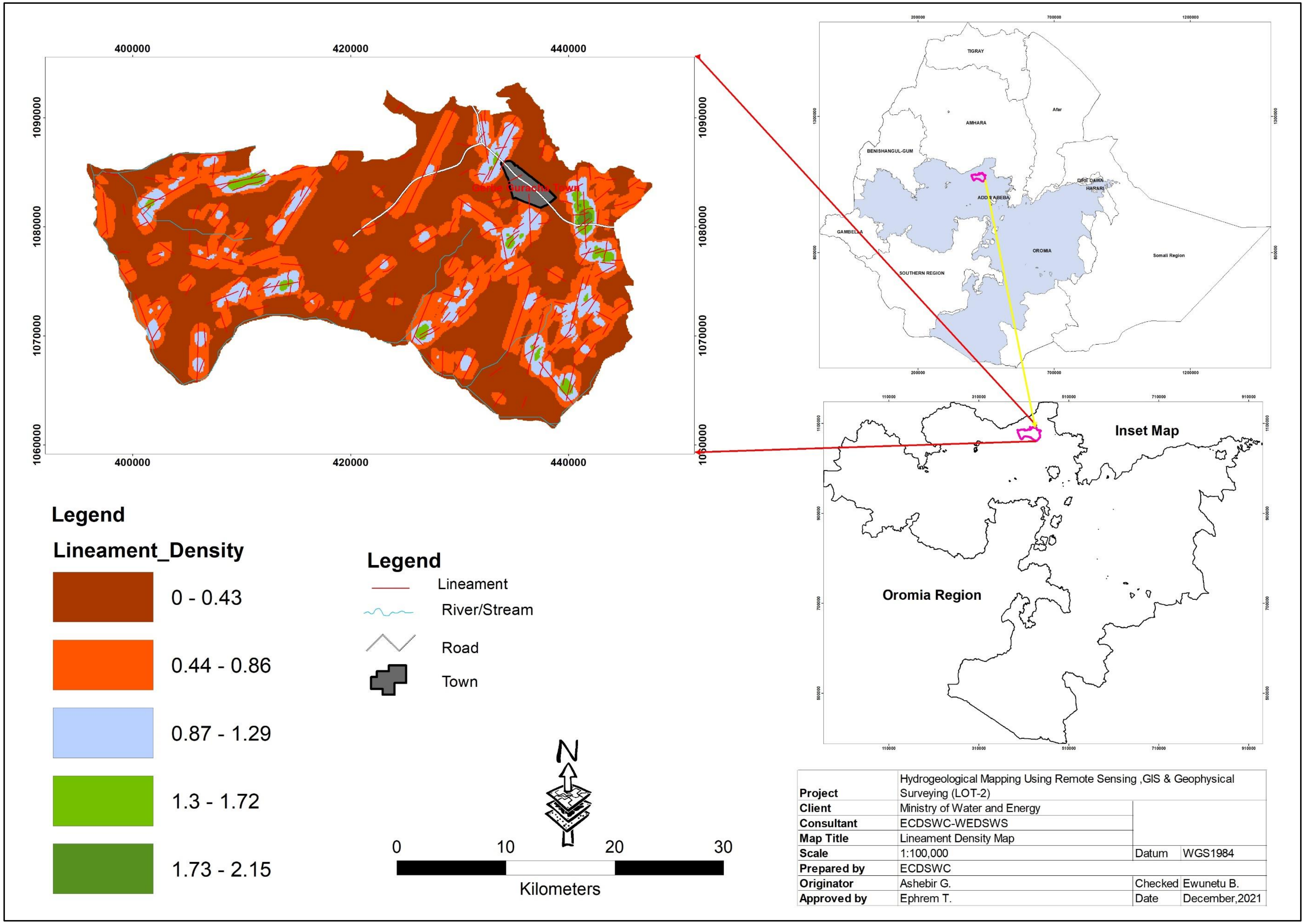


Figure 11: Lineament Density map of Kuyu wereda

4.2.5 Lineament Proximity thematic layers

There is a close relationship between lineament proximity and groundwater potential. Thus, the intensity of groundwater potential decreases with increasing distance from the lineaments and increases with decreasing distance from the lineament. The proximity from the lineament was derived by creating buffers based on conceptual understanding of the specific Study area. High weights are assigned to the areas nearby the lineament and low weights to distance locations. The proximity from the lineament map is shown in figure 12.

