The Federal Democratic Republic of Ethiopia
Ministry of Water and Energy

Consultancy Service for Hydrogeological Mapping Using Remote Sensing, GIS and Geophysical Surveying

Lot – 4

Procurement Reference Number: BDA/ICB/ GW01/2021

PHASE II

DEVELOPING GROUNDWATER POTENTIAL MAP FINAL MAIN REPORT

Submitted to:
Minstry of Water and Energy

Submitted by:
DH Consult
In association with
Golder Associate UK Ltd

DH Consult
P.O.Box: 19745
Tel.: +251-11-6628859
Fax: +251-11-6628860
Addis Ababa, Ethiopia
Email: dhorecha@gmail.com

GOLDER
Golder Associate UK Ltd
20 Eastboume Terrace, London,W26LG, UK
Company Registered in England No.1125149
Tel: +4402074230940

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Executive Summary

The main objective of the work is to increase access to safe and sustainable water for the people in 12 target Woredas by producing hydrogeological maps at woreda level, select potential sites and recommend two drilling sites i.e., one optimal drilling site and one alternative or optional drilling site, using these maps and geophysical field investigation and recommend the type of drilling

The phase II scope of the work covers groundwater mapping using remote sensing and GIS approach with some ground truthing to produce groundwater potential map of each target Woreda that will help identify the most suitable areas for further hydrogeological and geophysical investigation. The detailed scope of the work at this stage is to process the data obtained from remote sensing resource analysis and combine geological maps, lineament density maps, and wetness index maps and recharge zonation maps into one layer which displays different groundwater potential zones. To check the overlay analysis results by using information from secondary data (boreholes, springs and dug wells) to prioritize the selection of the target areas and conduct ground-truthing and identify two target areas in the woreda from areas highlighted with a high groundwater potential to priority population targets.

Target woredas are found in the SNNP, Oromia and Gambella regional states. The distribution of woredas in the regions is as followes; 6 in the SNNP region, 3 woredas in Oromia region and 3 woredass in Gambella region.

Most of the previous studies focused at regional scale area and generate more general information. Some of the works relevant to this study work include groundwater potential resources evaluation in major river basins.

Mapping of the groundwater potential zones using integrated GIS and RS techniques in conjunction with review of previous geological and hydrogeological works has been performed.

To have a broader view and understand the overall geological and hydrogeological settings of the study area and produce reliable thematic layers for each target woreda, a synoptic view of the continuity of lithology, lineaments, recharge, and storage area is essential. A synoptic view of geology, lineament, topographic wetness index and recharge is prepared for the area. The following lithologic units are identified in the synoptic area.

The lithology of the synoptic (SNNP and Bule Hora) view includes Maanetite-auartz-feldspar gneiss (Pmfg, Metaquartzite (Pmqz), Oligoclase-hornblende-biotite-quartz gneiss, calc-silicate, biotite, and biotite-hornblende gneisses (Pfbg): Augen biotite-quartz-feldspar gneiss anitized (Pmcg, Biotite-quartz-oligoclase gneiss, medium grained amphibolite and minor oligoclase-quartz-microcline gneiss (Pfqg). Biotite-microcline-quartz gneiss. Medium grained amphibolite garnet-staurolite schist and marble (Pbmg) Fine to medium grained amphibolite and plaqioclase-chloriteactinolite schist (Pcas), Phyllite. metasiltstone and metasandstone (Ppss), Shole Iqnimbrite (Pgs), Middle Basalt (Ngm), Elluvium (Qe), Alluvium (Qa).The lithology of the synoptic view Shashamanne is mainly covered by Nazret group and Dino formation (NQS) which covers an area of 81.5%. of the total woreda. The central volcanic complexes also cover 11% (Qwa, Qwo and Qwpu) from the total area and the lacustrine sediment has 7.2%. Basalts of the rift floor (Qwbp) which covers small area on the boundary the in northwestern direction. The lithology of the synoptic view (Jore, Akobo and Itang) includes Maanetite-auartz-feldspar gneiss (Pmfg, Metaquartzite (Pmqz), Oligoclase-hornblende-biotite-quartz gneiss, calc-silicate, biotite and biotite-hornblende gneisses (Pfbg): Augen biotite-quartz-feldspar gneiss anitized (Pmcg, Biotite-quartz- oligoclase gneiss, medium grained amphibolite and minor oligoclase-quartz-microcline gneiss (Pfqg). Biotite-microcline-quartz gneiss. Medium grained amphibolite garnet-staurolite schist and marble (Pbmg) Fine to medium grained amphibolite and plaqioclase-chloriteactinolite schist (Pcas), Phyllite. metasiltstone and metasandstone (Ppss), Shole Ignimbrite (Pgs), Middle Basalt (Ngm), eluvium (Qe), Alluvium (Qa). Three main lithologic units are identified in Liben woreda as; ***Basement rocks*** (Metamorphics) Metadiorite, biotite-amphibolite, metagabro and granite with banded quartzo-feldspar and gneiss, ***Mesozoic Sedimentary rocks*** (Limestone with mionor sandstone and conglomerate) and ***Tertiary volcanics*** (Dark grey to black aphanitic basalt) with Quaternary alluvials. Generally, most of the study areas are affected by lineaments and/or fractures consequent to several tectonic activities in the past due to its placement within the Main Ethiopian Rift. Lineaments and faults are aligned in the general trend of the Main Ethiopian Rift in NE-SW general direction.

Groundwater recharge has been estimated using annual rainfall and infiltration coefficient of each geological unit. The monthly rainfall Data were obtained from CHIRPS source of 2020 monthly series.

The Topographic wetness index, also known as the compound topographic index, is commonly used to quantify topographic control on hydrological processes. The index is a function of both the slope and the upstream contributing area per unit width orthogonal to the flow direction.

In Groundwater potential mapping preparation of the above indicated Thematic layers are prepared for the woreda.

The lithologic layers for each woreda are prepared by grouping the lithologies into different units taking their characteristics of hydrogeological significance into consideration.

Lineaments of respective study areas were extracted from a mosaicked Sentinel 2, 2020 and 2021 series combined with geomorphology of the area and mapped using ArcGIS 10.8 software, and subsequently lineament density map was computed.

Topographic Wetness Index (TWI) requires basically slope (in degree), flow direction and flow accumulation which are generated from elevation maps (DEM) extracted from SRTM (30m resolution) as an input.

Finally, recharge map layer was produced by calculating raster map of annual rainfall with infiltration coefficient of each geological unit in ArcGIS 10.8 platform.

The monthly rainfall data were obtained from open sources CHIRPS monthly series (from January to December 2019). All the layers were resampled into 100 m cell size Rastar Map

A weighted index overlay analysis method has been employed for the mapping using 4 thematic layers namely Lithology, Lineament density, Topographic Wetness Index and Recharge. Weights assigned to each class in all these thematic maps are based on the influence of each thematic layer on groundwater potential capacity through analytical hierarchical process techniques (AHP) method. Based on the assignment and normalized weighting of the individual features of the thematic layers, a potential groundwater index map was produced. The groundwater potential zone map thus obtained has been qualitatively classified into different classes.

To validate the classification of the groundwater potential zones as revealed by the GIS based groundwater potential map, data on existing wells (yield) were collected and used to check the potential zones identified.

Finally, target sites are identified and proposed for each target based on the identified groundwater potential zones, the productivity of the hydrostratigraphic units with their expected optimum borehole yield, proximity to beneficiaries and population density.

CHAPTER 1 : BACKGROUND

1.1. Introduction

The arid, semi-arid and dry sub-humid areas of Ethiopia account for about 70 % of the total land mass and 46% of the total arable land. Drought and flood events, loss of grazing land, range land degradation, change in ecosystems and biodiversity, loss of livestock, water & food insecurity, increased temperatures and aridity, deforestation, and desertification, treats to health and general wellbeing, displacement and resource-based conflicts are the common risks and vulnerability caused by extreme climates (Eli no and la Nina) recurring for decades as extreme changes in rainfall patterns in these areas. Therefore, to create resilient community to climate change impacts and bring about sustainable development, ensuring water security through assessing and utilizing the water resources potential (both surface and subsurface) of the areas for domestic and livestock purpose is an urgent local coping strategic priority.

Drought is the major natural disaster affecting the livelihood of Ethiopians, resulting in water insecurity which in turn causes disruption of livelihoods and loss of life. A significant proportion of the Ethiopian population still lacks access to clean water, even though Ethiopia successfully achieved the Millennium Development Goal (MDG) target of halving the number of people without access to improved drinking water. At the national level, 60 to 80 per cent of communicable diseases are attributed to limited access to safe water, and inadequate sanitation and hygiene services.

As part of its engagement, the Basin Development Authority of Ethiopia is committed in undertaking water resources study and mapping groundwater resources towards developing groundwater resources for the water needy community of Ethiopia. In line with this, the Basin Authority of Ethiopia in collaboration with the UK Department for International Development (DFID) has decided to undertake groundwater resources assessment using remote sensing and Geophysical surveying in selected drought prone areas of Ethiopia. The purpose of this undertaking is to identify priority water needy areas and locate potential groundwater sites that can be sources for water needy communities. Accordingly, a consultancy service agreement has been signed between FDRE, Basin Development Authority and DH Consult in JV with Golder Associate UK Ltd to undertake Hydrogeological Mapping using Remote Sensing, GIS, and Geophysical Survey in selected 12 woredas of Ethiopia. The project under this agreement is expected to be finalized within 10 months starting from May 2021. As part of the assignment, this phase II work presents approaches and methods that has been undertaken to develop groundwater potential map that would further help hydrogeological investigation employing classical methods.

1.2. Objective

1.2.1. General objective

The main objective of the work is to increase access to safe and sustainable water for the people in each target Woreda by producing hydrogeological maps at woreda level and recommend drilling sites which the Government of Ethiopia and other partners can use for developing groundwater resources of the woreda

1.2.2. Specific Objectives

The specific objectives of this project include the following:

- Create detailed groundwater potential maps for the Woreda,
- Identify one optimal drilling site and one alternative or optional drilling site for the woreda, using these maps and geophysical field investigation and recommend the type of drilling methodology to be employed,
- Build the capacity of WDC, BDA, Regional Governments and NGOs to use overlay analysis techniques for groundwater potential mapping in Ethiopia

1.3. Scope

This study/ GW characterization, mapping and advanced mapping work/ will take place in four (4) Lots in Amhara, Afar, Oromia, SNNP, Tigray, Gambela and Somali regions. The total project covers 53 woredas selected for groundwater mapping under the Terms of Reference. Lot 4 comprises 12 Woredas and produce 12 hydrogeological maps (one map per woreda) to identify the most suitable site for borehole drilling. A critical first step for this project will be the initial identification of target sites for borehole drilling. Target woredas are of 12 and the scope of the assignment for the woreda for Phase II Developing Groundwater Potential Map is as indicated hereunder.

i. Organize, coordinate, and facilitate a workshop with the Peer Review Committee to finalize overlay analysis weighting criteria

ii. Process the data provided by remote sensing analysis.

- For the woreda, the Consultant will use a GIS overlay analysis tool to combine remote sensing layers into one layer which displays the groundwater potential.
- To refine target areas, the Consultant will check the overlay analysis results by using information from secondary factors (Type 2 and Type 3 layers).
- At woreda level and in consultation with the Regional Water Bureaus and other partners, identify priority population targets and estimate water demand.
- Select two target sites in the woreda from areas highlighted with a high groundwater potential and close to priority population targets.
- Carry out field visits to all the woredas to ground-truth the information obtained from the input layers and the results from the overlay analysis.
- Carry out National Groundwater Risk Mitigation Strategy study and make recommendations

- Following the ground-truthing works and population targeting, select areas for detailed studies (detailed study areas)
  - Submission of groundwater potential maps at woreda level (1:100,000).
  - Development of conceptual models (hydrogeological cross-sections) of the Woredas for a better understanding of climate resilient groundwater system and the remote sensing and overlay analysis outputs,
  - Submitting a final report per Priority woreda detailing groundwater potential maps for each woreda with ground-truthed analysis of drilling potential.
  - Dissemination workshop of the groundwater potential resources mapping exercise and results among the main WASH stakeholders in Ethiopia.

1.4. Location of target woredas

Target woredas are found in the SNNP, Oromia and Gambella regional states. The distribution of woredas in the regions are as follows; 6 in the SNNP region, 3 woredas in Oromia region and 3 woredass in Gambella region. The location of target woredas in Lot – 4 are presented in figure 1.1

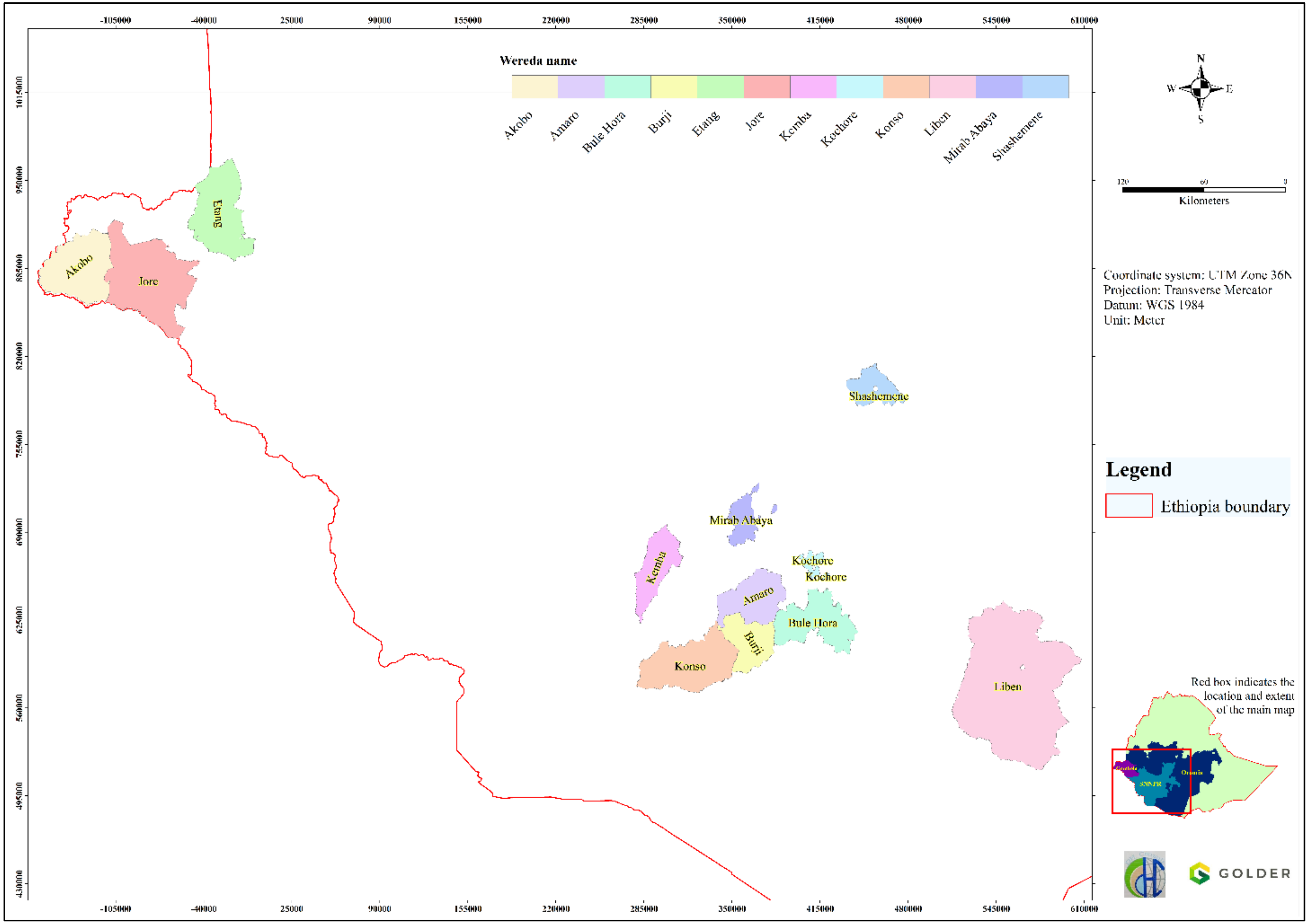


Figure 1.1. Location map of 12 target woredas in Lot – 4

CHAPTER 2 : DESCRIPTION OF TARGET WOREDAS

This section of the report presents the general information about each target woreda of the Lot - 4. Accordingly, the information related to location, population and demography, existing water supply situation, climate and physiography are included.

2.1. Bule Hora

2.1.1. Location

Bule Hora Woreda is found in the southern part of the country in Oromiya Regional Government, Borena Zone partly in Gelana River and partily in Dawa River basins. Garba is a capital town of the woreda accessed with a road running from Addis to Bule - Hora - Yabelo. The geographic location of Bule Hora Wordea is presented in the figure below (Figure 2.1).

2.1.2. Population and demographic map

The population the Woreda has been projected from the central statical agency (CSA) 2007 population and housing census data to the currently year which is 2021. Accordingly, Bule Hora Woreda has a total of 322,016 populations estimated from its 33 Kebeles. The highest and the least population Kebeles in the Woreda are 2,224 and 15,821 respectively. The demography map of Bule Hora by kebele is shown in Figure 2.2.

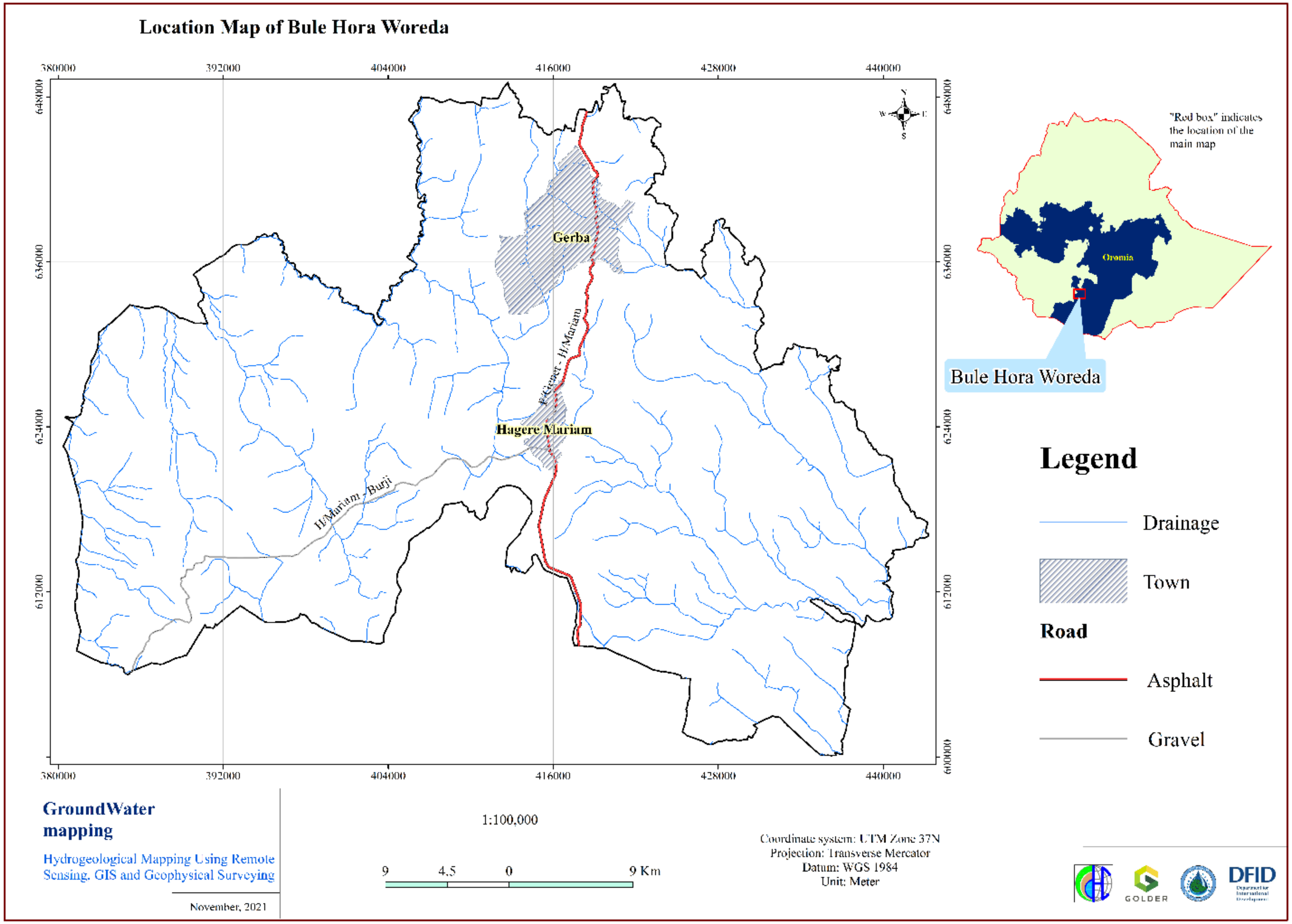


Figure 2.1. Location map of Bule Hora Woreda

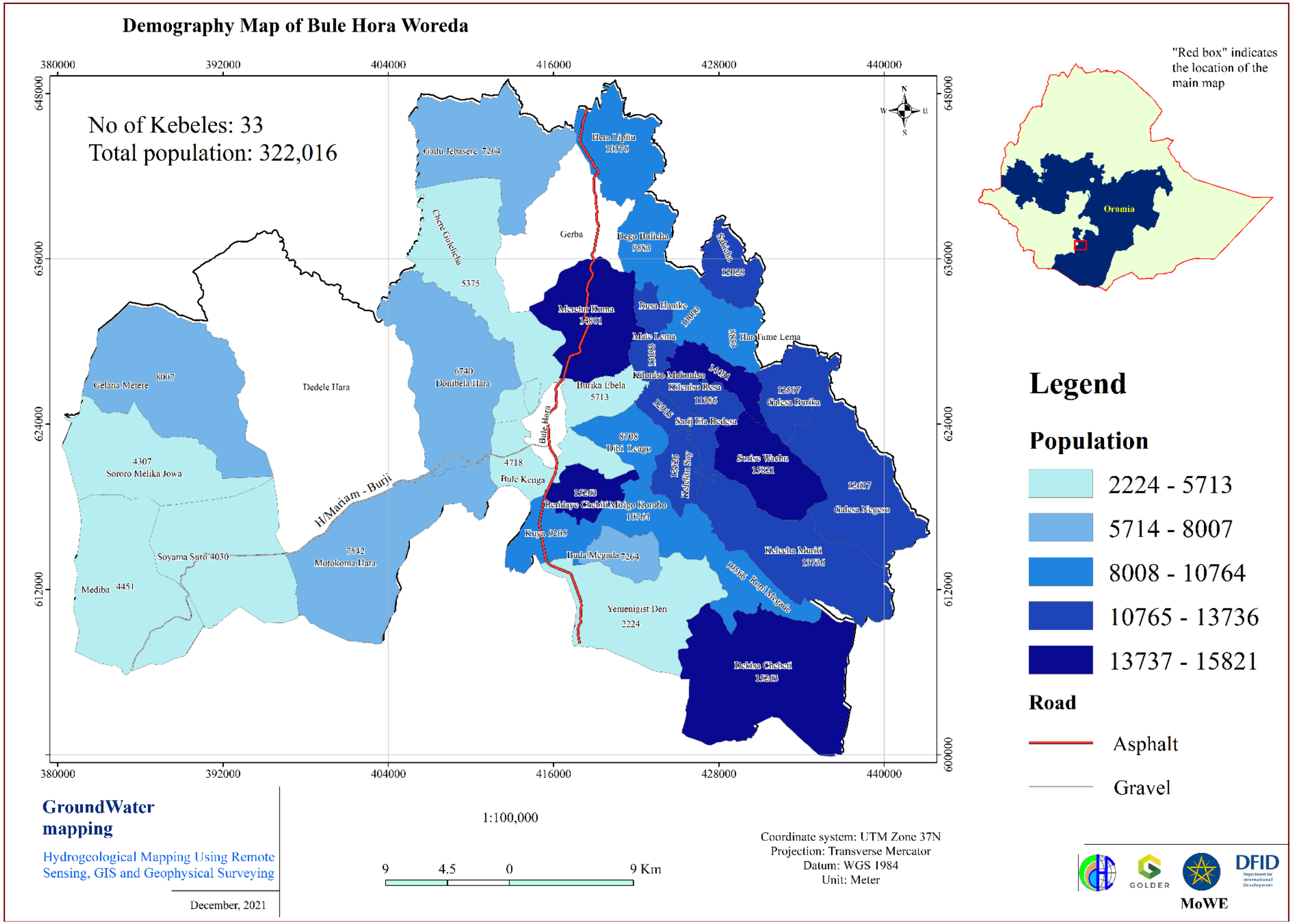


Figure 2.2. Demographic map of Bule Hora Woreda that presents the population projection of 2021.

2.1.3. Existing water supply situation

A number of shallow boreholes have been drilled in the eastern and south western parts of the woreda along and close to small stream banks. These wells belong to rural community, Gerba and Bule Hora town water supply. As far as the data we have is concerned, boreholes and dug wells in the area have depth less than 155m having shallow depth to the groundwater less than 53m are available in this area. Well yields vary from 0.5 l/s to 4 l/s. The dominant aquifer material observed at some of these wells is alluvial deposits underlain by weathered and slightly fractured basalts and basement rocks. These wells are located at places having relatively low relief.

2.1.4. Climate

The month with the highest rain in Bule Hora is April, with an average rainfall of 4.7 inches. The rainless period of the year lasts for 1.9 months, from December 15 to February 13. The month with the least rain in Hagere Maryam is January, with an average rainfall of 0.3 inches. The mean annual rainfall of Bule Hora Woreda is 1250 mm. The rainfall pattern is bimodal i.e. have two distinct rain seasons. The month with the least precipitation on average is January with an average of 32.83mm. The elevation ranges from 1300 to 2100 meters above sea level. In Bule Hora, the wet season is overcast, the dry season is partly cloudy, and it is warm year round. Over the course of the year, the temperature typically varies from 23°C to 29°C. The warmest month, on average, is March with an average temperature of 29°C. The coolest month on average is July, with an average temperature of 23°C (https://www.worldweatheronline.com).

2.1.5. Physiography

An attempt has been made to study the geomorphological details of the Bule Hora woreda and to demonstrate their relationship to aquifer geometry in the area. In this study a systematic analysis of variations in elevations of different land forms and their relationship with lineaments, drainage pattern and rock units have been made by integrating DEM and satellite imageries. The approach involved regional and local interpretation of features exposed at the surface. Erosional remnants of volcanic rocks form localized ridges. Eluvial and alluvial l sediments are found along small stream.

Sediment deposits are expected to have very thin at places and composition in the area having subsurface features of importance in groundwater storage less favorable aquifer disposition and various subsurface geomorphic features which are not that potential sites for ground water development. The geomorphologic evidences (map) will help to infer groundwater potential zones showing structural, lithological, geological, topographic and hydrological features of the area (Figure 2.3).

The drainage pattern depends on the rock types and geologic structures underlying a given area or catchment. Some types of rock are harder and more resistant to erosion than others. Some areas are impacted more by tectonic forces than other areas.

The patterns of the drainage system of the area is cumulative effect of these process (Fig 2.3). In Bule Hora woreda domain geologic structure dominantly determine patterns of drainage network due to proximity to the rift margin. Generally, the drainage pattern is controlled by tectonic structures having rectangular and dendritic pattern.

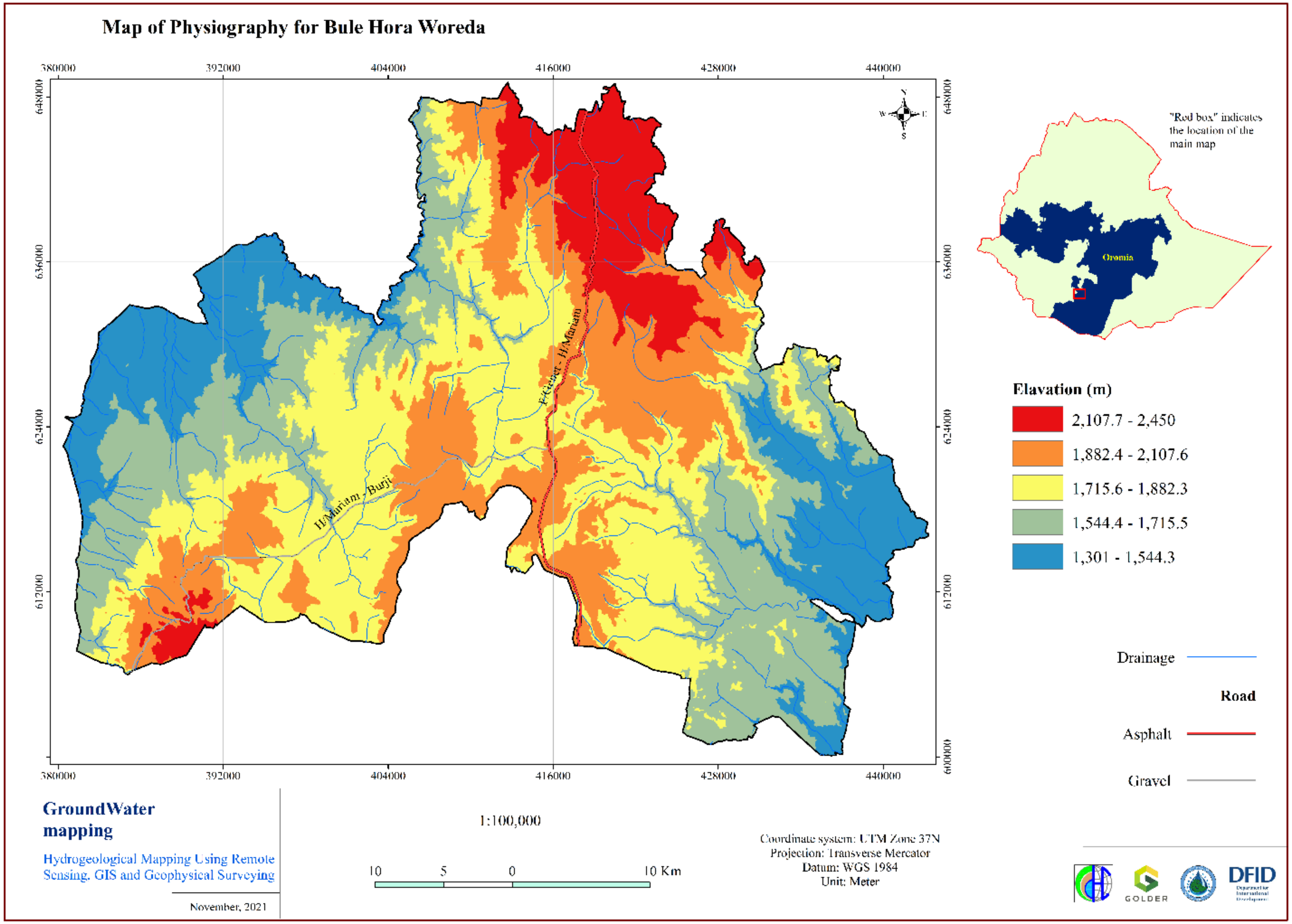


Figure 2.3. Map of physiography for Bule Hora Woreda

2.2. Mirab Abaya

2.2.1. Location

Mirab Abaya Woreda is found in the southern part of the country in SNNP Regional State. Birbir is a capital town of the woreda accessed with a road running from Wolayita Sodo to Arba Minch. The geographic location of Mirab Abaya Worada is presented in the figure below (Figure 2.4).

2.2.2. Population and demographic map

The population the Woreda has been projected from the central statical agency (CSA) 2007 population and housing census data to the currently year which is 2021. Accordingly, Mirab Abaya Woreda has a total of 103,270 populations estimated from its 24 Kebeles. The highest and the least population Kebeles in the Woreda are 9,293 and 1,167 respectively. The demography map of Mirab Abaya by kebele is shown in (Figure 2.5).

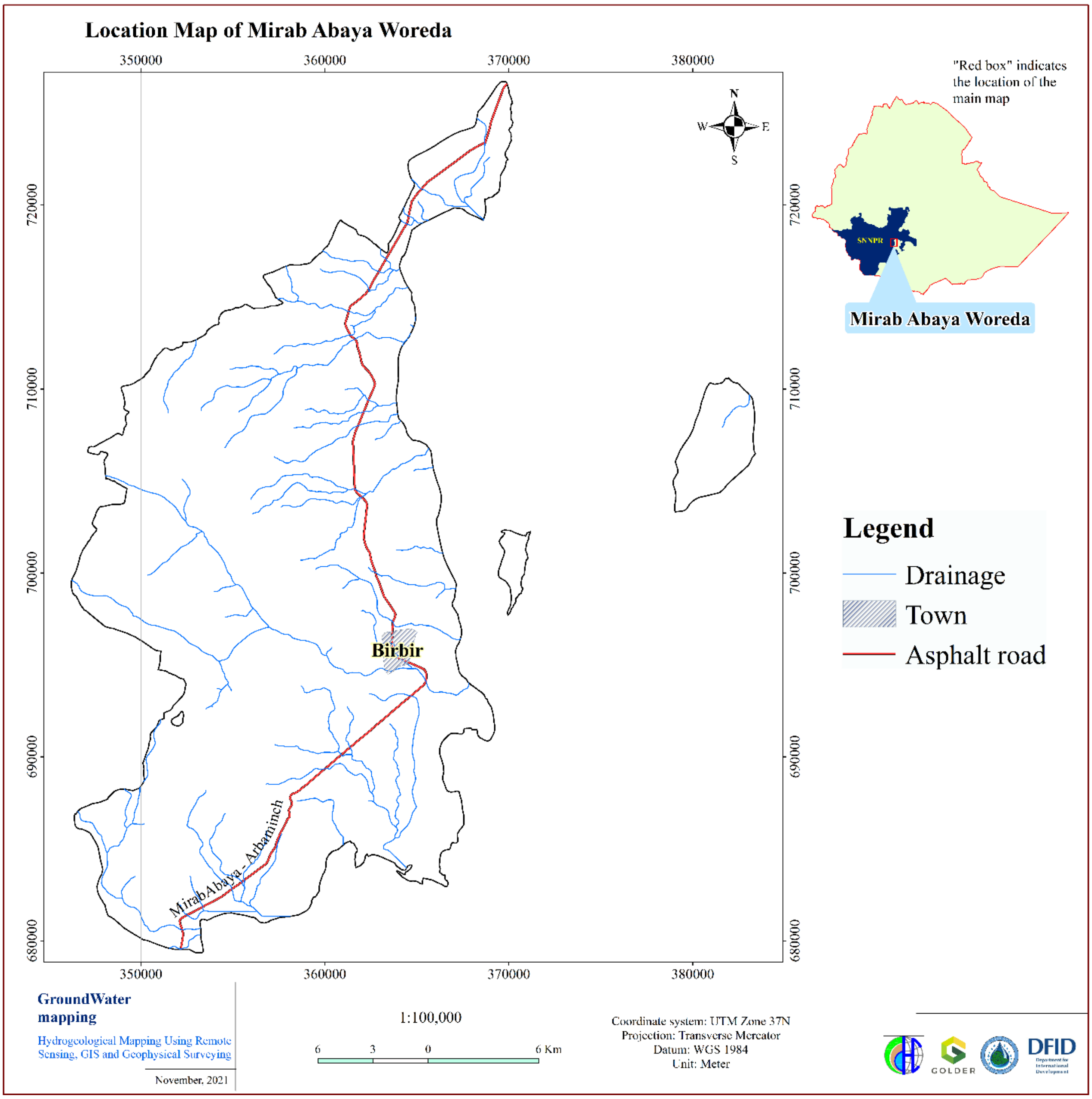


Figure 2.4. Location map of Mirab Abaya woreda

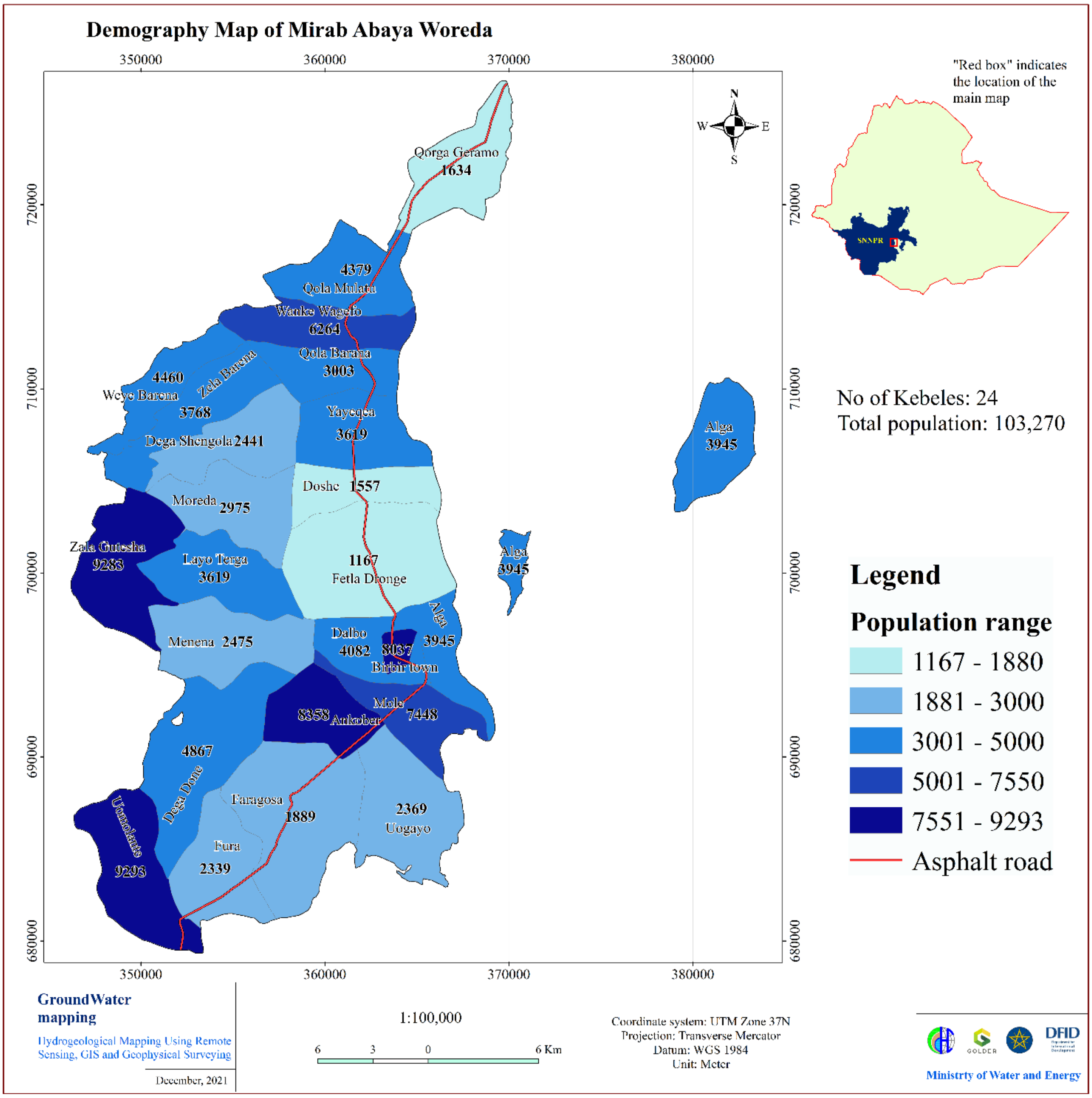


Figure 2.5. Demographic map of Mirab Abaya Woreda that presents the population for the year 2021..

2.2.3. Existing water supply situation

Only few drilled wells are available in the domain of the Mirab Abaya Woreda. Wells that fall in a similar geohydrologic envirnmnent in Arba Minch town area have been used to evaluate the hydrogeological system of the area. Theses wells belong to community Arba Minch town and Arba Minch University. As far as the data obtained is concerned, the boreholes in the area are shallow (<100m) and depth to the groundwater is also less than 30m. Well yields vary from 2 l/s to 8 l/s. The dominant aquifer material observed in the area is alluvial deposits underlain by weathered and sfractured basalts. These boreholes are located at places having relatively low relief and flat/gentle slopes.

2.2.4. Climate

Tropical savanna climates have monthly mean temperature above 180C in every month of the year and typically a pronounced dry season, with the driest month having low precipitation close to zero. The average amount of precipitation for the year in the area taken Arba Minch as representative of the area is 1486 mm (https://www.weatherbase.com › weather › weather-summary). The month with the least precipitation on average is January with an average of 30.5 mm and months with the largest precipitation are June, July, August with 618 mm mean precipitation. Elevation varies from 1172 to 2790 masl in Mirab Abaya Woreda. In Arba Minch, the minimum mean temperature 160C in December (coolest month) the maximum mean temperature is 270C usually in March (warmest month).

2.2.5. Physiography

An attempt has been made to study the geomorphological details of the Mirab Abaya woreda and to demonstrate their relationship to aquifer geometry in the area. In this study a systematic analysis of varriations in elevations of different land forms and their relationship with lineaments, drainage pattern and rock units have been made by integrating DEM and satellite immageries. The approach involved regional and local interpretation of features exposed at the surface.

Volcanic rocks form chains of redges west of vast Segon River plain. Elluvial and aluvial l sediments overlies the volcanic rocks in the area along sides of Lake Abaya. Sediment deposits are expected to have varying thickness and composition in the area having subsurface features of importance in groundwater storage favourable aquifer disposition and various subsurface geomorphic features which are potential sites for ground water development are identified. The geomorphologic evidences (map) will help to infer groundwater potential zones showing structural, lithological, geological, topographic and hydrological features of the area (Figure 2.6).

The drainage pattern depends on the rock types and geologic structures underlying a given area or catchment. Some types of rock are harder and more resistant to erosion than others. Some areas are impacted more by tectonic forces than other areas. The patterns of the drainage system of the area is commulative effect of these process (Figure 2.6). Streams (Uraye, Hageza, and Shupe) in Mirab Abaya Woreda drain into Lake Abaya. In Mirab Abaya woreda domain geologic structure dominantly determine patterns of drainage net work due to proximity to the rift margin. Generally, the parallel drainage pattern is controlled by tectonic structures and assumes rift fault trend.

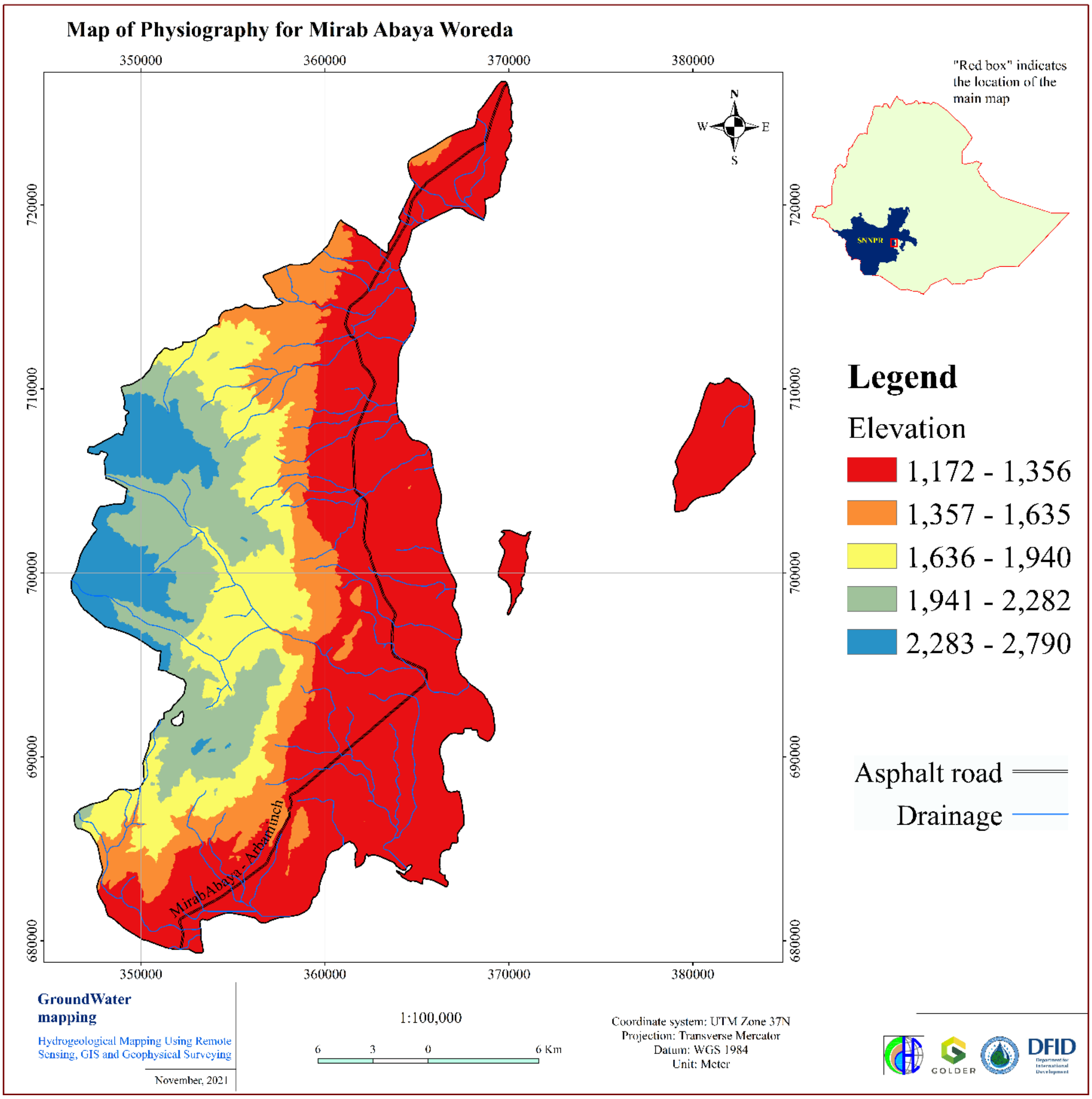


Figure 2.6. Map of physiography for Mirab Abaya Woreda

2.3. Konso

2.3.1. Location

Konso Special Woreda is found in the southern part of the country in SNNP Regional State. Konso is a capital town of the woreda accessed with a road running from Arba Minch to Jinka. The geographic location of Konso Wordas is presented in the figure below (Figure 2.7).

2.3.2. Population and demographic map

The population the Woreda has been projected from the central statical agency (CSA) 2007 population and housing census data to the currently year which is 2021. Accordingly, Konso Woreda has a total of 300,654 populations estimated from its 50 Kebeles. The highest and the least population Kebeles in the Woreda are 16,003 and 1,752 respectively. The demography map of Konso by kebele is shown in (Figure 2.8).

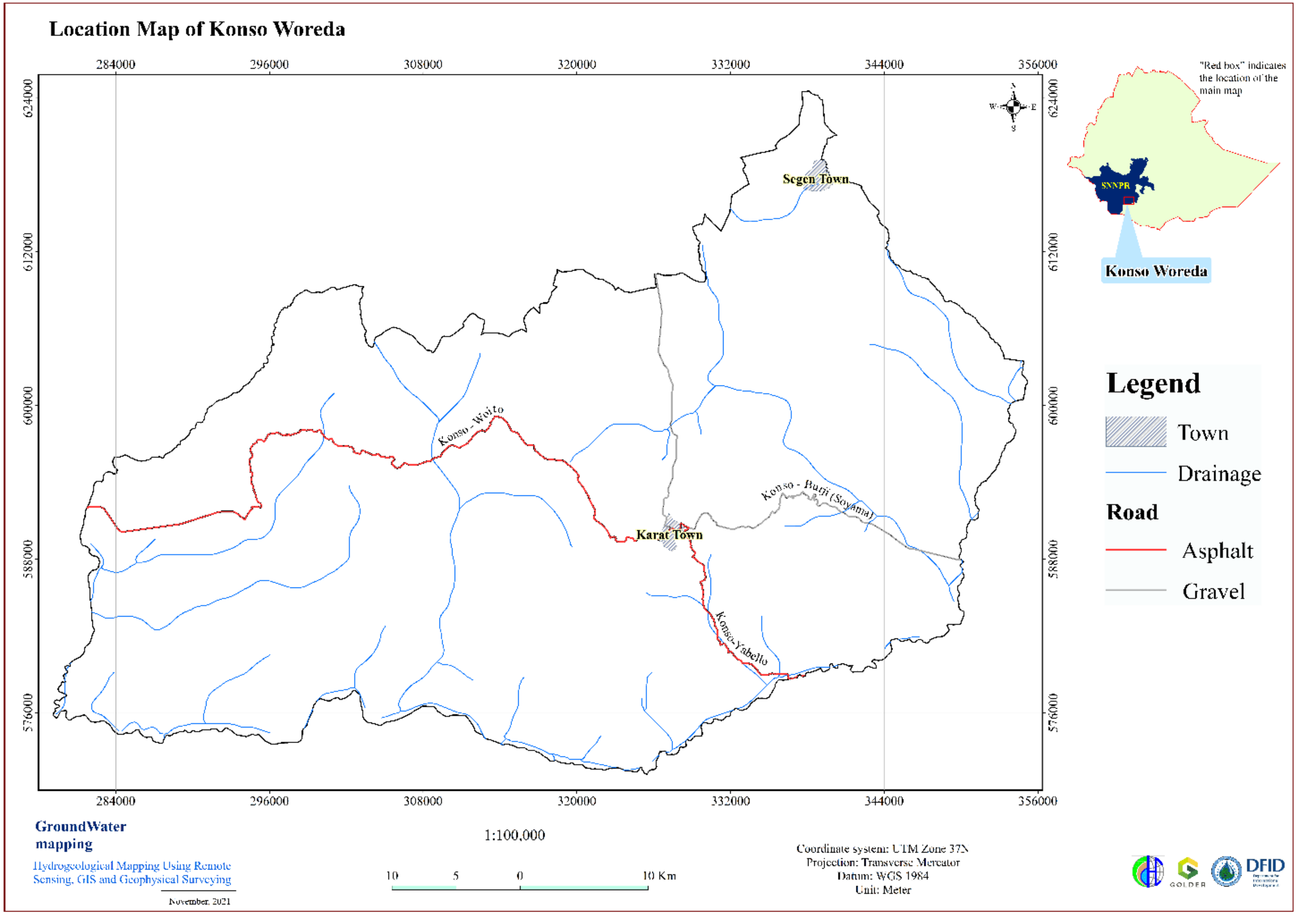


Figure 2.7. Location map of Konso woreda

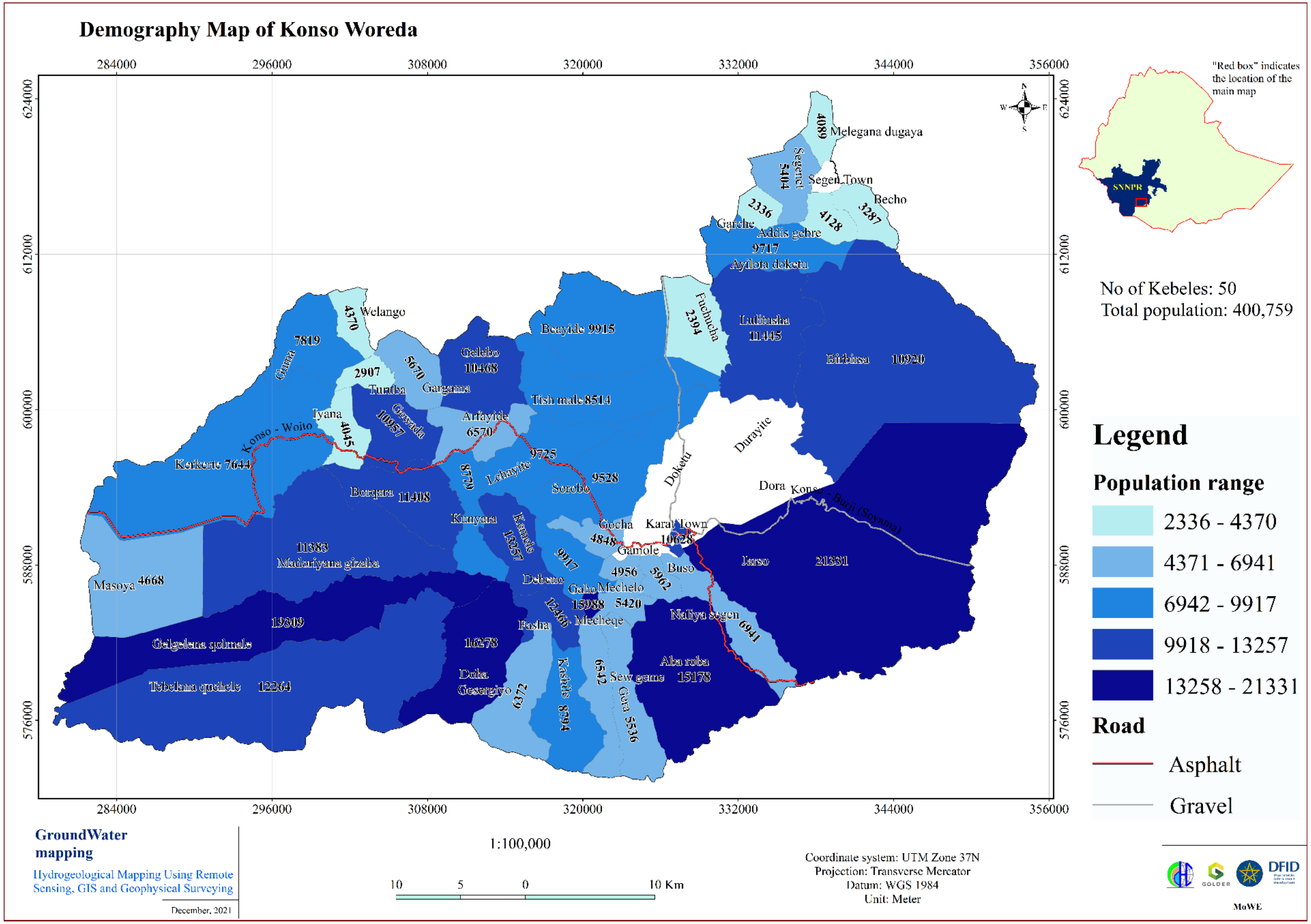


Figure 2.8. Demographic map of KonsoWoreda that presents the population projection of 2021

2.3.3. Existing water supply situation

A number of shallow dug and drilled wells are available in the eastern parts of the woreda along and close to stream banks. Theses wells belong to rural community and Konso/Bakawile town water supply purpose. As far as the data we have is concerned, boreholes and dug wells in the area have depth shallow depth and depth to the groundwater is also less than 10m. Well yields vary from 0.1 l/s to 5.6 l/s. The dominant aquifer material observed at some of these wells is alluvial deposits underlain by weathered and slightly fractured basalts and basement rocks. These wells are located at places having relatively low relief.

2.3.4. Climate

Tropical savanna climates have monthly mean temperature above 18^{0}C in every month of the year and typically a pronounced dry season, with the driest month having precipitation less than 60mm. The average amount of precipitation for the year in the area is about 825.5 mm. The month with the highest precipitation on average is April with 157.5 mm and the month with the least precipitation on average is January with an average of 22.9 mm. Elevation varies from 865 to 2665masl in Konso Woreda. The average annual temperature in the area is 21.6°C. The warmest month, on average, is March with an average temperature of 23.1°C. The coolest month on average is July, with an average temperature of 20.4°C (https://www.worldweatheronline.com).

2.3.5. Physiography

An attempt has been made to study the geomorphological details of the Konso Special woreda and to demonstrate their relationship to aquifer geometry in the area. In this study a systematic analysis of varriations in elevations of different land forms and their relationship with lineaments, drainage pattern and rock units have been made by integrating DEM and satellite immageries. The approach involved regional and local interpretation of features exposed at the surface.

Volcanic rocks form chains of redges west of vast Segon River plain. Elluvial and aluvial l sediments overlies the volcanic rocks in the area along perrenial and non perrrenial stream courses. Sediment deposits are expected to have varying thickness and composition in the area having subsurface features of importance in groundwater storage favourable aquifer disposition and various subsurface geomorphic features which are potential sites for ground water development are identified. The geomorphologic evidences (map) will help to infer groundwater potential zones showing structural, lithological, geological, topographic and hydrological features of the area (Figure 2.9).

The drainage pattern depends on the rock types and geologic structures underlying a given area or catchment. Some types of rock are harder and more resistant to erosion than others. Some areas are impacted more by tectonic forces than other areas. The patterns of the drainage system of the area is commulative effect of these process (Figure 2.9). Streams in Konso Special Woreda drain into Weyto River. In Konso Special woreda domain geologic structure dominantly determine patterns of drainage net work due to proximity to the rift margin. Generally, the drainage pattern is controlled by tectonic structures and assumes rift fault trend.

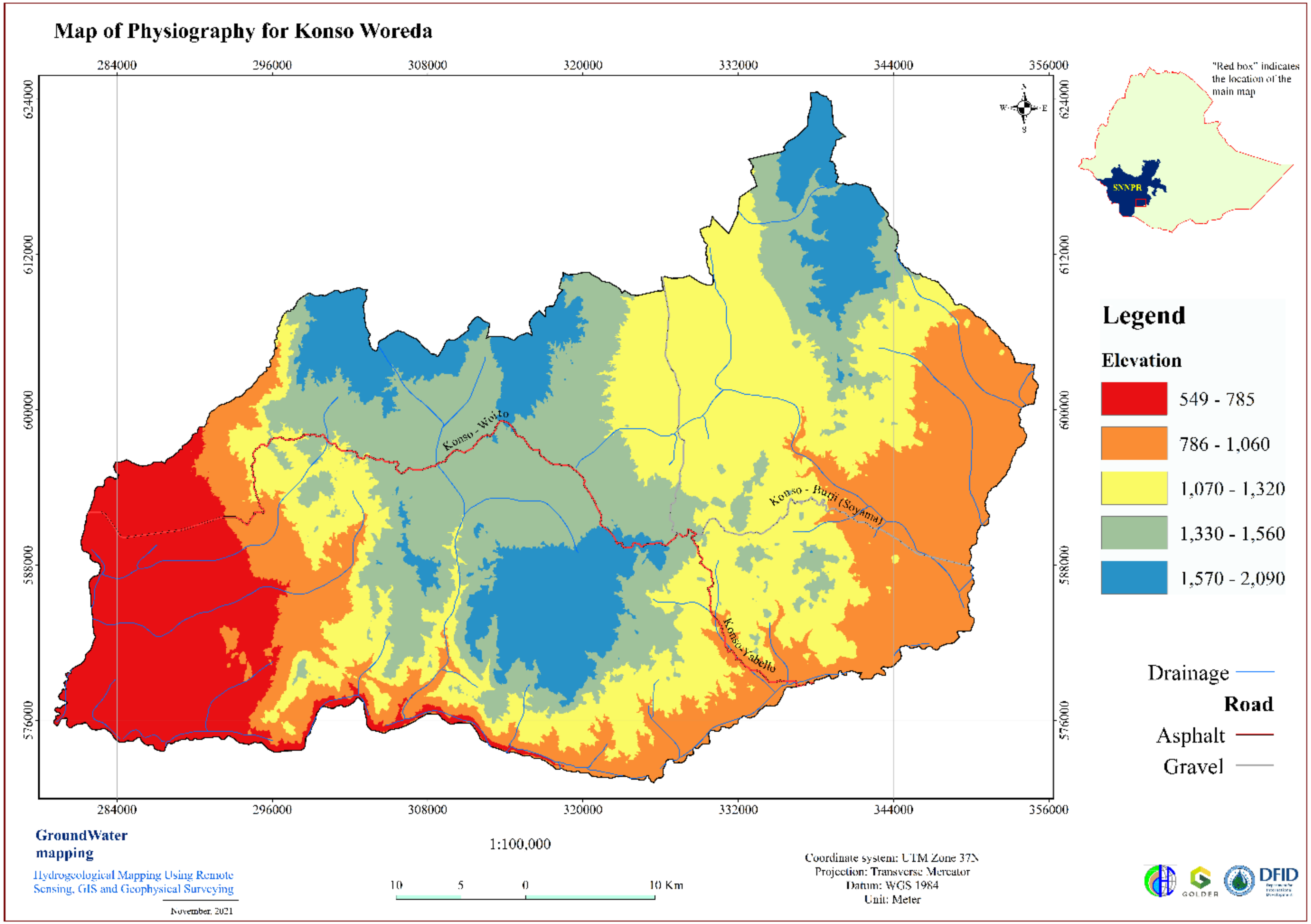


Figure 2.9. Map of physiography for Konso Woreda

2.4. Kochere

2.4.1. Location

Kochere Woreda is found in the southern part of the country in SNNP Regional State. Chelelktu is a capital town of the woreda accessed with a road running from Fiseha Genet to Soyama. The geographic location of Kochere Woreda is presented in the figure below (Figure 2.10).

2.4.2. Population and demographic map

The population the Woreda has been projected from the central statical agency (CSA) 2007 population and housing census data to the currently year which is 2021. Accordingly, Kochere Woreda has a total of 153,480 populations estimated from its 21 Kebeles. The highest and the least population Kebeles in the Woreda are 13,926 and 2,649 respectively. The demography map of Kochere by kebele is shown in figure 2.11.

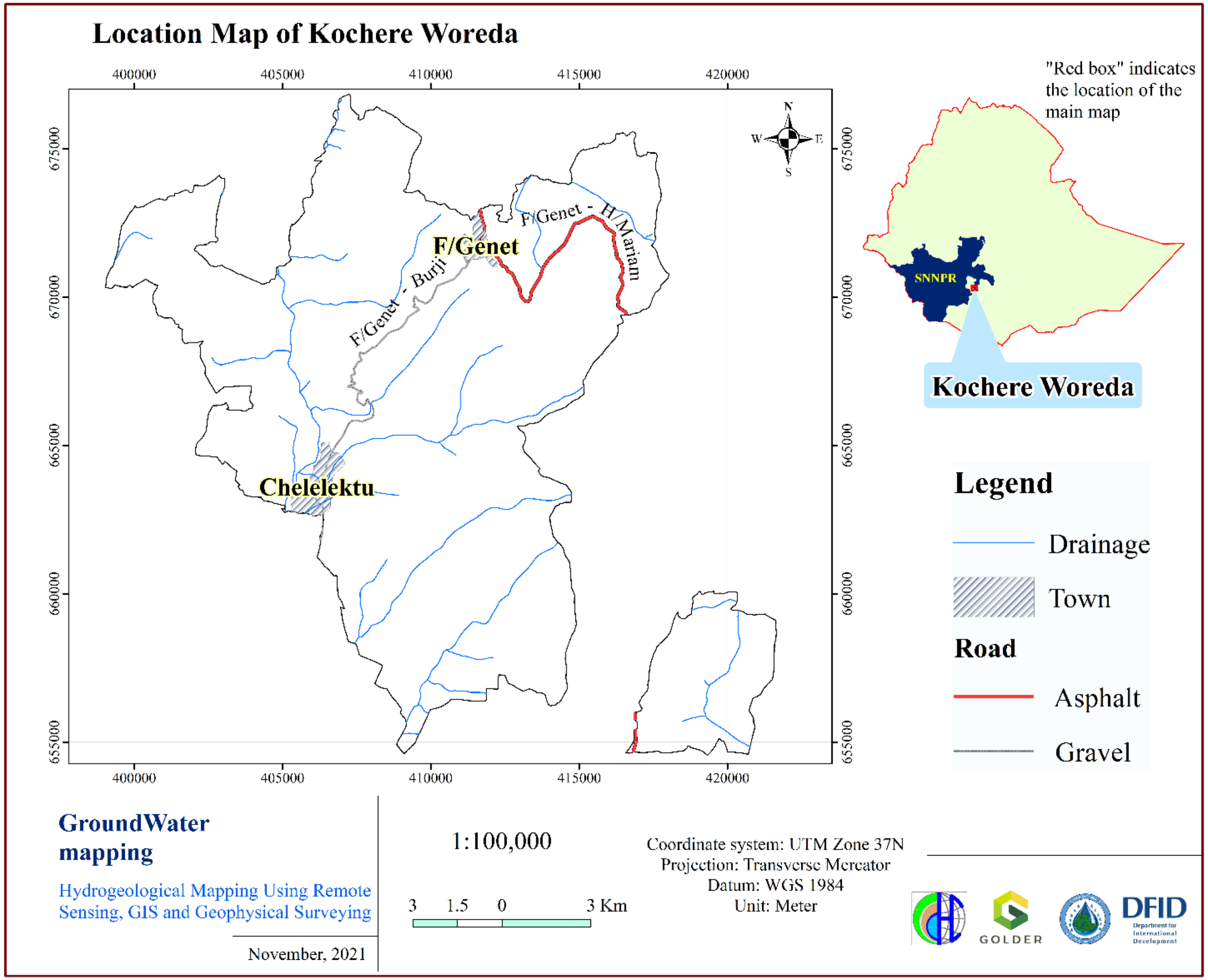


Figure 2.10. Location map of Kochere Woreda

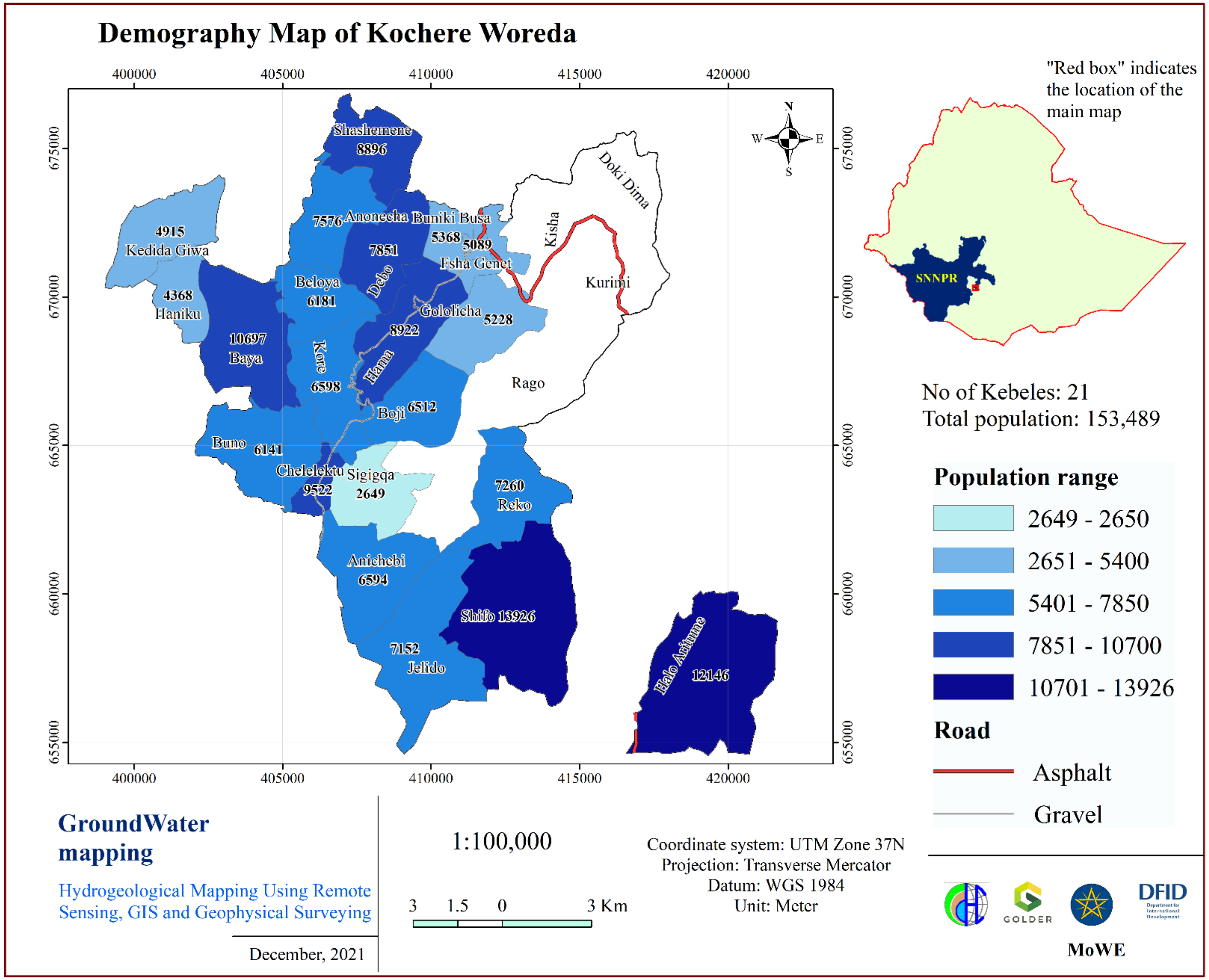


Figure 2.11. Demographic map of Kochere Woreda that presents the population for the year 2021.

2.4.3. Existing water supply situation

Several shallows dug and drilled wells are available in distributed in different parts of the woreda. Theses wells belong to rural community and Fiseha Genet town Woreda water supply. As far as the data we have is concerned, boreholes and dug wells in the area have shallow depth (<100m) and depth to the groundwater is also less than 60m. Well yields vary from 0.5 l/s to 5 l/s. The dominant aquifer material observed at some of these wells is alluvial deposits underlain by weathered and slightly fractured basalts and pyroclastic deposits. These wells are located at places having relatively low relief.

2.4.4. Climate

The driest month having precipitation less than 60mm. The average amount of precipitation for the year in the area is about 825.5 mm. The month with the highest precipitation on average is April with 157.5 mm and the month with the least precipitation on average is January with an average of 22.9 mm. Elevation varies from 865 to 2665masl in Kochere Woreda. The average annual temperature in the area is 21.6°C. The warmest month, on average, is March with an average temperature of 23.1°C. The coolest month on average is July, with an average temperature of 20.4°C (https://www.worldweatheronline.com).

2.4.5. Physiography

An attempt has been made to study the geomorphological details of the Kochere woreda and to demonstrate their relationship to aquifer geometry in the area. In this study a systematic analysis of variations in elevations of different landforms and their relationship with lineaments, drainage pattern and rock units have been made by integrating DEM and satellite immageries. The approach involved regional and local interpretation of features exposed at the surface.

Basic volcanic rocks, dominantly basalt form chains of ridges in the periphery of the woreda baoundary. Acidic volcanic rocks dominantly composed of rhyolites and trachyte's outcrop in the northern and central parts of the woreda. Basic volcanic rocks are expected to have varying thickness and composition in the area having subsurface features of importance in groundwater storage. The geomorphologic evidence (map) will help to infer groundwater potential zones showing structural, lithological, geological, topographic and hydrological features of the area (Figure 2.12).

The drainage pattern depends on the rock types and geologic structures underlying a given area or catchment. Some types of rock are harder and more resistant to erosion than others. Some areas are impacted more by tectonic forces than other areas. The patterns of the drainage system of the area is commulative effect of these process (Figure2.12). Tributary streams in Kochere Woreda drain into Gelana River with final destination of Lake Abaya. In Kochere woreda domain geologic structure dominantly determine patterns of drainage network due to proximity to the Main Ethiopian Rift margin. Generally, the drainage pattern is controlled by tectonic structures and assumes rift fault trend.

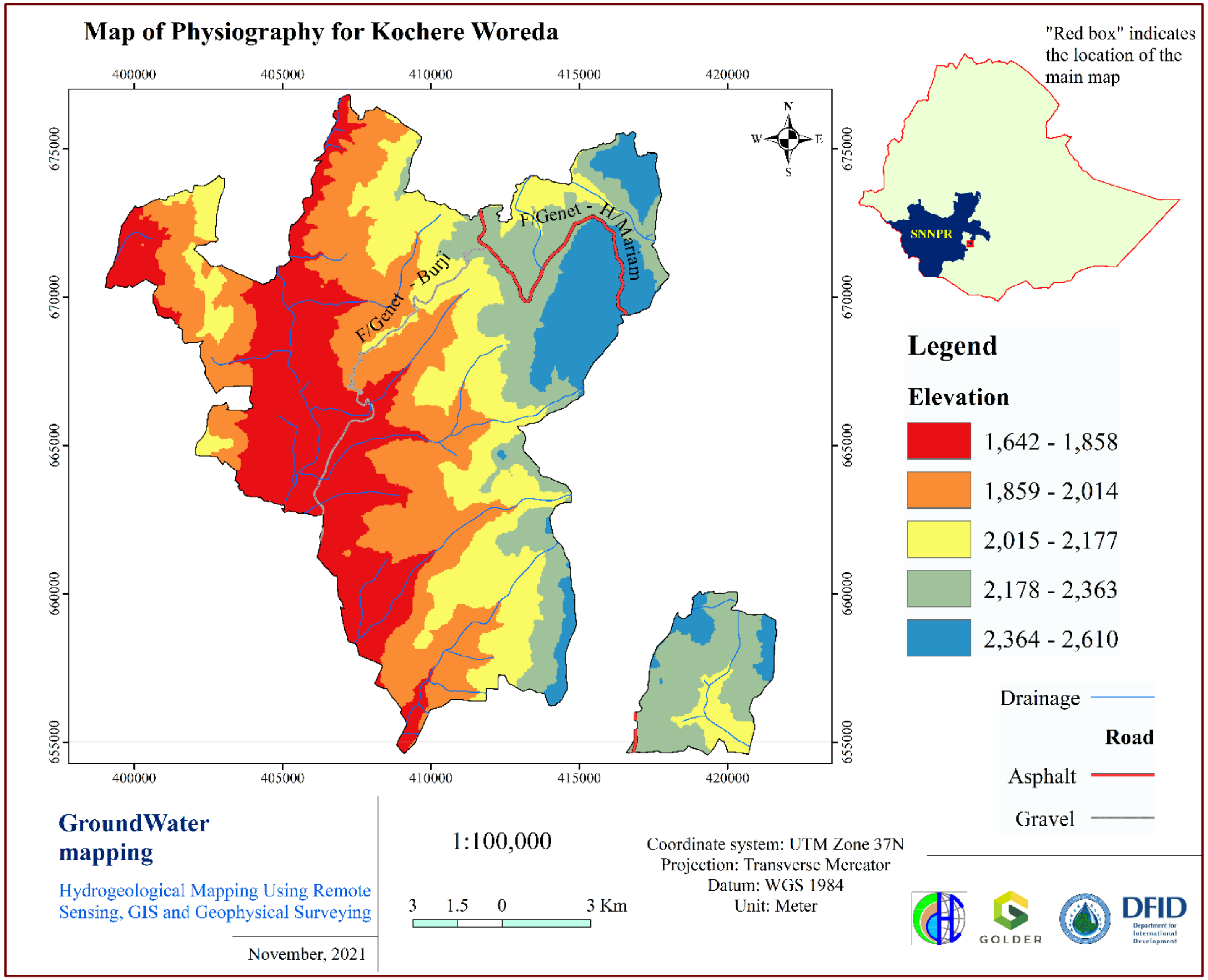


Figure 2.12. Map of physiography for Kochere Woreda

2.5. Kemba

2.5.1. Location

Kemba Woreda is found in the southern part of the country in SNNP Regional State. Kemba town is a capital of the woreda accessed with an asphalt road running from Sawla direction. The geographic location of Kemba Wordas presented in the figure below (Figure 2.13).

2.5.2. Population and demographic map

The population the Woreda has been projected from the central statical agency (CSA) 2007 population and housing census data to the currently year which is 2021. Accordingly, Kemba Woreda has a total of 156,631 populations estimated from its 28 Kebeles. The highest population and the least population number in the Woreda is 2,362 and 13,295 respectively. The demography map of Kemba by kebele is shown in Figure 2.14.

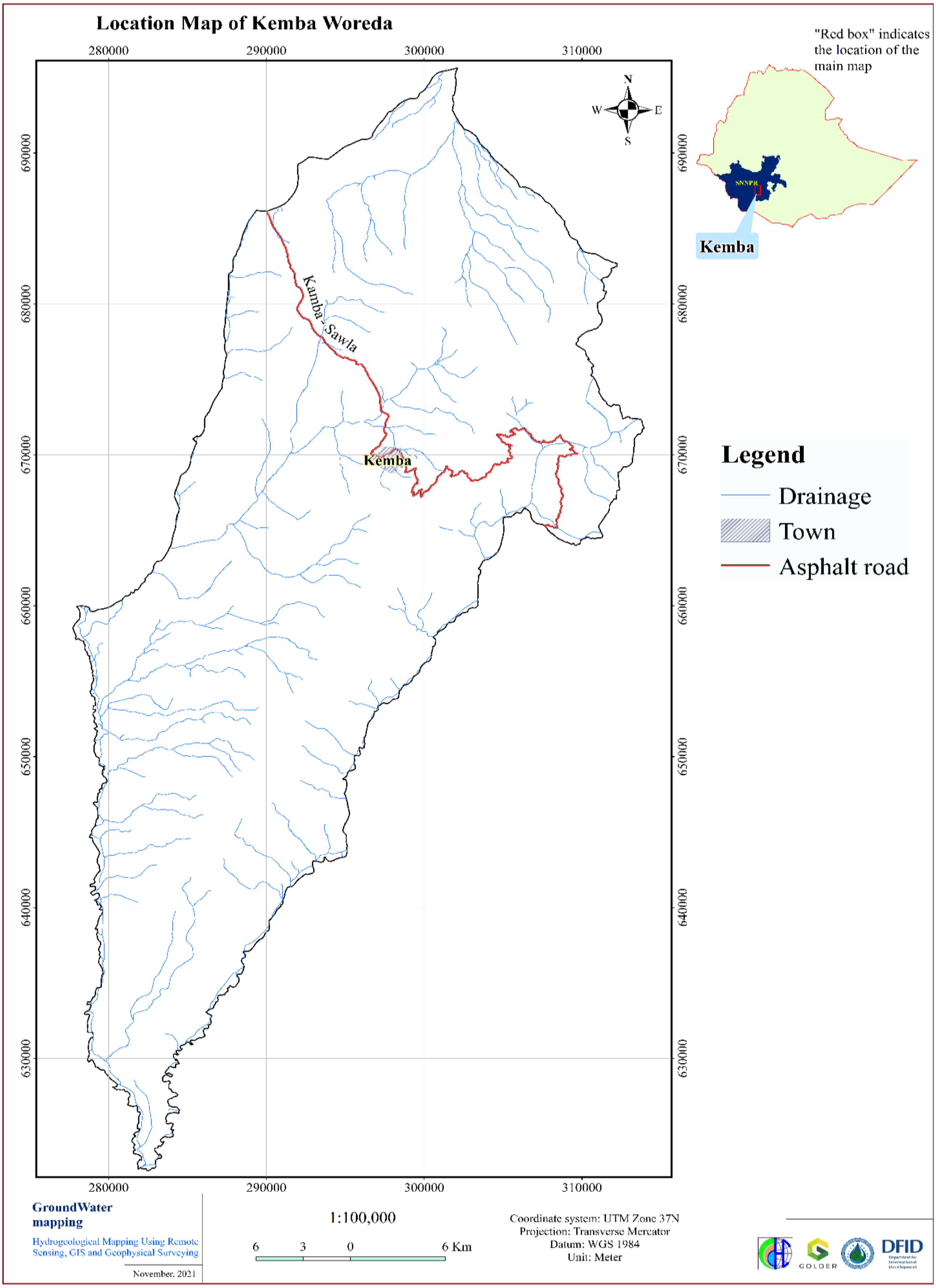


Figure 2.13. Location map of Kemba Woreda

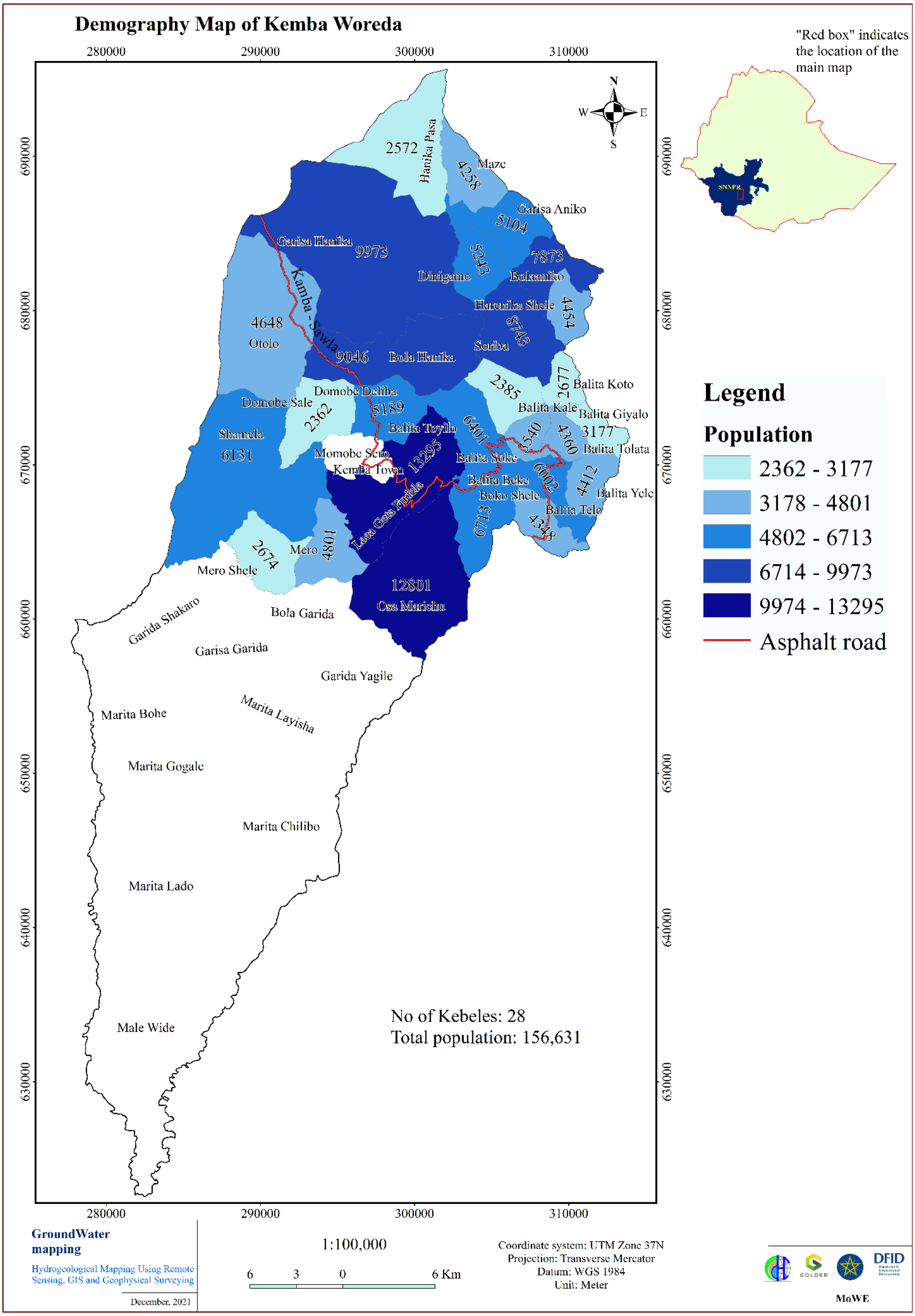


Figure 2.14. : Demographic map of Kemba Woreda that presents the population projection of 2021.

2.5.3. Existing water supply situation

Several shallows dug and drilled wells are available and distributed in different parts of the woreda. Only one well without yield information is available in the domain of the woreda. In addition, boreholes and dug wells available in similar geological and structural setting within the synoptic view are also considered. As far as the data we have is concerned, boreholes and dug wells in the area have shallow depth (< 100m) and depth to the groundwater is shallow (2.5m). Well yields vary from 0.2 l/s to 10 l/s. The dominant aquifer material observed at some of these wells is alluvial deposits underlain by weathered and slightly fractured basalts and basement rocks. These wells are located at places having relatively low relief.

2.5.4. Climate

In Kemba, during the entire year collects up to 1203mm of precipitation. The month with the highest precipitation on average is January with 527.97mm and the month with the least precipitation on average is January with an average of 55.71mm. Elevation varies from 706 to 3350masl in Kemba Woreda. The warmest month in Kemba is February, with an average high-temperature of 36.7°C and an average low-temperature of 20.8°C (www.worldweatheronline.com).

2.5.5. Physiography

An attempt has been made to study the geomorphological details of the Kemba Woreda and to demonstrate their relationship to aquifer geometry in the area. In this study a systematic analysis of variations in elevations of different landforms and their relationship with lineaments, drainage pattern and rock units have been made by integrating DEM and satellite imageries. The approach involved regional and local interpretation of features exposed at the surface.

Volcanic rocks form chains of ridges northeast of the woreda boundary. Elluvial and aluvial sediments overlies the volcanic rocks towards the mountain foot. Quaternary Sediment deposits are expected to have varying thickness and composition in the area having subsurface features of importance in groundwater storage favourable aquifer disposition and various subsurface geomorphic features which are potential sites for ground water development are identified. The geomorphologic evidences (map) will help to infer groundwater potential zones showing structural, lithological, geological, topographic and hydrological features of the area (Figure 2-15).

The drainage pattern depends on the rock types and geologic structures underlying a given area or catchment. Some types of rock are harder and more resistant to erosion than others. Some areas are impacted more by tectonic forces than other areas. The patterns of the drainage system of the area is commulative effect of these process (Figure 2.15). Streams in Kemba Woreda drain into the main river drainage systems. In Kemba Woreda domain geologic structure dominantly determine patterns of drainage net work due to proximity to the rift margin. Generally, the drainage pattern is controlled by tectonic structures and assumes rift fault trend.

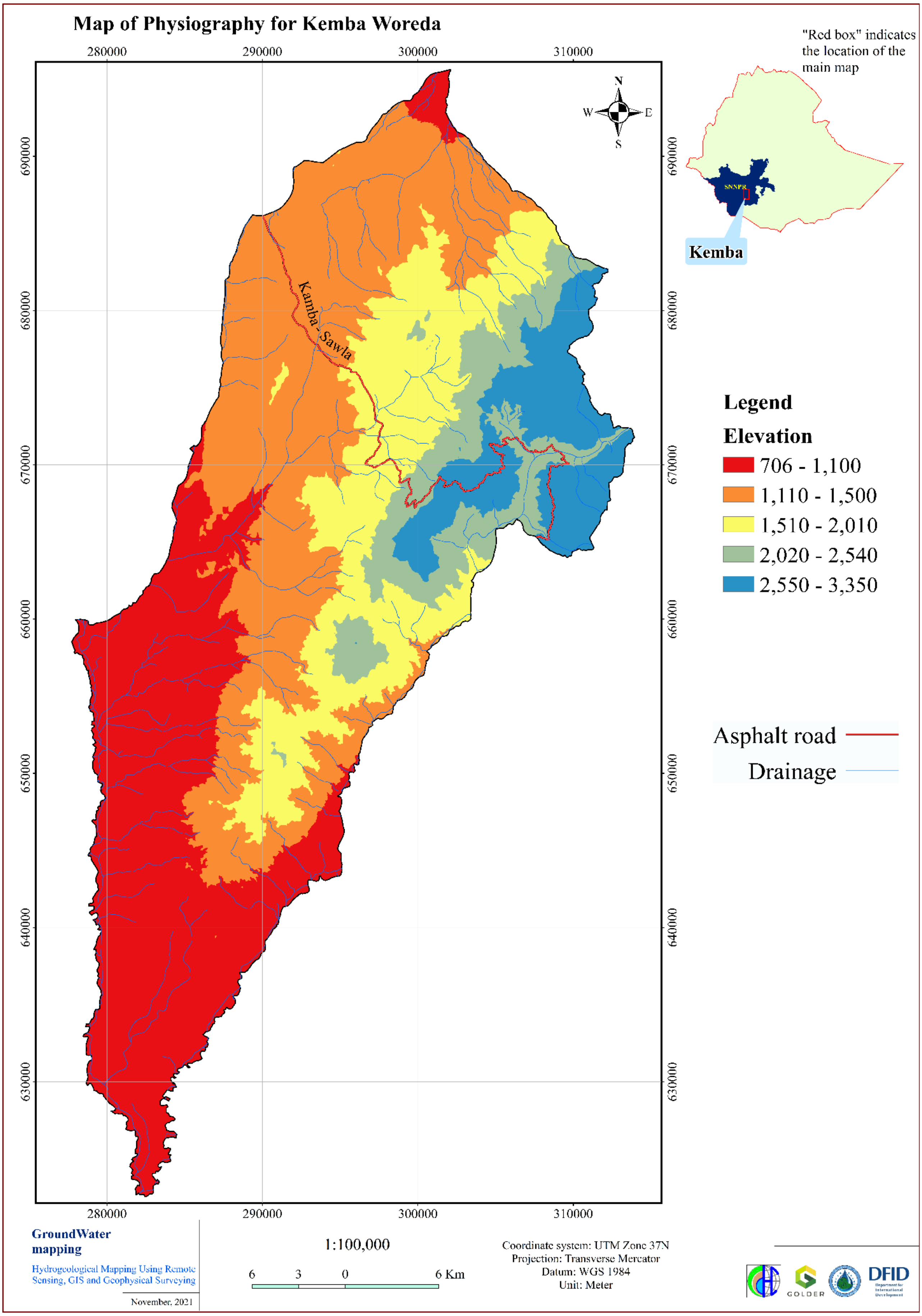


Figure 2.15. Map of physiography for Kemba Woreda

2.6. Burji

2.6.1. Location

Burji Special Woreda is found in the southern part of the country in SNNP Regional State, in Segen River catchment. Soyama is a capital town of the woreda accessed with a road running from Bule Hora to Soyama. The geographic location of Burji Special Worda is presented in the figure below (Figure 2.16).

2.6.2. Population and demographic map

The population the Woreda has been projected from the central statical agency (CSA) 2007 population and housing census data to the currently year which is 2021. Accordingly, Burji Woreda has a total of 68,060 populations estimated from its 26 Kebeles. The highest population and the least population number in the Woreda is 6,209 and 7 respectively. The demography map of Kemba by kebele is shown in Figure 2.17.

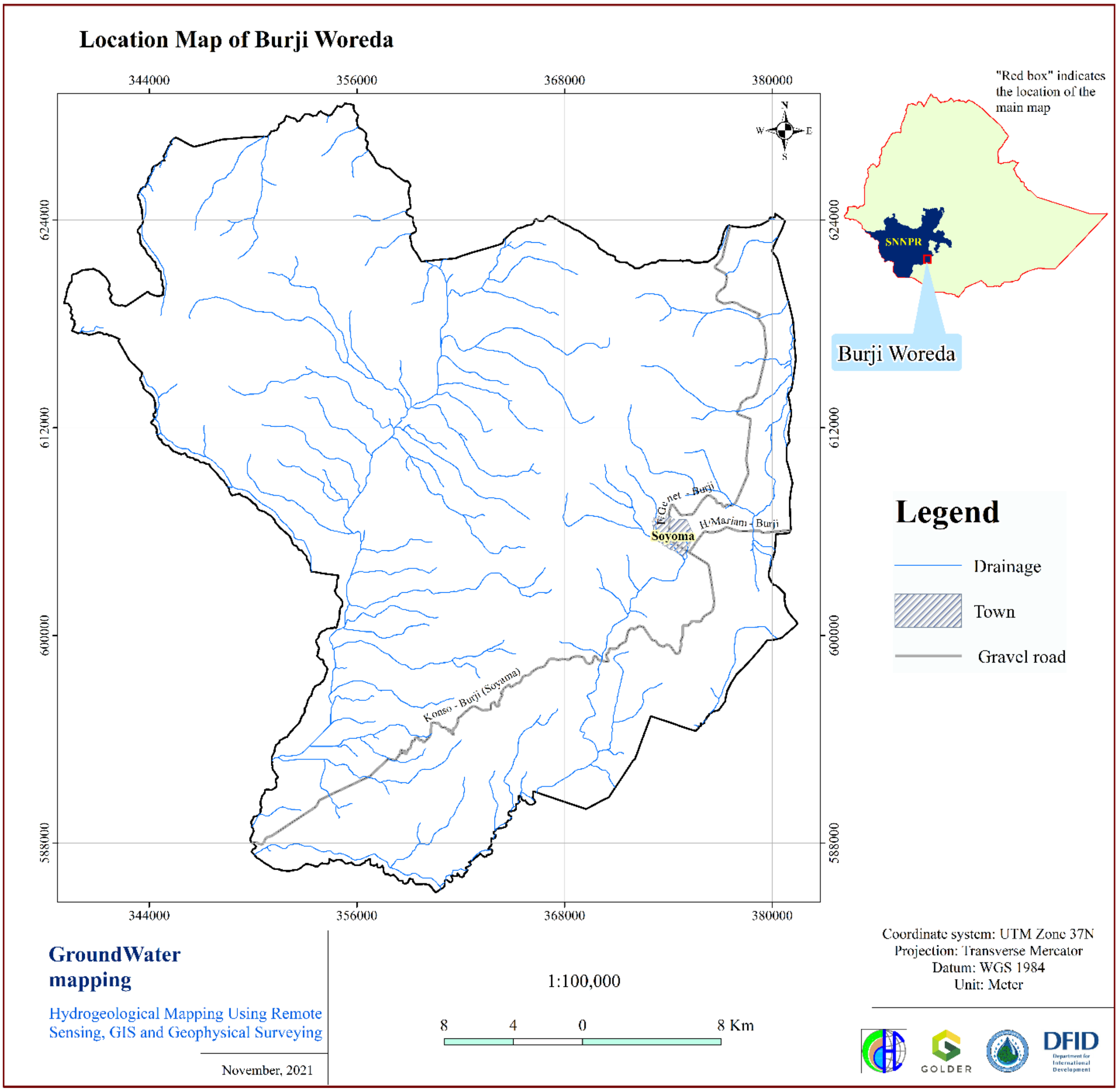


Figure 2.16. Location map of Burji Woreda

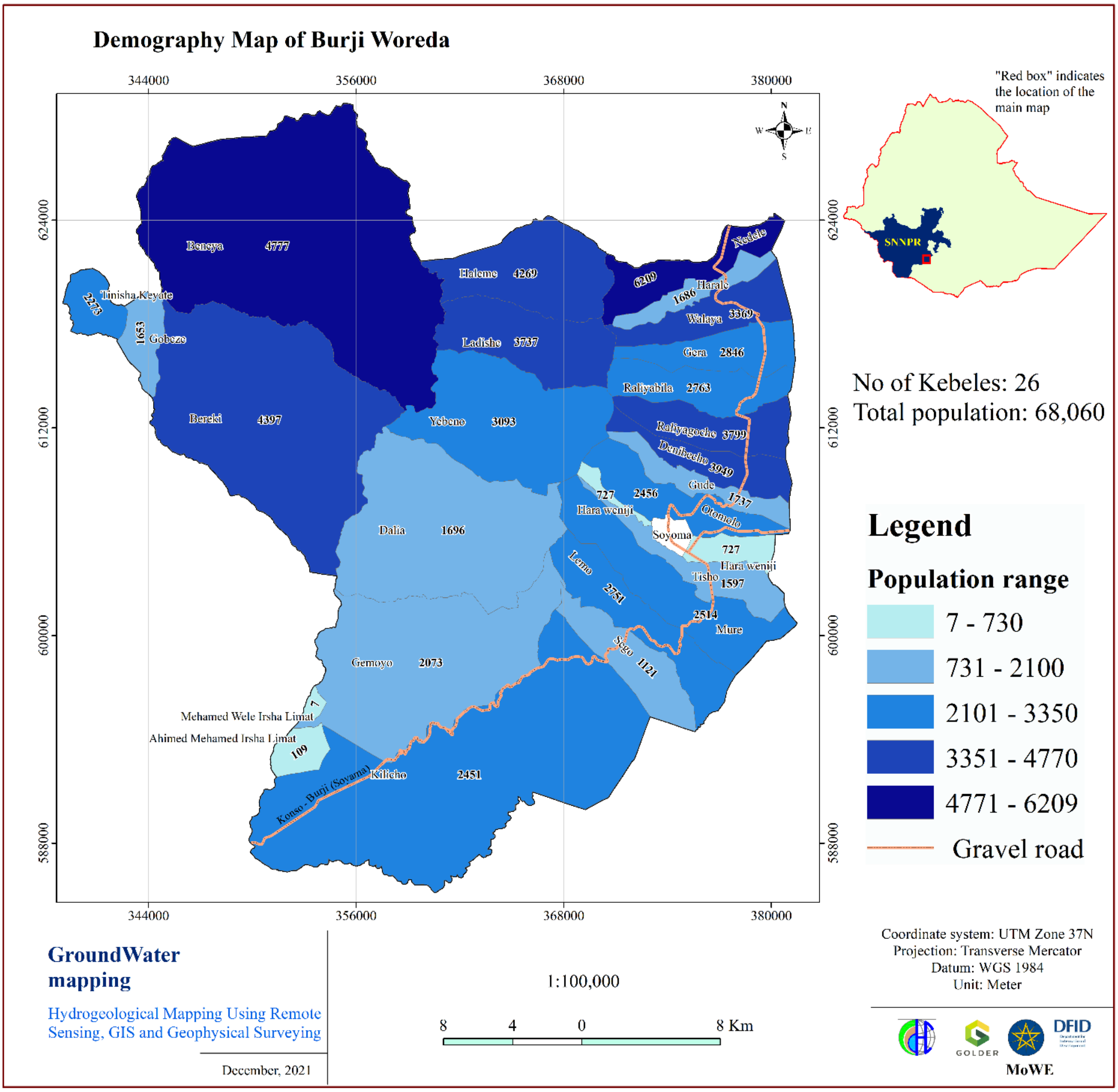


Figure 2.17. Demographic map of Burji woreda that represents the population for the year 2021

2.6.3. Existing water supply situation

A number of shallow boreholes have been drilled in the eastern and south western parts of the woreda along and close to stream banks. Theses wells belong to rural community and Soyama town water supply purpose. As far as the data we have is concerned, boreholes and dug wells in the area have depth less than 60m having shallow depth to the groundwater less than 10m are available in this area. Well yields vary from 0.5 l/s to 5.6 l/s. The dominant aquifer material observed at some of these wells is alluvial deposits underlain by weathered and slightly fractured basalts and basement roacks. These wells are located at places having relatively low relief.