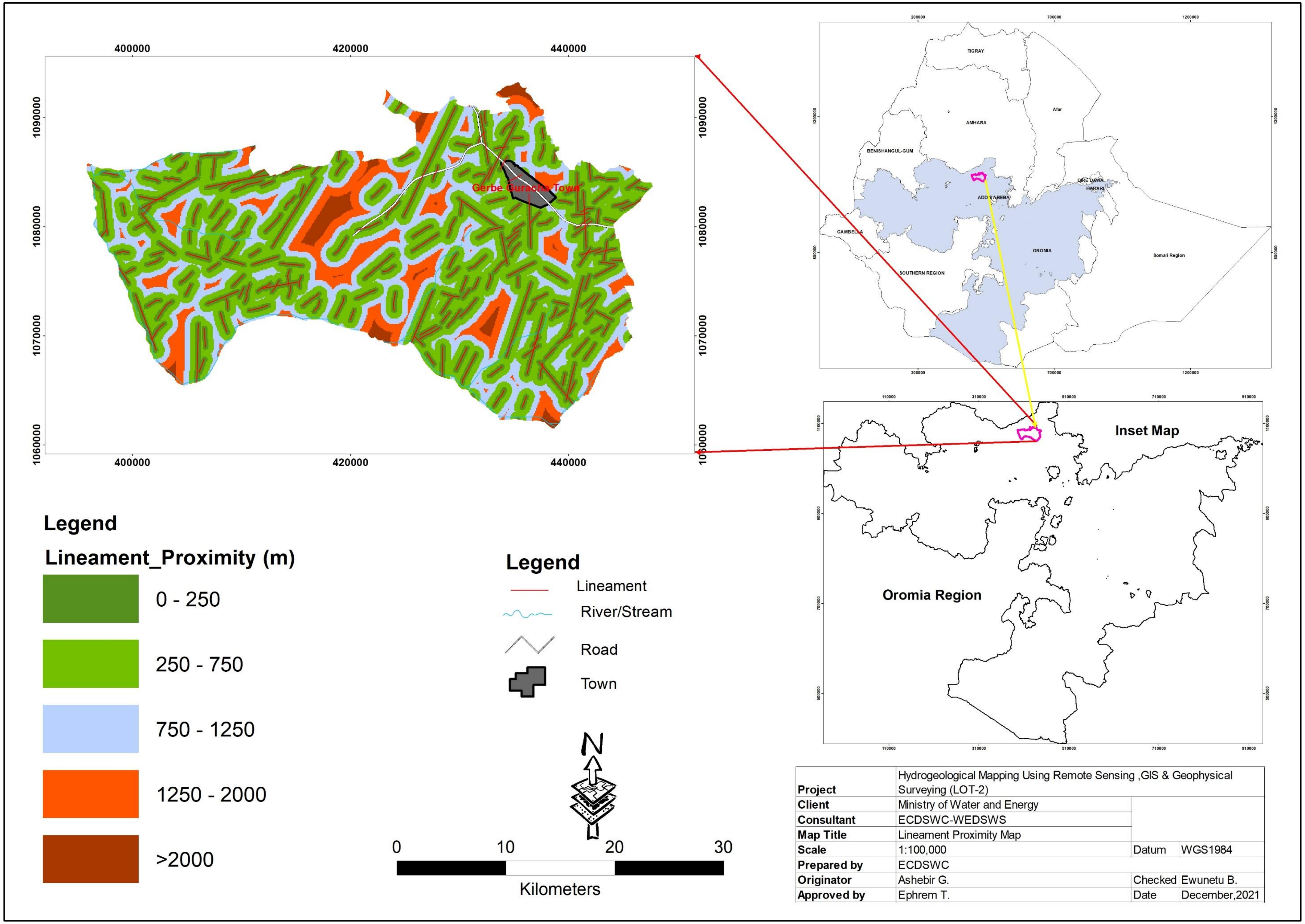


Figure 12 : Lineament Proximity Map of Kuyu wereda

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

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

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):