2.6.4. Climate

Tropical savanna climates have monthly mean temperature above 18^{0}C in every month of the year and typically a pronounced dry season, with the driest month having precipitation less than 60mm. The average amount of precipitation for the year in the area is about 825.5 mm. The month with the highest precipitation on average is April with 157.5 mm and the month with the least precipitation on average is January with an average of 22.9 mm. Elevation varies from 865 to 2665masl in Burji Special Woreda. The average annual temperature in the area is 21.6°C. The warmest month, on average, is March with an average temperature of 23.1°C. The coolest month on average is July, with an average temperature of 20.4°C (https://www.worldweatheronline.com).

2.6.5. Physiography

An attempt has been made to study the geomorphological details of the Burji Special woreda and to demonstrate their relationship to aquifer geometry in the area. In this study a systematic analysis of varriations in elevations of different land forms and their relationship with lineaments, drainage pattern and rock units have been made by integrating DEM and satellite immageries. The approach involved regional and local interpretation of features exposed at the surface.

Volcanic rocks form chains of redges west of vast Segon River plain. Elluvial and aluvial l sediments overlies the volcanic rocks in the area along perrenial and non perrrenial stream courses.

Sediment deposits are expected to have varying thickness and composition in the area having subsurface features of importance in groundwater storage favourable aquifer disposition and various subsurface geomorphic features which are potential sites for ground water development are identified. The geomorphologic evidences (map) will help to infer groundwater potential zones showing structural, lithological, geological, topographic and hydrological features of the area (Figure 2.18).

The drainage pattern depends on the rock types and geologic structures underlying a given area or catchment. Some types of rock are harder and more resistant to erosion than others. Some areas are impacted more by tectonic forces than other areas.

The patterns of the drainage system of the area is commulative effect of these process (Figure 2.18). In Burji Special woreda domain geologic structure dominantly determine patterns of drainage net work due to proximity to the rift margin. Generally, the drainage pattern is controlled by tectonic structures and assumes rift fault trend.

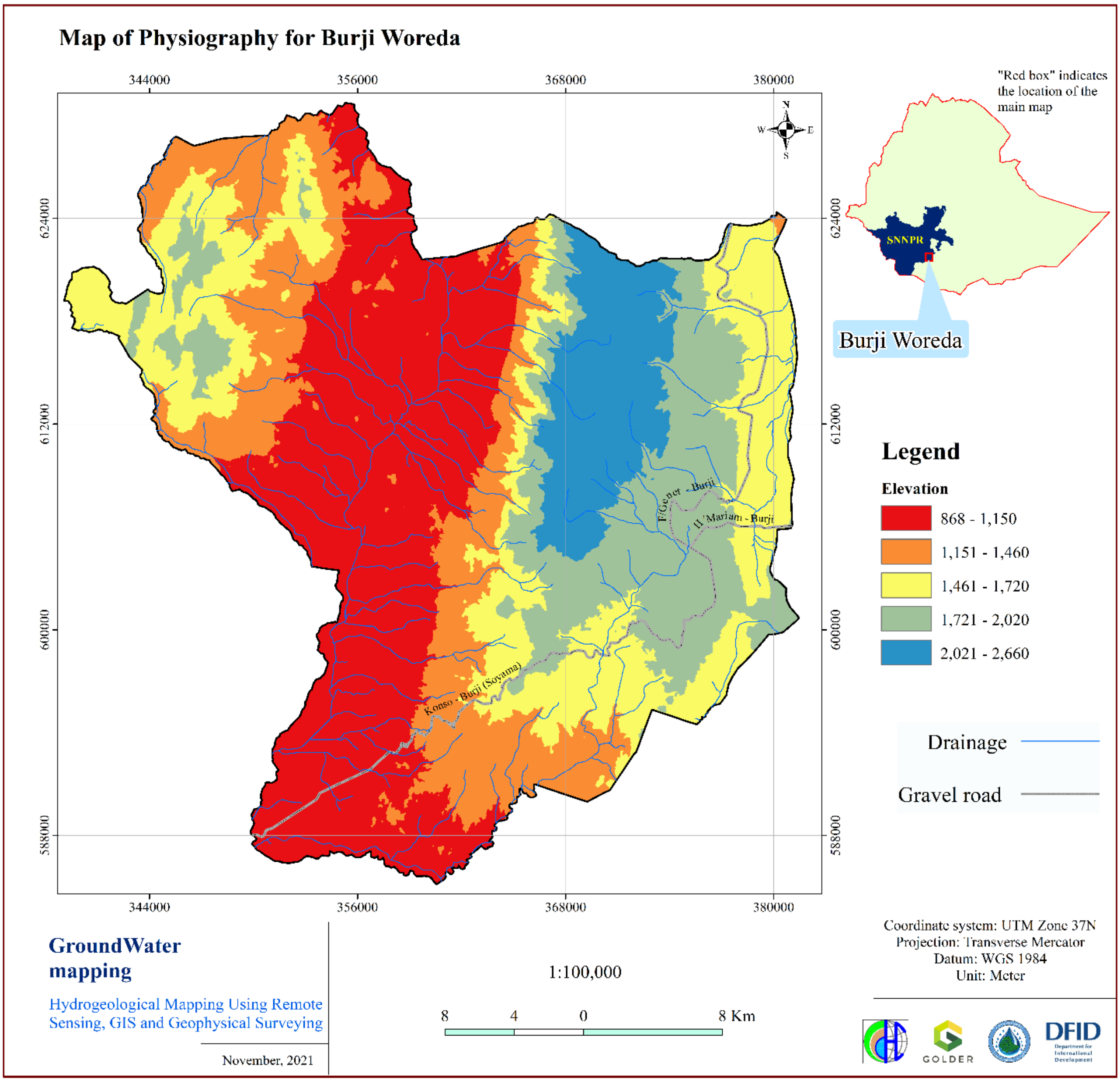


Figure 2.18. Map of physiography for Burji Woreda

2.7. Amaro

2.7.1. Location

Amaro special Woreda is found in the southern part of the country in SNNP Regional State. Amaro/Kele is a capital town of the woreda accessed with a road running from Arba Minch or grom Fesehagenet. The geographic location of Amaro Special Wordas is presented in the figure below (Figure 2.19).

2.7.2. Population and demographic map

The population the Woreda has been projected from the central statical agency (CSA) 2007 population and housing census data to the currently year which is 2021. Accordingly, Amaro Woreda has a total of 193,679 populations estimated from its 32 Kebeles. The highest population and the least population number in the Woreda is 11,352 and 1095 respectively. The demography map of Amaro by kebele is shown in (Figure 2.20).

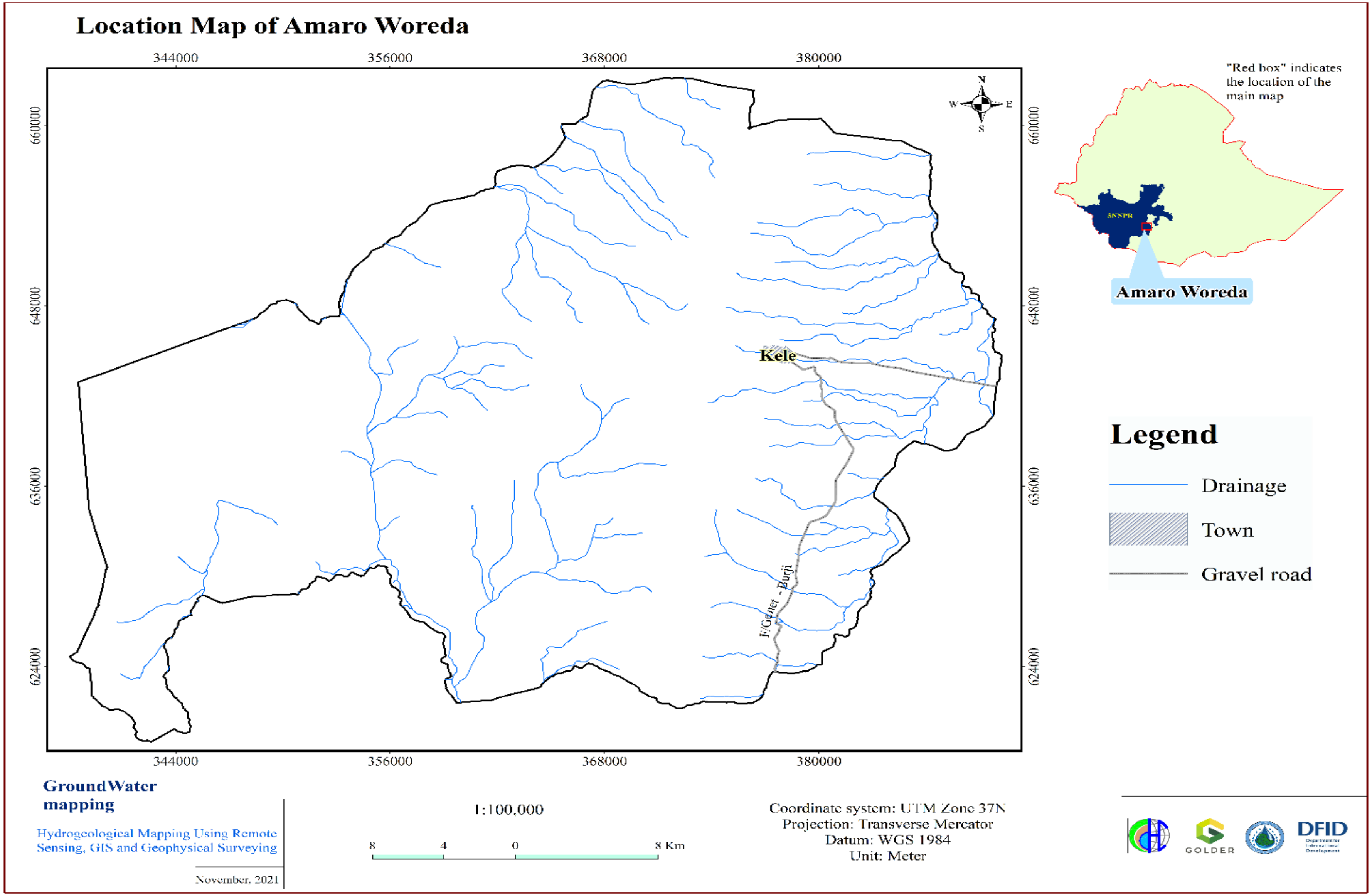


Figure 2.19. Location map of Amaro Woreda

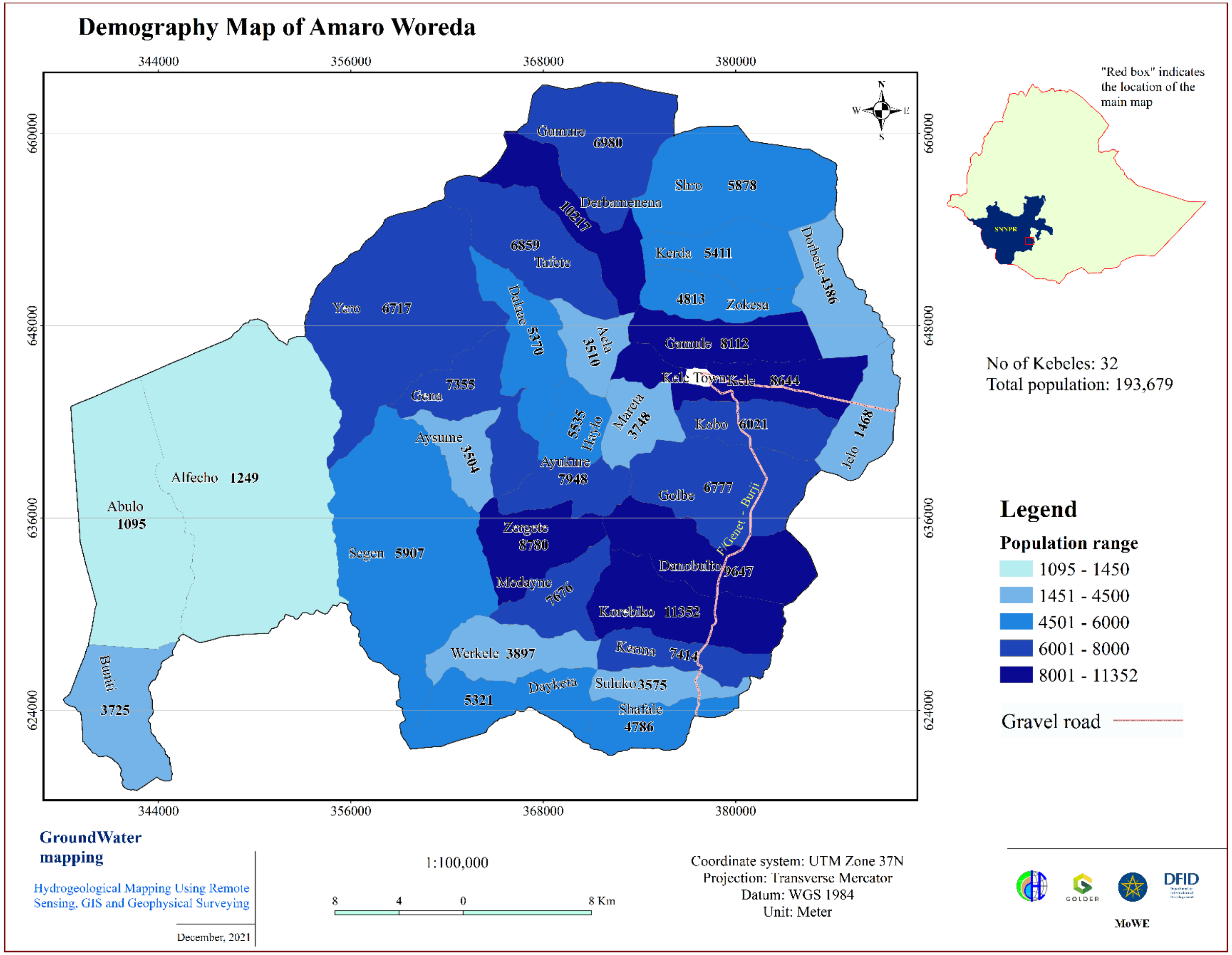


Figure 2.20: Demographic map of Amaro Woreda.

2.7.3. Existing water supply situation

A number of shallow dug and drilled wells are available especially in the eastern parts of the woreda along and close to Segen River bang and associated plains. These wells belong to rural community and Kele town water supply purpose. As far as the data we have is concerned, boreholes and dug wells in the area have shallow depth and depth to the groundwater is also less than 10m. Well yields vary from 0.1 l/s to 2.6 l/s. The dominant aquifer material observed at some of these wells is alluvial deposits underlain by weathered and slightly fractured basalts and basement rocks. These wells are located at places having relatively low relief.

2.7.4. Climate

Tropical savanna climates have monthly mean temperature above 18^0C in every month of the year and typically a pronounced dry season, with the driest month having precipitation less than 60mm. The average amount of precipitation for the year in the area is about 825.5 mm. The month with the highest precipitation on average is April with 157.5 mm and the month with the least precipitation on average is January with an average of 22.9 mm. Elevation varies from 865 to 2665masl in Amaro Special Woreda. The average annual temperature in the area is 21.6°C. The warmest month, on average, is March with an average temperature of 23.1°C. The coolest month on average is July, with an average temperature of 20.4°C (https://www.worldweatheronline.com).

2.7.5. Physiography

An attempt has been made to study the geomorphological details of the Amaro Special woreda and to demonstrate their relationship to aquifer geometry in the area. In this study a systematic analysis of varriations in elevations of different land forms and their relationship with lineaments, drainage pattern and rock units have been made by integrating DEM and satellite immageries. The approach involved regional and local interpretation of features exposed at the surface.

Volcanic rocks form chains of redges west of vast Segon River plain. Elluvial and aluvial l sediments overlies the volcanic rocks in the area along perrenial and non perrrenial stream courses. Sediment deposits are expected to have varying thickness and composition in the area having subsurface features of importance in groundwater storage favourable aquifer disposition and various subsurface geomorphic features which are potential sites for ground water development are identified. The geomorphologic evidences (map) will help to infer groundwater potential zones showing structural, lithological, geological, topographic and hydrological features of the area (Figure 2.21).

The drainage pattern depends on the rock types and geologic structures underlying a given area or catchment. Some types of rock are harder and more resistant to erosion than others. Some areas are impacted more by tectonic forces than other areas. The patterns of the drainage system of the area is commulative effect of these process (Figure 2.21). Streams in Amaro Special Woreda drain into Weyto River. In Amaro Special woreda domain geologic structure dominantly determine patterns of drainage net work due to proximity to the rift margin. Generally, the drainage pattern is controlled by tectonic structures and assumes rift fault trend.

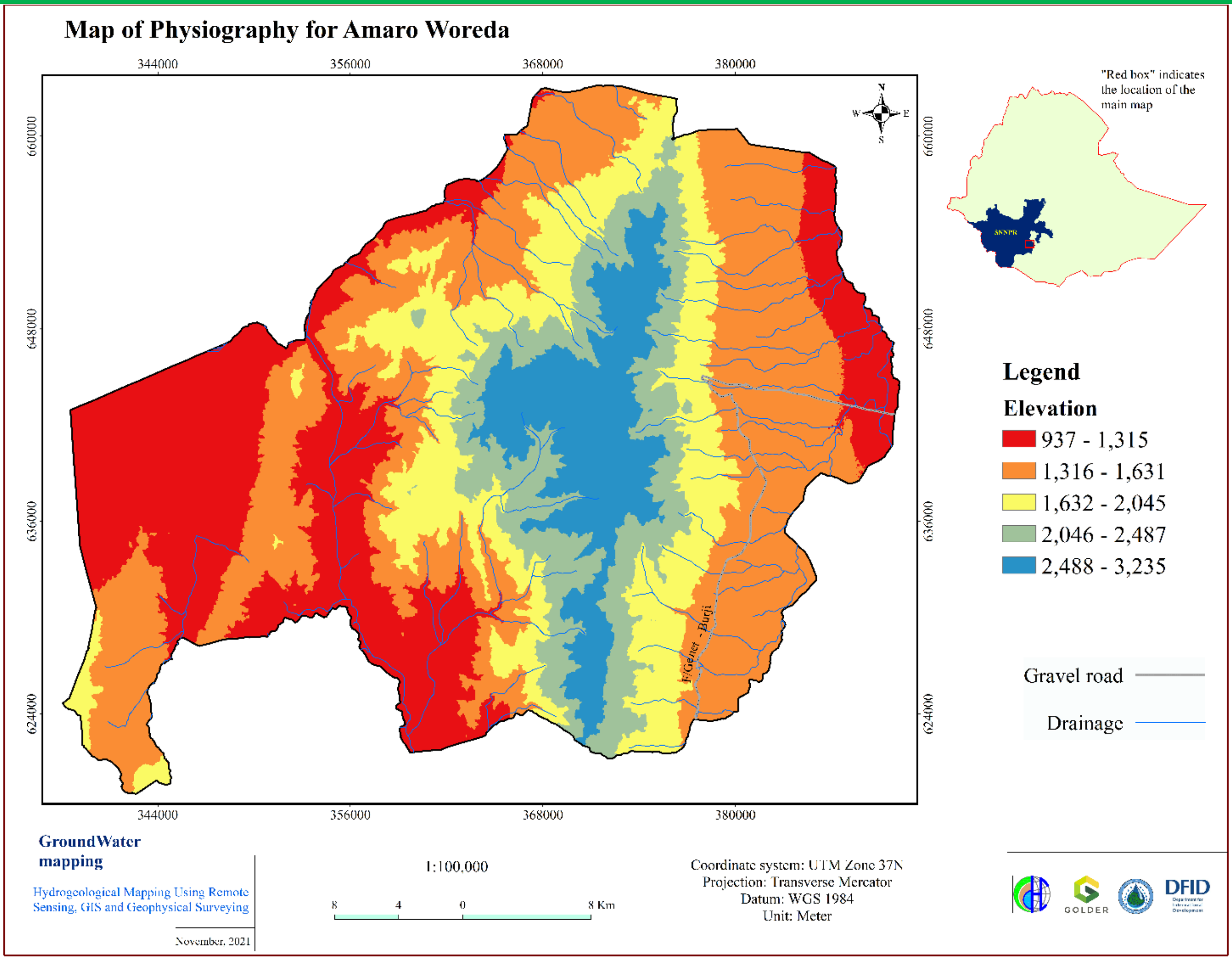


Figure 2.21. Map of physiography for Amaro Woreda

2.8. Akobo

2.8.1. Location

Akobo Woreda is found in the western part of the Gambela regional Government, zone-3 in Baro-Akobo River basin. Akobo is a capital town of the woreda accessed with a road running from Addis to Jimma-Metu Gambela. The geographic location of Akobo Wordas is presented in the figure below (Figure 2.22).

2.8.2. Population and demographic map

Akobo woreda is not covered by 2007 Population census and has undifferentiated Kebele boundaries. Thus population data of this woreda and its demographic map by kebele will be presented in Phase III by conducting field survey

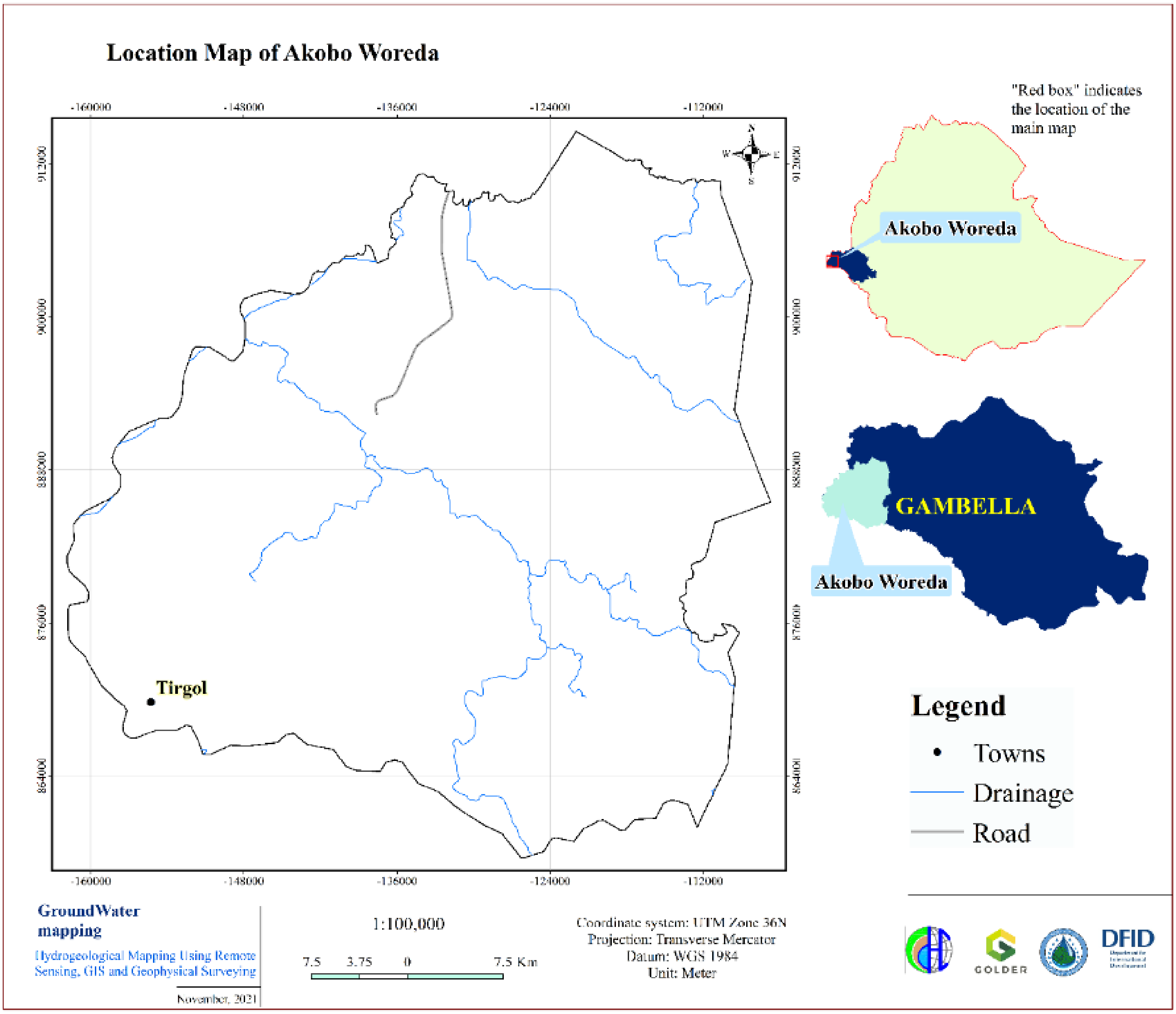


Figure 2.22. Location map of Akobo Woreda

2.8.3. Existing water supply situation

There is no water supply source data like boreholes; springs, dug wells and any other surface water development obtained which explains the type and distribution of water supply schemes in Akobo woreda. This part will be further assessed during the field survey mission under Phase III

2.8.4. Climate

In Akobo woreda, distributions of meteorological stations are sparse and sufficient records have been not available. Climate data from few stations shows it receive uniform annual precipitation over the entire woreda with annual rain fall average of 1450mm characterized by high monthly temperature contracts varying from 22 to 400C s (Taye et al, 2016).

2.8.5. Physiography

An attempt has been made to study the geomorphological details of the Akobo area and to demonstrate their relationship to aquifer geometry in the area. In this study a systematic analysis of varriations in elevations of different land forms and their relationship with lineaments, drainage pattern and rock units have been made by integrating DEM and satellite immageries. The approach involved regional and local interpretation of features exposed at the surface. Elluvial, aluvial and lacustrine sediments overlies the basement.

Sediment deposits are expected to have varying thickness and composition in the area having subsurface features of importance in groundwater storage favourable aquifer disposition and various subsurface geomorphic features which are potential sites for ground water development are identified. The geomorphologic evidences (map) will help to infer groundwater potential zones showing structural, lithological, geological, topographic and hydrological features of the area (Figure 2.23).

The drainage pattern depends on the rock types and geologic structures underlying a given area or catchment. Some types of rock are harder and more resistant to erosion than others. Erosion usualy modifies land forms at large. The pattern of the drainage system of the area is commulative effect of these processes. In Akobo Woreda drainage systems are not well developed as the region is covered by alluvial and elluvial deposits which favors recharge.

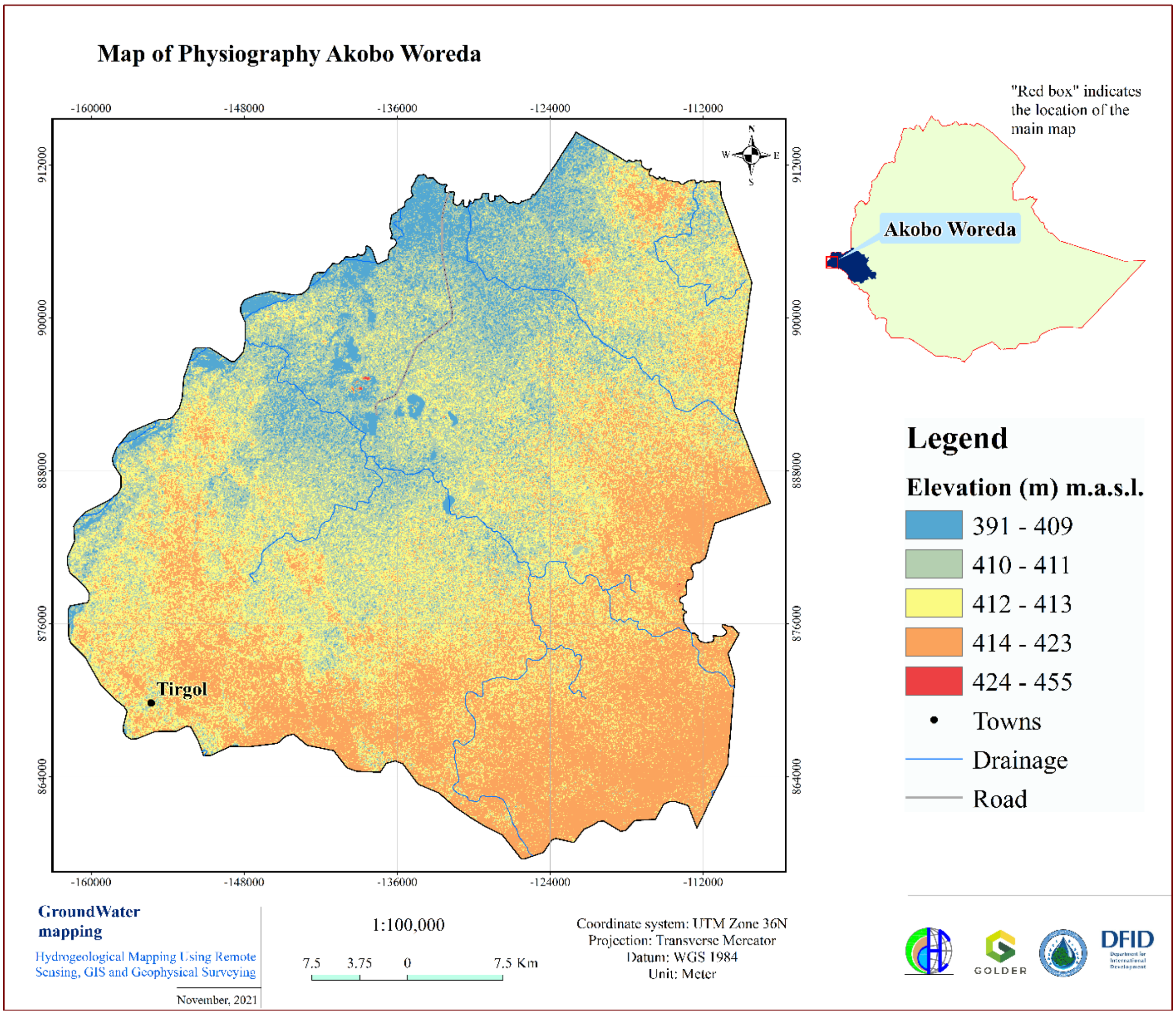


Figure 2.23. Map of physiography for Akobo Woreda

2.9. Jor

2.9.1. Location

Jor Woreda is found Anywaa Zone of the Gambella Regional State, at about 940 Km far from Addis Ababa. It is accessible through Addis Ababab-Jima-Metu-Gambela asphalt road. Geographically the project area is located with a coordinate of 548454, 618995 UTME and 829746, 916595 UTMN and an elevation range of 404-444 m.a.s.l (Figure 2.24).

2.9.2. Population and demographic map

The population the Woreda has been projected from the central statical agency (CSA) 2007 population and housing census data to the currently year which is 2021. Accordingly, Jor Woreda has a total of 13,395 populations estimated from its 15 Kebeles. The highest population and the least population number in the Woreda is 2,167 and 514 respectively. The demography map of Jor by kebele is shown in Figure 2.25.

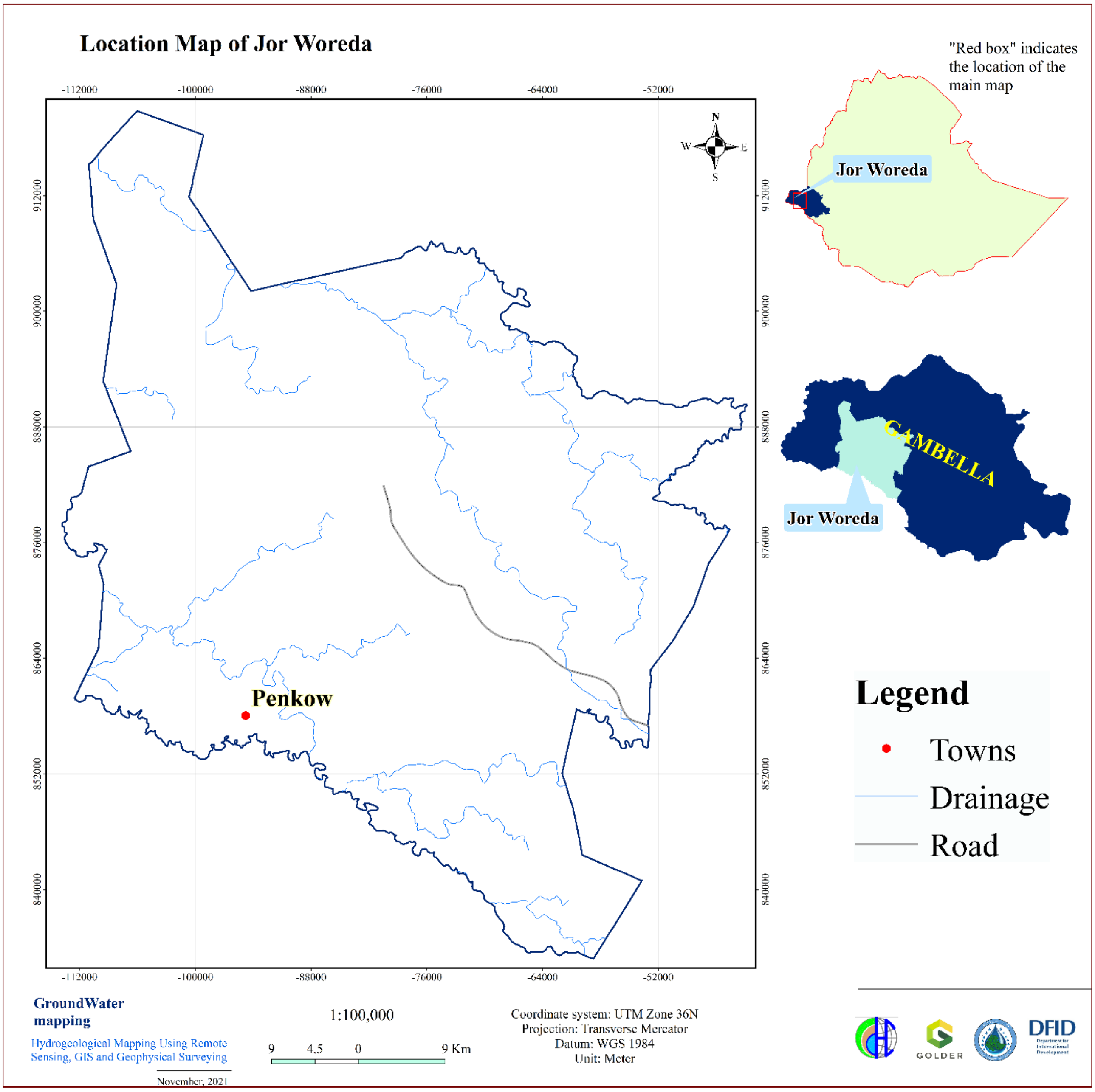


Figure 2.24. Location map of Jor Woreda

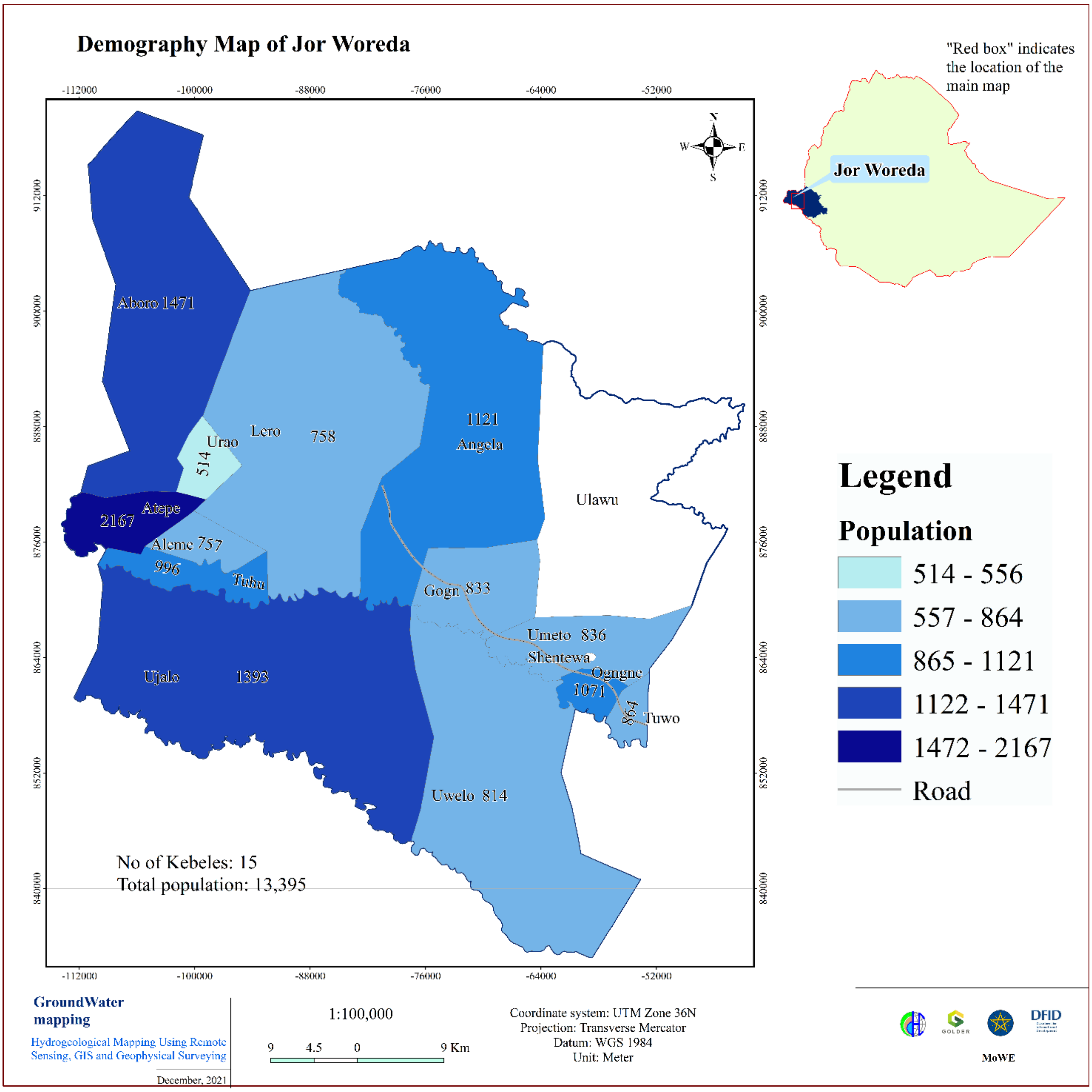


Figure 2.25. Demographic map of Jor Woreda that presents the population projection of 2021.

2.9.3. Existing water supply situation

There is no water supply source data like boreholes; springs, dug wells and any other surface water development obtained which explains the type and distribution of water supply schemes in Jor woreda. This part will be further assessed during the field survey mission under Phase III.

2.9.4. Climate

In Jor woreda, distributions of meteorological stations are sparse and sufficient records have been not available. Climate data from few stations shows it receive uniform annual precipitation over the entire woreda with annual rain fall average of 1450mm characterized by high monthly temperature contracts varying from 22 to 40C s (Taye et al, 2016). Generally, the climate of the entire area is characterized by a single monsoon wet season that runs from late May or early June to the end of September/early October. The wet season is followed by a long dry season. Rainfall is higher at altitudes of 2000 masl and over, where it reaches 2400mm but is only 900 to 1500 mm in the lower areas.80 to 90% of this rainfall occurs in the wet season. Mean annual air temperature also vary with altitude from a high of 280C in the low land to a low of 170C of the mountains. December is usually the coldest month and March, April and may are the hottest months, but the variability over the year is not large (Selkhozpromexport 1990).

2.9.5. Physiography

An attempt has been made to study the geomorphological details of the Jor area and to demonstrate their relationship to aquifer geometry in the area. In this study a systematic analysis of variations in elevations of different landforms and their relationship with lineaments, drainage pattern and rock units have been made by integrating DEM and satellite imageries. The approach involved regional and local interpretation of features exposed at the surface. The study area lies between two geomorphic regions with the largest part lies in the lowlands of Baro Akobo river plain with 400-450m whereas the northeastern part is characterized by elevation ranging between 1800-2000masl m asl

Sediment deposits are expected to have varying thickness and composition in the area having subsurface features of importance in groundwater storage favorable aquifer disposition and various subsurface geomorphic features which are potential sites for ground water development are identified. The geomorphologic evidence (map) will help to infer groundwater potential zones showing structural, lithological, geological, topographic, and hydrological features of the area

The drainage pattern depends on the rock types and geologic structures underlying a given area or catchment Jor Woreda physiography along with drainage system is shown (Figure 2.26).

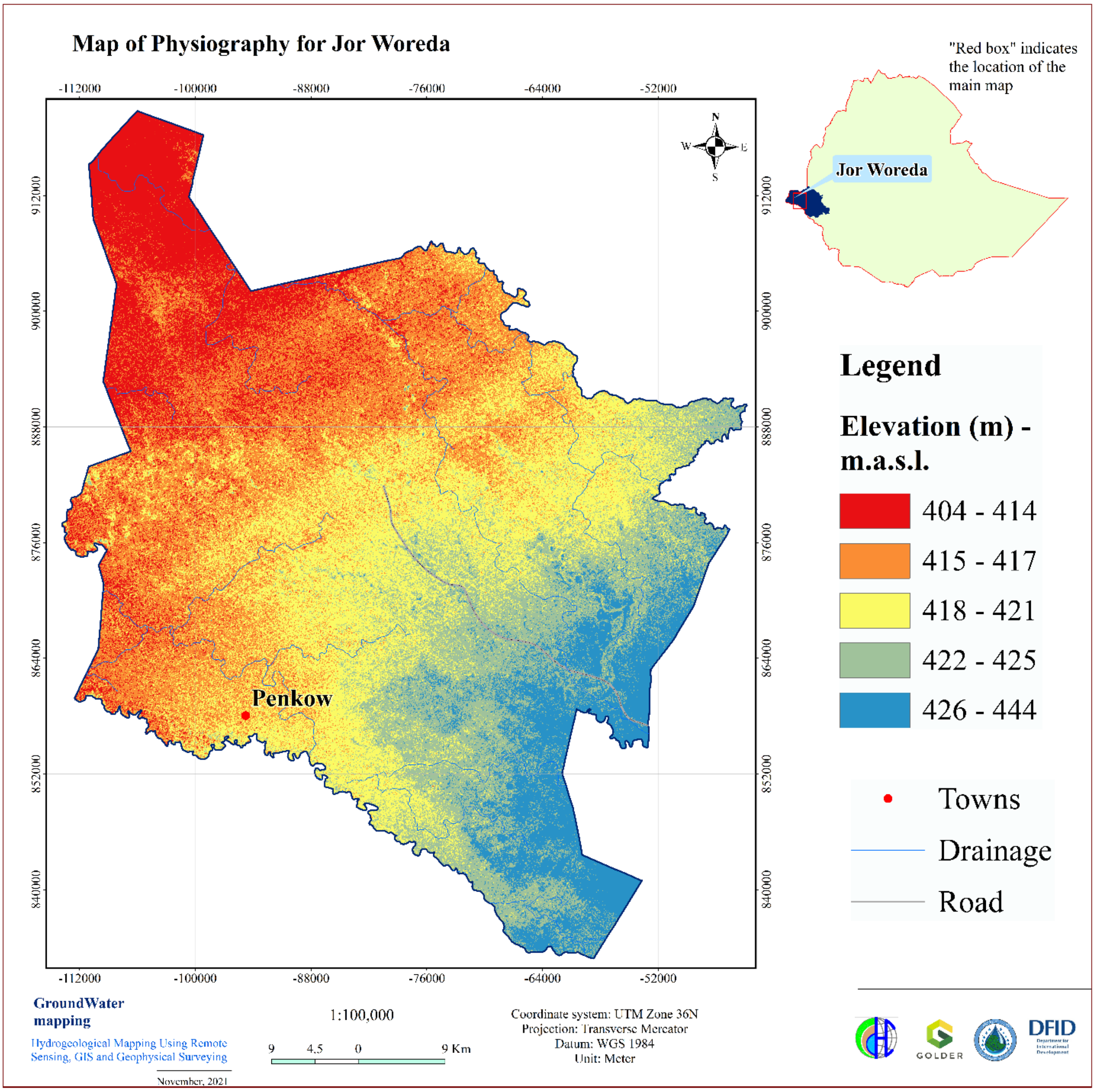


Figure 2.26. Map of physiography for Jor Woreda

2.10. Itang

2.10.1. Location

Itang Woreda is found Anywaa Zone of the Gambella Regional State, at about 956 Km far from Addis Ababa. Geographically the project area is located with a coordinate of 609631.790 659870.149UTME, and 887408.676, 962990.392 UTMN and an elevation range of of 402-727 m.a.s.l (Figure 2.27).

2.10.2. Population and demographic map

The population the Woreda has been projected from the central statical agency (CSA) 2007 population and housing census data to the currently year which is 2021. Accordingly, Itang Woreda has a total of 46,279 populations estimated from its 20 Kebeles. The highest and least population in the Woreda is 159 and 6,118 respectively. The demography map of Itang by kebele is shown in Figure 2.28.