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

Where W is the effective weight of each thematic layer

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

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

4.4.1 Single parameter Sensitivity analysis of Kuyu Wereda

The statistics of the single-parameter sensitivity analysis of Kuyu 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 Kuyu Wereda shows Lithologic units as the most effective layer in GWP mapping with mean effective weights of 47.2%.The next higher effective weighs of 26.7 % and 9.7% were recorded in groundwater recharge and Lineament proximity layers. The TWI and Lineament density tend to be less effective thematic layers with mean effective weightings of 9.3% and 6.6% respectively compared with their empirical weights of 11.7% and 7.6%.

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

The effective weight of Single parameter Sensitivity analysis of Kuyu Wereda					
		Effective Weight (%)			
	Empirical Weight (%)	Min	Mean	Max	SD
Lithology	48.3	40.2	47.2	54.4	8.5
Recharge	25.4	21.2	26.7	32.2	5.6
TWI	11.7	7.1	9.3	11.6	1.0
LD	7.6	5.4	6.6	7.8	0.4
LP	7.1	8.5	9.7	10.9	0.5

4.5 Validation using well data

Introduction

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

To validate the result of overlay analysis, ground-truthing of the work is conducted by comparing it with local and regional hydrogeological and geomorphological conditions and also previously drilled shallow and deep wells. In order to validate produced groundwater potential map, the following steps are followed. Geological and hydrogeological observations

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

Kuyu wereda

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

The Northern part of Kuyu wereda is mapped as moderate 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, Tarmaber, and Alluvial aquifers to store and convey groundwater through interconnected secondary and primary porosity. While the Southern part of Kuyu wereda is mapped as a low to very low groundwater potential zone because of the unfavorable topographic setup and the ability of the aquifer to store and transmit groundwater is very low to low potential natural.

A total of 2 wells and 2 springs were used for validation, the 2 wells and 1 spring yield values agree with the groundwater potential zone map of Kuyu wereda which fell within low to moderate potential. While the other spring which fell within a very high potential zone map has moderate groundwater potential, the unfit observed shall be verified during detailed investigation of Geophysical and Hydrogeological investigation.