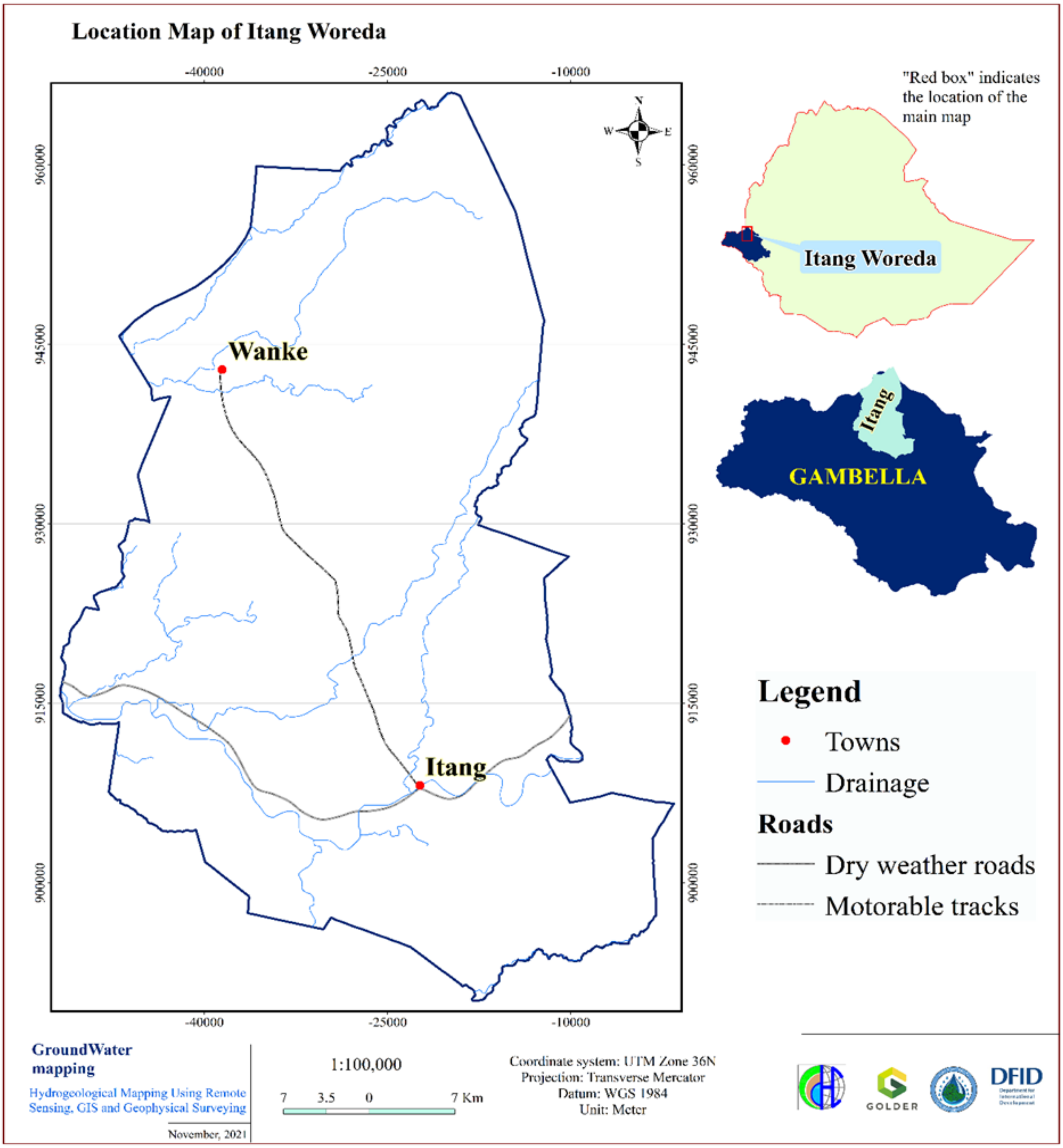


Figure 2.27. Location map of Itang Woreda

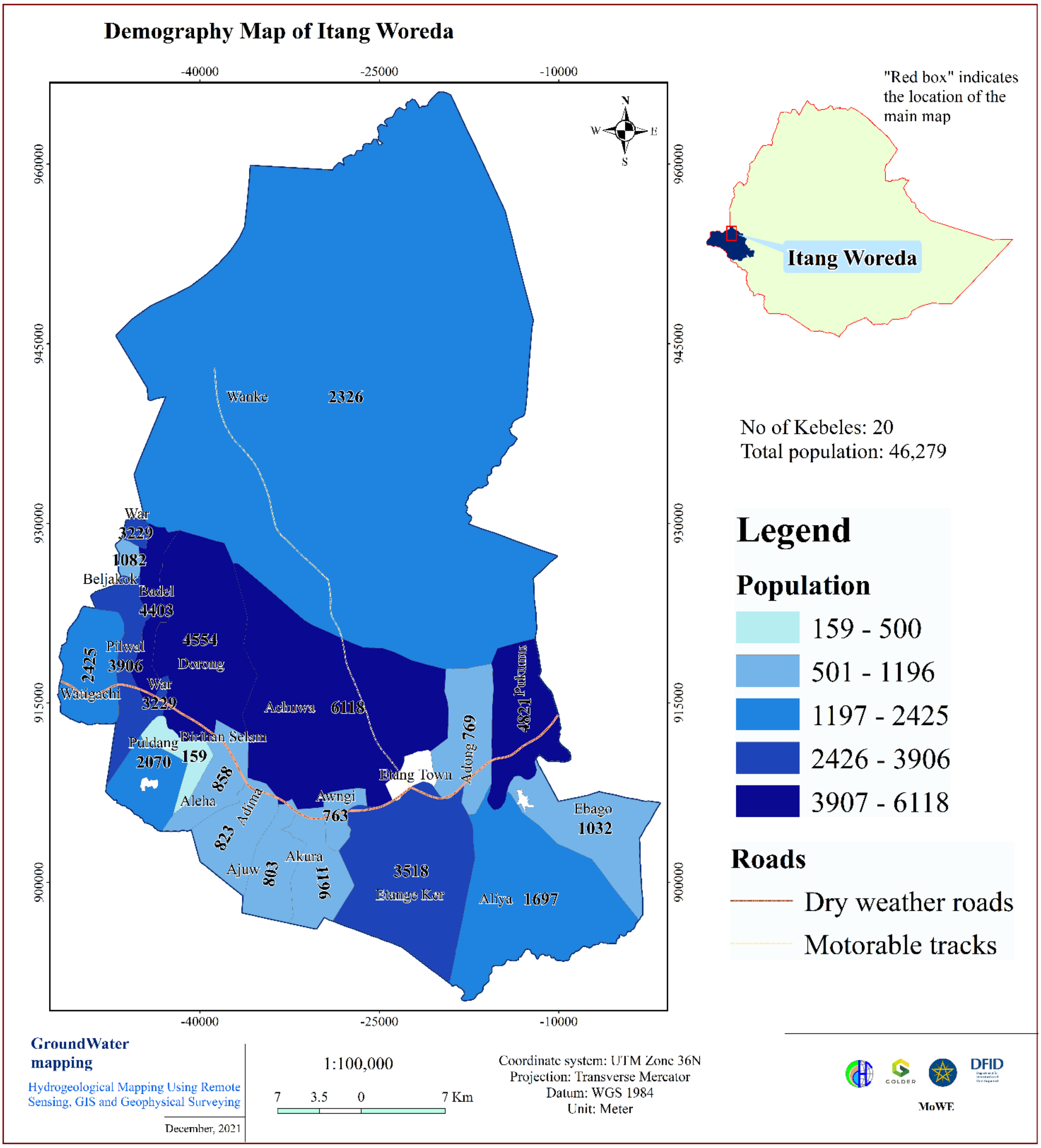


Figure 2.28. Demographic map of Itang Woreda that presents the population for the year 2021.

2.10.3. Existing water supply situation

There are water supply source data like boreholes were collected and surface water development obtained which explains the type and distribution of water supply schemes in Itang woreda. From the collected borehole data, most of the borehole are partially penetrated, there is no full data for borehole logs, transmissivity, hydraulic conductivity, and aquifer thickness. The collected borehole data was used for validation of the potential zones. Existing borehole data collection will be further assessed during the field survey mission under Phase III.

2.10.4. Climate

In Itang woreda, distributions of meteorological stations are sparse and sufficient records have been not available. Climate data from few stations shows it receive uniform annual precipitation over the entire woreda with annual rain fall average of 1450mm characterized by high monthly temperature contracts varying from 22 to 40C s (Taye et al, 2016). Climatically, the entire area is characterized by a single monsoon wet season that runs from late May or early June to the end of September/early October. The wet season is followed by a long dry season. Rainfall is higher at altitudes of 2000 masl and over, where it reaches 2400mm but is only 900 to 1500 mm in the lower areas.80 to 90% of this rainfall occurs in the wet season. Mean annual air temperature also vary with altitude from a high of 280C in the low land to a low of 170C of the mountains. December is usually the coldest month and March, April and may are the hottest months, but the variability over the year is not large (Selkhozpromexport 1990).

2.10.5. Physiography

An attempt has been made to study the geomorphological details of the Itang area and to demonstrate their relationship to aquifer geometry in the area. In this study a systematic analysis of varriations in elevations of different land forms and their relationship with lineaments, drainage pattern and rock units have been made by integrating DEM and satellite immageries. The approach involved regional and local interpretation of features exposed at the surface. The study area lies between two geomorphic regions with the largest part lies in the lowlands of Baro Akobo river plain with 400-450m whereas the north eastern part is characterized by elevation ranging from 500-750 m asl

Sediment deposits are expected to have varying thickness and composition in the area having subsurface features of importance in groundwater storage favourable aquifer disposition and various subsurface geomorphic features which are potential sites for ground water development are identified. The geomorphologic evidences (map) will help to infer groundwater potential zones showing structural, lithological, geological, topographic and hydrological features of the area

The drainage pattern depends on the rock types and geologic structures underlying a given area or catchment. Itang Woreda has poor drainage system as is covered by alluvial and elluvial deposits which favors recharge (Figure 2.29).

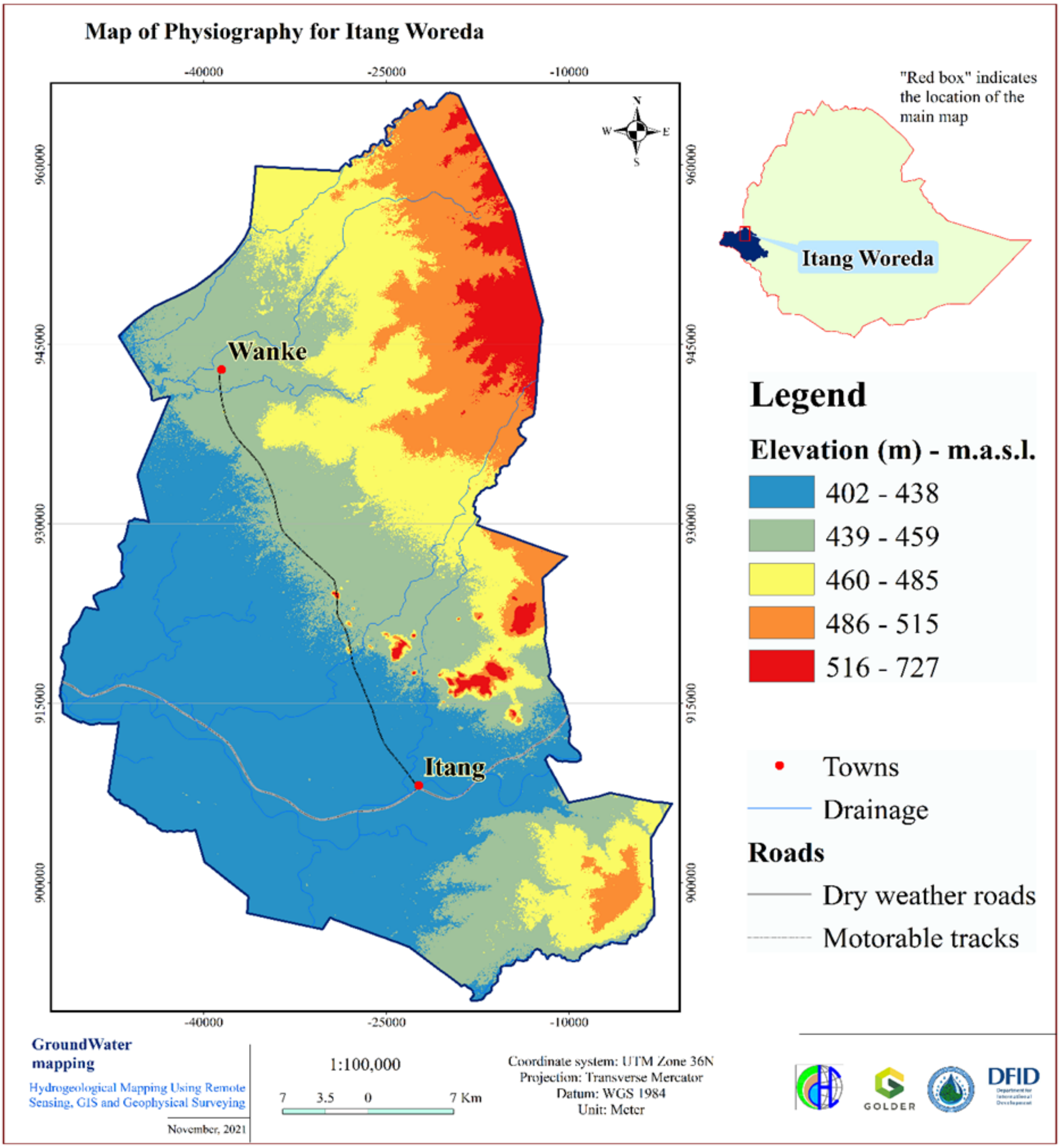


Figure 2.29. Map of physiography for Itang Woreda

2.11. Shashemene

2.11.1. Location

Shashamanne Woreda is found in west Arsi Zone of Oromiya regional Ste, Rift Valley Lakes basin. Shashamanne is a capital town of the woreda accessed with a road running from Addis to Hawassa. Geographically Shashamanne Wordas is bound with coordinates of 434441.8,478588.6 UTME,782805.4, 814851.8UTMN presented in the figure below (Fig 2.30).

2.11.2. Population and demographic map

The population the Woreda has been projected from the central statical agency (CSA) 2007 population and housing census data to the currently year which is 2021. Accordingly, Shashemene Woreda has a total of 318,077 populations estimated from its 44 Kebeles. The highest and least population in the Woreda is 46 and 17,983 respectively. The demography map of Shashemene by kebele is shown in Figure 2.31.

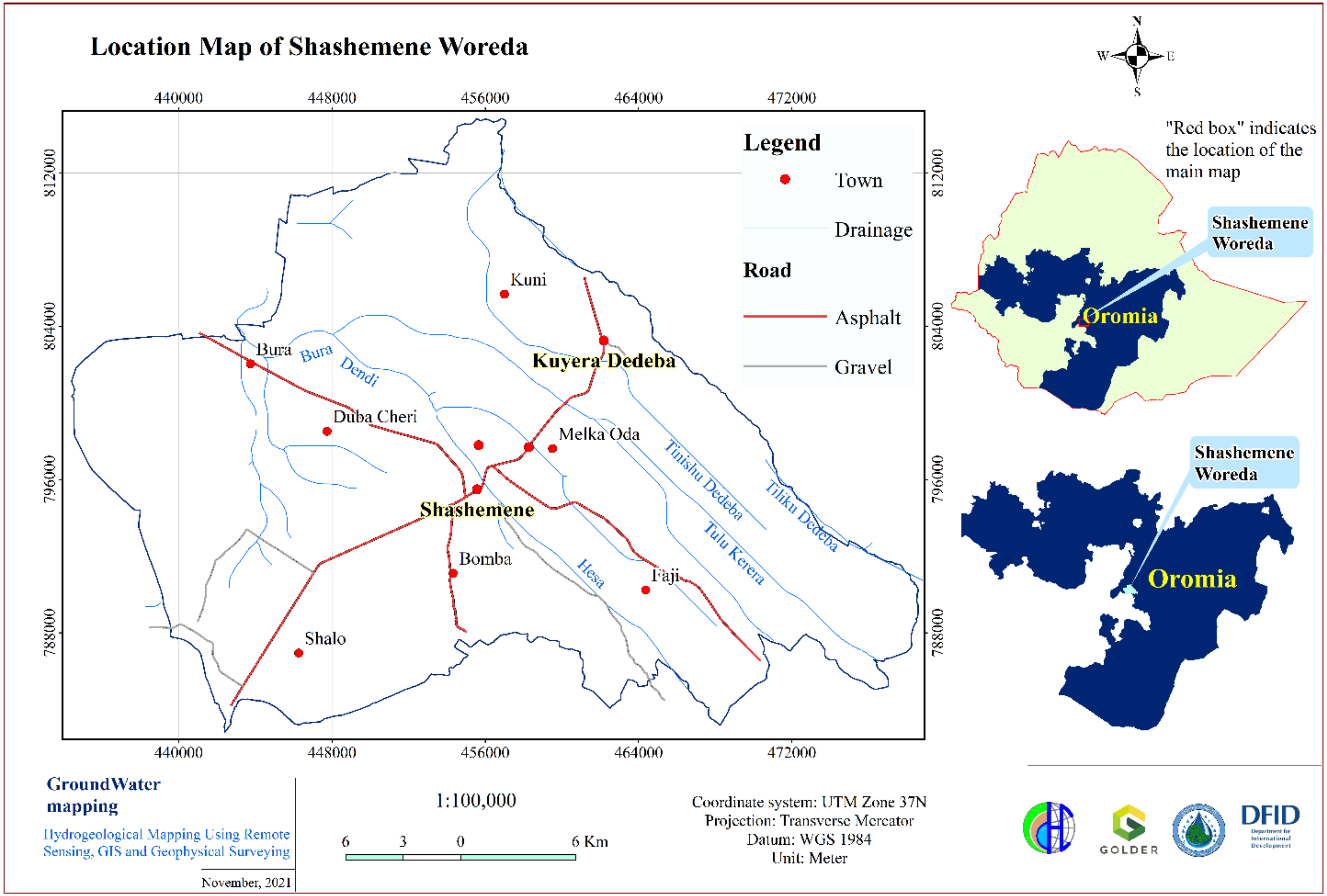


Figure 2.30. Location map of Shashemene Woreda

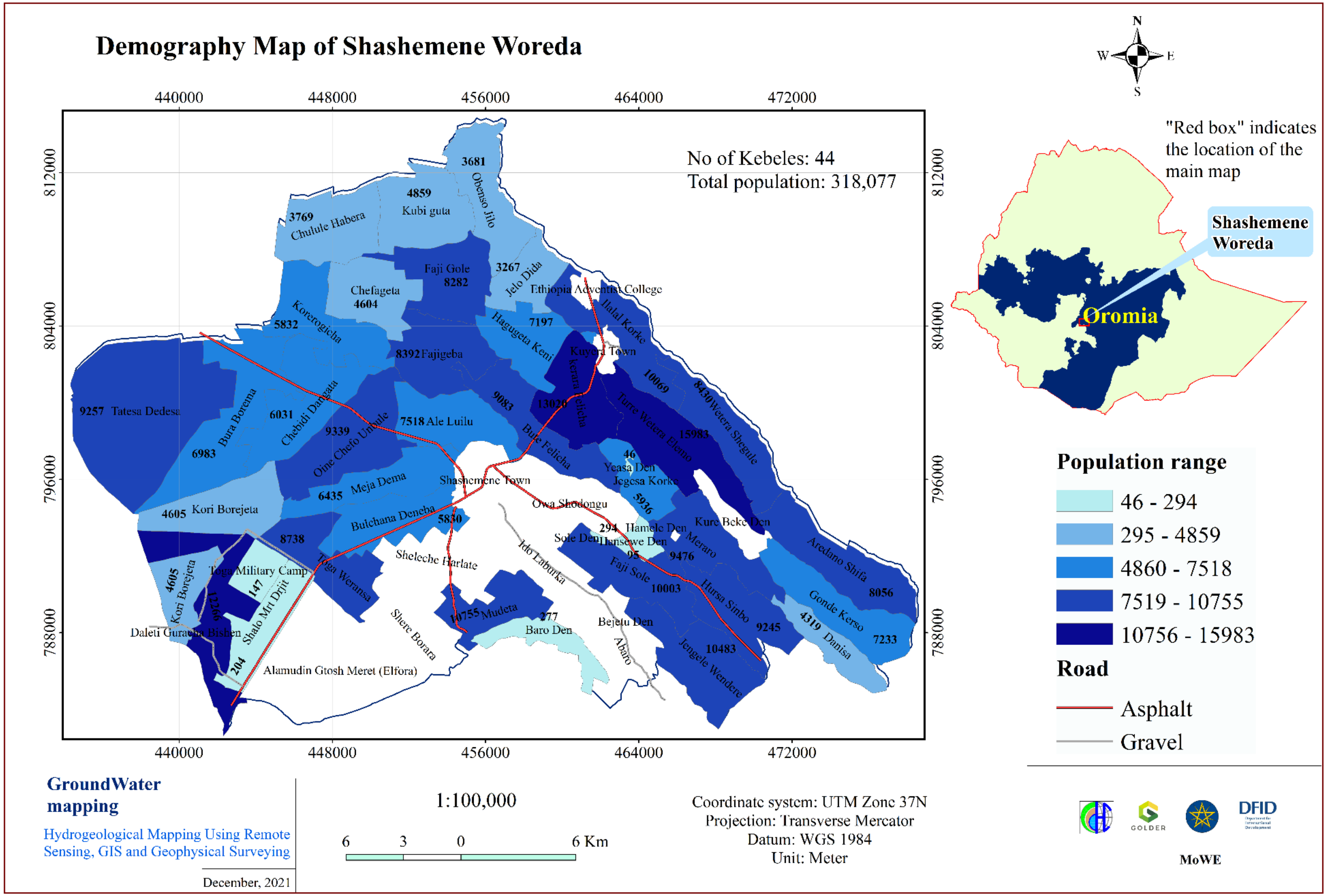


Figure 2.31. Demographic map of Shashemene Woreda that presents the population projection of 2021.

2.11.3. Existing water supply situation

For Shashashamanne woreda, surface waters that are readily availably for domestic water supply are scares. As a result, groundwater through drilled wells and springs is the majr sources supply water for the woreda. There are 31 boreholes collected whose depth ranges from medium to deep and yield 5 to 30 l/s. Ground waters in this woreda is strongly impaired by fluoride, thus potable groundwater is limited near escarpments exterior to Rift Valley main center. Ground water in this woreda, particularly those within Rift Valley main central zone are hot manifesting the activity of groundwater with deep geothermals.

2.11.4. Climate

The average temperature for the year in Shashamane is 18.3°C. The warmest month, on average, is March with an average temperature of 19.7°C. The coolest month on average is November, with an average temperature of (17.1°C). The average amount of annual precipitation for the year in Shashamane 1097.3 mm, with August is the month with the most precipitation (160 mm) whereas lowest precipitation (20.3 mm) is month of December.

2.11.5. Physiography

An attempt has been made to study the geomorphological details of the Shashamanne area and to demonstrate their relationship to aquifer geometry in the area. In this study a systematic analysis of varriations in elevations of different land forms and their relationship with lineaments, drainage pattern and rock units have been made by integrating DEM and satellite immageries. The approach involved regional and local interpretation of features exposed at the surface. The pyroclastic sediments rift volcanics which occupies wide areas of Shashamenne are expected to have varying thickness and composition in the area having subsurface features of importance in groundwater storage favourable aquifer disposition and various subsurface geomorphic features. The geomorphologic evidences (map) will help to infer groundwater potential zones showing structural, lithological, geological, topographic and hydrological features of the area (Figure 2.32).

The drainage pattern depends on the rock types and geologic structures underlying a given area or catchment. Some types of rock are harder and more resistant to erosion than others. Erosion usualy modifies land forms at large. The pattern of the drainage system of the area is commulative effect of these processes. Shashamanne has parallel drainage patterns developed along geological structures-oriented NW-SE. Physiography of Shashamanne woreda with drainage system is shown in Figure 2.32.

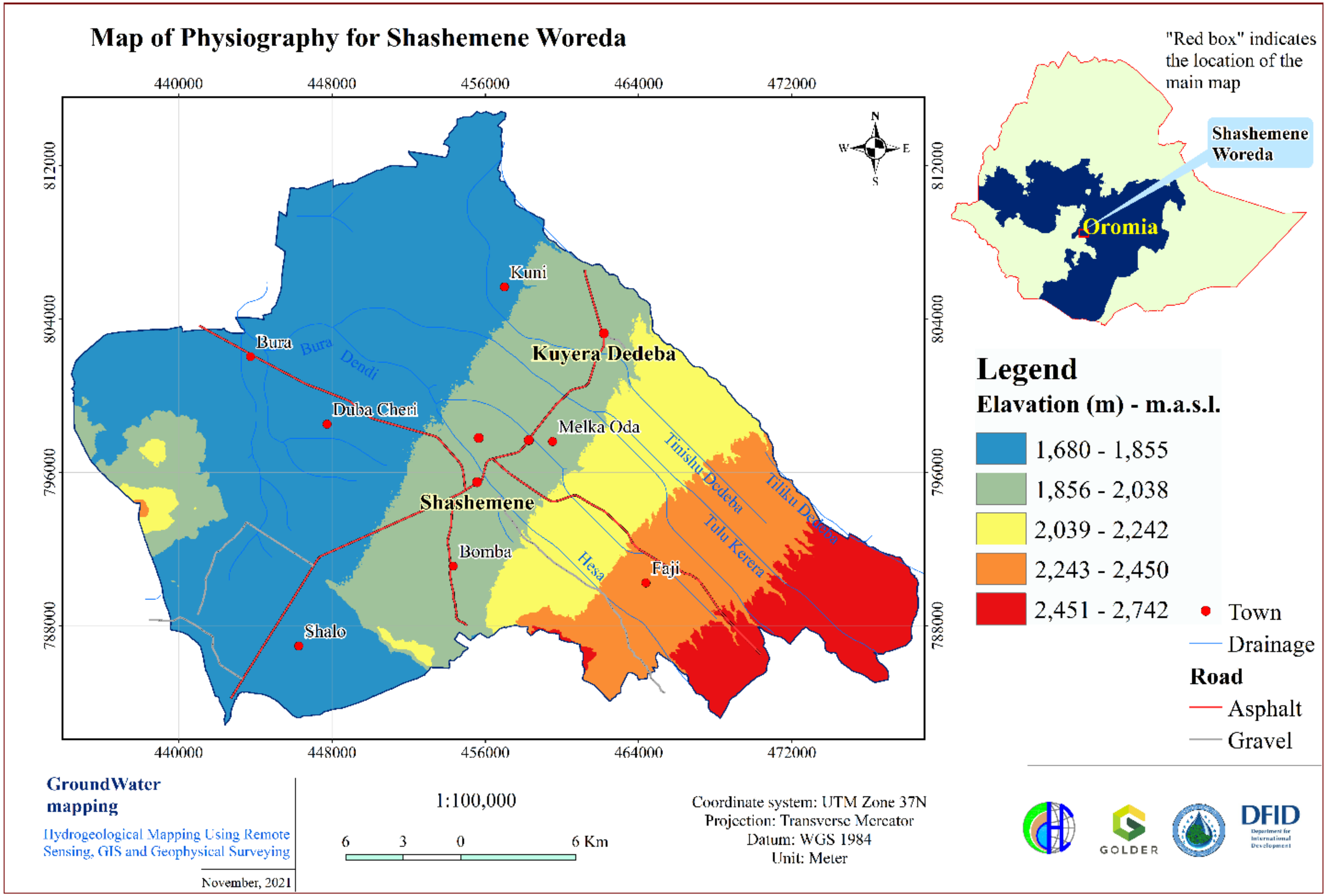


Figure 2.32. Map of physiography for Shashemene Woreda

2.12. Liben

2.12.1. Location

Liben Woreda is found in the Southern part of the country in Oromiya regional Government, Guji zone in Genale Dawa River basin. Negele Borena is capital town of the woreda accessed with an asphalt road running from Addis to Negele Borena. The geographic location of Liben Wordas is presented in the figure below (Figure 2.33).

2.12.2. Population and demographic map

Liben woreda is not covered by 2007 Population census and has undifferentiated Kebele boundaries. Thus, population data of this woreda and its demographic map will be presented in Phase III by conducting field survey

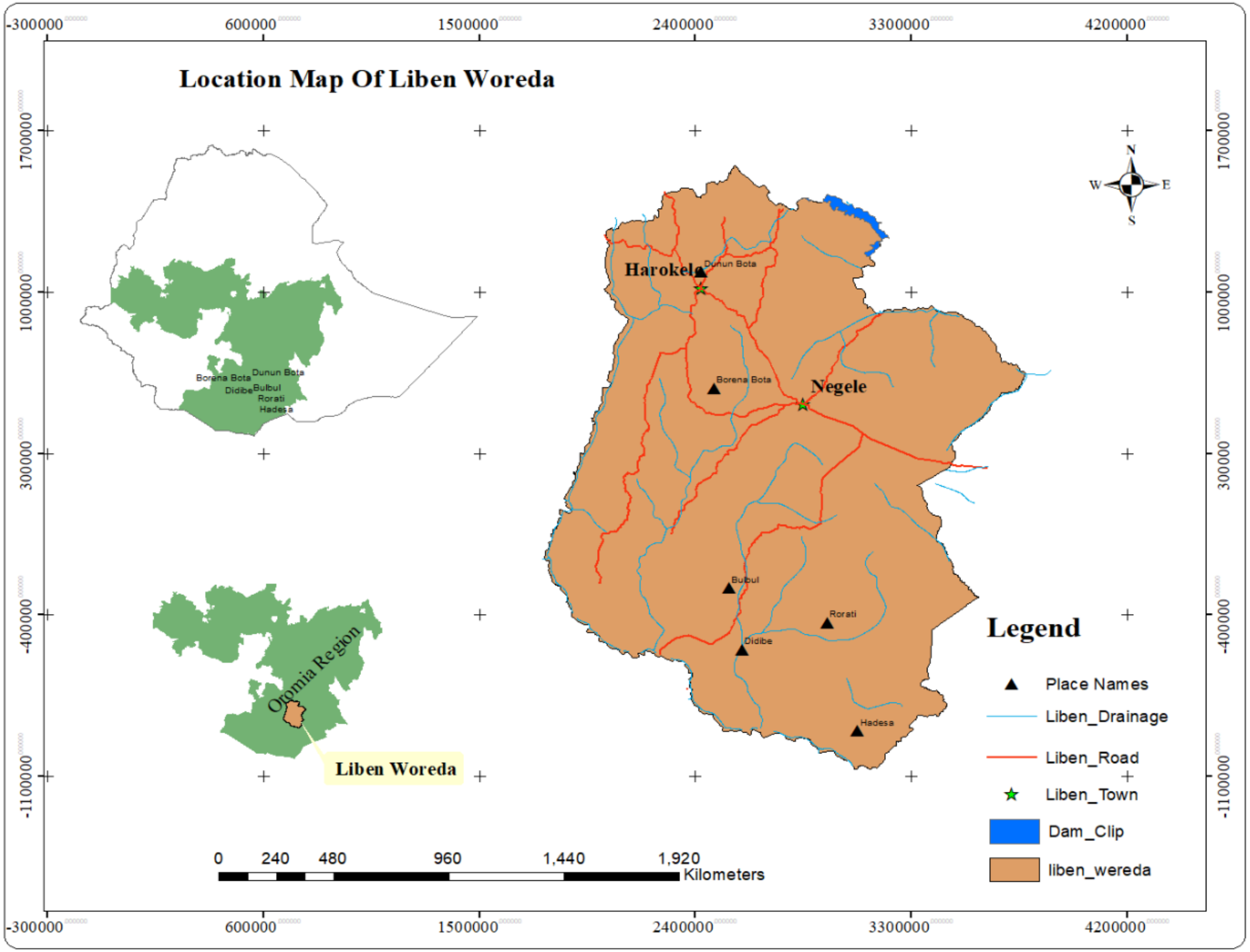


Figure 2.33. Location map of Liben Woreda

2.12.3. Existing water supply situation

A number of boreholes have been drilled in the northern and central part of the woreda. As far as the data we have is concerned, boreholes and dug wells with different depth range are available in this area. Well yields vary from 0.5 l/s to >7 l/s. The dominant aquifer material observed at some of these wells is tertiary volcanics and alluvial deposits underlain by weathered and slightly fractured Limestone rocks. These wells are located at places having relatively low relief.

2.12.4. Climate

The annual rainfall in Liben area ranges from 29.5 to 179.6 mm/yr (annual mean of 105 mm) as indicated by Eba Muluneh, 2017.

2.12.5. Physiography

An attempt has been made to study the geomorphological details of the Liben area and to demonstrate their relationship to aquifer geometry in the area. In this study a systematic analysis of varriations in elevations of different land forms and their relationship with lineaments, drainage pattern and rock units have been made by integrating DEM and satellite immageries. The approach involved regional and local interpretation of features exposed at the surface. Erosional reminants of sedimentary rocks form localized ridges overlying the basement rock units. Elluvial, aluvial and lacustrine sediments overlies the basement along perrenial and non perrrenial stream courses.

Sediment deposits are expected to have varying thickness and composition in the area having subsurface features of importance in groundwater storage favourable aquifer disposition and various subsurface geomorphic features which are potential sites for ground water development are identified. The geomorphologic evidences (map) will help to infer groundwater potential zones showing structural, lithological, geological, topographic and hydrological features of the area (Figure 2.34).

The drainage pattern depends on the rock types and geologic structures underlying a given area or catchment. Some types of rock are harder and more resistant to erosion than others. Some areas are impacted more by tectonic forces than other areas. Erosion usualy modifies land forms at large. The patterns of the drainage system of the area are commulative effect of these process (Figure2.34). In Liben Woreda domain bedrock lithology and geologic structure dominantly determine patterns of drainage net work. The crystalline basement dominantly composed of granites display parallel and rectangular drainage patterns in the area. Liben is entirely characterized arid to semi-arid physiography with altitude 620-1681masl.

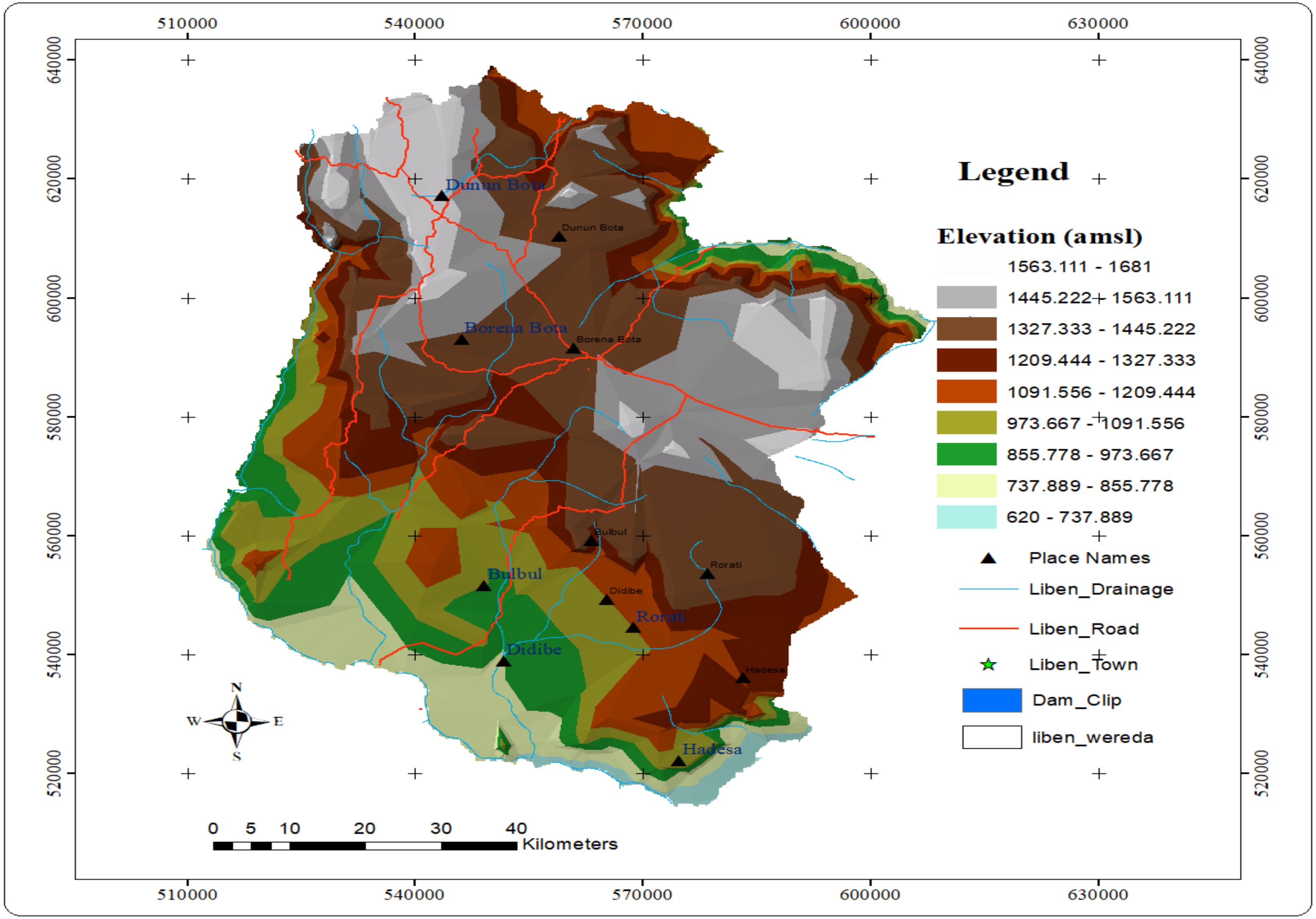


Figure 2.34. Map of physiography for Liben Woreda

CHAPTER 3 : REVIEW OF PREVIOUS WORKS

The ongoing review includes available literature on similar topic, interpretation of physical features from satellite images, geological reports, hydrogeological reports and existing water well data and well completion reporst. Basic data necessary for the assignment has been collected from Basin Authority, Regional Water Bureau, Public and private organization engaged in water works to help planning field work in subsequent project phases to get data gaps filled for further hydrogeological analysis.

Literatures and previous relevant studies have been assessed to learn more on major issues to be addressed as well as methods to be applied in describing hydrogeological framework and aquifer system of the project target areas. Satellite images have been used as baseline to identify major geological structures, relief features and topographic slopes to understand geospatial hydrological factors. Major geological structures including faults, lineaments and fissures controlling groundwater movement have been traced from from existing previouse work. Hydrological data including meteorology and river discharge have been collected to be used to assess the hydrological system of the target areas. Previouse reviewed documents and details of methodology have been discussed under their respective chapters and sections,

Most of the previous studies focused at regional scale area and generate more general information. Some of the works relevant to this study work include groundwater potential resources evaluation in Genale Dawa River basin, where Liben woreda is located.at extreme north (Oromia Water Works Design and Supervision Enterprise, 2012) The hydrogeological characteristics, geological set-ups and main lithological units and structures important for controlling groundwater occurrence and movement have been described in this work at a regional scale.

CHAPTER 4 : SYNOPTIC AREA MAPPING

4.1. General

The present study addresses the aspect of characterization of the groundwater potential zones using integrated GIS and remote sensing (RS) techniques in conjunction with review of previous geological and hydrogeological works. The overall study concept involved the integration of four thematic layers (geology, lineament, topographic wetness index and recharge). We did divide 12 woredas into four clusters to have a broader view and understand the overall geological and hydrogeological settings of the study area and produce reliable thematic layers. A synoptic rectangular boundary buffering with minimum of 10km from the woreda boundary has been used. The groundwater potential map has been developed on GIS environment using overlay analysis of the four thematic layers. All the map themes were presented in UTM Projection with varied Zones, Datum WGS84 and 100 meters spatial resolution. The groundwater potential map finally clipped for the woreda boundary.

4.2. Preparation of thematic layers

4.2.1. Methodology

The groundwater potential mapping is made using the GIS overlay analysis method using remote sensing and conventional input data. Existing hydrogeological and relevant data on geological/lithological units, structural features or lineaments, geomorphologic and climatic conditions of cluster woredas were collated first. The overall study concept involved integration of four thematic layers.

Geological units/lithologies prepared for woredas within a synoptic rectangular boundary buffering the woreda area are grouped into a certain classis taking their characteristics of hydrogeological significance into consideration.

As first defined by (Hobbs, 1904), lineaments are geological features that are identified as significant lines in a landscape caused by joints and faults, associated with the hidden architecture of the rock basement. They are the manifestation of linear features that can be identified directly on the rock units or from remote sensing data. Lineaments and their intersections play a significant role in the occurrence and movement of groundwater resources in sedimentary, volcanic and crystalline rocks. The presence of lineaments may act as a conduit for groundwater movement which results in increased secondary porosity and, therefore, can serve as groundwater potential zone (Rao, 2006; Prasad et al., 2008). Accordingly, detailed lineaments of the study area have been extracted from a mosaicked Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) and Sentinel 2 imagery combined with geomorphology of the area. The DEM was accessed from National Aeronatical Space Administration open access hub (NASA, 2021) and Sentinel 2 from European Space agency (Copernicus, 2017). Extraction of lineament features have been carried out using ArcGIS version 10.8 software and subsequently lineament density map was drived which expressed in terms of length of the lineament per unit area (km/Km2).

The other thematic layer is Topographic Wetness Index (TWI) wich plays important role in the occurrence and development of groundwater. The topographic wetness index (TWI), also known as the compound topographic index (CTI), is a steady state wetness index. It is commonly used to quantify topographic control on hydrological processes. The index is a function of both the slope and the upstream contributing area per unit width orthogonal to the flow direction. TWI was initially designed for hill slope catena's by (Beven & Kirkby, 1979). Accumulation numbers in flat areas will be very large.

To produce Topographic Wetness Index (TWI) requires basically slope (in degree), flow direction and flow accumulation which are generated from elevation maps (DEM) extracted from SRTM (30m resolution) as an input layer. The DEM with gaps/voids were initially filled and then all the input layers were resampled into 100 m cell size. Accordingly, TWI map layer was prepared for synoptic cluster boundaries using a raster calculations algorithm in ArcGIS 10.8 software based on the following procedure.

1) fd = flow direction (DEM)
2) fa = flow accumulation (fd)
3) slope (DEM)
4) slope = (slope (DEM)*1.570796)/90
5) tan_slp = con (slope > 0, tan(slope), 0.001)
6) fa_scaled = (fa + 1) *cell size; cell size = 100m
7) TWI = ln(fa_scaled/tan_slp)

Finally, recharge map layer was produced using equation 1 by calculating the annual rainfall with infiltration coefficient of each lithology units in ArcGIS 10.8 platform.

R = RF*IC………………………………………………………………………....1

Where, R= Recharge (mm/y), RF = Annual Rainfall (mm/y), IC = Infiltration Coefficient

The annual rainfall data (2011 - 2020) of Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) were obtained from the Climate Hazards Center (CHC) of University of California (https://chc.ucsb.edu). First, all the annual rainfall data of the study area were re-projected with the required projection and resampled to 100 m cell sizes and then added up using a raster calculation algorithm on ArcGIS so that to have the 10 years of average annual rainfall amount of the area. Whereas the infiltration coefficient of lithological units was obtained from Abay River Basin Integrated Resources Development Master Plan Study report (MoWR, 2007). According to the master plan study, the IC of various lithological units could be developed based on the results obtained from recharge estimations made using an integrated approach that considered an important parameter and correlating with different lithological units identified within the basin. Therefore, for the current study, the IC values were extracted from the basin study that have similar properties of lithological units found in the current study area and accordingly assigned to each lithological unit. Then, the lithology has been converted to raster based on the assigned value of IC with cell size of 100m on ArcGIS platform. Finally, the average annual rainfall and IC of lithological units were multiplied using a raster calculation algorithm in ArcGIS to obtain spatial map of average annual recharge amount for the synoptic areas.

After the preparation of all the different thematic maps (including recharge, TWI, geology, and lineament) with varied attributes, the layers were converted into raster format and then assigned suitable weights in order of their hierarchy in groundwater potentiality using the analytic hierarchy process (AHP) (Saaty 1980, 1992). All the normalized weighted thematic layers were integrated and processed in ArcGIS 10.8 platform to demarcate the potential groundwater zone in the cluster areas. The details of the procedures adopted for this study is summarized graphically as flow-chart in Figure 4.1 (while further details on the AHP and weight assignments are highlighted in the following section).

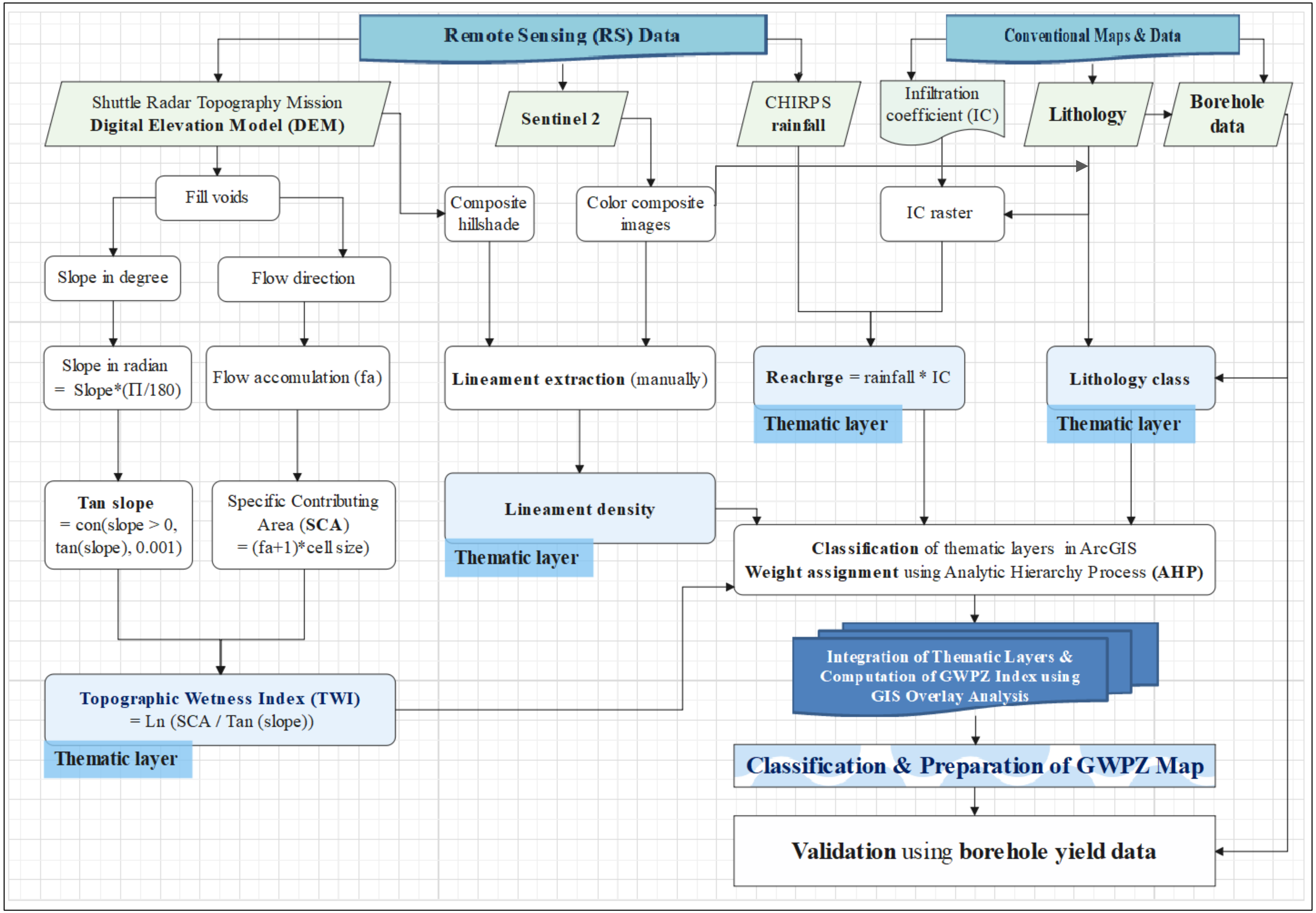


Figure 4.1. Flowchart for mapping of groundwater potential zones using using GIS Overlay technique.

4.3. SNNP and Bule Hora Synoptic Area

4.3.1. Geology

In preparation of the geological map of the target Synobtic Area, major lithological units, their spatial coverage and geomorphological condition of the area has been assessed from existing data and previous studies and maps from the Geological Survey of Ethiopia and using sentinel 2 multispectral image for verification and modification of the existing maps. This initial stage of the work encompasses extracting base map features, through the manipulations of topographic map in a GIS environment. The topographic map illustrates geographic references (Example, localities, names of rivers, road network and etc.) useful to mark widely distributed control points for accurate geo-referencing of previous geologic maps that is available in different scales. At regional scale, the following geological units are exposed in the synoptic area:

- Precambrian rock units that include undifferentiated gneisses, Syntectonic granite and metasedimentary rocks.
- Volcanic rocks – Tertiary volcanics and Quaternary flows,
- Unconsolidated Quaternary sediments and lacustrine deposits.

At local scale, in the cluster woredas, the following geological units were identified:

Maanetite-auartz-feldspar gneiss (Pmfg): The main rock type making up this unit is composed predominantly of quartz, feldspar, and magnetite with little or no biotite. It is dominantly fund northwestern area of the area,

Metaquartzite (Pmqz): This unit occurs as narrow, elongate ridges trending NNW to SE direction and covers very small area. It is fine to medium grained, brown to pink to light grey, ferruginous and typically banded. The banding is defined by layers of differing grain size and by variable iron oxide content. The rock is composed predominantly of quartz, with a little magnetite and garnet.

Oligoclase-hornblende-biotite-quartz gneiss, calc-silicate, biotite, and biotite-hornblende gneisses (Pfbg): This unit is found on the central part elongated N-S direction in the area and it is fine to medium grained, mesocratic, and layered. Mesocratic and layered. Layers of calc-silicate, biotite and biotite-hornblende gneisses occur interlayered.