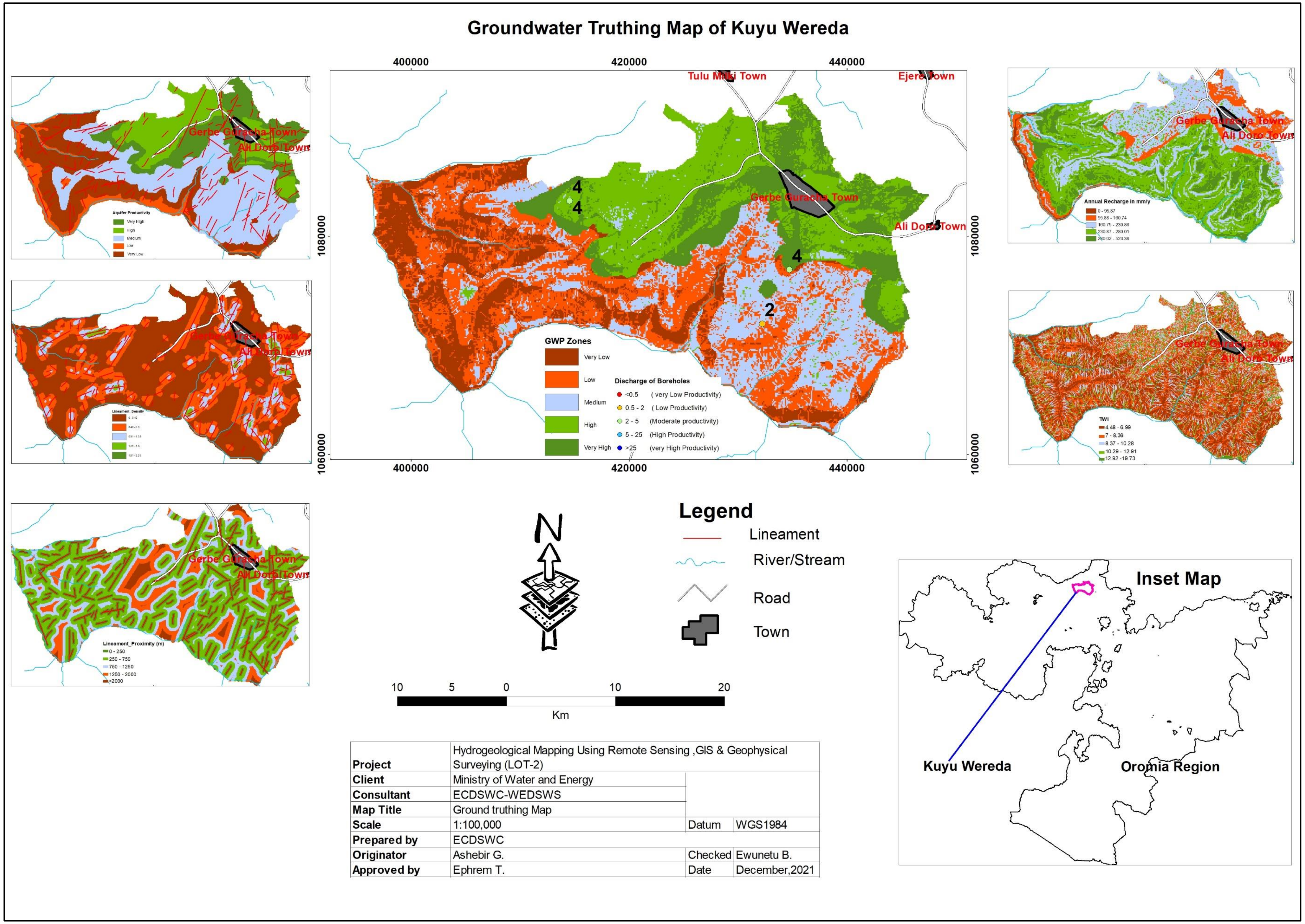


Figure 13 : Groundwater potential truthing of Kuyu wereda

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

To estimate the water demand of the Study area 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 Kuyu wereda for water supply of small-town, livestock & rural water supplies water demand are summarized in the table below.

4.6.1water demand of Kuyu Wereda

	Kuyu Wereda	
year	**Kuyu Rural AVG water Demand m3/day**	**Gerba Guracha town AVG water Demand m3/day**
2021	4414	2997
2025	5069	3442
2030	5887	3997
2035	6721	4563

Wereda	**Livestock Category**											**Water Demand in m3/day**
	Shoats	0.01	Cattle	0.7	Camel	1	Donkey	0.6	Chicken	0.001	TLU	
Kuyu	70500	705	135333	94733.1	0	0	33827	20296.2	122443	122.443	115734.3	2,893

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 zone (GWPZ)

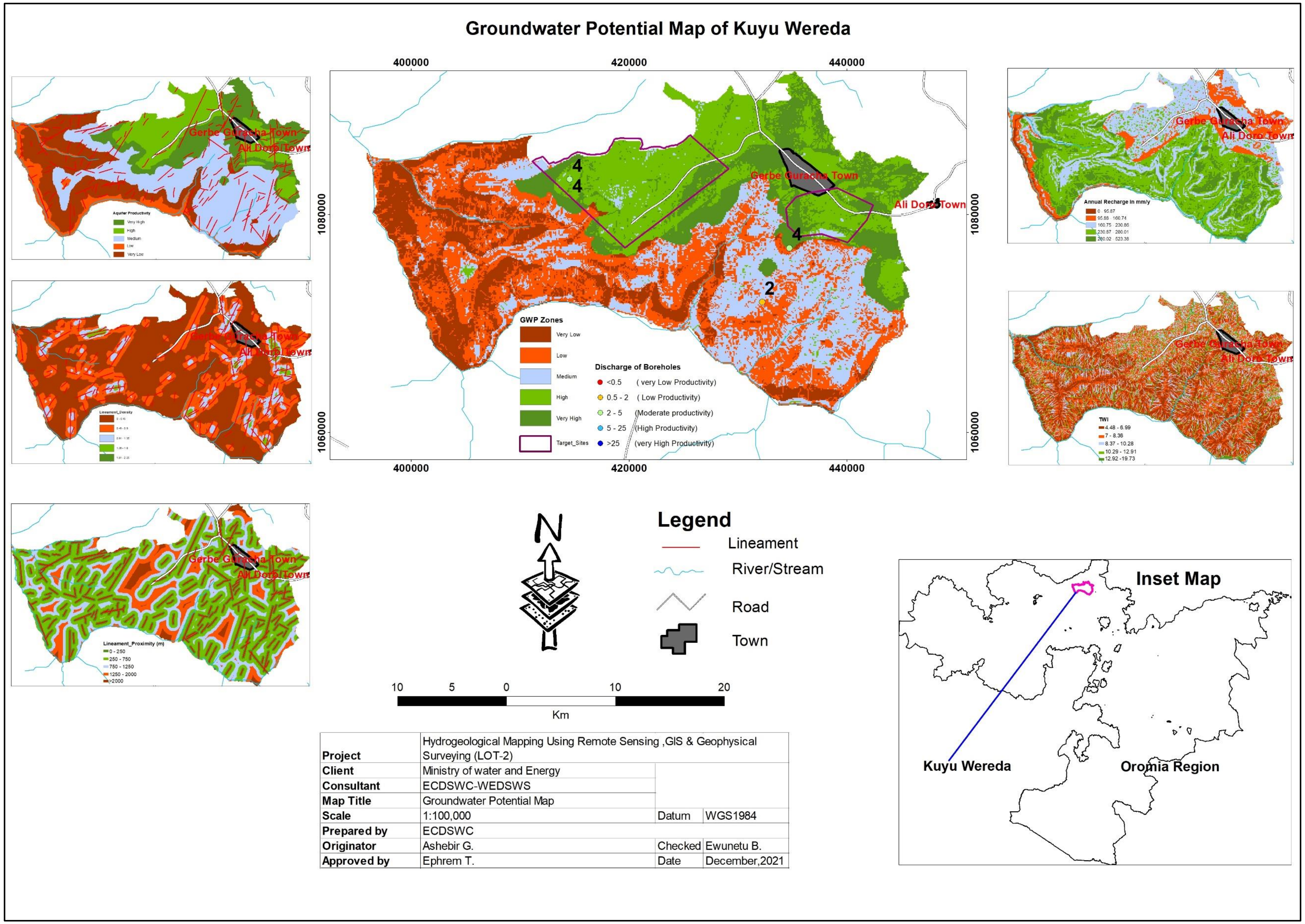


Figure 14: GWP map Kuyu Wereda

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 reginal governments,NGO partners and other relevant stkakeholders.					
3.17	**Training 3** :Capacity building of 60 national counterparts					

LEGEND: Phase I; Phase III; Report; Worksho; Submission of Reports; Phase II; Field work; Office; Training

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 Kuyu 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 Kuyu Wereda.