Augen biotite-quartz-feldspar gneiss anitized (Pmcg)**:** This rock unit forms a large north-south running belt that widens southwards on the central part of the area. The rocks of this unit are exposed as discontinuous ridge forming granitic bodies, and as well-developed gneisses outcropping mainly along riverbeds. It has light grey to pink rock made up of pink feldspars which are commonly augen, plagioclase, quartz, biotite, and magnetite with or without hornblende. It is gneissose to weakly foliated and resembles an intrusive plutonic rock.

Biotite-quartz- oligoclase gneiss, medium grained amphibolite and minor oligoclase-quartz-microcline gneiss (Pfqg): This unit is widely distributed in the northeastern and southern part of the synoptic view. It is by and large homogeneous, with rare, thin interbeds of quartzite, amphibolite's and muscovite or biotite bearing schists and gneisses. The dominant oligoclase-quartz-microcline gneiss is a leucocratic, fine to medium grained rock that is mostly friable.

Biotite-microcline-quartz gneiss. Medium grained amphibolite garnet-staurolite schist and marble (Pbmg): This lithologic unit is exposed in the eastern and southern part of the project. The dominant rock type, biotite-microcline-quartz gneiss, is a medium grained, leucocratic rock with a mostly schistose, but at places banded fabric.

Fine to medium grained amphibolite and plaqioclase-chloriteactinolite schist (Pcas): This unit is found in southern part of the area. It is a light to dark grey, generally fine grained and fissile rock. The medium to coarse grained variety that occurs at places is characteristically massive and hard.

Phyllite. metasiltstone and metasandstone (Ppss): This unit is found in southeastern of the area. It is grey to black, fine grained and fissile, with poorly developed foliation.

Intrusive rocks: The intrusive rocks granite with different mineral content, Biotite-garnet, subvolcanic amphibolite's, serpentinite, hornblende, talc-tremolite schist, metaquartz diorite, quartz syenite, metagabro, gneiss, foliated biotite metagranite are the dominant in the area mainly southern, southwestern, and southeastern part of the project area

Shole Iqnimbrite (Pgs): This unit is found Northwest of Dimtu town and northwest and northeast of Gerba. This unit is well to poorly welded and locally shows columnar jointing. Occasionally pumice fragments show flattening. Cavity filling secondary minerals is locally common. The ignimbrite is overlain by a white to light yellow, fine grained, well bedded tuff, possibly reworked.

Middle Basalt (Ngm): The middle basalt is well exposed on the Northern and eastern part of Amaro town. It consists of a single basalt flow which is similar in mineral composition throughout the area. This basalt is generally dark grey, fresh, aphanitic, and partly vesicular. It contains small phenocrysts, as well as zeolite and calcite amygdales. Columnar jointing is common.

Elluvium (Qe): This unit is found western margin of the area and northeastern of the study area loose residual material ranging from accumulations of cobble sized fragments to soils.

Alluvium (Qa) consists of sandy gravel, silt, and clay, mainly occurring along river courses of very low gradient. In contrast to the eluvium, alluvial sediments are predominantly fine grained.

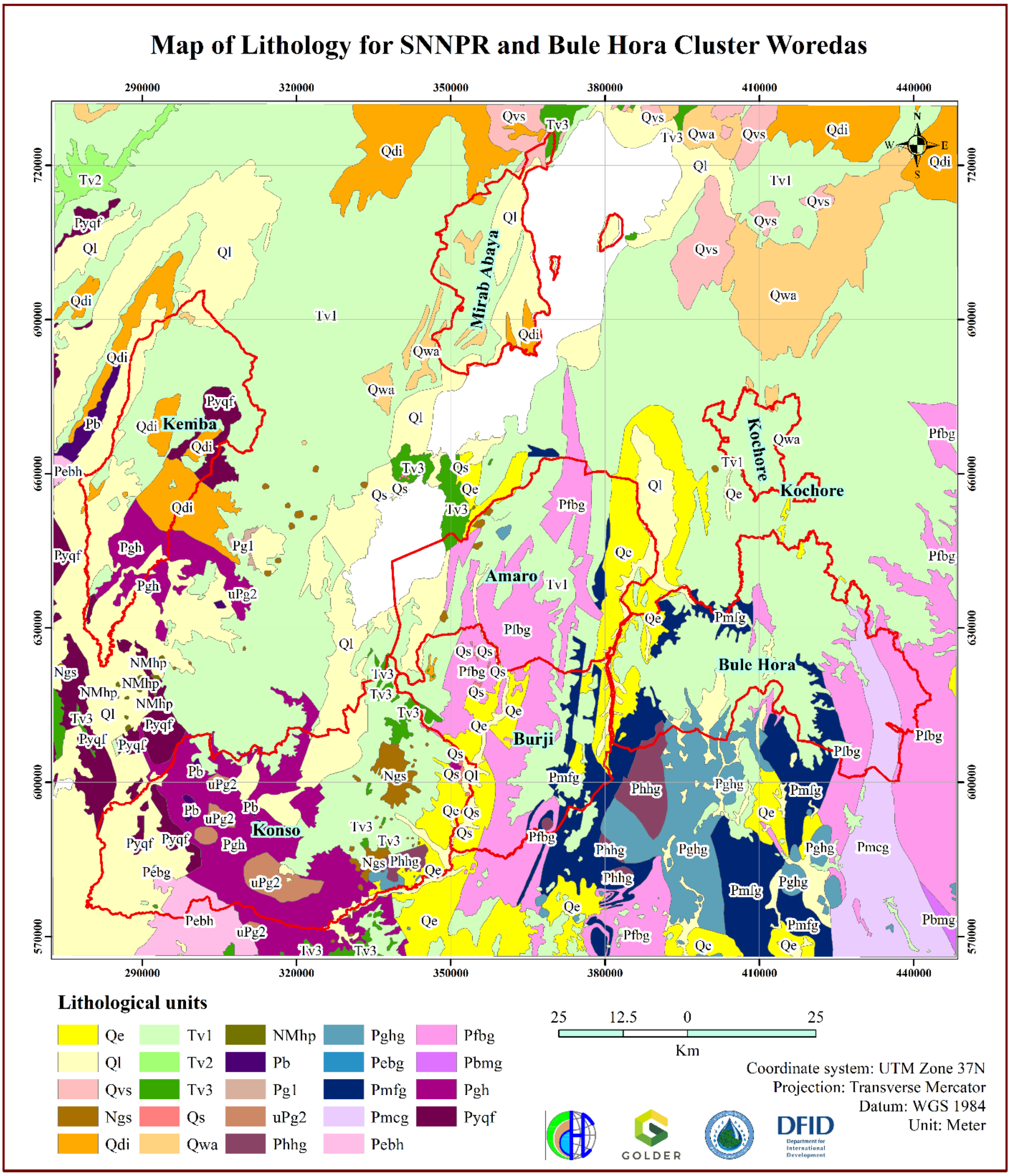


Figure 4.2. Map of lithology for SNNP and Bule Hora cluster Woredas in synoptic view

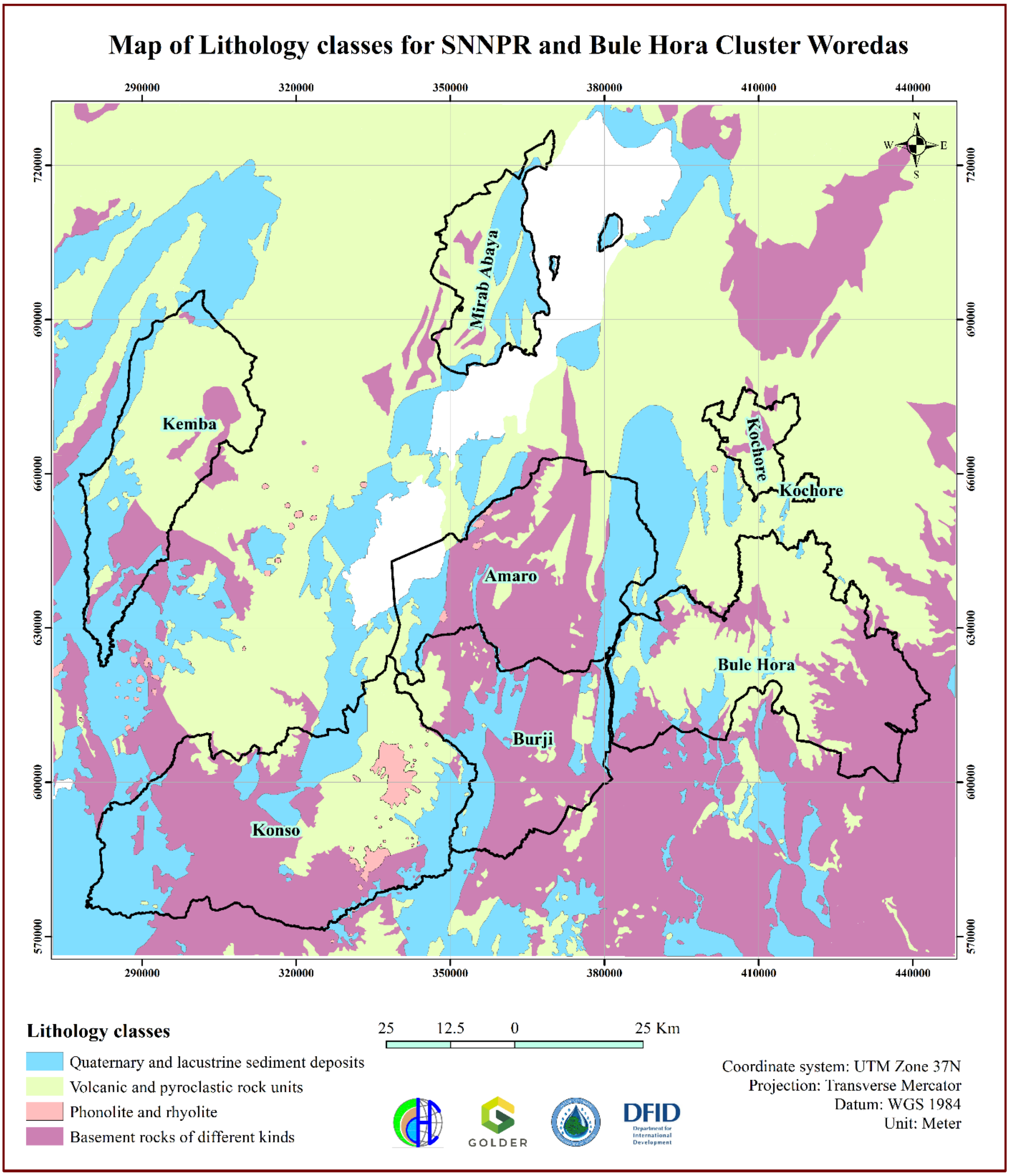


Figure 4.3. Map of lithology class for SNNP and Bule Hora cluster Woredas in synoptic view

Table 4-1. Description of lithology classes within synoptic view

Lithology class	Groundwater prospect	Area in Km^2	Area in %
Phonolite and rhyolite	Very poor	130.219	0.460
Basement rocks of different kinds	Poor	8372.198	29.552
Basic volcanic and pyroclastic rock units	Good	13907.785	49.091
Quaternary volcanics and lacustrine sediment deposits	Very good	5920.521	20.898

4.3.2. Geological structures/Lineaments

The primary aim of the structural study is to provide lithological, structural, tectonics and physiographic understanding of the area as a basis for hydrogeological and related studies on the groundwater potential of the target areas.

A lineament is a linear feature in a landscape which is an expression of an underlying geological structure such as a fault. Lineaments are often apparent in geological or topographic maps and can appear obvious on aerial or satellite photographs. Lineaments are manually extracted with great care from DEM (https://earthexplorer.usgs.gov/), Satellite images (Sentinel 2 from https://scihub.copernicus.eu/) and exisiting geological maps of the area.

The study area is highly affected by lineaments and/or fractures consequent to rift related tectonic activities in the past. Lineaments and faults are aligned in the general trend of the Main Ethiopian Rift in NE-SW general direction (refer the Rose plot on lineament map). Usually, lineaments are presented in the form of lineament density. Lineament density map is a measure of quantitative length of linear feature per unit area which can indirectly reveal the groundwater potentials as the presence of lineaments usually denotes a permeable zone.

For the synoptic area, the lineament density varies from less than 0.06 km/Km2 to 0.74 km/Km2 (Figure 4.5). Though the lineaments are widespread across the study area, however, the distribution of lineaments suggests structural control with areas underlain by volcanic rocks. Thus, areas with higher lineament density are regarded as having good contribution for groundwater recharge and storage.

Structures shown on the synoptic area map in different orientation and the major orientation of the fault within the area have NNE-SSSW, general orientation assuming rift forming fault orientation.

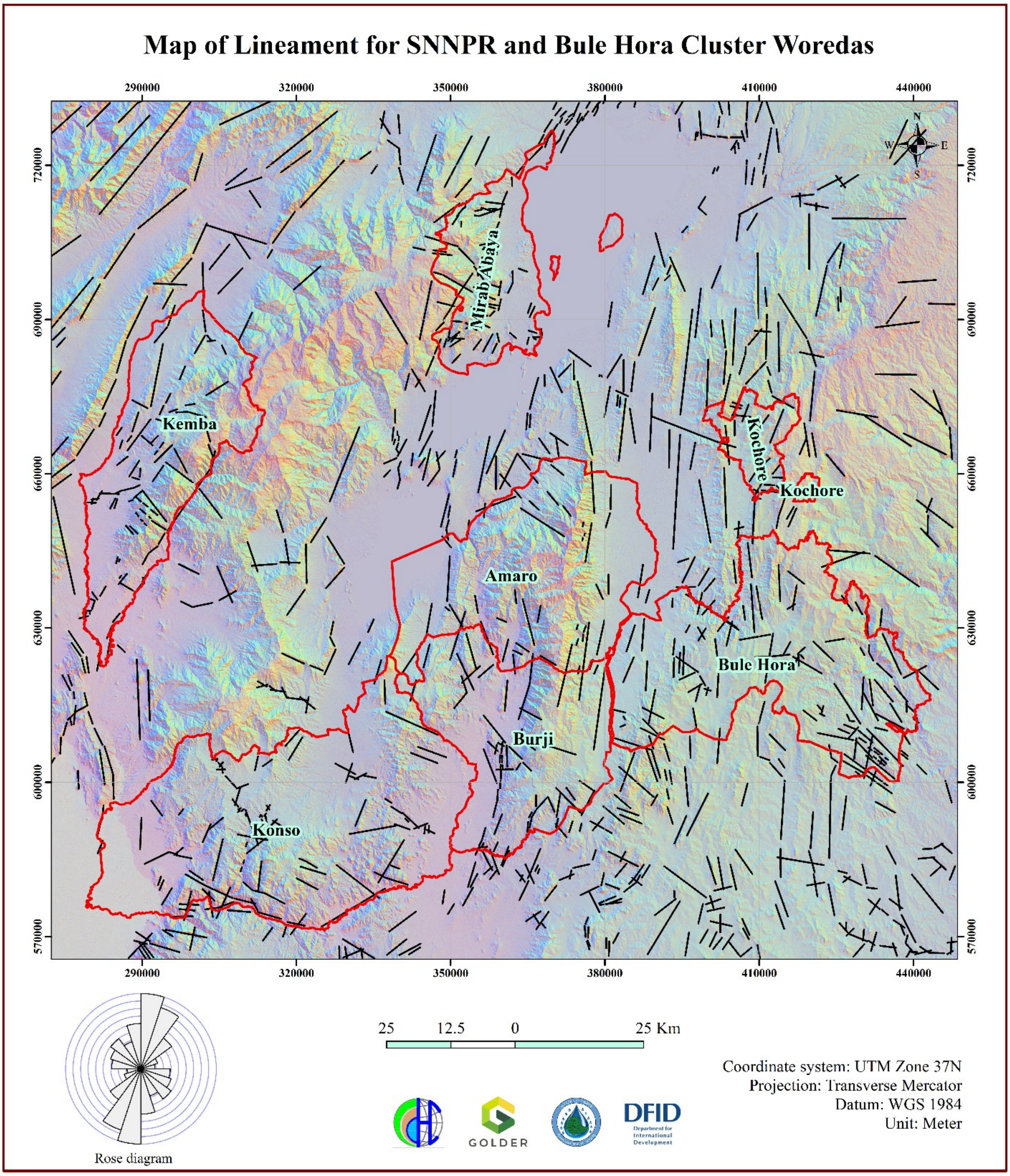


Figure 4.4. Map of lineaments for SNNP and Bule Hora cluster Woredas together with rose diagram (rose plot) of lineament directions within a synoptic boundary.

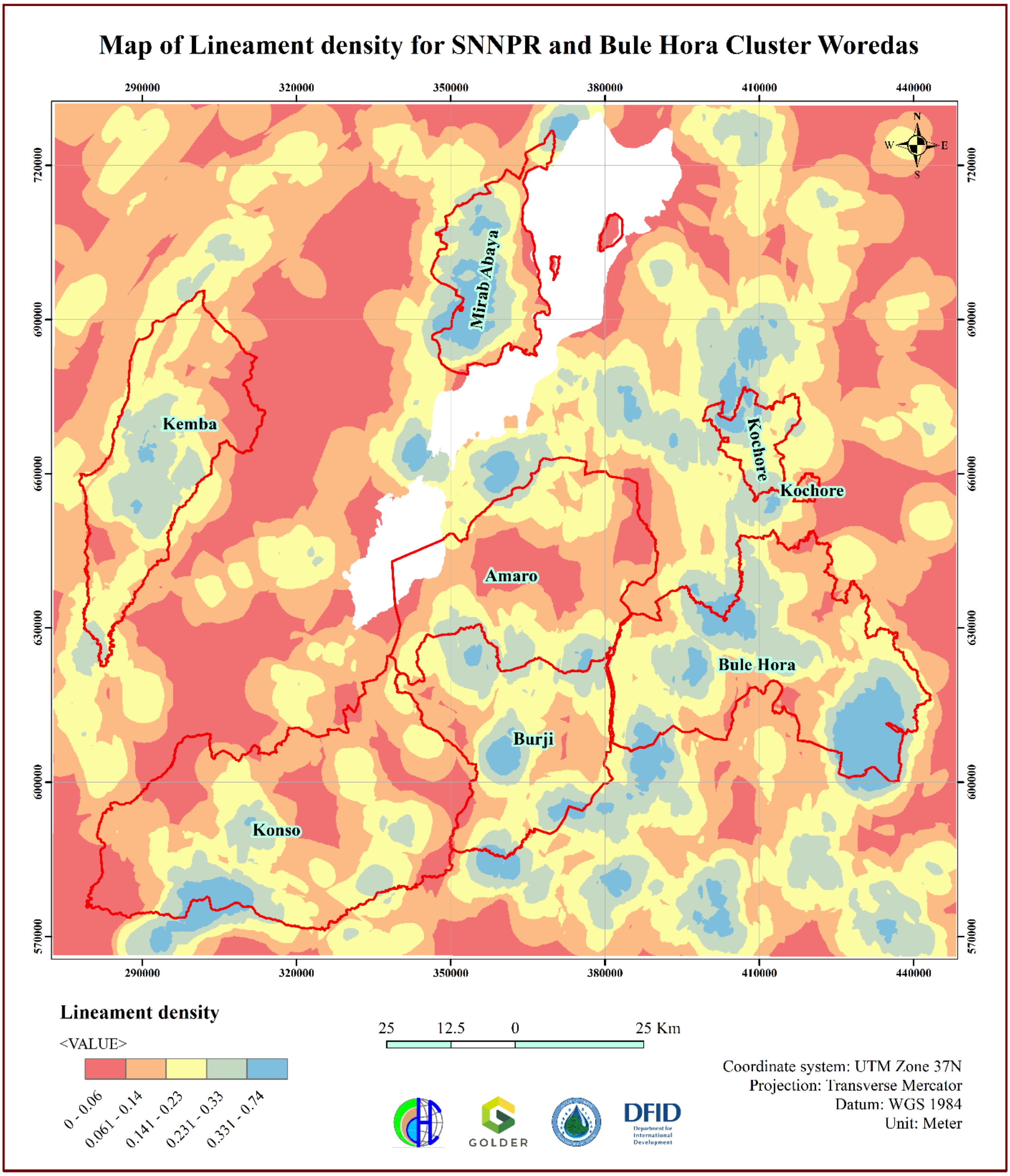


Figure 4.5. Map of lineament desnity for SNNP and Bule Hora cluster Woredas within synoptic view

Table 4-2. *Description of lineament density classes within synoptic view*

Lineament class	Importance for the groundwater occurrence
0 – 0.06	Very low
0.061 – 0.14	Low
0.141 – 0.23	Moderate
0.231 – 0.33	High
0.331 – 0.74	Very high

4.3.3. Recharge

Climate and hydrological data are essential elements in the assessment of surface water resources, groundwater resource mapping and any water resources development study. In this regard this study encompassed the investigation of the groundwater recharge that presumed to mapping the groundwater resource for the woredas. In respect to the water resources study, the major hydrological parameters are rainfall and river discharge. Groundwater recharge has been estimated using annual rainfall and infiltration coefficient of each geological unit. The average annual (2011 - 2020) rainfall data of Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) were obtained from the Climate Hazards Center (CHC) of University of California (https://chc.ucsb.edu). The infiltration coefficients of geological units were obtained from Abay River Basin Integrated Resources Development Master Plan Study report (MoWR, 1999). According to the master plan study, the IC of various lithological units could be assigned based on the results obtained from recharge estimations made using an integrated approaches including base flow separation and estimation of proportion of annual rainfall amount that to be percolated to the subsurface based on correlation made between each lithological unit identified within the basin using a developed mathematical equation. Therefore, for the current study, the IC values were extracted from the basin study that have similar properties of lithological units found in the current study area and accordingly assigned to each lithological unit (Table 4.3). Then, the geological map converted to raster based on the assigned value of IC with cell size of 100m on ArcGIS platform. Finally, the raster maps of rainfall and IC of lithological units were multiplied using a raster calculation algorithm in ArcGIS in order to obtain spatial map of 10 years average annual recharge amount for the area in a synoptic view (Figure 4.7).

Table 4-3. Assigned infiltration coefficient for lithological units (SNNP & Bule Hora) correlated with Abay River Basin Integrated Master Plan (MoWR, 1998).

SNNP & Bule Hora Cluster Woredas (study area)		Assigned IC	Abay River Basin Integrated Master Plan	
Symbol	**Lithology description**		**Symbol**	**Lithology description**
Qe	Eluvium, silts, sands, gravel	0.05	Qel	Eluvial sediments/soil: reddish brown silty to sandy soil containing rock fragments
Ql	Quaternary and lacustrine sediment deposits: silts, clays, diatomite's, volcano clastic sediments and tuffs	0.15	Ql	Lacustrine sediments: silts, clays, diatomite, with minor volcanoclastic sediments and tuffs
Qvs	Volcano sedimentary rocks, lacustrine, predominantly volcano sediments tuffs	0.15	»	»
Ngs	Sharenga rhyolite: rhyolite and quartz latite plugs and flows	0.1	Tvc4	Choke rhyolite; K-feldspar, plagioclase and quartz phenocrysts containing rhyolite; exposed at the top of the Choke mountain, near the peak
Qdi	Pyroclastic flows: Ignimbrites, tuffs, water laying pyroclastic, occasional lacustrine beds	0.1	Qdi	Upper Dino Formation: ignimbrites, tuffs, water lain pyroclastics (surges), occasional lacustrine beds
Tv1	Lower basalt flows: stratified basalt flows with rare basaltic pyroclastic and rhyolite	0.1	Tv1	Lower Basalt: extensively layered, grey to dark grey, slightly to moderately weathered, aphyric and porphyritic basalt with lesser vesicular basalt, minor alkali trachyte

SNNP & Bule Hora Cluster Woredas (study area)		Assigned IC	Abay River Basin Integrated Master Plan	
Symbol	**Lithology description**		**Symbol**	**Lithology description**
				flows and pyroclastic deposits (tuffs) at the top, and alkali syenite intrusions
Tv2	Tertiary middle basalt	0.15	Tv2	Middle Basalt: stratified, compact, hard, massive ankaramite and lesser olivine-phyric basalt; at places laterally grading to basaltic pyroclastic; unconformably laying over the lower Basalt
Tv3	Upper basalt: porphyritic basalt	0.15	Tv3	Upper Basalt: dark grey, often columnar jointed aphyric basalt, with local intercalation of basaltic pyroclastic, vesicular basalt and scoriaceous basalt; often forming the plateau surface
Qs	Basaltic lava cones	0.1	Qb3	Young, fresh aphyric basalts
Qwa	Rhyolitic and trachytic lava flows and plugs	0.1	Tty	Trachyte flows and plugs: whitish, greenish and pinkish grey, fine-grained, containing phenocrysts of plagioclase and alkali feldspars; unevenly distributed rhyolite domes, and broad-based gentle sloping circular to elliptical hills, composed of alkali feldspars, mica and quartz.
NMhp	Hypabyssal phonolite	0.1	»	»
Pb	Gabbro	0.03	Pgb	Metagabbro: late to post tectonic, weakly to moderately foliated, leuco to melanocratic, medium to coarse grained, consisting of amphibole, pyroxene and plagioclase; forms high ridges and small hills
Pgl	Pre-tectonic or syntectonic granite and pegmatite	0.03	Pgt1	Syntectonic granite: weakly foliated granite
uPg2	Post-tectonic granite, granodiorite, minor syenite	0.03	Pgt2	Late to post-tectonic granite
Phhg	Hypersthene hornblende granite	0.03	»	»
Pghg	Gneissose hornblende-biotite meta-granite	0.03	»	»
Pebg	Metasedimentary gneiss; layer biotite-quartz-feldspar gneiss, locally with muscovite, grant, sillimanite; minor interlayered amphibolitic, quartzose, pyritic, graphitic and calc-silicate gneiss, and marble	0.03	Pbgn	Biotite gneiss: dark grey, medium to coarse-grained, banded and migmatized
Pmcg	Augen biotite-quartz-feldspar gneiss, strongly granitized	0.03	»	»
Pmfg	Magnetite-quartz-feldspar gneiss	0.03	»	»
Pfbg	Oligoclase-hornblende-biotite-quartz gneiss, calc-silicate, biotite and biotite-hornblende gneisses	0.03	»	»
Pbmg	Biotite-microcline-quartz gneiss, medium grained amphibolite garnet-staurolite gneiss, graphitic shist and marble	0.03	»	»
Pgh	Granulite facies including gneiss, amphibolite's and two pyroxene granulite	0.03	»	»
Pebh	Undivided gneiss; includes predominantly biotite and hornblende gneiss, migmatitic in part, with minor metasedimentary gneiss, quartzo-felspathic gneiss, amphibolite and granitoid orthogneiss	0.03	Pmggn	Undifferentiated gneisses: containing biotite gneiss, quartzofeldspathic gneiss, biotite- amphibole gneiss, migmatites, and lenses of dolomitic marble and meta-ultramafic
Pyqf	Granulite facies: includes characteristics magnetite-quartz-feldspar granulite	0.03		

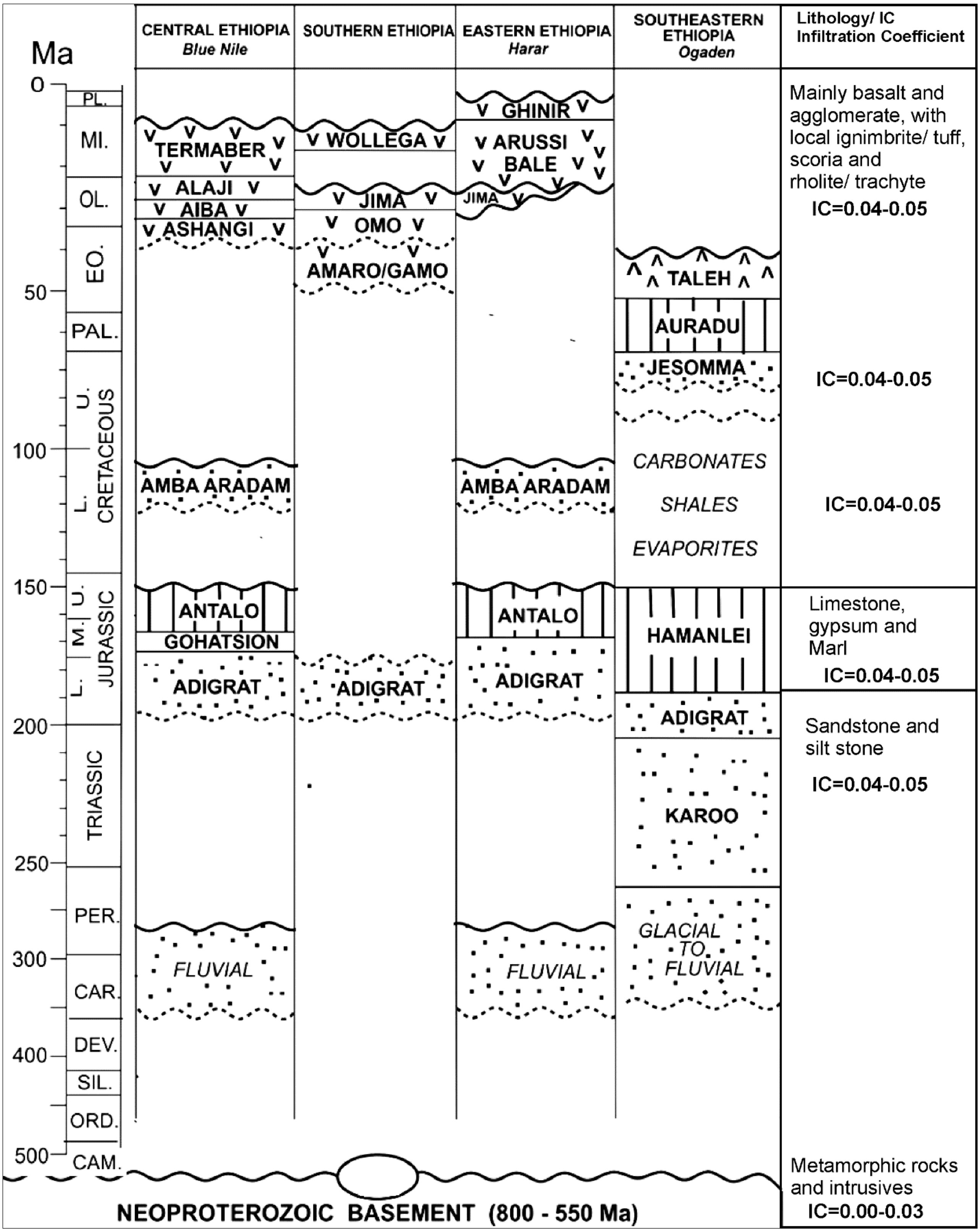


Figure 4.6. *Correlation of geological formation of the study area with Abay basin*

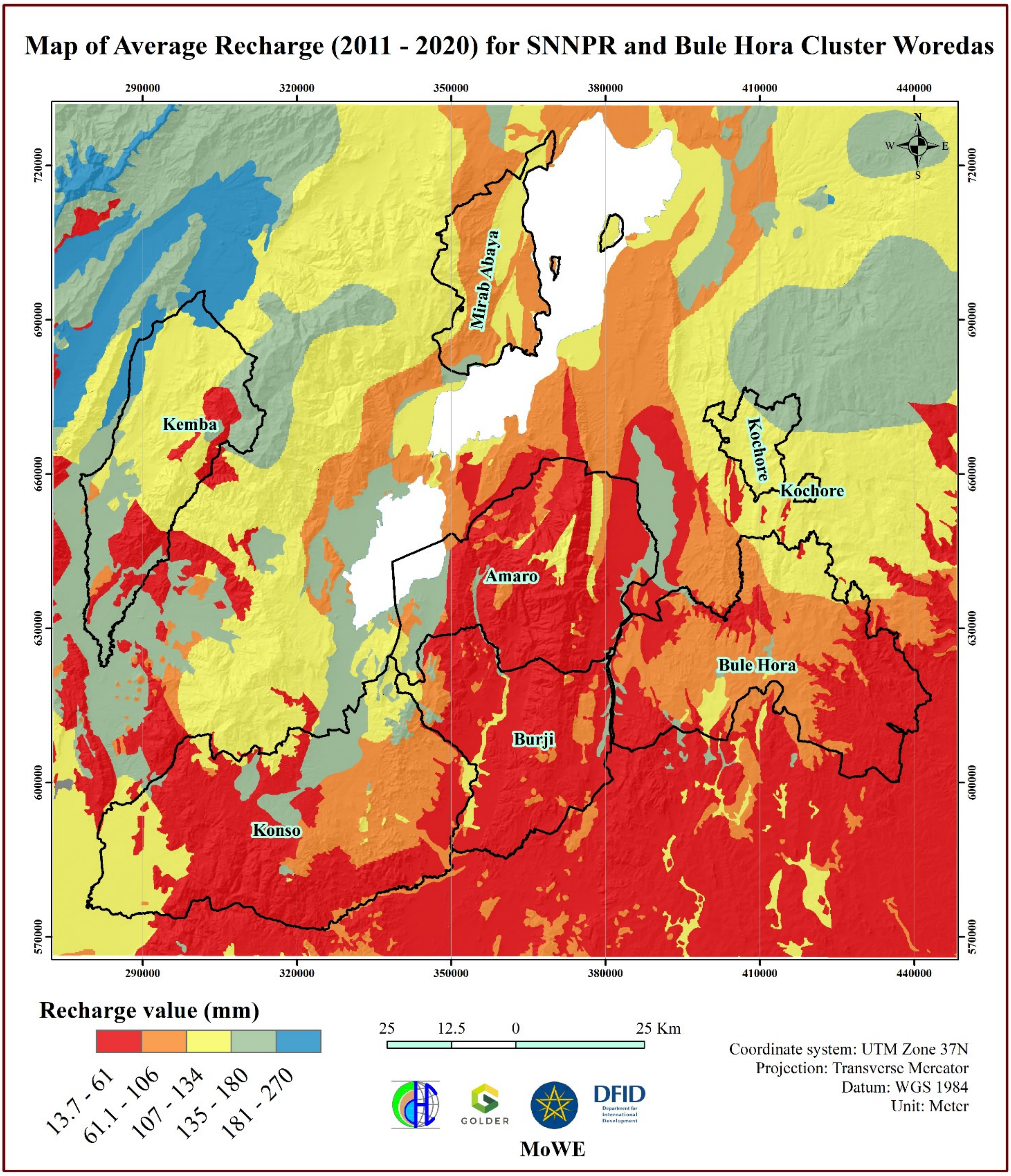


Figure 4.7. Map of average recharge from 2011 to 2020 for SNNP and Bule Hora cluster Woredas.

Table 4-4: *Description of recharge classes in synoptic view for SNNP & Bule Hora Woredas*

Recharge class	Importance for the groundwater occurrence
13.61 – 61	Very low
61.1 – 106	Low
107 – 134	Moderate
135 – 180	High
181 – 270	Very high

4.3.4. Topographic Wetness Index (TWI)

The Topographic wetness index, also known as the compound topographic index, is commonly used to quantify topographic control on hydrological processes. The index is a function of both the slope and the upstream contributing area per unit width orthogonal to the flow direction. The topographic wetness index (TWI) is a useful model to estimate where water will accumulate in an area with elevation differences (Sorensen, R; Zinko, U.; Seibert, J. (2006). Topographic wetness is a unitless quantity and it is represented by index with relative physical property. The topographic wetness index as a layer plays a significant role in line with other selected layers to delineate groundwater potential areas based on priority/ranking and weightage as per the layers' relative importance for groundwater enhancement potentiality.

Table 4-5. *Description of topographic wetness index (TWI) classes within synoptic view*

TWI class	Importance for the groundwater occurrence
4.22 – 7.14	Very low
7.14 – 8.92	Low
8.92 – 11.26	Moderate
11.26 – 14.82	High
14.82 – 24.84	Very high

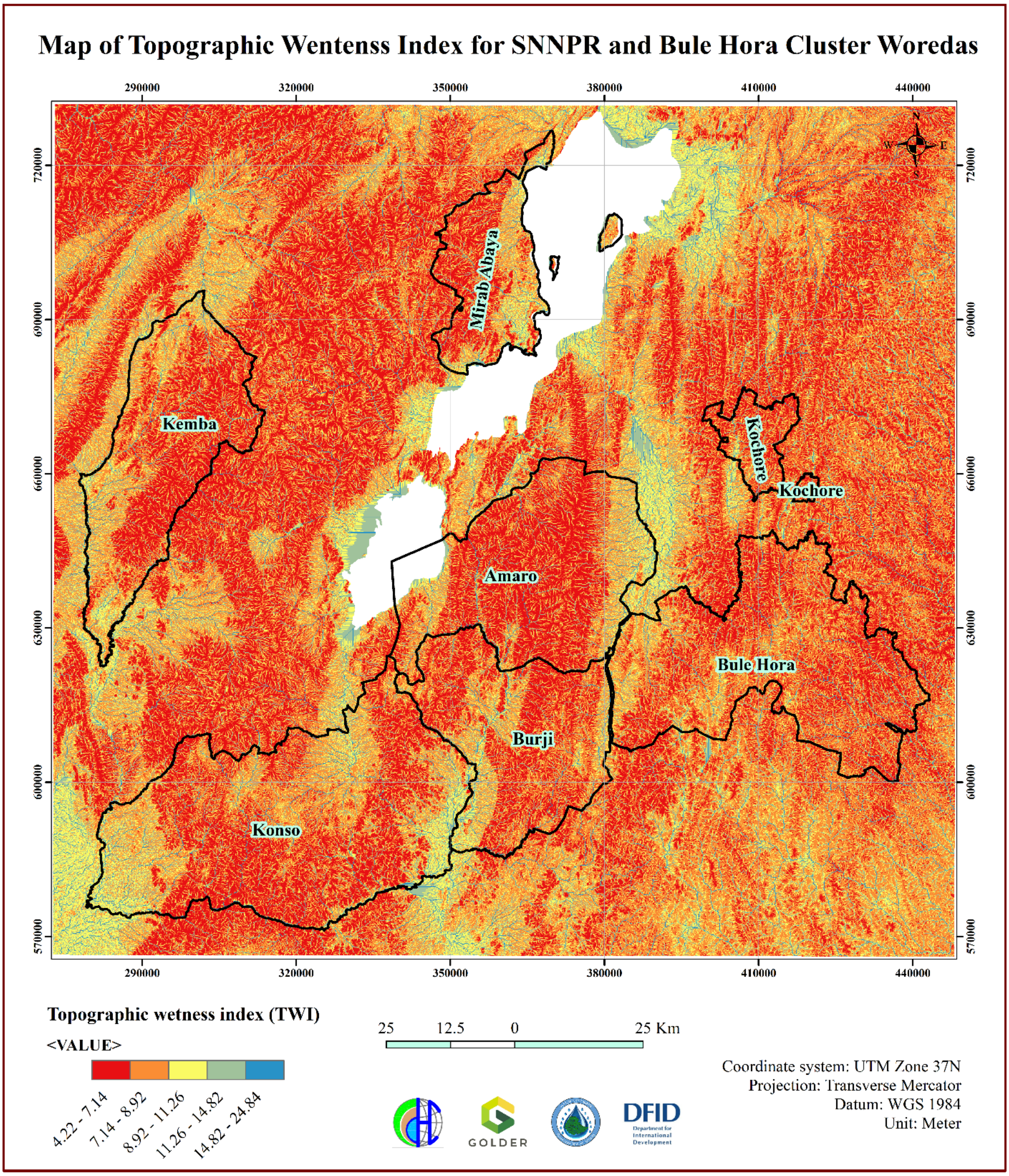


Figure 4.8: Map of topographic wetness index (TWI) for SNNP and Bule Hora cluster Woredas in synoptic view

4.3.5. Analytical Hierarchy Process (AHP) and Weights Assignments

The analytic hierarchy approach (AHP) developed by Saaty (1980, 1986, 1992) was used in this study as a decision aiding method to finalize the weights assigned to different themes and their respective features used in deciphering groundwater potentiality. AHP is a simple mathematical matrix-based technique that allows users to assess the relative weight of multiple criteria in an intuitive manner. It allows efficient group decision-making, where group members can use their experience, values and knowledge to breakdown a problem into a hierarchy and solve it by AHP steps (Chowdhury et al. 2009). It also incorporates systematic checks on the consistency of judgments, which is one of the strongest points over the other multi-attribute value processes.

The weightage employed is in accordance with the respective importance of the map theme to groundwater occurrence following the approach of Saraf and Choudhary (1998), Rao and Jugran (2003), Prasad et al. (2008), Jha et al. (2010), Machiwal et al. (2011), Mukherjee et al. (2012) and Singh et al. (2013). The weights of the individual themes and their associated features were then normalized by the Saaty's AHP was used to reduce the subjectivity associated with the assigned weights (Table 4.8). The Consistency Index (CI) of the assigned weights was calculated following the procedure suggested by Saaty (1980, 1992) while the Consistency Ratio, which indicates the probability that the matrix ratings were randomly generated, was also computed using the values of Random Consistency Index (RI) which is the average value of CI for random matrices using the Saaty scale obtained by Forman (1983, 1990) based on the following relations:

Consistency Index = $(\lambda_{max} - n)/(n-1)$.

Consistency Ratio =CI/RI

Where n is the number of criteria or factors

It should be noted that the CR value should be less than 0.10 for consistent weights; otherwise, corresponding weights should be re-evaluated to avoid inconsistency (Saaty 1980, 1986, 1992). For this study, the CR was estimated to be 0.04 which is far below the threshold consistency value of 0.10.

Suitable weights were assigned to the four themes and their individual features after understanding their hydrogeological importance in causing groundwater occurrence in the synoptic area. The normalized weights of the individual themes and their different features were obtained through the Saaty's analytical hierarchy process (AHP). Furthermore, each of the thematic maps was then assigned weight in the range of 1–9 according to Saaty's scale of assignment (Table 4.6), which depicts the relative importance of the respective themes to groundwater availability. The weights assigned to the respective thematic maps as presented in Table 4.8 indicate that geology was ranked the dominant factor with a normalized weight value of 0.46 while recharge is the least accounted factor with a normalized weight of 0.05 for groundwater occurrence in the study target woredas.

After deriving the normal weights of all the thematic layers and feature under individual themes, all the thematic layers were integrated with one another using ArcGIS software in order to demarcate groundwater potential zones index (GWPZI) in the target woreda. The index was computed by the integration of the total normalized weights of different polygons using equation stated below. This technique is associated with the study of locations of geographic phenomena together with their spatial dimension and associated attributes (Prasad et al., 2008).

GWPZI = (GGwGGwi + LDwLDwi + TWIwTWIwi + GRwGRwi)

Where, GG is the geology, LD is lineament density, TWI is topographic wetness index, GR is Recharge, w is normalized weight of a theme and TWI is the normalized weight of individual classes.

Thus, using raster calculator tools in ArcGIS 10.8 platform, a composite groundwater potential index (GWPI) for the study area was generated based on which the overall groundwater potential zones map was produced. In the final integrated layer was divided into four equal classes, i.e., 'very high', 'high', 'moderate' and 'low or poor', to delineate groundwater potential zones (chapter five). Finally, well/ borehole data (e.g., yield) was collated from existing wells in the study area. This data was used for the purpose of validation of the proposed groundwater potential map, as a useful guide for a quick assessment of groundwater occurrence on regional scale in the study area.

Table 4-6. Explanation of intensity scales for weight assignment and its interpretation showing the pair-wise comparison process (Saaty 1980, 1986, 1992).

Intensity	**Definition**	**Explanation**
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, it dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2,4,6,8 can be used to express intermediate values		

Table 4-7. Pair-wise comparision of the four thematic layers for groundwater potential mapping based on a new AHP template (Goepel, 2013)

Criteria		More important?	Scale
A	**B**	**A or B**	**(1-9)**
Lithology	Lineament density	A	2
	Recharge	A	5
	TWI	A	1
Lineament density	Recharge	A	3
	TWI	B	1
Recharge	TWI	B	3

Table 4-8. Normalized weights and pair-wise comparison matrix of the four thematic layers in the SNNP and Bule Hora cluster woredas for groundwater potential mapping

Theme	**Theme**				**Normalized weight**
	GG	LD	GR	TWI	
GG	1	2	16	1	0.46
LD	1/2	1	4	1	0.21
GR	0	1/4	1	1/4	0.05
TWI	1	1	4	1	0.27

4.3. Gambella Synoptic Area

4.3.1. Geology

The geological map of the Synoptic area has been obtained from Ethiopian Geological Survey Agency (EGSA) with scale 1:250,000. This geological map has been modified using sentinel 2 multispectral image and compiled by georeferencing, digitized, and harmonized/standardized in ArcGIS 10.8 software platform within a synoptic rectangular boundary buffering the respective woreda area with 10 km radius so that to have a better view and understanding the overall settings of the study area (Figure 4.10)

The general framework of the mapped area can be divided in to four groups. These are the Quaternary alluvial deposits which covers wide areas of Synoptic area and its north adjacent region, eluvial soils covers the northwest part of the cluster woreda and southeast adjacent regions, Tertiary volcanics located at far northeast of the cluster woreda, and The Precambrian basement located at far southeast of the study area.

The Quaternary alluvial deposits which cover the wide central areas and the eluvial soils in southeast and northwest margin are major lithologic units in the cluster woreda (Figure 4.10).