The spatial distribution of the Study area GWP zones generally matches with the conceptual understanding of the Study area 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 is recommended that this study must be supported by detailed Hydrogeological, Geophysical, and test well drilling to more understand the groundwater system of the Kuyu Wereda.

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Annex 1: Observation during groundwater truthing and validation

Kuyu Wereda

No.	Region	Wereda	Locality	UTM E	UTM N	Characteristic of validation point
1	Oromia	Kuyu Wereda	Derach cagi	414526	1083262	▪ The observation point is plain land with moderate recharge and runoff potential. ▪ Alluvial aquifer with moderate 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 4l/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, further geophysical investigation and detail hydrogeological mapping will verify the groundwater potential map of this area.
2			Dawicha Kerensa	434702	1076942	▪ The observation point is mountainous and sloppy land. ▪ One spring is observed with discharge of 4 l/s at contact of Aiba basalt and Antalo Limestone. ▪ The area is mapped as high to very high groundwater potential zone. Generally, further test well drilling , detail hydrogeological and geophysical investigation will be required to verify the aquifer potential of this area.
3			Jila Keransa	432189	1071983	▪ The observation point is mountainous and sloppy land. The area is characterized as high runoff potential and low recharge potential. ▪ One spring is observed with discharge of 2 l/s at contact of Antalo Limestone and gypsum. ▪ The area is mapped as low to moderate groundwater potential zone which highly agree with the spring discharge observed in this zone.

Annex 2: Water point inventory data

Kuyu Wereda

SN	UTME	UTMN	ELEV, M	Site_Name	Region	Wereda	Well_Type	Depth	SWL	DWL	DD	Q	K	T
1	422683	1081808	2527	"	Oromia	Kuyu	HDW							
2	415471	1076931	2370	" 1ffaa	Oromia	Kuyu	HDW							
3	412978	1079239	2561	abdarii barkoo	Oromia	Kuyu	HDW							
4	419815	1080198	2516	abdarii ko'etii	Oromia	Kuyu	HDW							
5	410912	1079462	2517	alaltu	Oromia	Kuyu	HDW							
6	420870	1079363	2526	b/guddina	Oromia	Kuyu	HDW							
7	425511	1086060	2545	B/hawaas 1ffaa	Oromia	Kuyu	HDW							
8	426092	1087718	2549	B/hawaas 2ffaa	Oromia	Kuyu	HDW							
9	423524	1081361	2543	B/iyyaasoo	Oromia	Kuyu	HDW							
10	425657	1085579	2561	B/milkii	Oromia	Kuyu	HDW							
11	435586	1091951	2201	B/shibuu	Oromia	Kuyu	HDW							
12	424102	1081864	2569	bantuu	Oromia	Kuyu	HDW							
13	424179	1082396	2557	bantuu 1ffaa	Oromia	Kuyu	HDW							
14	424178	1082151	2560	bantuu 2ffaa	Oromia	Kuyu	HDW							
15	422830	1081725	2526	borcoska	Oromia	Kuyu	HDW							
16	425968	1082263	2519	burqa gada	Oromia	Kuyu	HDW							
17	425673	1081545	2508	burqa muni	Oromia	Kuyu	HDW							
18	433785	1092229	2334	burqaa akalee	Oromia	Kuyu	spring							
19	425832	1083890	2565	burqaa boorii 1ffaa	Oromia	Kuyu	HDW							
20	425864	1083877	2563	burqaa boorii 2ffaa	Oromia	Kuyu	HDW							
21	425890	1083878	2562	burqaa boorii 3ffaa	Oromia	Kuyu	BH							

SN	UTME	UTMN	ELEV, M	Site_Name	Region	Wereda	Well_Type	Depth	SWL	DWL	DD	Q	K	T
22	436587	1088886	2311	burqaa borinee	Oromia	Kuyu	HDW							
23	423946	1083354	2540	burqaa galee	Oromia	Kuyu	HDW							
24	426093	1079535	2284	C/alaltuu	Oromia	Kuyu	HDW							
25	424883	1084683	2563	caancoo	Oromia	Kuyu	BH							
26	436403	1091524	2201	cabaree	Oromia	Kuyu	HDW							
27	411952	1079565	2528	caffee kuchuu	Oromia	Kuyu	HDW							
28	406560	1083914	1847	caffee laaloo	Oromia	Kuyu	HDW							
29	427915	1080725	2342	cimoo	Oromia	Kuyu	HDW							
30	428500	1079445	2534	darara	Oromia	Kuyu	HDW							
31	427573	1082257	2585	daree 2ffaa	Oromia	Kuyu	HDW							
32	434702.7	1076943	2375	Dawicha keransa	Oromia	Kuyu	Sp.f					4		
33	414526	1083262	2575	derach cagi	Oromia	Kuyu	BH		18			4		
34	414526	1083262	2575	Derodannisa	Oromia	Kuyu	SW		18			4		
35	417640	1077628	2550	dimoo	Oromia	Kuyu	HDW						0	
36	415922	1077192	2381	ejersa maye	Oromia	Kuyu	HDW							
37	418579	1077184	2558	ejersa warjii 1ffaa	Oromia	Kuyu	HDW							
38	419151	1077788	2534	ejersa warjii 2ffaa	Oromia	Kuyu	BH							
39	425090	1082650	2539	finoo 1ffaa	Oromia	Kuyu	HDW							
40	424817	1082586	2554	finoo 2ffaa	Oromia	Kuyu	HDW							
41	425054	1082707	2547	finoo 3ffaa	Oromia	Kuyu	HDW							
42	424323	1085250	2551	gatira fi simbo	Oromia	Kuyu	HDW							
43	415922	1077192	2382	gora dinquu 2ffaa	Oromia	Kuyu	HDW							
44	426585	1080239	2342	H/meettaa	Oromia	Kuyu	spring							
45	422740	1085325	2543	haqaqoo	Oromia	Kuyu	HDW							
46	416133	1077026	2357	hara waaxuu	Oromia	Kuyu	HDW							
47	421083	1079545	2537	harbu ko'etii	Oromia	Kuyu	HDW							
48	422017	1084944	2547	harbu lodee	Oromia	Kuyu	HDW							
49	406370	1082233	1883	haroo	Oromia	Kuyu	HDW							
50	428117	1085297	2573	harsadii 1ffaa	Oromia	Kuyu	HDW							
51	427980	1085067	2588	harsadii 2ffaa	Oromia	Kuyu	HDW							
52	427684	1082207	2592	husoo	Oromia	Kuyu	HDW							
53	421002	1082824	2553	iyaso 1ffaa	Oromia	Kuyu	HDW							
54	423951	1082713	2553	iyaso 1ffaa	Oromia	Kuyu	HDW							
55	424217	1082566	2552	iyasoo 3ffaa	Oromia	Kuyu	HDW							
56	432189.7	1071984	2300	Jila Keransa	Oromia	Kuyu	Sp.d					2		
57	436430	1090827	2208	katabaa	Oromia	Kuyu	HDW							
58	423067	1081808	2545	ko'a fi iyasoo 1ffaa	Oromia	Kuyu	HDW							
59	427606	1083419	2578	kolobo fi warji 1ffaa	Oromia	Kuyu	HDW							
60	427596	1083398	2577	kolobo fi warji 2ffaa	Oromia	Kuyu	HDW							
61	427417	1083114	2602	kolobo fi warji 3ffaa	Oromia	Kuyu	HDW							
62	427059	1084729	2562	kombolcha	Oromia	Kuyu	BH							
63	406287	1082477	1932	laga badhaasa	Oromia	Kuyu	HDW							
64	406110	1082413	1907	laga hundee	Oromia	Kuyu	HDW							