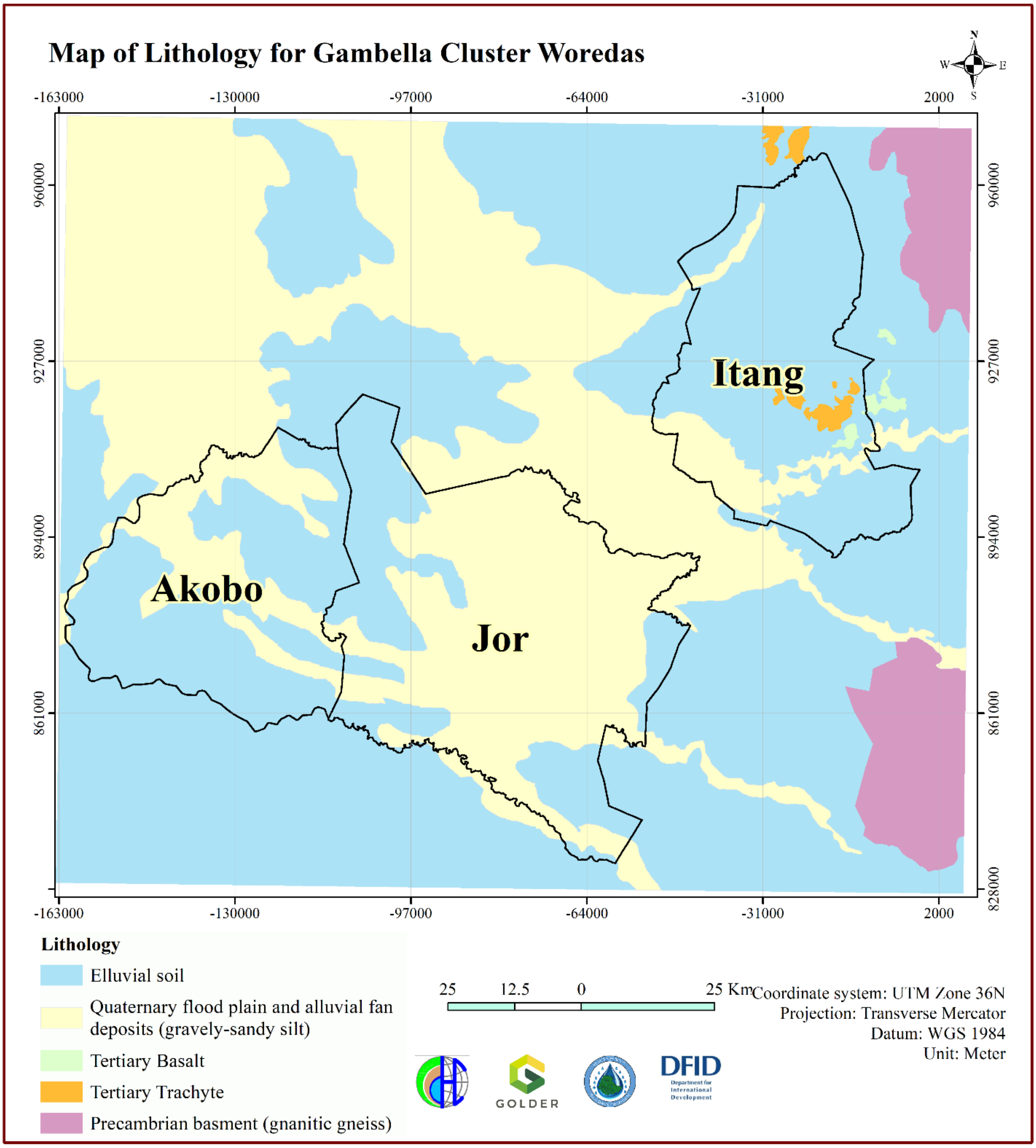


Figure 4.9. Map of lithology for Gambella cluster Woredas in synoptic view

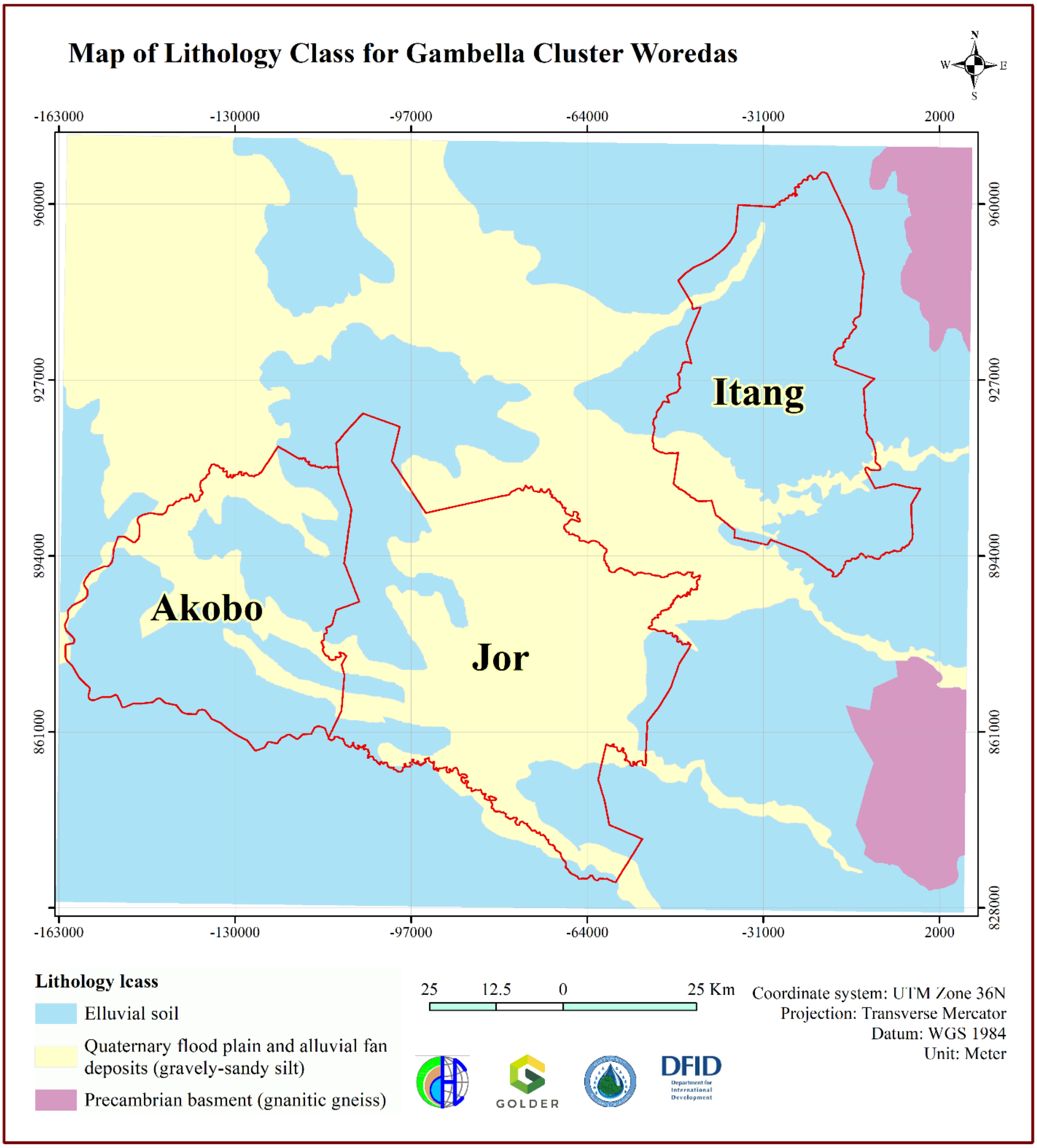


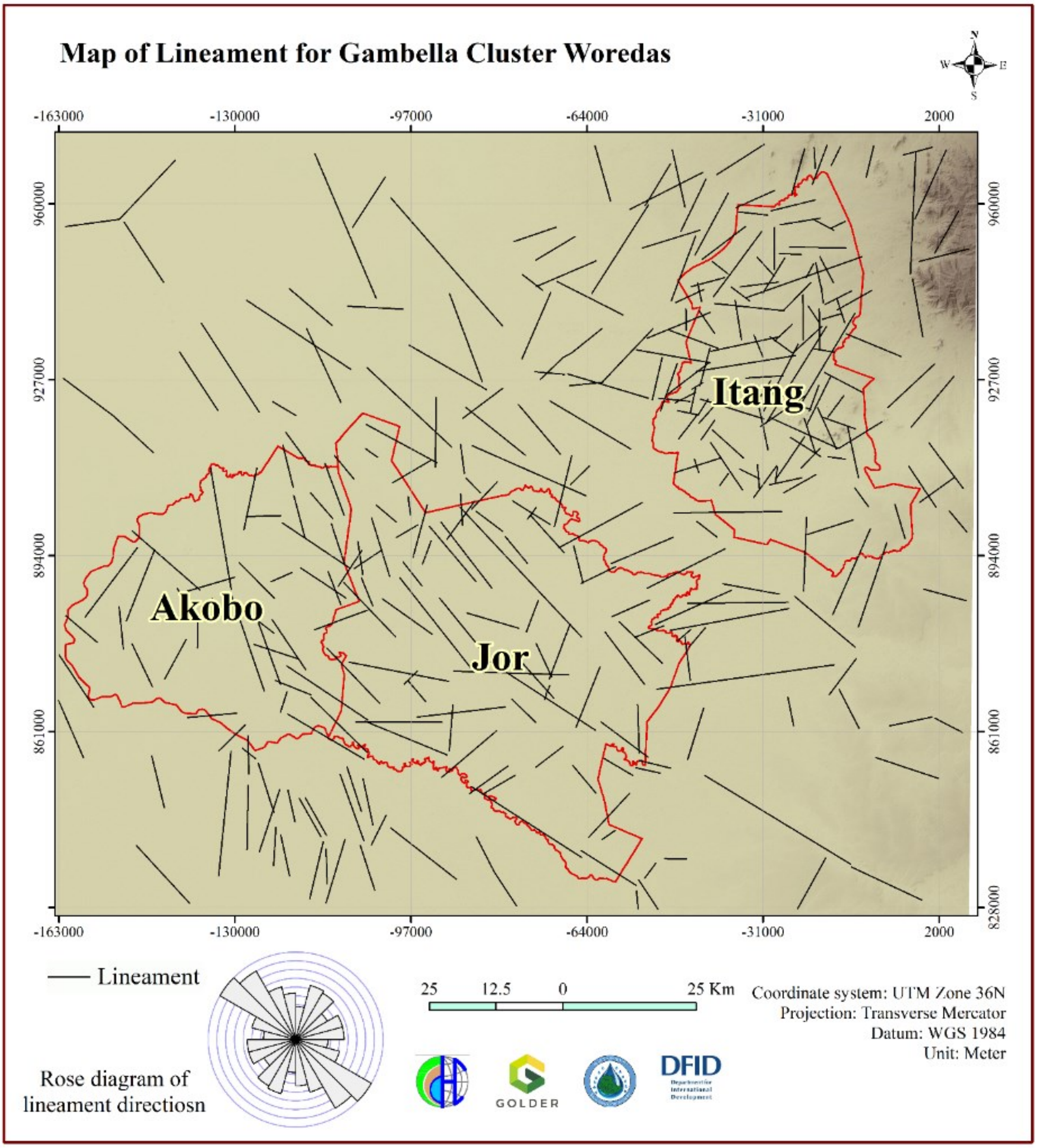
Figure 4.10: Map of lithology class for Gambella cluster Woredas in synoptic view

4.3.2. Geological structures/Lineaments

Lineaments are manifestation of linear features that can be identified directly on the rock units or from remote sensing data. Lineaments and their intersections play a significant role in the occurrence and movement of groundwater. The presence of lineaments may act as a conduit for groundwater movement which results in increased secondary porosity and, therefore, can serve as groundwater potential zone (Rao, 2006; Prasad et al., 2008). Accordingly, detailed lineaments of the study area were extracted from a mosaicked Cloud Free Images Sentinel-2 selected from the year 2020 to 2021 series combined with geomorphology of the area and mapped using ArcGIS 10.8 software, and subsequently lineament density map was computed in using GIS algorithm and expressed in terms of length of the lineament per unit area (km/Km2).

Some bedding-like structures are developed in the recent alluvial deposits, which are a primary structure noted in alluvial formation layers. These structures are produced based on the horizontal depositions of the layer by sedimentation compactions of transgressed materials (GSE, 2018).

The lineament density varies from less than 0.15 km/Km2 to 0.63 km/Km2 with the central, southwest, and central north have relatively high lineament density (Figure 4.11, bottom). Though the lineaments are widespread across the study area, however, the distribution of lineaments suggests geologic control with areas covered by Quaternary sediment in central area have higher lineament density of 0.33 – 0.63km/Km2) which is good for groundwater development. Consequently, higher weightage of 0.43 was assigned to area with high density of lineaments, while a low weightage of 0.12 was assigned to areas with low lineament density.


Map of Lineament for Gambella Cluster Woredas
N
W
E
S
-163000
-130000
-97000
-64000
-31000
2000
960000
927000
894000
861000
828000
Itang
Akobo
Jor
Lineament
Rose diagram of
lineament directiosn
25
12.5
0
25 Km
Coordinate system: UTM Zone 36N
Projection: Transverse Mercator
Datum: WGS 1984
Unit: Meter
GOLDER
DFID

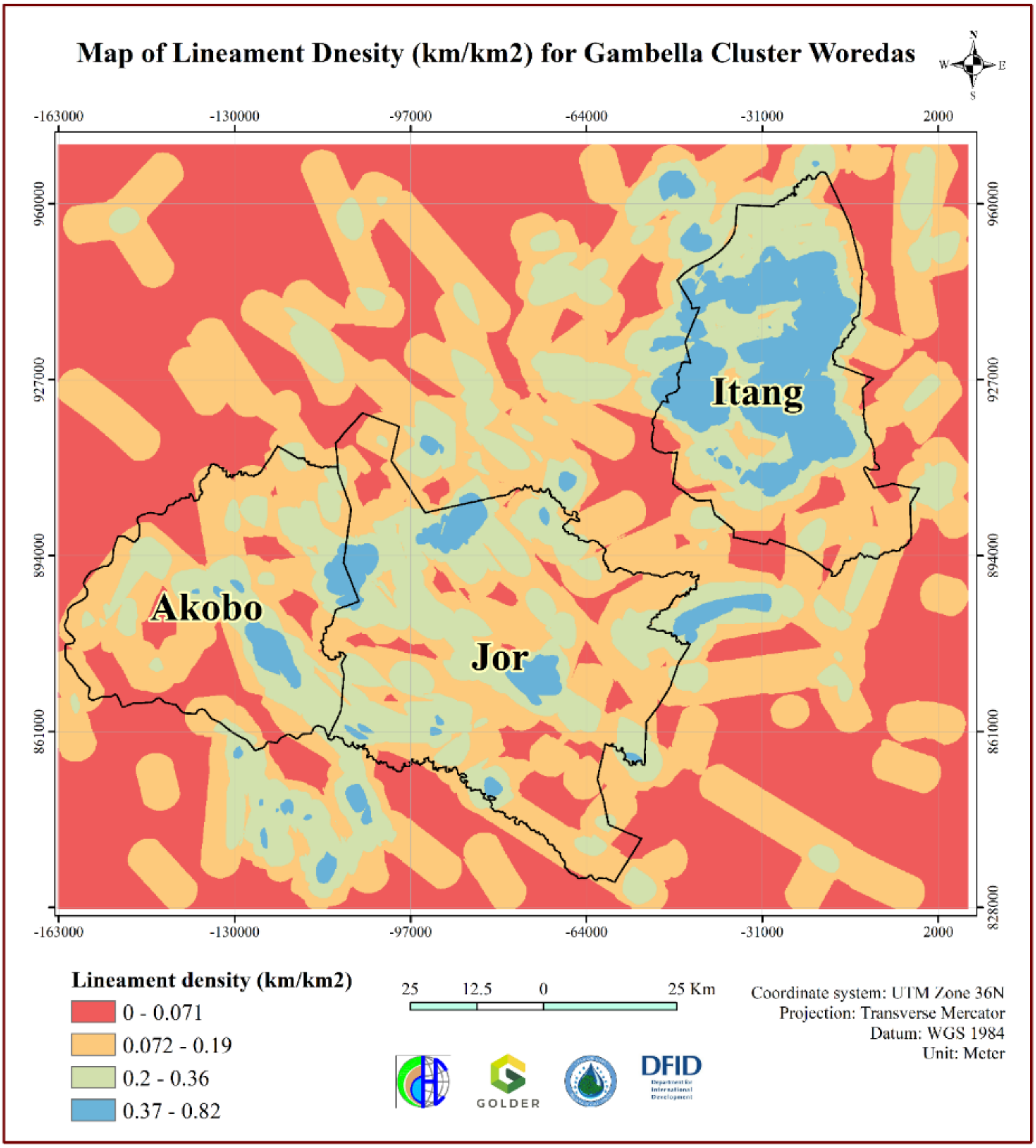


Figure 4.11. Map of lineaments (top) and lineament density (bottom) for Gambella cluster Woredas in synoptic view

4.3.3. Recharge

Climate and hydrological data are essential elements in the assessment of surface water resources, groundwater resource mapping and any water resources development study. In this regard this study encompassed the investigation of the groundwater recharge that presumed to mapping the groundwater resource for the woredas. In respect to the water resources study, the major hydrological parameters are rainfall and river discharge. Groundwater recharge has been estimated using annual rainfall and infiltration coefficient of each geological unit. The average annual (2011 - 2020) rainfall data of Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) were obtained from the Climate Hazards Center (CHC) of University of California (https://chc.ucsb.edu). The infiltration coefficients of geological units were obtained from Abay River Basin Integrated Resources Development Master Plan Study report (MoWR, 1999). According to the master plan study, the IC of various lithological units could be assigned based on the results obtained from recharge estimations made using an integrated approaches including base flow separation and estimation of proportion of annual rainfall amount that to be percolated to the subsurface based on correlation made between each lithological unit identified within the basin using a developed mathematical equation. Therefore, for the current study, the IC values were extracted from the basin study that have similar properties of lithological units found in the current study area and accordingly assigned to each lithological unit (Table 4-9). The infiltration coefficient of geological units was obtained from Abay River Basin Integrated Resources Development Master Plan Study report (MoWR, 2007). According to the master plan study, the IC of various lithological units could be developed based on the results obtained from recharge estimations made using an integrated approach that considered an important parameter and correlating with different lithological units identified within the basin. Therefore, for the current study, the IC values were extracted from the basin study that have similar properties of lithological units found in the current study area and accordingly assigned to each lithological unit. Then, the geological map converted to raster based on the assigned value of IC with cell size of 100m on ArcGIS platform. Finally, the raster maps of rainfall and IC of lithological units were multiplied using a raster calculation algorithm in ArcGIS to obtain spatial map of 10 years average annual recharge amount for the project area.

Table 4-9. Assigned infiltration coefficient for lithological units (Gambela) correlated with Abay River Basin Integrated Master Plan (MoWR, 1998).

Gembella Cluster Woredas (study area)		Assigned IC	Abay River Basin Integrated Master Plan	
Symbol	**Lithology description**		**Symbol**	**Lithology description**
Qe	Eluvial soil	0.15	Qel	Eluvial sediments/soil: reddish brown silty to sandy soil containing rock fragments
Qa	Quaternary flood plain and alluvial fan deposits (gravely-sandy silt)	0.2	Qal	Alluvial deposit: black to dark brown and greyish white soil; marsh to boggy clay-silt deposit
Tr	Tertiary trachyte	0.1	Tty	Trachyte flows and plugs: whitish, greenish and pinkish grey, fine-grained, containing phenocrysts of plagioclase and alkali feldspars; unevenly distributed rhyolite domes, and broad-based gentle sloping circular to elliptical hills, composed of alkali feldspars, mica and quartz.
Tb	Tertiary basalt	0.1	Qb3	Young, fresh aphyric basalts
Pb	Precambrian basement (granitic gneiss)	0.03	Ptgn	Granite gneiss: show compositional banding but at places massive, and is medium to coarse grained.

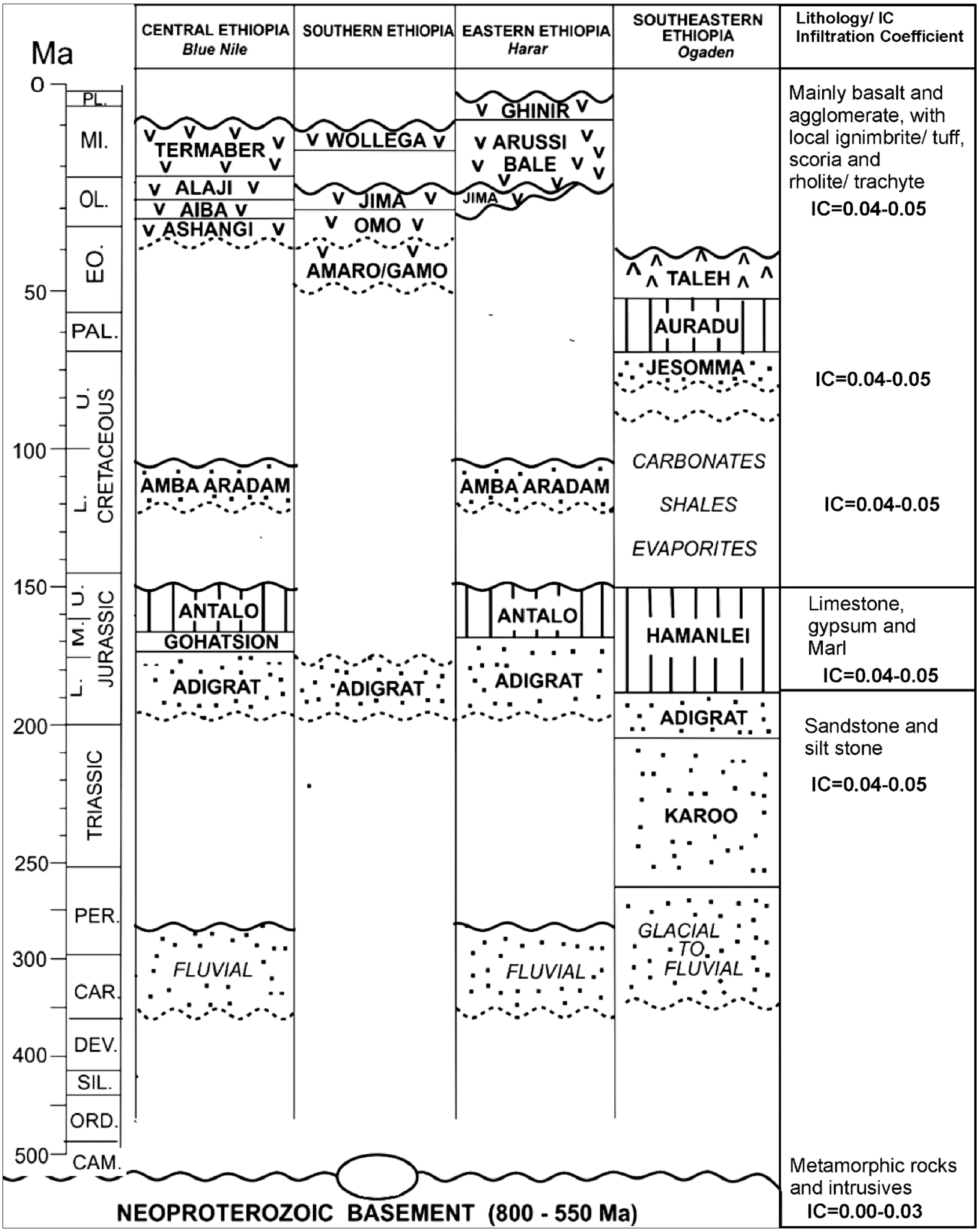


Figure 4.12. Correlation of geological formation of the study area with Abay basin

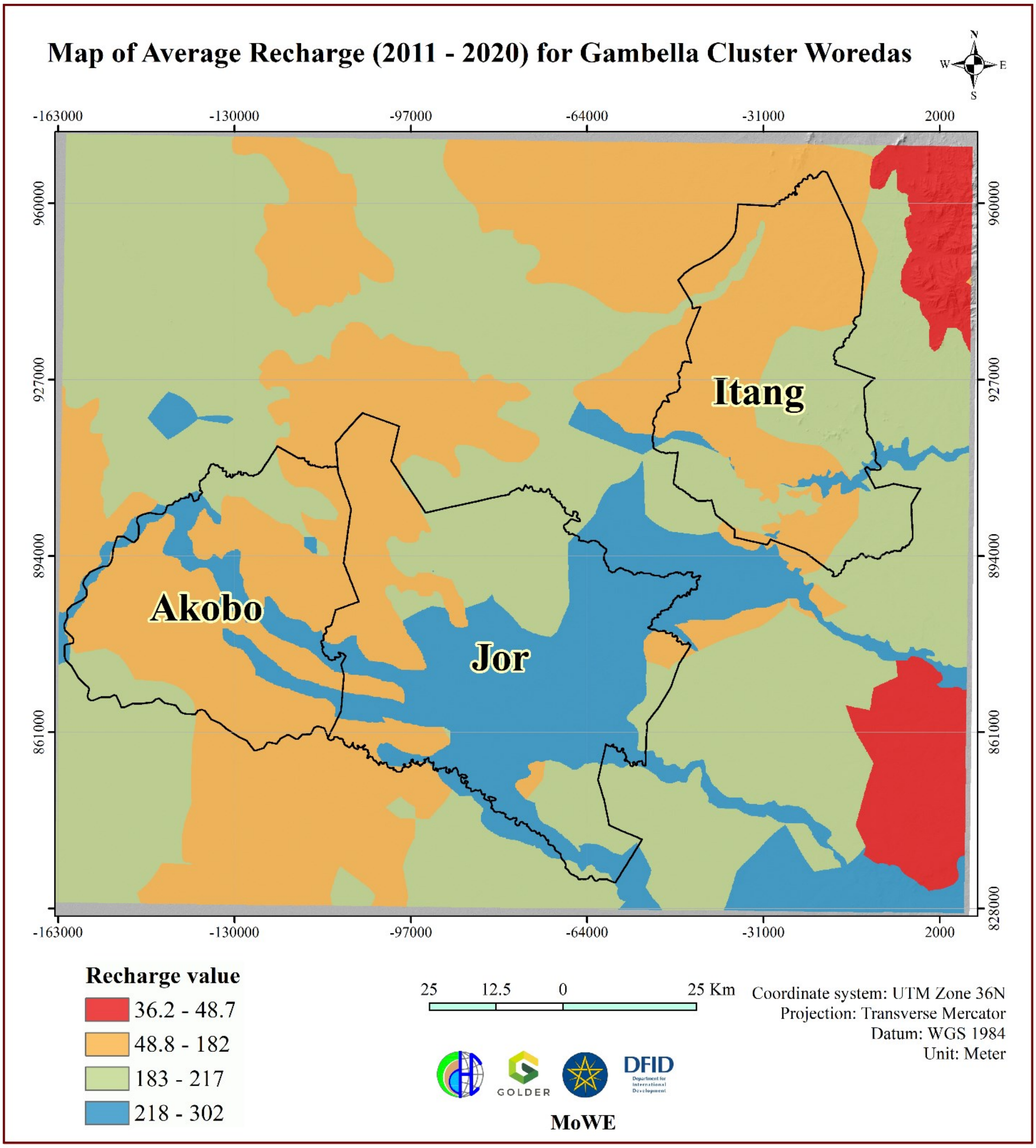


Figure 4.13. Map of average recharge (2011 – 2020) for Gambella cluster Woredas in synoptic area

4.3.4. Topographic Wetness Index (TWI)

The Topographic wetness index, also known as the compound topographic index, is commonly used to quantify topographic control on hydrological processes. The index is a function of both the slope and the upstream contributing area per unit width orthogonal to the flow direction. The topographic wetness index (TWI) is a useful model to estimate where water will accumulate in an area with elevation differences (Sorensen, R; Zinko, U.; Seibert, J. (2006). Topographic wetness is a unitless quantity and it is represented by index with relative physical property. The topographic wetness index as a layer plays a significant role in line with other selected layers to delineate groundwater potential areas based on priority/ranking and weightage as per the layers' relative importance for groundwater enhancement/Potentiality. The TWI for Synoptic area is shown in Figure 4.14.

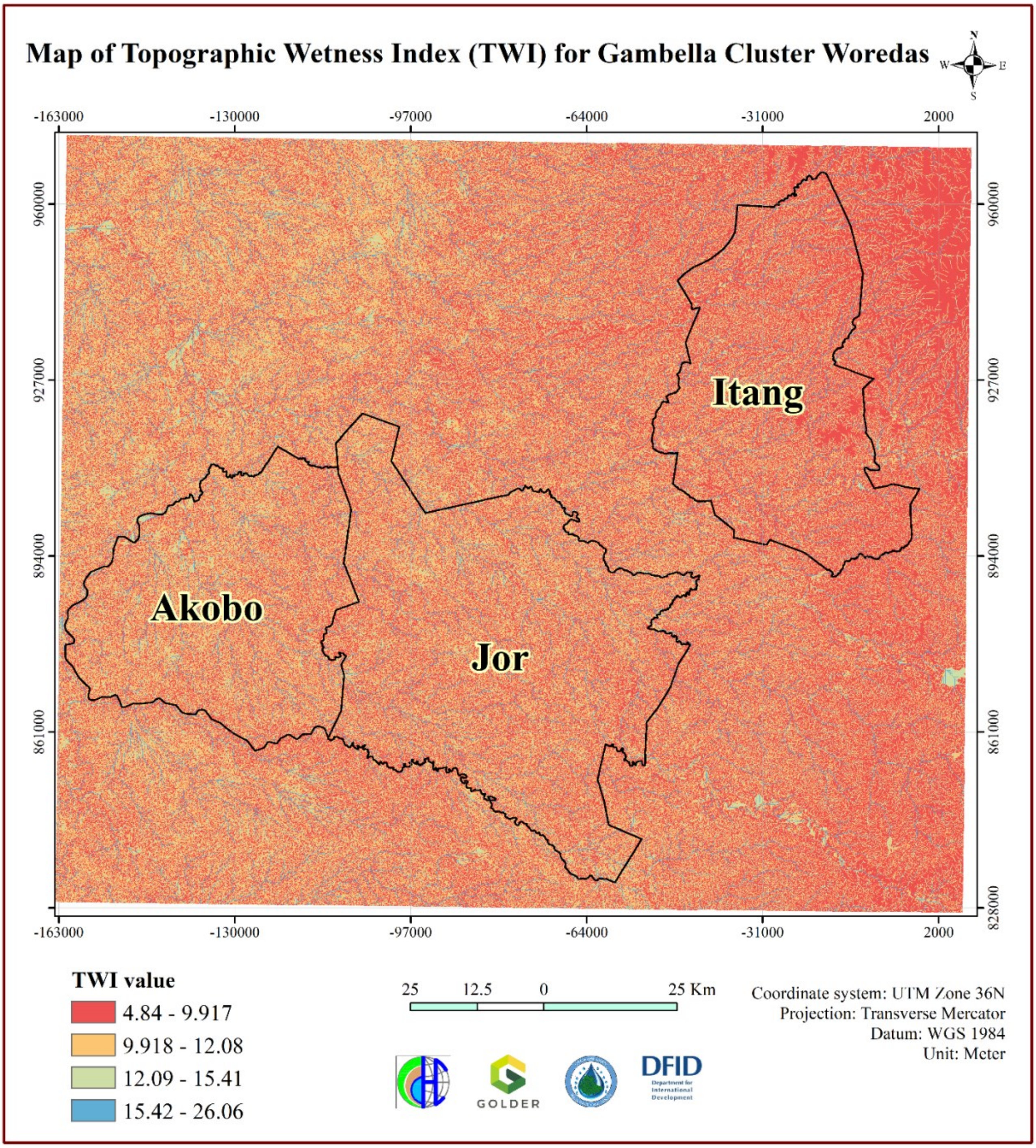


Figure 4.14. Map of topographic wetness index (TWI) for Gambella cluster Woredas in synoptic view

4.3.5. Analytical Hierarchy Process (AHP) and Weights Assignments

The analytic hierarchy approach (AHP) developed by Saaty (1980, 1986, 1992) was used in this study as a decision aiding method to finalize the weights assigned to different themes and their respective features used in deciphering groundwater potentiality. AHP is a simple mathematical matrix-based technique that allows users to assess the relative weight of multiple criteria in an intuitive manner. It allows efficient group decision-making, where group members can use their experience, values and knowledge to breakdown a problem into a hierarchy and solve it by AHP steps (Chowdhury et al. 2009). It also incorporates systematic checks on the consistency of judgments, which is one of the strongest points over the other multi-attribute value processes.

The weightage employed is in accordance with the respective importance of the map theme to groundwater occurrence following the approach of Saraf and Choudhary (1998), Rao and Jugran (2003), Prasad et al. (2008), Jha et al. (2010), Machiwal et al. (2011), Mukherjee et al. (2012) and Singh et al. (2013). The weights of the individual themes and their associated features were then normalized by the Saaty's AHP was used to reduce the subjectivity associated with the assigned weights (Table 4.12). The Consistency Index (CI) of the assigned weights was calculated following the procedure suggested by Saaty (1980, 1992) while the Consistency Ratio, which indicates the probability that the matrix ratings were randomly generated, was also computed using the values of Random Consistency Index (RI) which is the average value of CI for random matrices using the Saaty scale obtained by Forman (1983, 1990) based on the following relations:

Consistency Index = $(\lambda_{max} - n)/(n-1)$;

Consistency Ratio =CI/RI

Where n is the number of criteria or factors

It should be noted that the CR value should be less than 0.10 for consistent weights; otherwise, corresponding weights should be re-evaluated to avoid inconsistency (Saaty 1980, 1986, 1992). For this study, the CR was estimated to be 0.05 which is far below the threshold consistency value of 0.10.

Suitable weights were assigned to the four themes and their individual features after understanding their hydrogeological importance in causing groundwater occurrence in the Gambella sysnptic area. The normalized weights of the individual themes and their different features were obtained through the Saaty's analytical hierarchy process (AHP). Furthermore, each of the thematic maps was then assigned weight in the range of 1–9 according to Saaty's scale of assignment (Table 4.10), which depicts the relative importance of the respective themes to groundwater availability. The weights assigned to the respective thematic maps as presented in Table 4.12 indicate that geology was ranked the dominant factor with a normalized weight value of 0.4 while recharge is the least accounted factor with a normalized weight of 0.06 for groundwater occurrence in the study area.

After deriving the normal weights of all the thematic layers and feature under individual themes, all the thematic layers were integrated with one another using ArcGIS software in order to demarcate groundwater potential zones index (GWPZI) in Gambella area. The index was computed by the integration of the total normalized weights of different polygons using equation stated below. This technique is associated with the study of locations of geographic phenomena together with their spatial dimension and associated attributes (Prasad et al., 2008).

GWPZI = (GGwGGwi + LDwLDwi + TWIwTWIwi + GRwGRwi)

Where, GG is the geology, LD is lineament density, TWI is topographic wetness index, GR is Recharge, w is normalized weight of a theme and with the normalized weight of individual classes.

Thus, using raster calculator tools in ArcGIS 10.8 platform, a composite groundwater potential index (GWPI) for the study area was generated on the basis of which the overall groundwater potential zones map was produced. In the final integrated layer was divided into four equal classes, i.e., 'high', 'moderate', 'low and very low', in order to delineate groundwater potential zones. Finally, well/ borehole data (e.g. yield) was collated from existing wells in the study area. This data was used for the purpose of validation of the proposed groundwater potential map, as a useful guide for a quick assessment of groundwater occurrence on regional scale in the study area.

Table 4-10: Saaty's scale for assignment of weights and its interpretation showing the pair-wise comparison process (Saaty 1980, 1986, 1992)

Less important				Equally important	More important			
Extremely	Very Strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extremely
1/9	1/7	1/5	1/3	1	3	5	7	9

2, 4, 6 and 8 are intermediate values that denotes comprise

Table 4-11: Weights of the four thematic layers for groundwater potential zoning in Gambella synoptic area

Themes	**Assigned Weights**
Geology (GG)	9
Lineament density (LD)	7
Topographic Wetness Index (TWI)	5
Recharge (GR)	3

Table 4-12: Weights of the four thematic layers for groundwater potential zoning in Gambella synoptic area

Theme	**Theme**				**Normalized weight**
	GG	LD	TWI	GR	
GG	1	1	3	5	0.40
LD	1	1	3	5	0.39
TWI	1/3	1/3	1	3	0.15
GR	1/5	1/5	1/3	1	0.06

4.4. Shashemene Synoptic Area

4.4.1. Geology

Shashemane Worda is found in Rift Valley Lake region basin where a succession of rocks ranging in age from late Miocene to Holocene. The major rock units exposed in the Woreda is described briefly as follows

Nazreth Group and Dino Formation Undifferentiated (NQs)

This rock unit is found southeastern of the project with relatively higher area coverage in the Woreda. It contains different types of lithological units such as Ignimbrites, rhyolites, Basalts, and tuffs.

Dino Formation (Qdi)

Dino formation covers vast of the area on the woreda with variable thickness and it comprises a number of flows of compacted fiamme ignimbrites in place intercalated with aphyric basalt and unwelded pyroclastics.

Basalts of the Rift floor (Qwpb)

This rock unit found on the margin of western part of the woreda and has small areal coverage. The alkali basalts consist of magnesian olivine, augitic clinopyroxene, labradorite and opaque phenocrysts, while in the groundmass these minerals are sometimes accompanied by alkali feldspar. Very close mineral logically are transitional alkali basalts, but they completely lack alkali feldspar, and clinopyroxne occurs mainly in the groundmass (GSE 2012). The basalts are clearly controlled by extensional fractures and generally display fresh aa surfaces. Chains of scoraceous cones follow the lines of fractures.

Central volcanic complex (Qwa, Qwo and Qwpu)

Most of the central volcanoes of the Wonji group are disposed along the axial zone of the rift, the Wonji fault belt. They are either huge conical mountains or calderas formed in the place of older volcanoes. The main volcanic centers from north to south within the rift include Aluto, Shala and Corbetti (GSE 2012).

These units are Rhyolite with trachyte lava flow (Qwa), Obsidian and pitch stone (Qwo) and pumice with unwelded tuff (Qwpu). These units found North western, southern and western area within the woreda.

Lacustrine sediment (Ql)

In the rift Quaternary sediments and mostly lacustrine origin are intercalated with Pliocene to Pleistocene ignimbrites both in the rift floor and rift shoulders. The older sediments are lacustrine diatomites, tuffaceous clays and silts inter-bedded with basal ignimbrites of the Nazret Group. The lacustrine sediments are intercalated with redeposit volcanic ash and tuffs (GSE, 2012). The thickness of this unit is variable in the area. This unit is also found in southern region on the project area. Shashamanne geological units and its spatial distribution is shown in Figure 4.15.

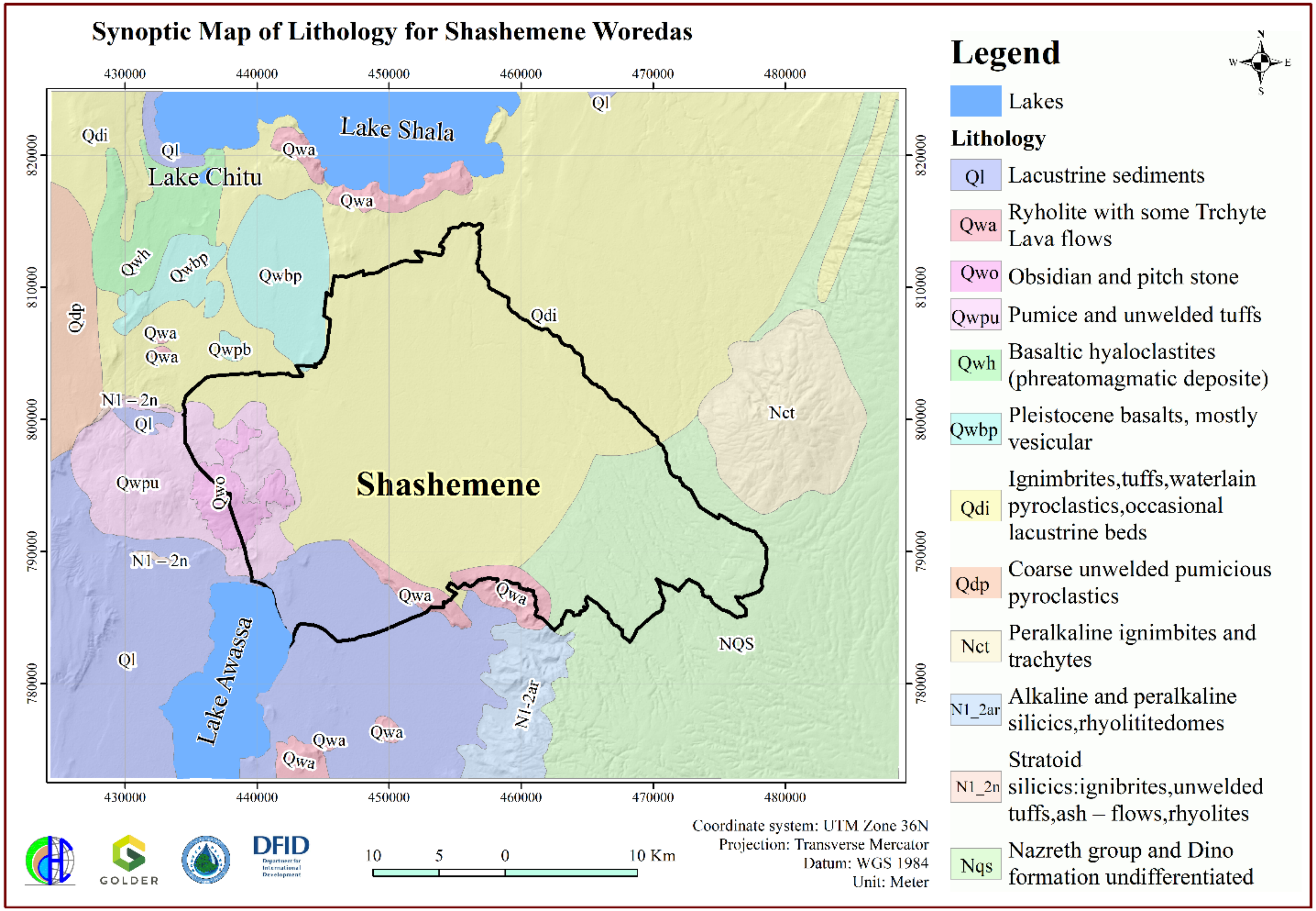


Figure 4.15: Map of lithology for Shashemene Woreda in synoptic view

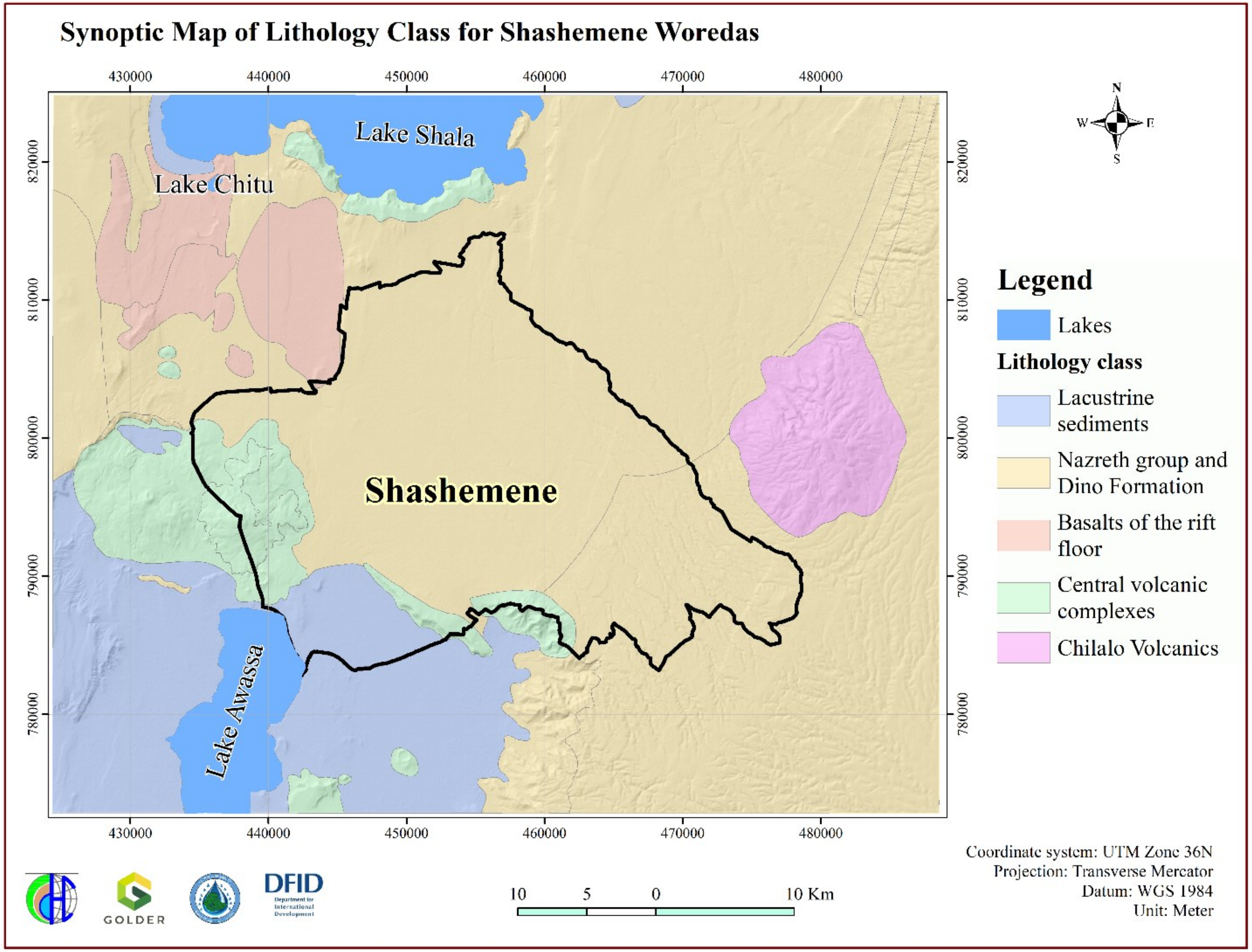


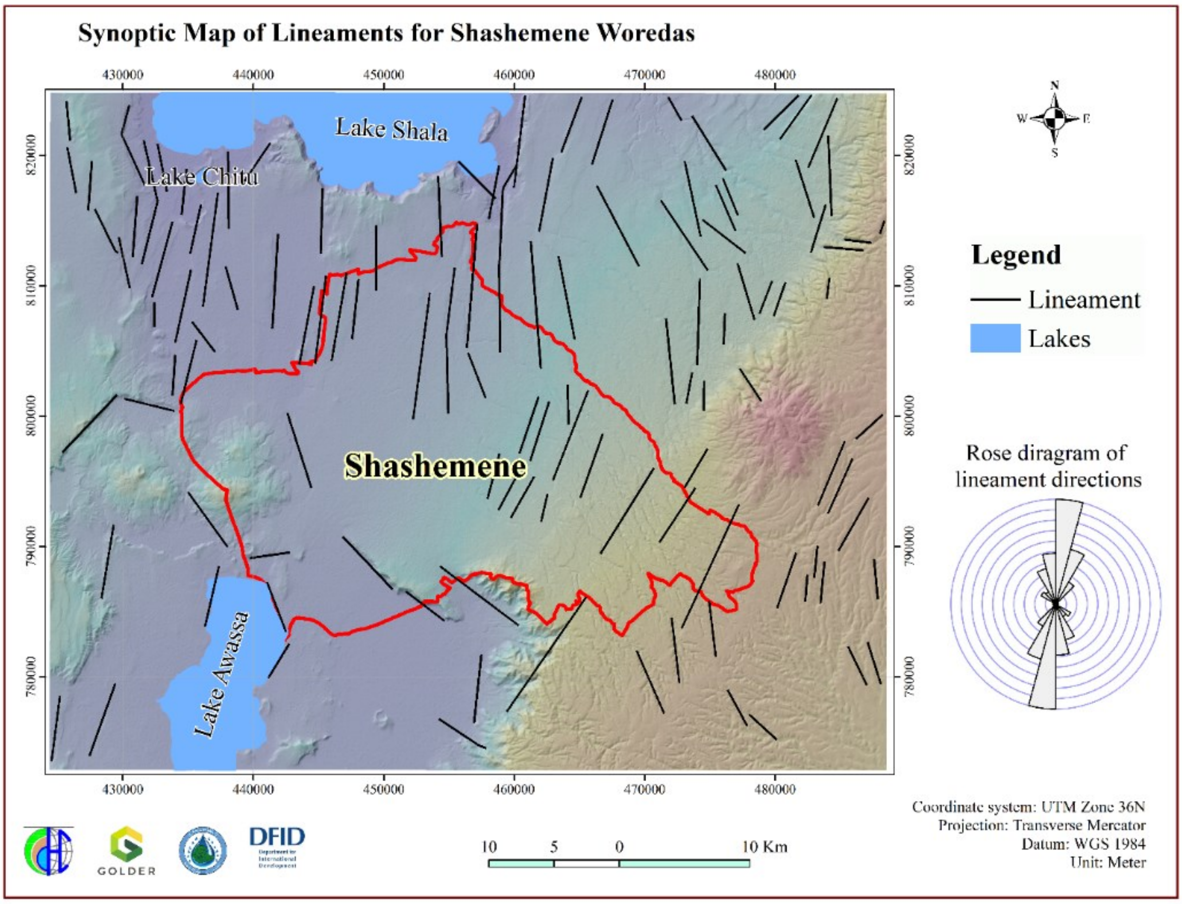
Figure 4.16: Map of lithology class for Shashemene Woreda in synoptic view

4.4.2. Geological structures/Lineaments

Lineaments are manifestation of linear features that can be identified directly on the rock units or from remote sensing data. Lineaments and their intersections play a significant role in the occurrence and movement of groundwater. The presence of lineaments may act as a conduit for groundwater movement which results in increased secondary porosity and, therefore, can serve as groundwater potential zone (Rao, 2006; Prasad et al., 2008). Accordingly, detailed lineaments of the study area were extracted from a mosaicked cloud free Images Sentinel-2 selected from the year 2020 to 2021 series combined with geomorphology of the area and mapped using ArcGIS 10.8 software, and subsequently lineament density map was computed in using GIS algorithm and expressed in terms of length of the lineament per unit area (km/Km2).

Some bedding-like structures are developed in the pyroclatic deposits, which are a primary structure noted in this formation layers. These structures are produced based on the horizontal depositions of the layer by sedimentation compactions of transgressed materials (GSE, 2018). Shashamanne geological units and its spatial distribution is shown in Figure 4.17.

The lineament density varies from less than 0.09 km/Km2 to 0.71 km/Km2 with the north, northeast, and southeast has relatively high lineament density. Though the lineaments are widespread across the study area, however, the distribution of lineaments suggests geologic control with areas covered by pyroclasts and volcanic rocks (Ignimbrite, undifferentiated Dino formations) have higher lineament density of which is good for groundwater development. Consequently, higher weightage of 0.46 was assigned to area with high density of lineaments, while a low weightage of 0.11 was assigned to areas with low lineament density.



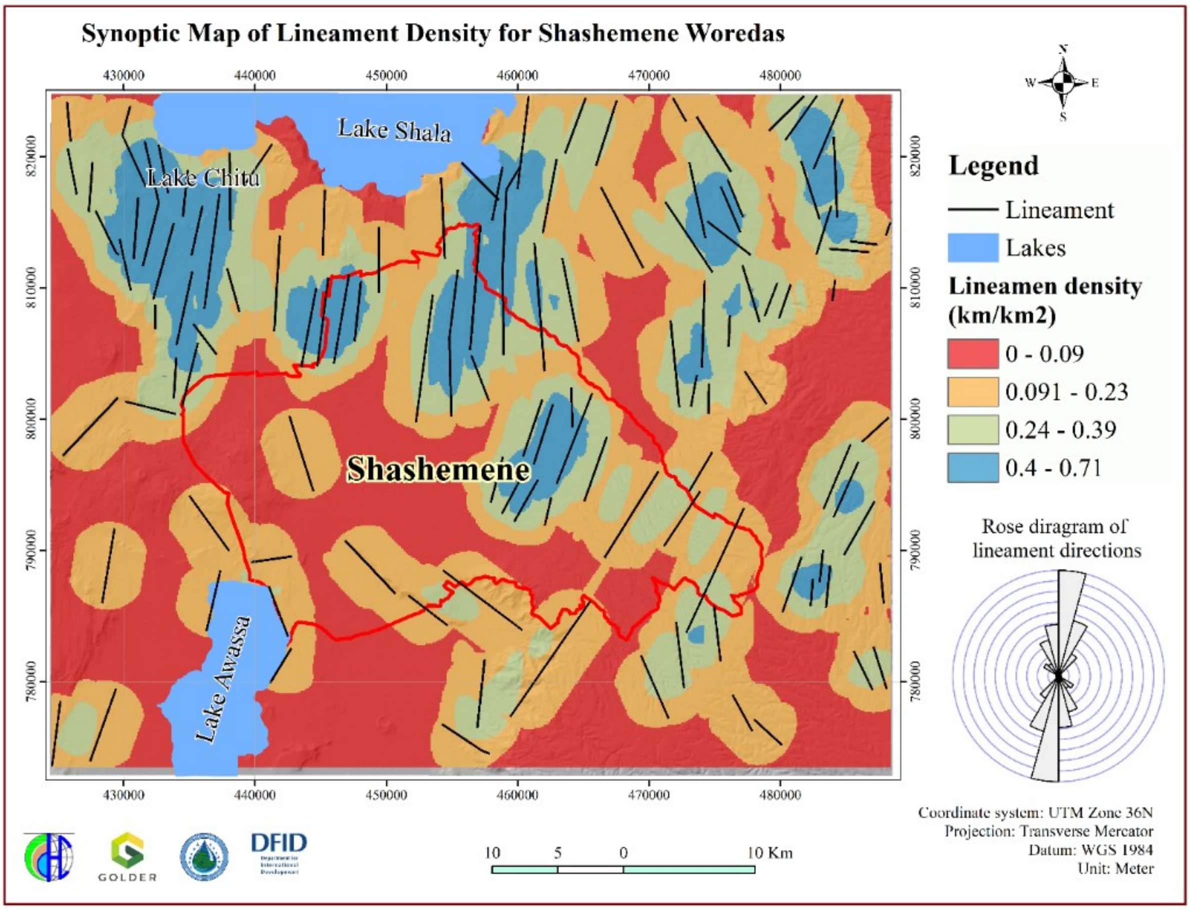


Figure 4.17: Map of lineament (top) and lineament density (bottom) for Shashemene Woreda in synoptic view

4.4.3. Recharge

Climate and hydrological data are essential elements in the assessment of surface water resources, groundwater resource mapping and any water resources development study. In this regard this study encompassed the investigation of the groundwater recharge that presumed to mapping the groundwater resource for the woredas. In respect to the water resources study, the Shashamanne hydrological parameters are rainfall and river discharge. Groundwater recharge has been estimated using annual rainfall and infiltration coefficient of each geological unit. The average annual (2011 - 2020) rainfall data of Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) were obtained from the Climate Hazards Center (CHC) of University of California (https://chc.ucsb.edu). The infiltration coefficients of geological units were obtained from Abay River Basin Integrated Resources Development Master Plan Study report (MoWR, 1999). According to the master plan study, the IC of various lithological units could be assigned based on the results obtained from recharge estimations made using an integrated approaches including base flow separation and estimation of proportion of annual rainfall amount that to be percolated to the subsurface based on correlation made between each lithological unit identified within the basin using a developed mathematical equation. Therefore, for the current study, the IC values were extracted from the basin study that have similar properties of lithological units found in the current study area and accordingly assigned to each lithological unit (Table 3-1). The infiltration coefficient of geological units was obtained from Abay River Basin Integrated Resources Development Master Plan Study report (MoWR, 2007). According to the master plan study, the IC of various lithological units could be developed based on the results obtained from recharge estimations made using an integrated approaches that considered an important parameter and correlating with different lithological units identified within the basin. Therefore, for the current study, the IC values were extracted from the basin study that have similar properties of lithological units found in the current study area and accordingly assigned to each lithological unit. Then, the geological map converted to raster based on the assigned value of IC with cell size of 100m on ArcGIS platform. Finally, the raster maps of rainfall and IC of lithological units were multiplied using a raster calculation algorithm in ArcGIS to obtain spatial map of 10 years average annual recharge amount for the project area.

Table 4-13. Assigned infiltration coefficient for lithological units (Shashamane) correlated with Abay River Basin Integrated Master Plan (MoWR, 1998).

Shashemene Synoptic area (study area)		Assigned IC	Abay River Basin Integrated Master Plan	
Symbol	**Lithology description**		**Symbol**	**Lithology description**
Ql	Lacustrine sediments	0.15	Ql	Lacustrine sediments: silts, clays, diatomite, with minor volcanoclastic sediments and tuffs
Qwa	Rhyolite with some trachyte lava flows	0.1	Tvc4	Choke rhyolite; K-feldspar, plagioclase and quartz phenocrysts containing rhyolite
Qwo	Obsidian and pitch stone	0.1	Qop	Obsidian flows and pitchstone deposits
Qwpu	Pumice and unwelded tuffs	0.1	Qdi	Upper Dino Formation: ignimbrites, tuffs, water lain pyroclastics (surges), occasional lacustrine beds
Qdi	Ignimbrites, tuffs, water lain pyroclastics, occasional lacustrine beds	0.1	»	»
Qdp	Coarse unwelded pumicious pyroclastics	0.1	»	»
Qwh	Basaltic hyaloclastites (phreatomagmatic deposit)	0.15	Ql	Lacustrine sediments: silts, clays, diatomite, with minor volcanoclastic sediments and tuffs

Shashemene Synoptic area (study area)		**Assigned IC**	**Abay River Basin Integrated Master Plan**	
Symbol	**Lithology description**		**Symbol**	**Lithology description**
Qwpb	Pleistocene basalts, mostly vesicular	0.15	Qb1	Vesicular basalts
Nct	Peralkaline ignimbrites and trachyte's	0.05	Npt	Alkali trachyte flows, trachybasalts and minor plugs forming the silicic peaks of Bale Mountains, and the Chilalo, Galma, Kaka, and Hunkulo volcanic centres; trachyte's are light grey, fine-grained to porphyritic
N1-2ar	Alkaline and peralkaline silicic, rhyolite domes	0.05	Qra	Rhyolitic lava flows
N1 - 2n	Stratoid silicic: ignimbrites, unwelded tuffs, ash - flows, rhyolites	0.05	»	»
NQS	Nazreth group and Dino formation undifferentiated	0.15	Nwp	Nazareth Group: welded pyroclastic flows, ash flow tuff, lapilli tuff, massive pantelleritic ignimbrites, unwelded tuffs, base surge deposits, volcanic breccia, trachytic tuffs with minor basalt and alkali trachyte flows and sediments

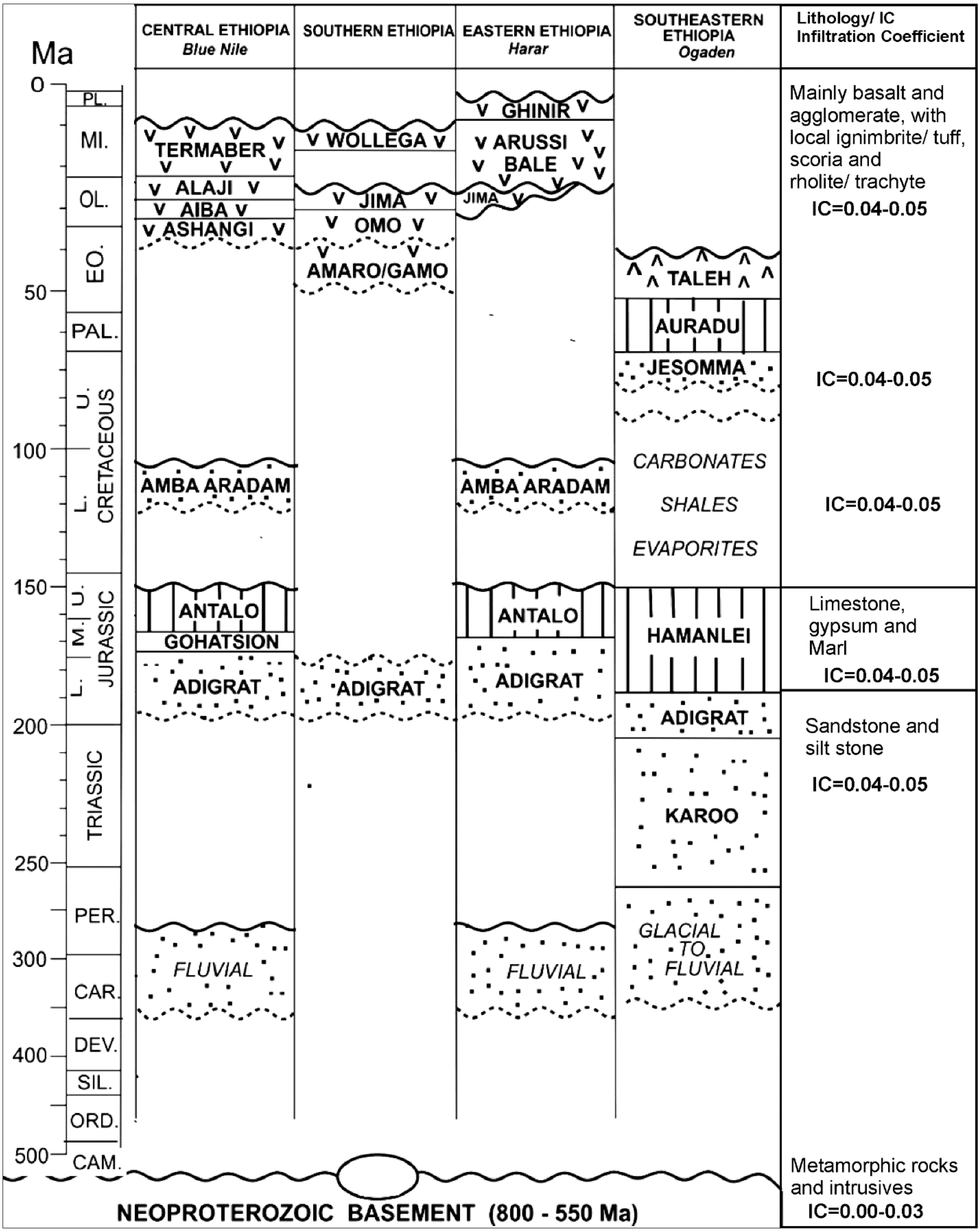


Figure 4.18. Correlation of geological formation of the study area with Abay basin

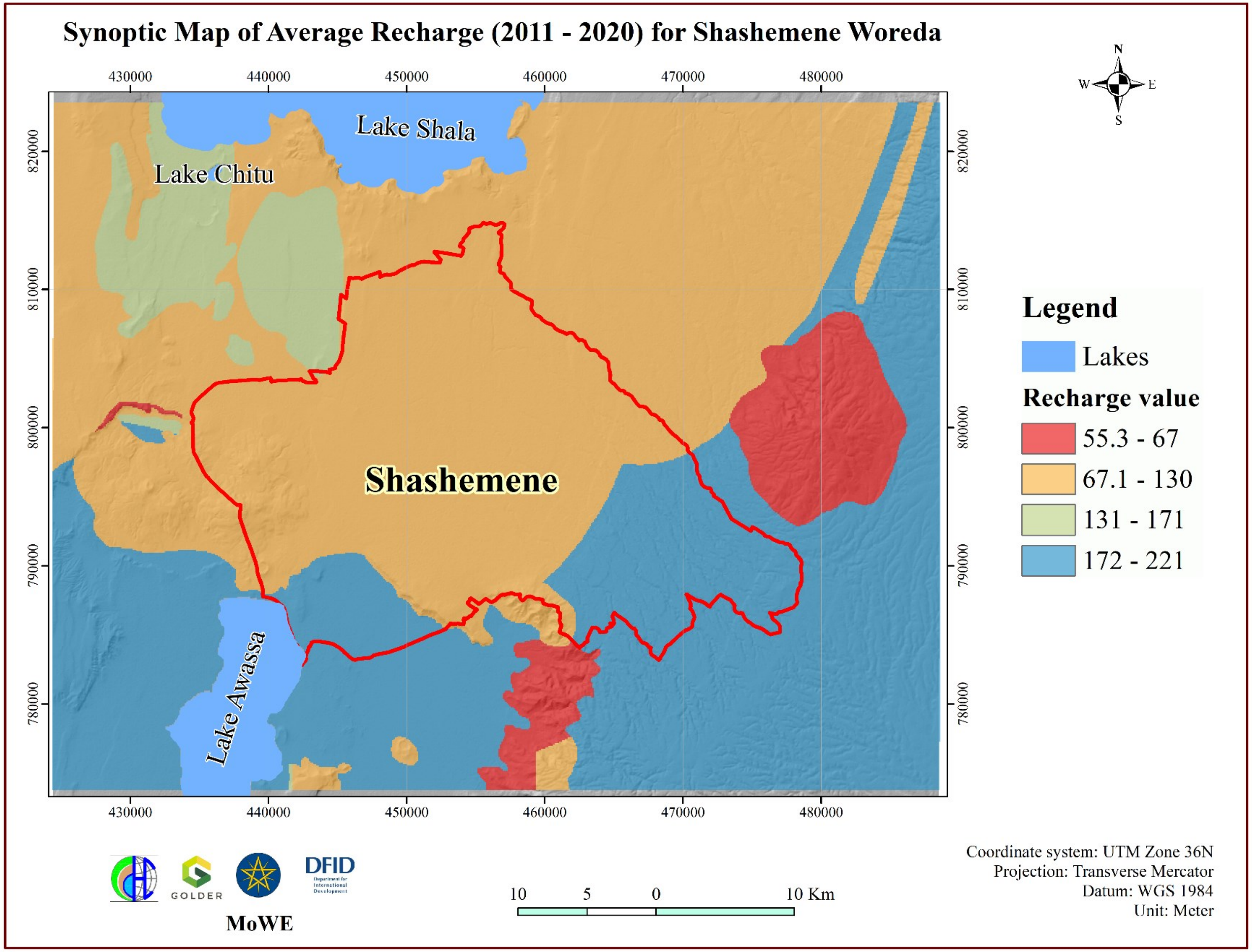


Figure 4.19. Map of average recharge (2011 - 2020) for Shashemene Woreda in synoptic view

4.4.4. Topographic Wetness Index (TWI)

The Topographic wetness index, also known as the compound topographic index, is commonly used to quantify topographic control on hydrological processes. The index is a function of both the slope and the upstream contributing area per unit width orthogonal to the flow direction. The topographic wetness index (TWI) is a useful model to estimate where water will accumulate in an area with elevation differences (Sorensen, R; Zinko, U.; Seibert, J. (2006). Topographic wetness is a unitless quantity and it is represented by index with relative physical property. The topographic wetness index as a layer plays a significant role in line with other selected layers to delineate groundwater potential areas based on priority/ranking and weightage as per the layers' relative importance for groundwater enhancement/Potentiality.

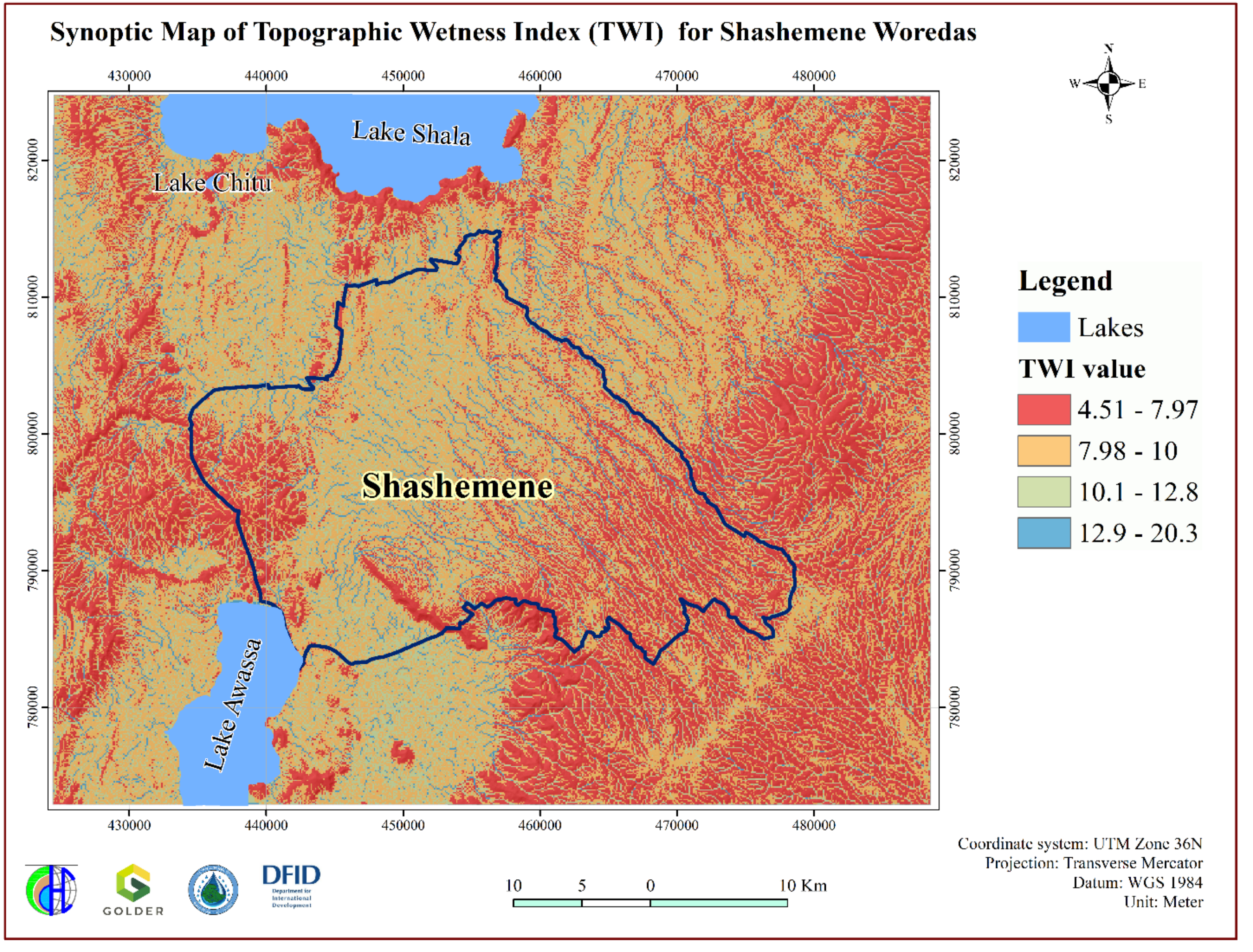


Figure 4.20: Map of topographic wetness index (TWI) for Shashemene Woreda in synoptic view

4.4.5. Analytical Hierarchy Process (AHP) and Weights Assignments

The analytic hierarchy approach (AHP) developed by Saaty (1980, 1986, 1992) was used in this study as a decision aiding method to finalize the weights assigned to different themes and their respective features used in deciphering groundwater potentiality. AHP is a simple mathematical matrix-based technique that allows users to assess the relative weight of multiple criteria in an intuitive manner. It allows efficient group decision-making, where group members can use their experience, values and knowledge to breakdown a problem into a hierarchy and solve it by AHP steps (Chowdhury et al. 2009). It also incorporates systematic checks on the consistency of judgments, which is one of the strongest points over the other multi-attribute value processes.

The weightage employed is in accordance with the respective importance of the map theme to groundwater occurrence following the approach of Saraf and Choudhary (1998), Rao and Jugran (2003), Prasad et al. (2008), Jha et al. (2010), Machiwal et al. (2011), Mukherjee et al. (2012) and Singh et al. (2013). The weights of the individual themes and their associated features were then normalized by the Saaty's AHP was used to reduce the subjectivity associated with the assigned weights (Table 4.16). The Consistency Index (CI) of the assigned weights was calculated following the procedure suggested by Saaty (1980, 1992) while the Consistency Ratio, which indicates the probability that the matrix ratings were randomly generated, was also computed using the values of Random Consistency Index (RI) which is the average value of CI for random matrices using the Saaty scale obtained by Forman (1983, 1990) based on the following relations:

Consistency Index = $(\lambda_{max} - n)/(n-1)$;

Consistency Ratio =CI/RI

Where n is the number of criteria or factors

It should be noted that the CR value should be less than 0.10 for consistent weights; otherwise, corresponding weights should be re-evaluated to avoid inconsistency (Saaty 1980, 1986, 1992). For this study, the CR was estimated to be 0.01 which is far below the threshold consistency value of 0.10.

Suitable weights were assigned to the four themes and their individual features after understanding their hydrogeological importance in causing groundwater occurrence in the Shashamanne woreda. The normalized weights of the individual themes and their different features were obtained through the Saaty's analytical hierarchy process (AHP). Furthermore, each of the thematic maps was then assigned weight in the range of 1–9 according to Saaty's scale of assignment (Table 4.14), which depicts the relative importance of the respective themes to groundwater availability. The weights assigned to the respective thematic maps as presented in Table 4.16 indicate that geology was ranked the dominant factor with a normalized weight value of 0.49 while recharge is the least accounted factor with a normalized weight of 0.03 for groundwater occurrence in the study Shashamanne woreda.

After deriving the normal weights of all the thematic layers and feature under individual themes, all the thematic layers were integrated with one another using ArcGIS software in order to demarcate groundwater potential zones index (GWPZI) in the Shashamanne woreda. The index was computed by the integration of the total normalized weights of different polygons using equation stated below. This technique is associated with the study of locations of geographic phenomena together with their spatial dimension and associated attributes (Prasad et al., 2008).

GWPZI = (GGwGGwi + LDwLDwi + TWIwTWIwi + GRwGRwi)

Where, GG is the geology, LD is lineament density, TWI is topographic wetness index, GR is Recharge, w is normalized weight of a theme and wi is the normalized weight of individual classes.

Thus, using raster calculator tools in ArcGIS 10.8 platform, a composite groundwater potential index (GWPI) for the study area (Shashamanne woreda) was generated on the basis of which the overall groundwater potential zones map was produced. In the final integrated layer was divided into four classes, i.e., 'very high', 'high', 'moderate' and 'low or poor', in order to delineate groundwater potential zones (chapter five). Finally, well/ borehole data (e.g., yield) was collated from existing wells in the study area. This data was used for the purpose of validation of the proposed groundwater potential map, as a useful guide for a quick assessment of groundwater occurrence on regional scale in the study area.

Table 4-14:-Saaty's scale for assignment of weights and its interpretation showing the pair-wise comparison process (Saaty 1980, 1986, 1992)

Less important				Equally important	More important			
Extremely	Very Strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extremely
1/9	1/7	1/5	1/3	1	3	5	7	9

2, 4, 6 and 8 are intermediate values that denotes comprise

Table 4-15:-Weights of the four thematic layers for groundwater potential zoning in Shashemene synoptic area

Themes	**Assigned Weights**
Geology (GG)	9
Lineament density (LD)	7
Topographic Wetness Index (TWI)	5
Recharge (GR)	3

Table 4-16:-Normalized weights and pair-wise comparison matrix of the four thematic layers for groundwater potential zoning in Shashemene synoptic area

Theme	**Theme**				**Normalized weight**
	GG	LD	TWI	GR	
GG	1	1	3	5	0.49
LD	1	1	3	5	0.38
TWI	1/3	1/3	1	3	0.18
GR	1/5	1/5	1/3	1	0.03

4.5. Liben Synoptic Area

4.5.1. Geology

In preparation of the geological map of the target woreda, major lithological units, their spatial coverage and geomorphological condition of the wereda has been assessed from existing data and previous studies and maps from the Geological Survey of Ethiopia and using sentnial 2 multispecgtral image for verfication and modification of the existing maps. This initial stage of the work encompasses extracting base map features, through the manipulations of topographic map in a GIS environment. The topographic map illustrates geographic references (Example, localities, names of rivers, road network and etc.) useful to mark widely distributed control points for accurate geo-referencing of previous geologic maps that is available in different scales. At regional scale, the following geological units are exposed as rectangular synoptic view, in Liben Area (Figure4.21):

- Basement rocks (Metamorphics)Metadiorite, biotite-amphibolite, metagabro and granite with banded quartzo-feldspar and gneiss
- Mesozoic Sedimentary rocks (Limestone with mionor sandstone and conglomerate)
- Tertiary volcanics (Dark grey to black aphanitic basalt) with Quaternary Alluvials (Brown-red silt, clay and sand with local gray-white calcrete (Alluvial deposit)
- Superficial deposits.
- Metamafic Ultramafic rock
- Felsic Intrusives
- Meta volcano sedimentary
- Migmatitic gneiss

At local scale, in Liben Woreda the follwong geological units were identified (Figure 4.22):

Metamafic Ultramafic rock.

This rock unit is typical of metamorphic and comprised of granite, gneiss, diorite, gabbro with subordinate biotite and hornblende and intercalations of green schist and quartzo-feldspatic schist with meta graywacke and meta-rhyodacite with metagabbro. Besides it comprised of various types of schists like Talc-tremolite-chlorite-talc, chlorite-actinolite and actinolite schist and found distributed dominantly on central and southern part of the area, the occurrence is also observed as a patch scattered on the eastern tip of the area. It covers an area of about 1,240.8 Km2.

Felsic Intrusives;

This rock unit is typical of metamorphic and comprised of granite, gneiss, meta-gabbro with subordinate hornblende and intercalations of green schist and quartzo-feldspatic gneiss. Besides it comprised of various types of schists like Talc-tremolite-actinolite-talc, and found distributed dominantly on central and northern part of the area the occurrence is also observed as a patch scattered on the eastern tip of the area. It covers an area of about 288Km2.

Mesozoic Sedimentary rocks (**Limestone with mionor sandstone and conglomerate**);

This rock unit is comprised of limestone with very minor basal sandstone and conglomerate and found distributed dominantly on central and southern part of the area with uniform chainage laterally. It covers an area of about 1,554.7 Km2.

Tertiary volcanics (Dark grey to black aphanitic basalt);

These are the olivine basalt, Dark grey to black aphanitic basalt and Dark brown to black clayey soil located at south and south eastern part of the area scattered as a patch with the Brown-red silt, clay and sand with local gray-white calcrete (alluvial deposit), undifferentiated Elluvium and alluvium located on southern and central part of the area with an areal coverage of 111 Km2.

Meta volcano sedimentary.

This rock unit is comprised of granite, gneiss, diorite, gabbro with subordinate biotite and hornblende and intercalations of green schist and quartzo-feldspatic schist with meta graywacke and meta-rhyodacite with metagabbro. Besides it comprised of various types of schists like Talc-tremolite-chlorite-talc, chlorite-actinolite and actinolite schist and found distributed dominantly on central and southern part of the area the occurrence is also observed as a patch scattered on the eastern tip of the area. It covers an area of about 3,500 Km2.

Migmatitic gneiss.

These are the Quartz-feldspar gneiss with interbeds of biotite gneiss, banded biotite-amphibole gneiss and biotite gneiss with minor granodiorite, Banded quartz-feldspar, pyroxene-amphibole and amphibole-quartz-feldspar gneiss. located on western part of the area covering almost half part of the woreda with an areal coverage of 556 Km2.

Superficial deposits.

These are the Brown-red silt, clay and sand with local gray-white calcrete (alluvial deposit), undifferentiated Elluvium and alluvium located on southern and central part of the area with an areal coverage of 288 Km2.

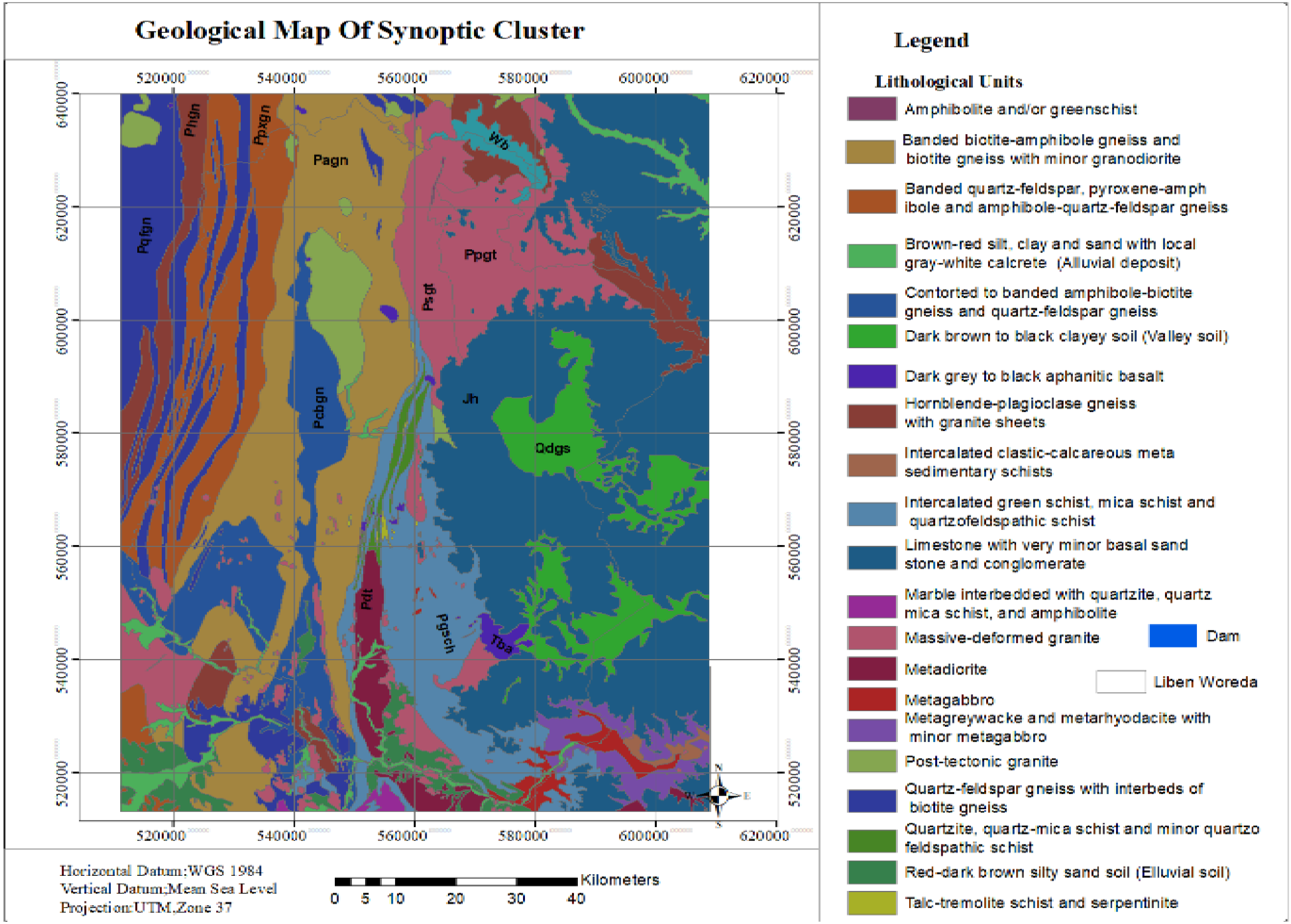


Figure 4.21. Maps of lithology for Liben Woreda in synoptic view

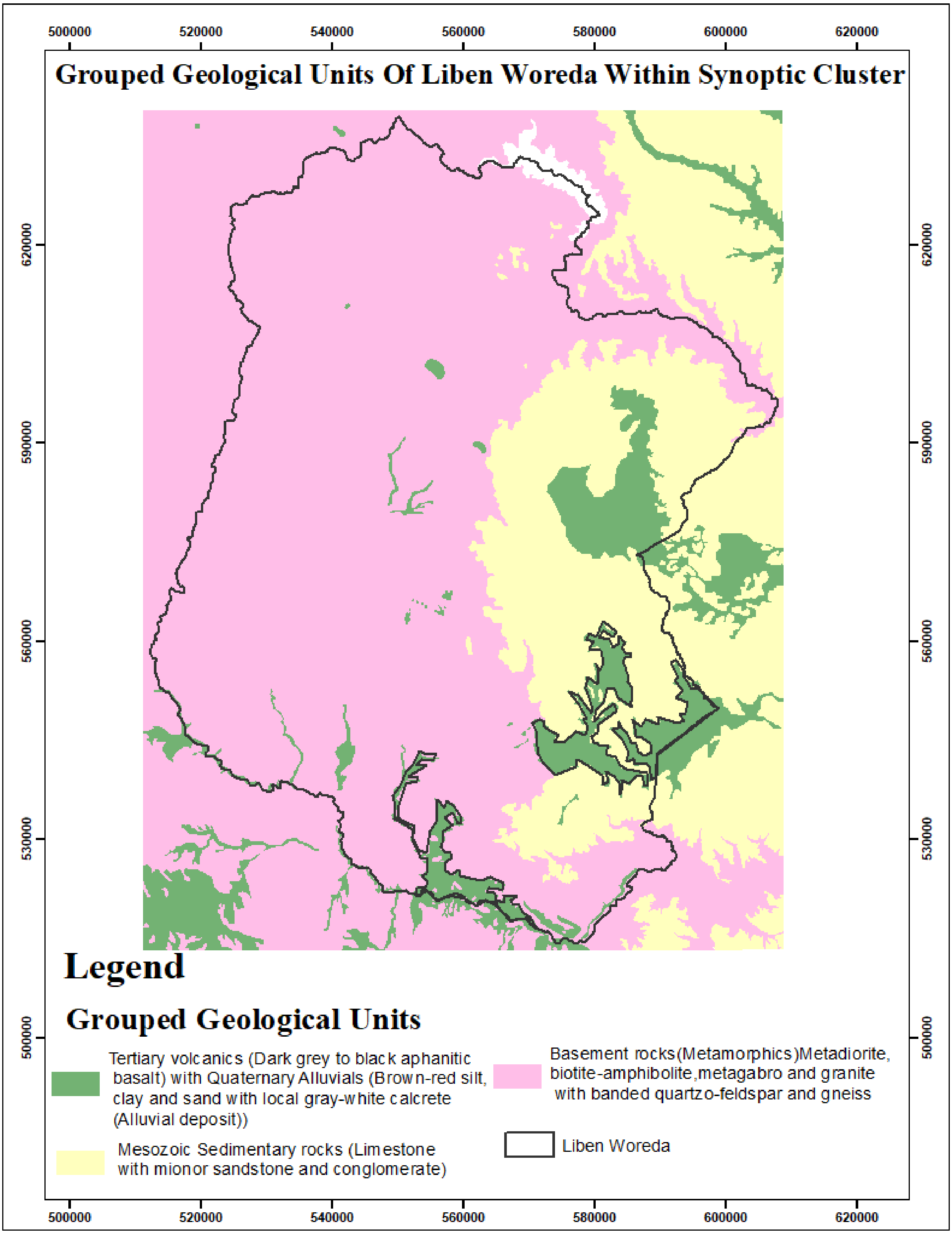


Figure 4.22. Map of lithology class for Liben Woreda in synoptic view

4.5.2. Geological structures/Lineaments

The primary aim of the structural study is to provide lithological, structural, tectonics and physiographic understanding of the area as a basis for hydrogeological and related studies on the groundwater potential of the project areas.

A lineament is a linear feature in a landscape which is an expression of an underlying geological structure such as a fault. Lineaments are often apparent in geological or topographic maps and can appear obvious on aerial or satellite photographs. Lineaments are manually extracted with great care from DEM (https://earthexplorer.usgs.gov/), Satellite images (Sentinel 2 from https://scihub.copernicus.eu/) and exisiting geological maps of the area.

The study area is highly affected by lineaments and/or fractures consequent to a number of tectonic activities in the past. Two prominent directions identified are N–S, and NW-SE trending lineaments. Usually, lineaments are presented in the form of lineament density. Lineament density map is a measure of quantitative length of linear feature per unit area which can indirectly reveal the groundwater potentials as the presence of lineaments usually denotes a permeable zone.

For Liben Woreda, the lineament density varies from less than 0.3 km/Km2 to 2.0 km/Km2 (Figure 4.23). Though the lineaments are widespread across the study area, however, the distribution of lineaments suggests geologic control with areas underlain by crystalline basement complex and limestone rocks associated with quaternary sediments having relatively higher lineament density of 1.5 – 2.0 km/Km2) compared with areas underlain by sedimentary rocks of Mesozoic limestone and lower sandstone with Tertiary volcanics with lower lineament densities of (< 0.5 km/Km2).

Thus, areas with higher lineament density are regarded as having good contribution for groundwater recharge and storage.

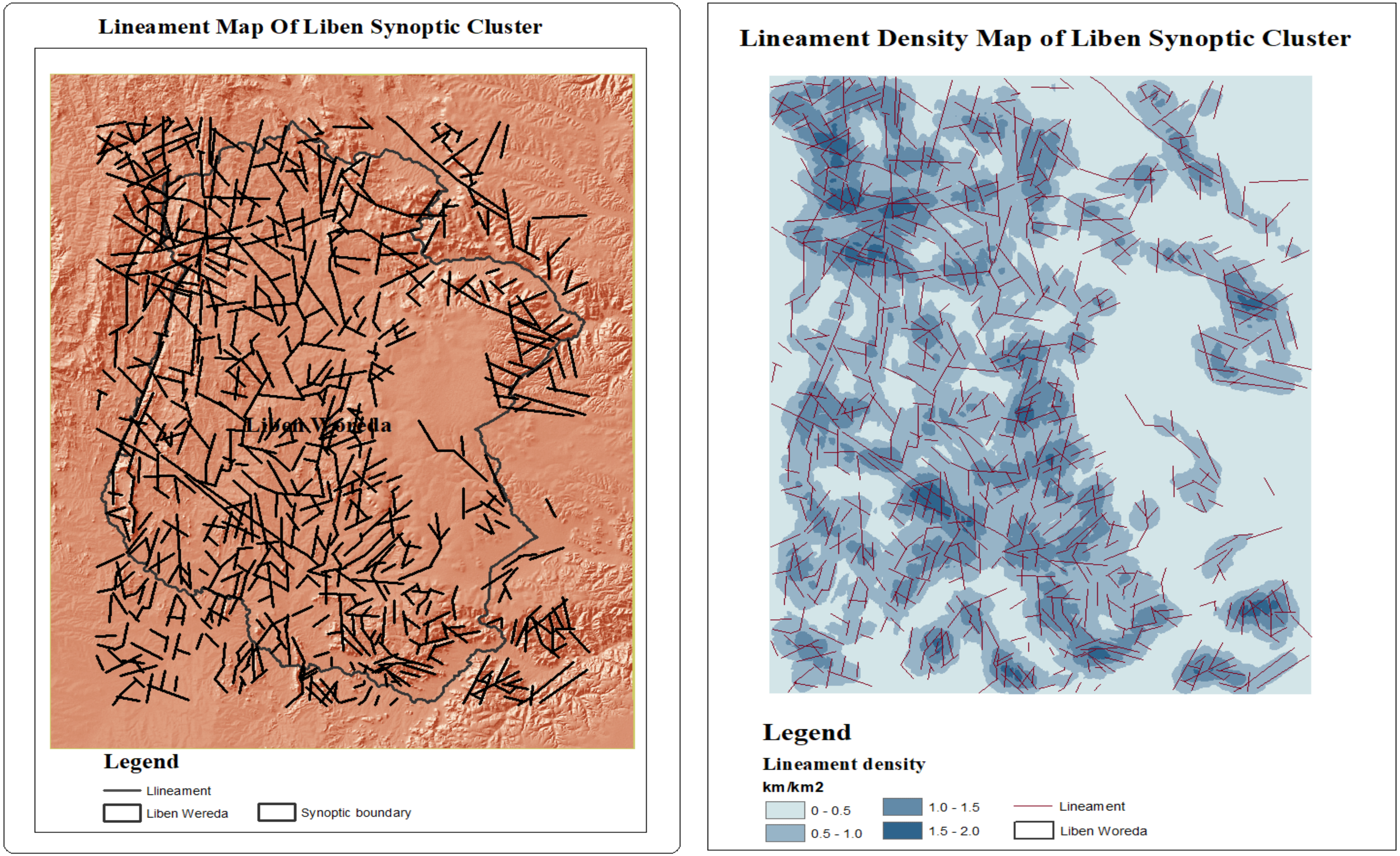


Figure 4.23. Map of lineaments (left) and lineament density (right) for Liben Woreda in synoptic view

4.5.3. Recharge

Climate and hydrological data are essential elements in the assessment of surface water resources, groundwater resource mapping and any water resources development study. In this regard this study encompassed the investigation of the groundwater recharge that presumed to mapping the groundwater resource for the woredas. In respect to the water resources study, the major hydrological parameters are rainfall and river discharge. Groundwater recharge has been estimated using annual rainfall and infiltration coefficient of each geological unit. The average annual (2011 - 2020) rainfall data of Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) were obtained from the Climate Hazards Center (CHC) of University of California (https://chc.ucsb.edu). The infiltration coefficients of geological units were obtained from Abay River Basin Integrated Resources Development Master Plan Study report (MoWR, 1999). According to the master plan study, the IC of various lithological units could be assigned based on the results obtained from recharge estimations made using an integrated approaches including base flow separation and estimation of proportion of annual rainfall amount that to be percolated to the subsurface based on correlation made between each lithological unit identified within the basin using a developed mathematical equation. Therefore, for the current study, the IC values were extracted from the basin study that have similar properties of lithological units found in the current study area and accordingly assigned to each lithological unit (Table 4-17). The infiltration coefficient of geological units was obtained from Abay River Basin Integrated Resources Development Master Plan Study report (MoWR, 2007). According to the master plan study, the IC of various lithological units could be developed based on the results obtained from recharge estimations made using an integrated approach that considered an important parameter and correlating with different lithological units identified within the basin. Therefore, for the current study, the IC values were extracted from the basin study that have similar properties of lithological units found in the current study area and accordingly assigned to each lithological unit. Then, the geological map converted to raster based on the assigned value of IC with cell size of 100m on ArcGIS platform. Finally, the raster maps of rainfall and IC of lithological units were multiplied using a raster calculation algorithm in ArcGIS to obtain average annual recharge amount for the project area.

Table 4-17. *Assigned infiltration coefficient for lithological units (Liben) correlated with Abay River Basin Integrated Master Plan (MoWR, 1998).*

Lithological Units (Study area)		Assigned IC	Lithological Units (Abay Basin)	
Symbol	**Description**		**Symbo**	**Description**
Gt1	Metamorphics	0,03	QAll	
Jlst	Limestone with basal sand stone	0.05	QAll	Antalo Limestone
Pagn	Banded biotite amphibolite	0,03	QAll	Neoproterozoic Basement
Pbg	Biotite gneiss	0,03	QLAC	Neoproterozoic Basement
Pcas	Actinolite schist with epidotite	0,03	QAll	Neoproterozoic Basement
Pcbgn	Contorted to banded amphibolite	0,03	QCB2	Neoproterozoic Basement
Pdt	Meta diorite	0,03	QCB3	Neoproterozoic Basement
Pgsch	Intercalated green schist, mica	0,03	TBNB	Neoproterozoic Basement
Pgw	Metagraywacke and metagabbro	0,03	QATB	Neoproterozoic Basement

Phgn	Hornblende plagioclase gneiss	0,03	TBNB	Neoproterozoic Basement
Pmg	Metagebbro	0,03	QATB	Neoproterozoic Basement
Ppgt	Post tectonic pegmatoidal	0,03	TASB	Neoproterozoic Basement
Pqbs	Quartz biotite, quartz sericite	0,03	TAAB	Neoproterozoic Basement
Pqfm	Quartzofeldspatic quartz gneiss	0,03	TASB	Neoproterozoic Basement
Pqkg	Biotite plagioclase subordinate	0,03	TASB	Neoproterozoic Basement
Pqt	Quartzite quart mica schist and	0,03	TBNB	Neoproterozoic Basement
Psgt	Meta granitoids	0,03	KAA2`	Neoproterozoic Basement
Ptts	Talc-tremolite-chlorite-	0,03	JANL	Neoproterozoic Basement
Q	Brown-red silt, clay and sand	0.2	TBNB	Alluvium
Qdgs	Dark brown to black clayey soil	0.1	KAA2`	Alluvium
Qrs	Rhyolitic volcanic, subordinate	0.1	JANL	Blue Nile Basalts
Tab	Dark grey to black aphanitic	0.1	JANL	Alluvium
Tv	Olivine basalt	0.1		Blue Nile Basalts

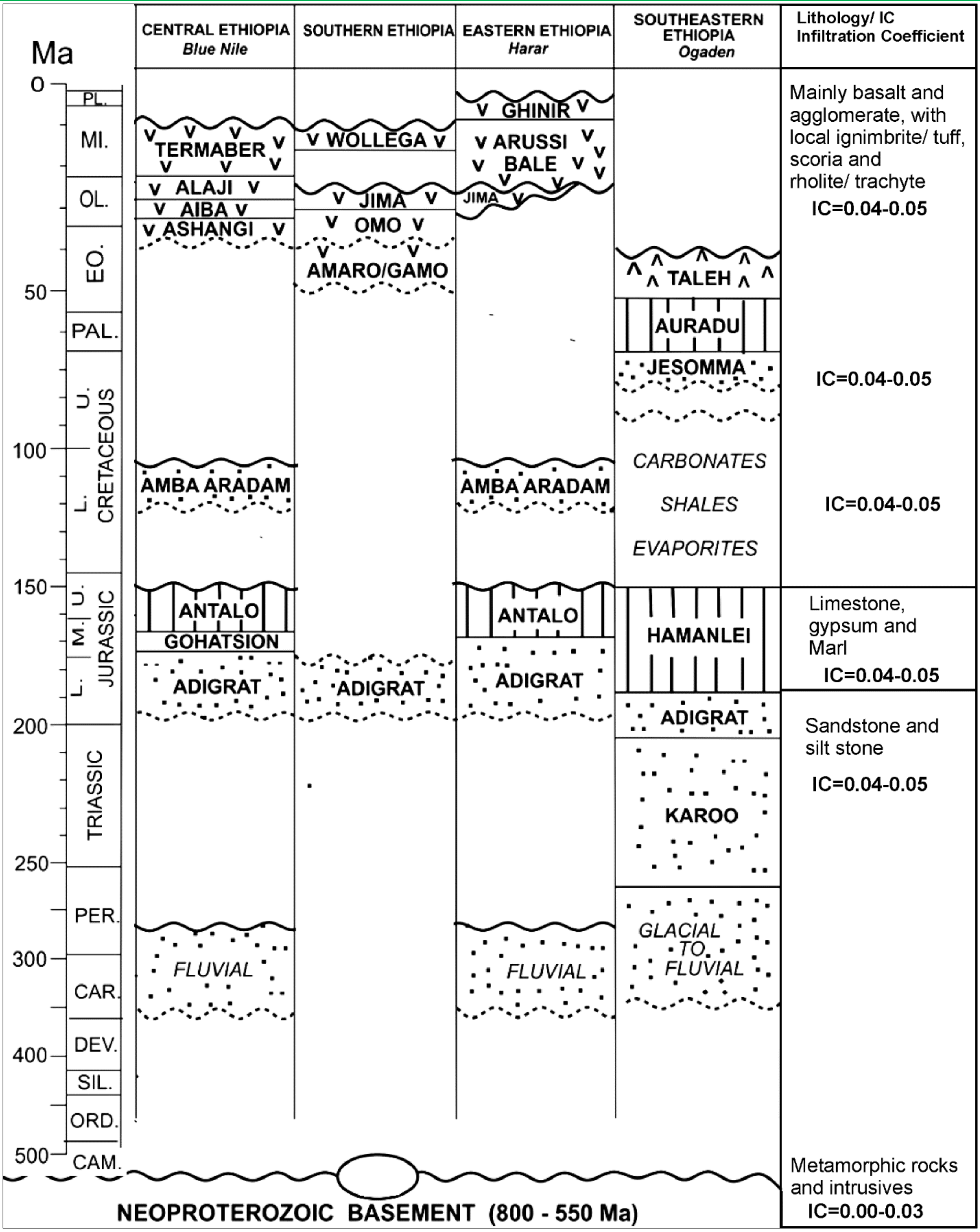


Figure 4.24. Correlation of geological formation of the study area with Abay basin

4.5.4. Topographic Wetness Index (TWI)

The Topographic wetness index, also known as the compound topographic index, is commonly used to quantify topographic control on hydrological processes. The index is a function of both the slope and the upstream contributing area per unit width orthogonal to the flow direction. The topographic wetness index (TWI) is a useful model to estimate where water will accumulate in an area with elevation differences (Sorensen, R; Zinko, U.; Seibert, J. (2006). Topographic wetness is a unitless quantity and it is represented by index with relative physical property. The topographic wetness index as a layer plays a significant role in line with other selected layers to delineate groundwater potential areas based on priority/ranking and weightage as per the layers' relative importance for groundwater enhancement/Potentiality.