SN	UTME	UTMN	ELEV, M	Site_Name	Region	Wereda	Well_Type	Depth	SWL	DWL	DD	Q	K	T
65	408670	1082079	1914	laga macaa	Oromia	Kuyu	HDW							
66	429349	1080651	2220	laga nisee	Oromia	Kuyu	HDW							
67	419194	1079284	2517	laga qallaa	Oromia	Kuyu	BH							
68	423735	1084627	2557	M/B/bondee	Oromia	Kuyu	HDW							
69	427237	1081924	2585	M/B/H/boosee	Oromia	Kuyu	HDW							
70	428694	1081339	2329	M/B/H/darso	Oromia	Kuyu	HDW							
71	421065	1079909	2547	M/B/H/school	Oromia	Kuyu	HDW							
72	427962	1084777	2584	M/B/L/gulanta	Oromia	Kuyu	HDW							
73	420101	1079344	2530	M/B/lakk 1	Oromia	Kuyu	HDW							
74	420111	1079269	2530	M/B/lakk 2	Oromia	Kuyu	HDW							
75	420044	1079224	2528	M/B/lakk 3	Oromia	Kuyu	HDW							
76	435144	1089797	2662	M/B/logee	Oromia	Kuyu	HDW							
77	420501	1079233	2529	M/looni lakk 1	Oromia	Kuyu	HDW							
78	420451	1079137	2530	M/looni lakk 2	Oromia	Kuyu	HDW							
79	420594	1079230	2532	M/looni lakk 3	Oromia	Kuyu	HDW							
80	406476	1080939	1642	madabii (heekoo)	Oromia	Kuyu	HDW							
81	420978	1078711	2526	maram mangasha	Oromia	Kuyu	HDW							
82	427007	1080605	2365	micaa	Oromia	Kuyu	spring							
83	420938	1079485	2534	network	Oromia	Kuyu	HDW							
84	423846	1081134	2530	oddoo 1ffaa	Oromia	Kuyu	HDW							
85	423830	1081138	2540	oddoo 2ffaa	Oromia	Kuyu	HDW							
86	421693	1079213	2519	q/meettaa 1ffaa	Oromia	Kuyu	HDW							
87	421863	1079345	2519	q/meettaa 2ffaa	Oromia	Kuyu	HDW							
88	421486	1079077	2525	q/meettaa 3ffaa	Oromia	Kuyu	BH							
89	421051	1079806	2555	qaban	Oromia	Kuyu	BH							
90	420110	1078259	2535	qaree qimissi	Oromia	Kuyu	BH							
91	423089	1079932	2520	qumburee 1ffaa	Oromia	Kuyu	HDW							
92	423084	1079942	2519	qumburee 2ffaa	Oromia	Kuyu	HDW							
93	421605	1085120	2550	sayoo	Oromia	Kuyu	HDW							
94	423490	1084715	2549	shixuu	Oromia	Kuyu	HDW							
95	425410	1079726	2357	shunqurii	Oromia	Kuyu	HDW							
96	412617	1079534	2520	siisuu fi arsame	Oromia	Kuyu	HDW							
97	421247	1079565	2515	tulluu boombii	Oromia	Kuyu	HDW							
98	422779	1083135	2523	tuutii	Oromia	Kuyu	HDW							
99	420122	1078234	2535	ula booyiv	Oromia	Kuyu	HDW							
100	421711	1079752	2535	urgee	Oromia	Kuyu	BH							
101	422205	1080186	2539	urgee 3ffaa	Oromia	Kuyu	HDW							
102	414200	1083318	2566	urufa qillee	Oromia	Kuyu	HDW							
103	414131	1083383	2583	urufa qillee	Oromia	Kuyu	HDW							
104	412976	1079239	2565	wallensuu	Oromia	Kuyu	HDW							
105	417842	1077033	2505	waraba bulee	Oromia	Kuyu	spring							
106	420773	1085499	2540	xarusee 1ffaa	Oromia	Kuyu	HDW							
107	421079	1085389	2548	xarusee 2ffaa	Oromia	Kuyu	HDW							

Annex 3: Geologic map and cross section of Kuyu Wereda