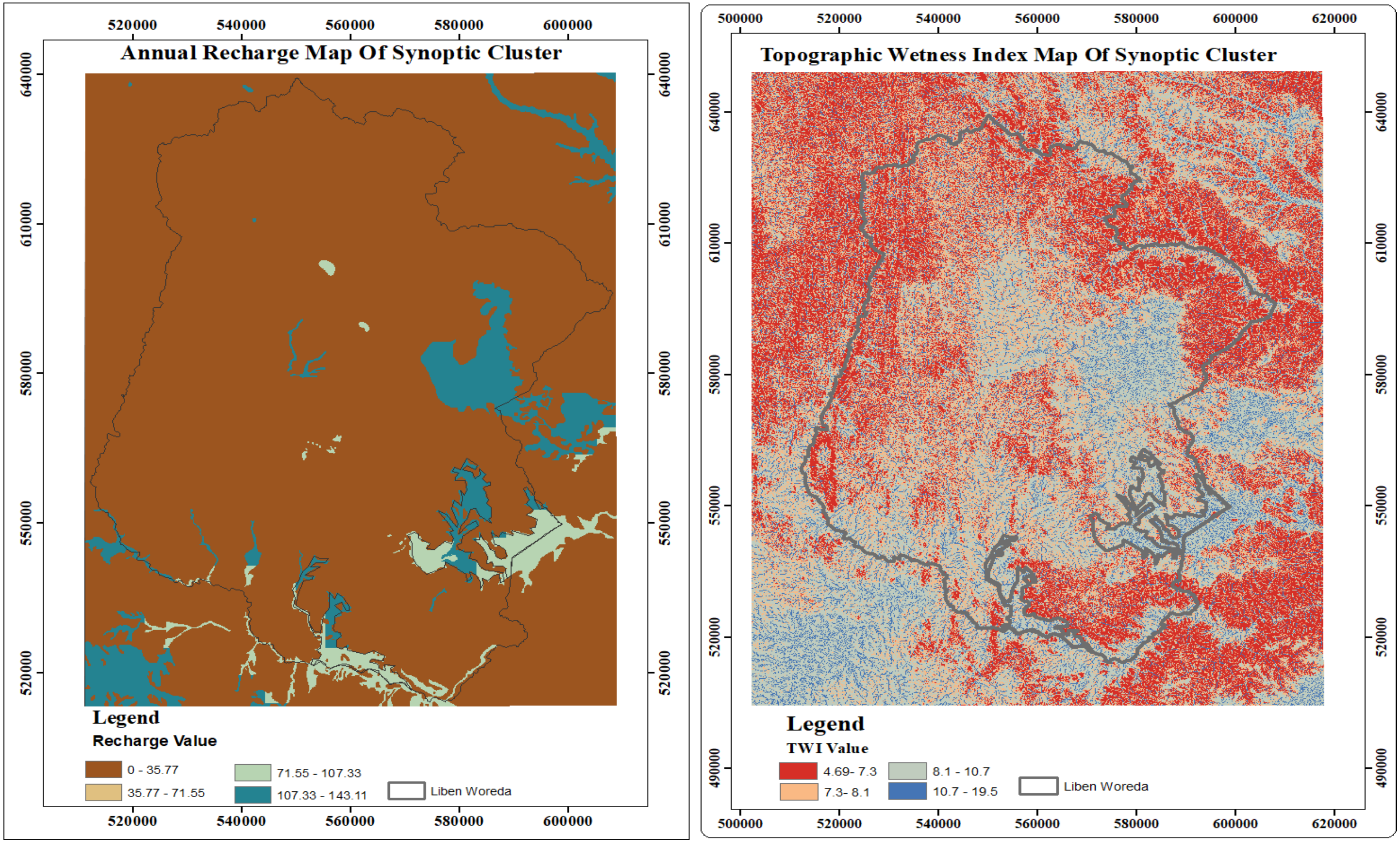


Figure 4.25. Map of TWI (right) and annualy recharge (left) for Liben Woreda in synoptic view

4.5.5. Analytical Hierarchy Process (AHP) and Weights Assignments

The analytic hierarchy approach (AHP) developed by Saaty (1980, 1986, 1992) was used in this study as a decision aiding method to finalize the weights assigned to different themes and their respective features used in deciphering groundwater potentiality. AHP is a simple mathematical matrix-based technique that allows users to assess the relative weight of multiple criteria in an intuitive manner. It allows efficient group decision-making, where group members can use their experience, values and knowledge to breakdown a problem into a hierarchy and solve it by AHP steps (Chowdhury et al. 2009). It also incorporates systematic checks on the consistency of judgments, which is one of the strongest points over the other multi-attribute value processes.

The weightage employed is in accordance with the respective importance of the map theme to groundwater occurrence following the approach of Saraf and Choudhary (1998), Rao and Jugran (2003), Prasad et al. (2008), Jha et al. (2010), Machiwal et al. (2011), Mukherjee et al. (2012) and Singh et al. (2013). The weights of the individual themes and their associated features were then normalized by the Saaty's AHP was used to reduce the subjectivity associated with the assigned weights (Table 4.20). The Consistency Index (CI) of the assigned weights was calculated following the procedure suggested by Saaty (1980, 1992) while the Consistency Ratio, which indicates the probability that the matrix ratings were randomly generated, was also computed using the values of Random Consistency Index (RI) which is the average value of CI for random matrices using the Saaty scale obtained by Forman (1983, 1990) based on the following relations:

Consistency Index = $(\lambda_{max} - n)/(n-1)$;

Consistency Ratio =CI/RI

Where n is the number of criteria or factors

It should be noted that the CR value should be less than 0.10 for consistent weights; otherwise, corresponding weights should be re-evaluated to avoid inconsistency (Saaty 1980, 1986, 1992). For this study, the CR was estimated to be 0.05 which is far below the threshold consistency value of 0.10.

Suitable weights were assigned to the four themes and their individual features after understanding their hydrogeological importance in causing groundwater occurrence in the Liben woreda. The normalized weights of the individual themes and their different features were obtained through the Saaty's analytical hierarchy process (AHP). Furthermore, each of the thematic maps was then assigned weight in the range of 1–9 according to Saaty's scale of assignment (Table 4.18), which depicts the relative importance of the respective themes to groundwater availability. The weights assigned to the respective thematic maps as presented in Table 4.19 indicate that geology was ranked the dominant factor with a normalized weight value of 0.43 while recharge is the least accounted factor with a normalized weight of 0.08 for groundwater occurrence in the Liben synoptic woreda.

After deriving the normal weights of all the thematic layers and feature under individual themes, all the thematic layers were integrated with one another using ArcGIS software in order to demarcate groundwater potential zones index (GWPZI) in the Liben woreda. The index was computed by the integration of the total normalized weights of different polygons using equation stated below. This technique is associated with the study of locations of geographic phenomena together with their spatial dimension and associated attributes (Prasad et al., 2008).

GWPZI = (GGwGGwi + LDwLDwi + TWIwTWIwi + GRwGRwi)

Where, GG is the geology, LD is lineament density, TWI is topographic wetness index, GR is Recharge, w is normalized weight of a theme and wi is the normalized weight of individual classes.

Thus, using raster calculator tools in ArcGIS 10.8 platform, a composite groundwater potential index (GWPI) for the study area (Liben woreda) was generated on the basis of which the overall groundwater potential zones map was produced. In the final integrated layer was divided into four equal classes, i.e., 'high', 'moderate', 'low and very low', in order to delineate groundwater potential zones (chapter five). Finally, well/ borehole data (e.g., yield) was collated from existing wells in the study area. This data was used for the purpose of validation of the proposed groundwater potential map, as a useful guide for a quick assessment of groundwater occurrence on regional scale in the study area.

Table 4-18 Saaty's scale for assignment of weights and its interpretation showing the pair-wise comparison process (Saaty 1980, 1986, 1992)

Less important				Equally important	More important			
Extremely	Very Strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extremely
1/9	1/7	1/5	1/3	1	3	5	7	9

2, 4, 6 and 8 are intermediate values

Table 4-19 Weights of the four thematic layers for groundwater potential zoning in Liben synoptic area

Themes	**Assigned Weights**
Geology (GG)	9
Lineament density (LD)	7
Topographic Wetness Index (TWI)	5
Recharge (GR)	3

Table 4-20 Normalized weights and pair-wise comparison matrix of the four thematic layers for groundwater potential zoning in Liben synoptic area

Theme	**Theme**				**Normalized weight**
	GG	LD	TWI	GR	
GG	1	1	3	5	0.43
TWI	1	1	1	3	0.21
GR	1/3	1	1	3	0.08
LD	1/5	1/3	1/3	1	0.28

CHAPTER 5 : GROUNDWATER POTENTIAL MAPPING FOR EACH WOREDA

After the preparation of all thematic layers required for groundwater potential mapping using GIS overlay analysis, the subsequent tasks were to assign weightage and make reclassification of each layer. Accordingly, the analytical hierarchy processes (AHP) were used to make the weight assignment. Following AHP weight assignment, all thematic layers have been used together to produce groundwater potential maps for each target Woreda using overlay analysis. This section presents all the thematic layers within each target Woreda boundary, result of overlay analysis in a GIS environment and selected potential target sites for further study in Phase III.

5.1. Bule Hora Woreda

The four thematic layers which were integrated for groundwater potential mapping in Bule Hora Woreda are summarized in table 5.1 below. The notes on the description of each thematic layers including classification of potential zones, validation with borehole and scheme datasets, population projection, water demand and selected target sites presented in the sub-sections.

Table 5-1. Assigned and normalized weights for the individual features of the four thematic layers for groundwater potential zoning in Bule Hora Woreda

Class	Class interval	Class Weight	Pixel count	Area (Km2)	Area (%)	Weight	Groundwater prospect
	Lineament layer						
1	0.02 - 0.12	8	43588	435880	25.8	0.21	Very low
2	0.14 - 0.23	14	51518	515180	30.5		Low
3	0.23 - 0.33	18	44183	441830	26.2		Moderate
4	0.33 - 0.49	24	20791	207910	12.3		High
5	0.49 - 0.74	36	8712	87120	5.2		Very high
	Topographic Wetness Index (TWI) layer						
1	4.95 - 7.22	8	66736	667360	39.5	0.27	Very low
2	7.22 - 8.74	14	62422	624220	37.0		Low
3	8.74 - 11.02	18	25333	253330	15.0		Moderate
4	11.02 - 14.39	24	10221	102210	6.1		High
5	14.39 - 22.61	36	4080	40800	2.4		Very high
	Recharge layer						
1	26.1 – 57	8	71761	717610	42.6	0.05	Very low
2	57.1 – 93	14	30711	307110	18.2		Low
3	93.1 – 102	18	33505	335050	19.9		Moderate
4	103 – 116	24	24854	248540	14.8		High
5	116 – 148	36	7510	75100	4.5		Very high

	Lithology layer						
2	Basement rocks of different kinds	12	15792	157920	9.4		Poor
3	Volcanic and pyroclastic rock units	32	89210	892100	52.9	0.46	Good
5	Quaternary and lacustrine sediment deposits	56	63790	637900	37.8		Very good

5.1.1. Integration of Thematic Layers for Groundwater Potential Zoning

The details of geology, rainfall, lineament density, geomorphology, land slope, soil type, land use/land cover, groundwater depth and drainage density together with their spatial distribution in Bule Hora woreda are presented below:

I. Geology/lithology

In general, most parts of the Bule Hora woreda are underlain by volcanic rocks (basalt and pyroclastic deposit) and basement complexes of intrusive granitic and gneissic rocks. Quaternary deposits of alluvial and lacustrine sediments cover limited area in the woreda in the southern periphery. Whereas volcanic rocks outcropped at the central and western part of the woreda and the basement outcrops in the eastern parts of the woreda.

However, the lithological units found in the woreda area are further classified into three major groups based on their significances to groundwater occurrence and productivity using borehole data on yield and transmissivity analysis.

- Recent Quaternary alluvium and lacustrine deposits
- Volcanic rocks (basalt and pyroclastic deposit)
- Basement rocks of granitic and gneissic rocks overlain by thin eluvium at places

The crystalline basement and volcanic rocks underlain by Quaternary sediment are the main lithologic framework of the Bule Hora woreda (Figure 5.1).

Usually, massive unfractured lithologic units in basement complex settings have little influence on groundwater availability except in cases with secondary porosity through the development of weathered regolith, and fractured bedrock units, which form potential groundwater zones. Hence, based on the presence and nature of the weathered regolith units and fracture systems, appropriate weights are assigned to the different lithological units in the study area. The weightage (Figure 5.1) in terms of increasing groundwater potentiality is in the order of poor productivity of basement rocks and phonolites and rhyolites (0.12), moderate productivity of volcanic rocks (0.32) and high productivity Quaternary deposits (0.56).

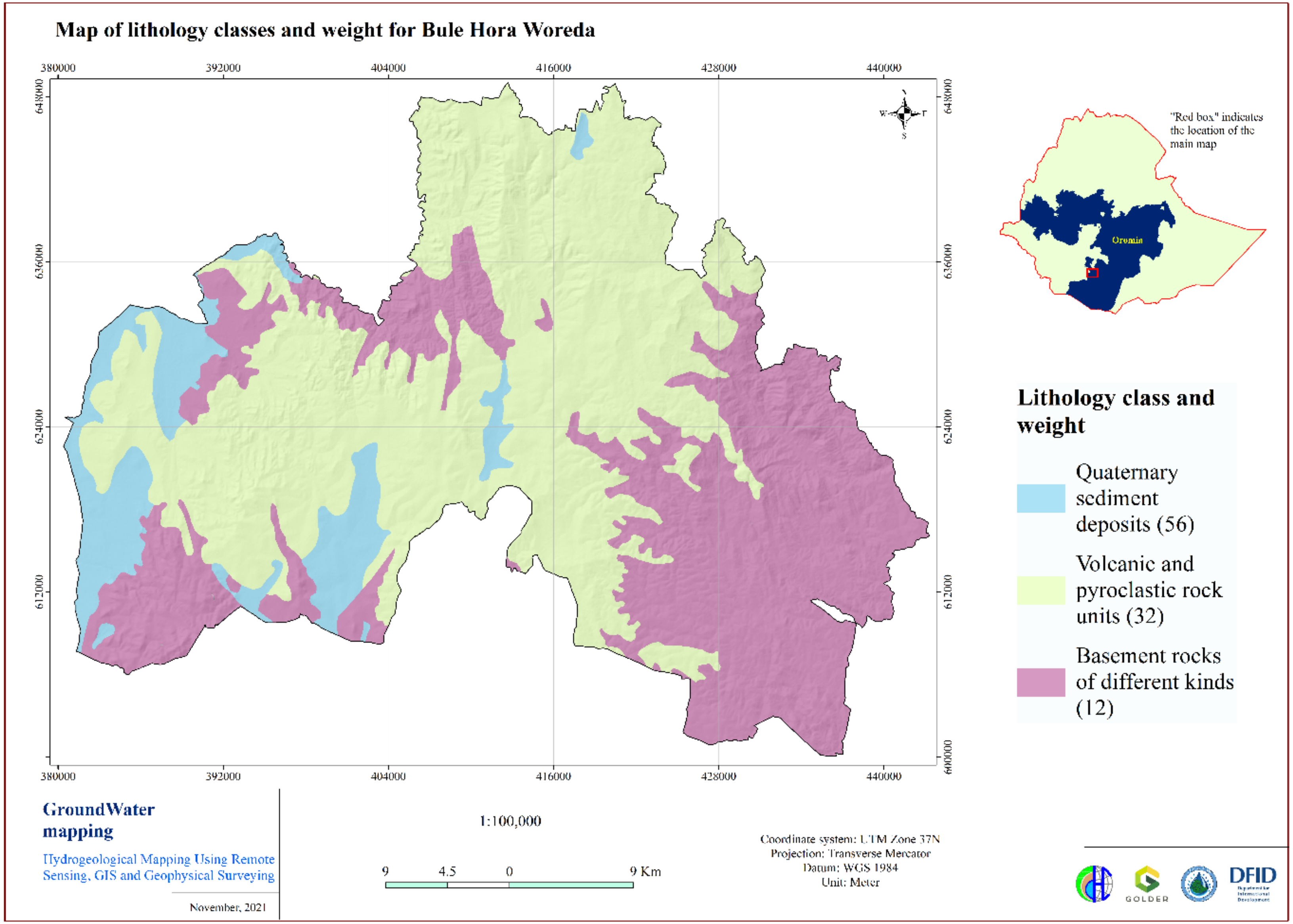


Figure 5.1. Map of lithology classes and weight for Bule Hora Woreda

II. Lineaments and lineament density

The study area is moderately affected by lineaments and/or fractures consequent to several tectonic activities in the past. Two prominent directions identified are NW-SE and N–S trending lineaments. Usually, lineament density map is a measure of quantitative length of linear feature per unit area which can indirectly reveal the groundwater potentials as the presence of lineaments usually denotes a permeable zone. For most of the study area, the lineament density varies from less than 0.12 km/Km2 to 0.74 km/Km2 (Figure 5.2). Though the lineaments are widespread across the study area, however, the distribution of lineaments suggests geologic control with areas underlain by crystalline basement complex and associated volcanics having relatively higher lineament density of 0.49 – 0.74 km/Km2.

Thus, areas with higher lineament density are regarded as good for groundwater development. Consequently, higher weightage of 0.36 was assigned to area with high density of lineaments, while a low weightage of 0.12 was assigned to areas with low lineament density (Figure 5.2).

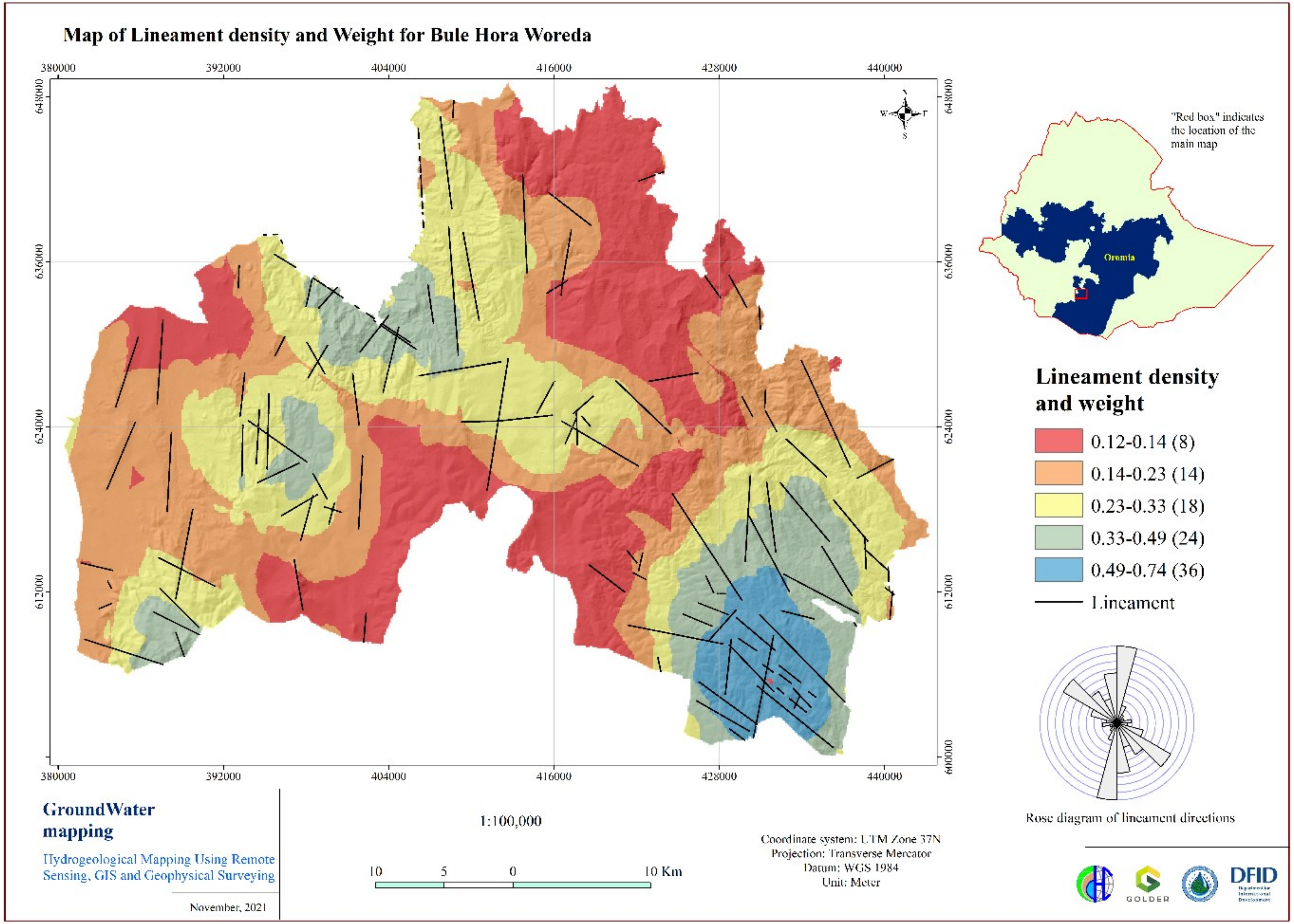


Figure 5.2. Map of lineament density and weight for Bule Hora Woreda

III. **Topographic Wetness Index (TWI)**

In this study area, the TWI value ranges between 4.95 and 22.61 (Figure 5.3). A closer look at the classification revealed that most the high elevated areas and drainage systems with steep slopes have relatively lower TWI value while the low-lying areas and drainage systems with gentle and flat slopes such as the central and western periphery of the Woreda.

These are area with higher wetness index value are supposed to be where runoff waters from highlands flow and accumulates mostly. Therefore, an area with higher value of TWI has good prospect for groundwater occurrence and flow, and accordingly high weightage value of 0.56 was assigned to this class. Whereas areas with lowest TWI value are steep slopes which triggers runoff were considered with low groundwater prospect and given low weightage value of 0.13 (Figure 5.3).

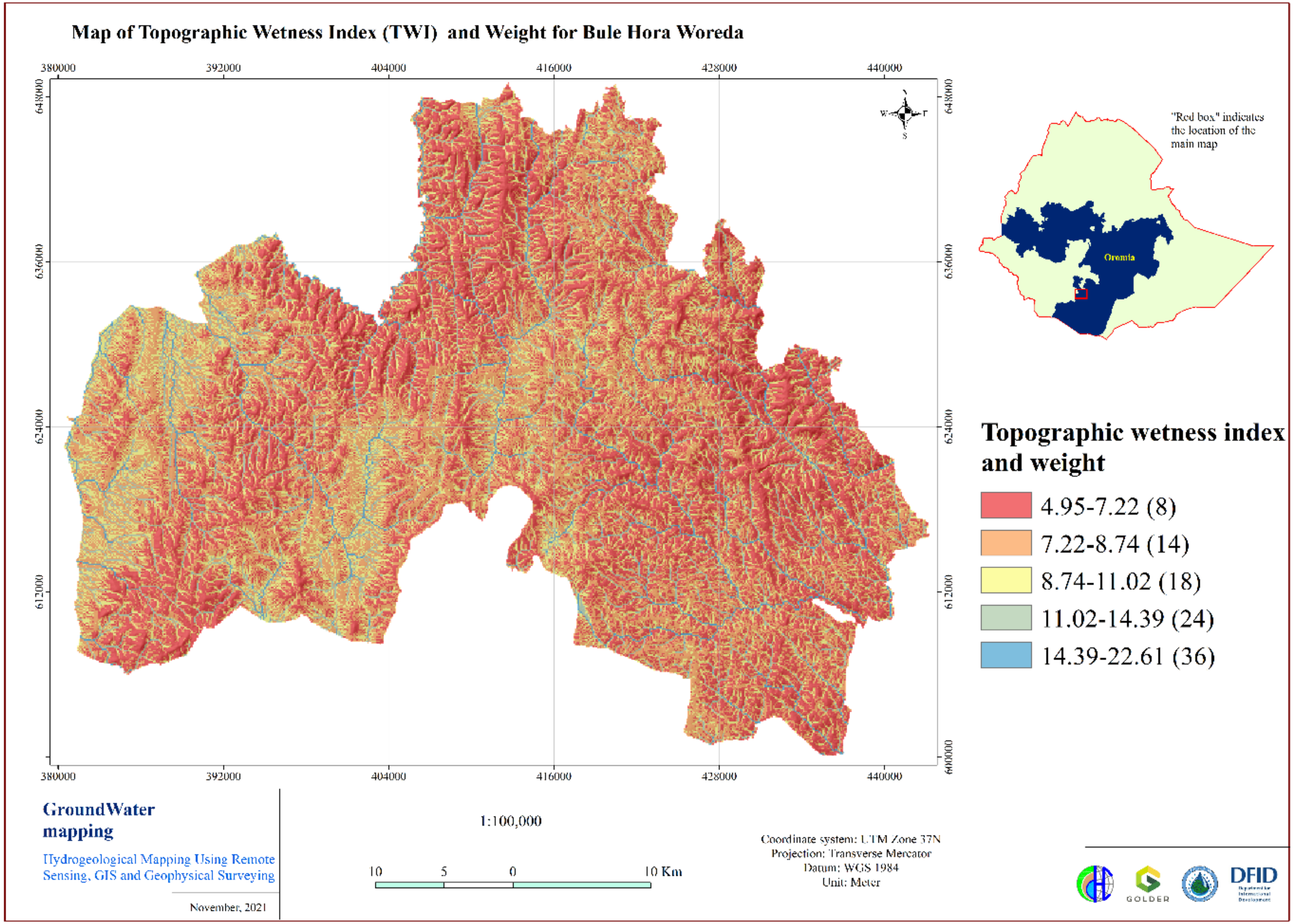


Figure 5.3. Map of topographic wetness index (TWI) and weight for Bule Hora Woreda

IV. **Recharge**

The 10 years spatial average annual recharge rate distribution in the Bule Hora woreda ranges from 26.1 to 148 mm suggesting groundwaters in most part of the woreda area underlain by basement complex receive low amount of recharge while areas underlain by volcanic rocks and Quaternary sediments have relatively higher recharge amount (Figure 5.4). Accordingly, areas with higher and moderate amount of recharge have weightage factor of 0.24 and 0.36, respectively signifying very good and moderate groundwater potential, while areas with the lowest amount of recharge have weightage factor of 0.8, suggesting poor groundwater potentiality. A closer look at the recharge thematic map revealed that most of the eastern parts of the woreda have relatively lower recharge. Generally, the study area is characterized by very low to low mean annual recharge amount, whereas only limited parts of the Woreda have moderate to high mean annual recharge amount 117 - 148 mm per 10 years but the dominant part of the areas at the center and southern parts have low mean recharge amount of < 57 mm (Figure 5.4).

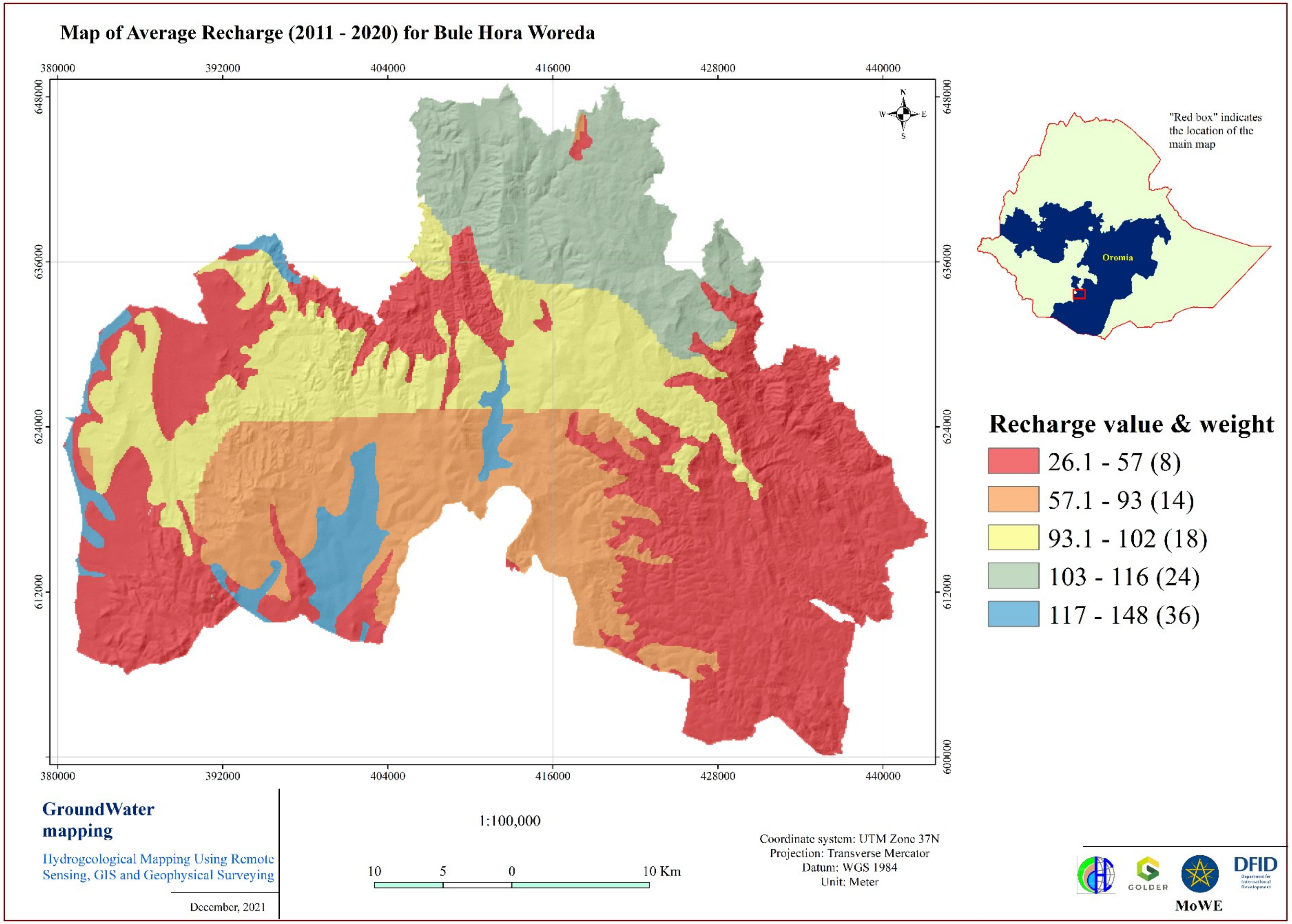


Figure 5.4. Map of average recharge (2011 – 2020) in millimeters and weight for Bule Hora Woreda

5.1.2. Classification of Groundwater Potential Zones

The hydrogeological system of Bule Hora woreda is comprised of four main lithological units as Quaternary deposits, different volcanic rocks, Phonolites and rhyolites and crystalline basement rocks. At regional scale, Quaternary deposits form extensive and moderately productive aquifers. Within the domain of Bule Hora woreda, theses, Quaternary deposits form aquifers with high groundwater potential.

At regional scale, volcanic rocks form extensive and moderately productive aquifer. However, at local scale, within the domain of Bule Hora woreda, due to the geomorphic setup, the volcanic rocks form moderately productive aquifer as revealed from existing borehole yields.

Only the upper weathered and slightly fractured part of the crystalline basement rocks along lineamnets and faults have potential to store groundwater at shallow depth. Weathered and slightly fractured Crystaline basement rocks with overlying Quaternary deposit form potential aquifer within the domain of Bule Hora Woreda along lineament and fault lines and associated plains.

Hydrogeological data from water point inventory, hydro-chemical data and geophysical investigation outcome of the next phase will help to improve the understanding of hydrogeological frame work of the area.

On the basis of the assignment and normalized weighting of the individual features of the thematic layers, a potential groundwater map was produced (Figure 5.5). The potential groundwater zones (PGWIZ) of Bule Hora woreda revealed four distinct zones, namely low (unsuitable), moderate, high and very high zones whose distribution and extents are presented in Table 5.2.

The potential map, as presented in Figure 5.5, gives a quick assessment of the occurrence of groundwater resources in the study area. The groundwater potential map revealed that most elevated areas in the northeastern and southwestern parts of the Bule Hora Woreda generally have low potential while low grounds in the west and at central parts generally exhibits high to very high groundwater potential. Generally high to very high groundwater potentiality of the study area is a confirmation of generally moderate to high productive aquifers of Quaternary alluvial and lacustrine deposits, whereas low and very low groundwater potential areas have an indication of limited aquifers capabilities of basement complex terrain and other rocks in elevated areas.

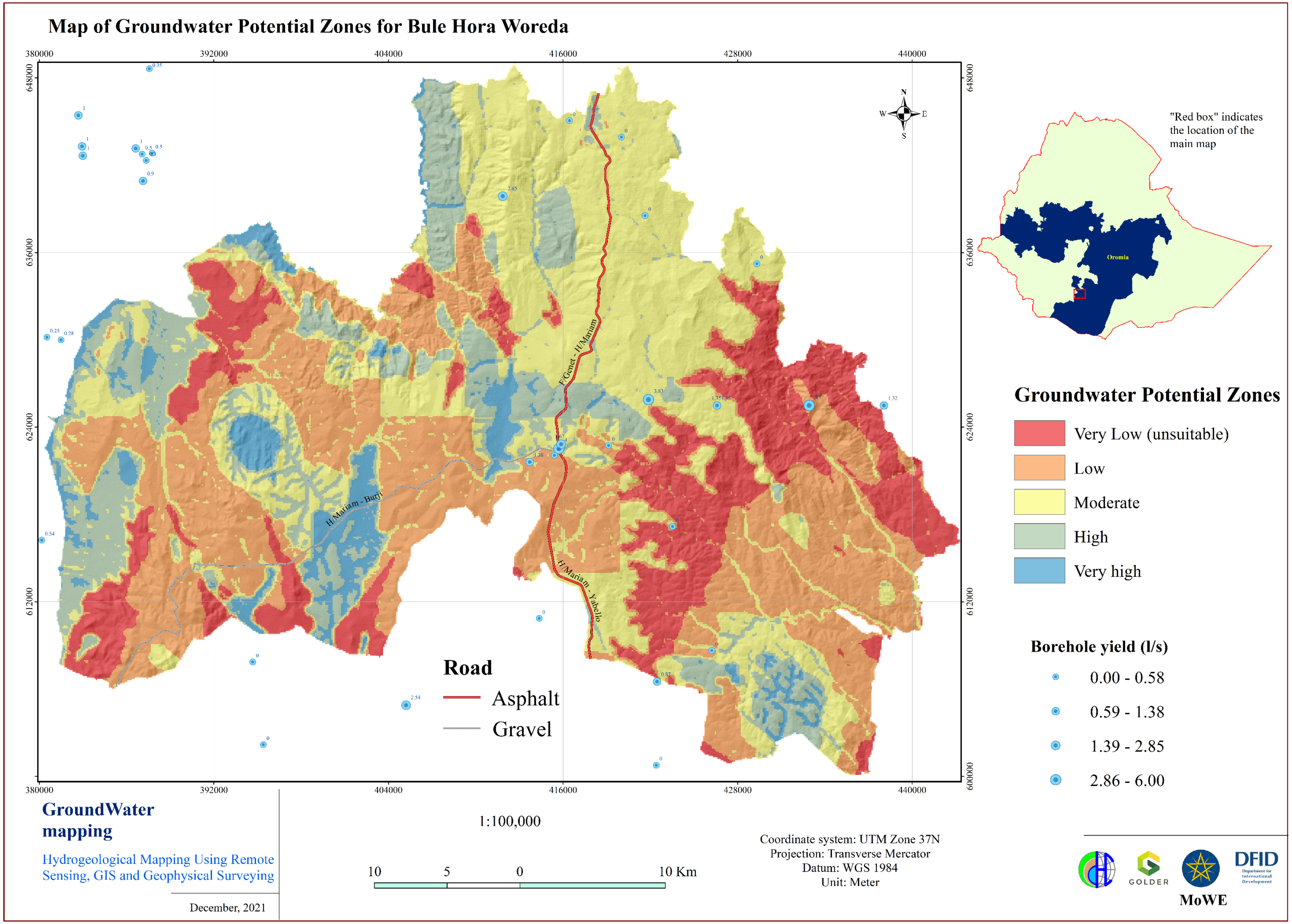


Figure 5.5. Map of groundwater potential zones showing five zones identified by the GIS overlay analysis in Bule Hora Woreda

Furthermore, a closer assessment of the groundwater potential map revealed that the distribution is a reflection of the geology and lineament density in addition to the topographic wetness index control. In Quaternary sediments underlain by volcanic rocks especially in the central part of the woreda are characterized having dense lineaments and apparently deep fracturing and weathering have high and very high groundwater potential. On the other hand, areas underlain by crystalline basement complexes in the western and eastern peripheries of the woreda areas are characterized by small ridges and steep slopes, lower recharge, and lineament densities, exhibit low groundwater potential. Moreover, low drainage densities and predominance of crystalline rock outcrops can be attributed to the observed low groundwater potentials at the peripheries of the study area. However, predominance of Quaternary sediments underlain by volcanic rocks having high lineament density, high recharge and low slope which can enhance infiltration of water into the groundwater system can be attributed to the observed high groundwater potential. Summary of the groundwater potential zones identified in the Bule Hora woreda is presented in the table below (Table 5.2).

Table 5-2. *Classification of groundwater potential zones and coverage areas alongside the respective yield categories in Bule Hora Woreda*

Class	Class interval	Pixel count	Area (Km2)	Area (%)	Well yield (l/s)	Groundwater prospect
1	132 - 150.87	27552	275520	16.3	-	Very low
2	150.87 - 174.78	53626	536260	31.8	0.5 - 1.6	Low
3	174.78 - 196.56	53369	533690	31.6	1.6 - 2.4	Moderate
4	196.56 - 219.44	25661	256610	15.2	1.6 - 3.83	High
5	219.44 - 281.88	8584	85840	5.1	1.6 - 4.0	Very high

5.1.3. Validation with Borehole Yield Data

To validate the classification of the groundwater potential zones as revealed by the GIS based groundwater potential map, data on existing wells (yield) were collected for over 35 dug and drilled wells in and around Bule Hora woreda. Since the wells were drilled for water supply purpose without proper pumping test, they lack necessary information about aquifer properties and most of them have even no yield information.

The available dug well and borehole data were superimposed on the groundwater potential map and numbers of wells with different yield ranges for different groundwater potential zones were crudely evaluated. As far as the secondary data we have is concerned, the yields of the deep drilled boreholes in the woreda and its surrounding areas vary from 0.22 to 4.54 lit/sec (Figure 5.4). As shown in the same figure, the occurrence of relatively high yield wells is associated with high lineament zone and Quaternary sediments underlain by volcanic rocks. This is also consistent with the low, moderate, high and very high groundwater potential classification of the GIS map for these rocks' unit.

The validation clearly highlights the efficiency of the integrated RS and GIS methods employed in this study as useful modern approach for proper groundwater resource evaluation and sustainable

groundwater development. Nonetheless, the groundwater potential zonation map presented here can be applied only for further study by providing quick prospective guides for groundwater in such complex volcanic and basement area.

5.1.4. Population projection and water demand

5.1.4.1. Population

It is essential that the water supply system is designed to meet the requirements of the population expected to be living in the community at the end of design period by taking into account the design period and annual growth rate. Hence in order to avoid or minimize the aforementioned population related risks, efforts are made to review & justify the credibility of the available population data and growth rate figures.

Population projection is made making use of the geometric growth rate method by using the base population figure estimated by the central statistical Authority. The CSA has set average growth rates for urban and rural areas of the country varying at different times during the design period as shown in the table below. Accordingly these values are adopted in forecasting future population of the town.

Table 5-3 CSA Rural Population Growth Rates

Rural Population Projection Growth Rate of Regions: 2008-2037						
YEAR / Growth Rate % (Rural)	2008-2012	2013-2017	2018-2022	2023-2027	2028-2032	2033-2037
Oromia Region	2.74	2.54	2.29	2.03	1.8	1.56
SNNP Region	2.49	2.37	2.31	2.03	1.82	1.57
Somali Region	2.75	2.63	2.35	2.05	1.89	1.83
Gambela Region	3.52	3.1	3.13	2.76	2.46	2.31

Source: CSA Population Projection for Ethiopia 2007-2037, Addis Ababa July 2013

Geometric method forecasting formula

$$P=Po\,(1+r)^{n}$$

Where P – projected population

Po – current population

n – Number of years for projection

r – Population growth rate

The population of Bule Hora Woreda has been projected forward until 2036 using the projected scale of Oromia Regional State. The minimum and maximum population in the Woreda is 2,967 and 21,113 respectively. The total population of the Bule Hora Woreda in 2036 is going to be 429,735. Figure 5.6 presents the projected population for each kebele in the Woreda.

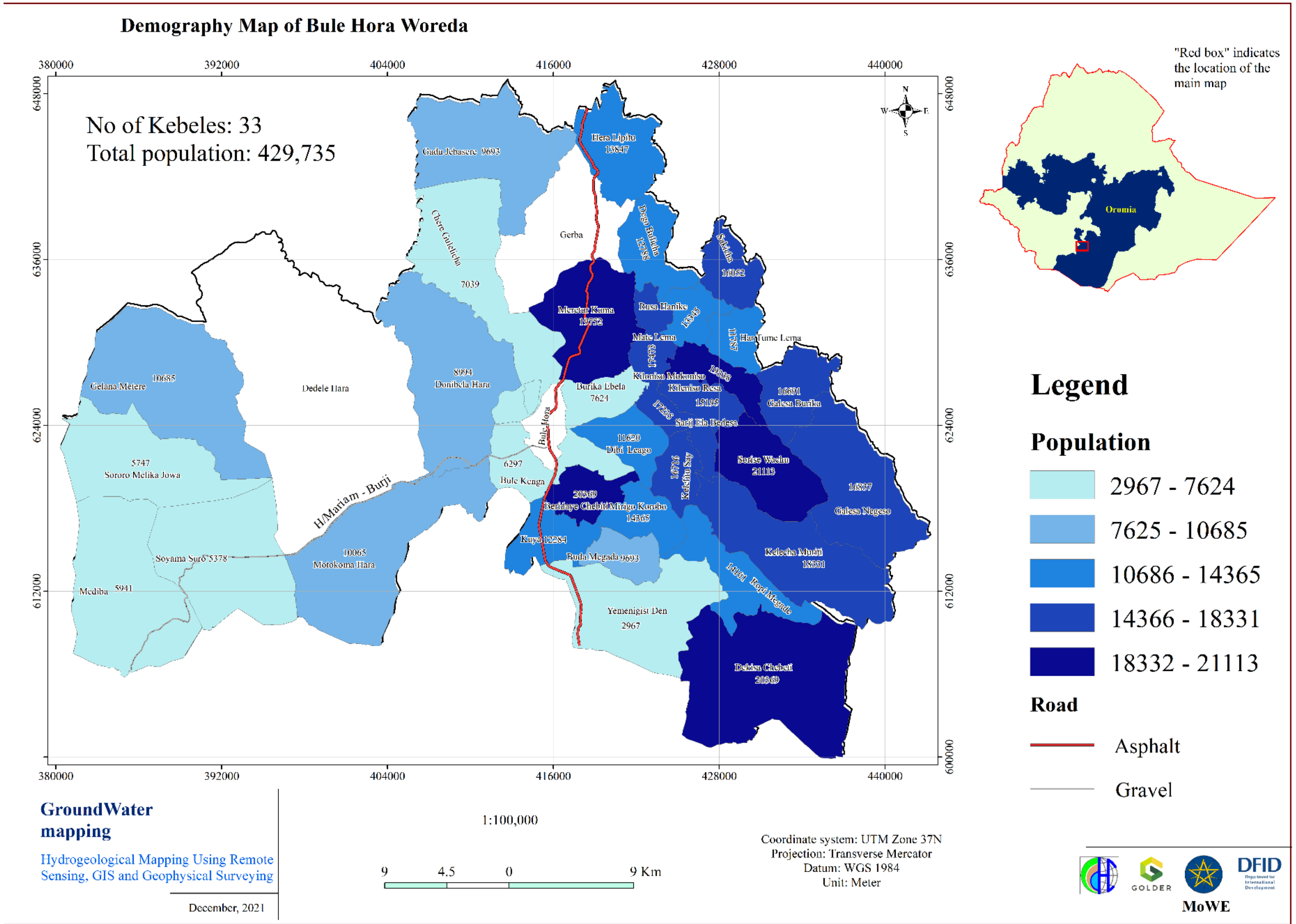


Figure 5.6. Map of projected population (2036) for Bule Hora Woreda.

5.1.4.2. Water Demand Projection

Projected Water Demand

Estimating water demands mainly depends on the size of the population to be served, their standard of living and activities. To make the demand projection reliable and suitable for rural areas it is better to classify in details as domestic and non-domestic demands.

Domestic Water Demand

Domestic water demand is the amount of water needed for drinking, food preparation, washing, cleaning, bathing and other miscellaneous domestic purposes. The amount of water used for domestic purposes greatly depends on the lifestyle, living standard, and climate, mode of service and affordability of the users.

Domestic water demand service can be categorized according to the level of service to be provided and amount of per capita water required satisfying the demand served by the level of service. Modes of services used for our projection are classified into four categories, namely: -

- Traditional Source users (TSU)
- Public tap users (PTU)
- Yard connections and Neighbourhood (shared) connections (YCO) & (YCS)
- House tap connections (HTU)

In projecting the domestic water demand, the following procedures were followed:

- Determining population percentage distribution by mode of service and its future projection
- Establishment of per capita water demand by purpose for each mode of service;
- Projected consumption by mode of service;
- Adjustment for climate;
- Adjustment due to socio-economic conditions.

After considering the necessary mode of services, per-capita demand and applying the adjustment factors the domestic demand for the corresponding year and population has been calculated.

Non-Domestic Water Demand

Non-domestic water demand was also determined systematically. We have classified it into three major categories based on our projection:

- Institutional water demands (Public and governmental);
- Commercial water demand;
- Livestock water demand

N.B: - The use of a reliable base population figure is very important for optimizing the water sources but adopting 2007 CSA data as a base population has real impact on the projection so to compensate some unforeseen situation like migration and unplanned rural town growth. To compensate for such

- To estimate the demand of public institutions and commercial services we have adopted 15% - 20% of the domestic demand for our consumption.
- The demand for livestock watering adopted in the projection is 10% -15% of the domestic demand.

Total Average daily day demand

The average daily day demand is taken to be the sum of domestic demands and non-domestic demand. The water demand in a day varies with time according to the consumer's life style. It is the total sum of adjusted domestic, public and livestock demand.

Maximum Day Demand

The maximum day demand is the highest demand of any one 24-hour period over any specific year. It represents the change in demand with season. This demand is used to design source capacity. The deviation of consumption from the average day demand is taken care of as per the maximum daily coefficient figures. Usually a value from1.1 to 1.3 is adopted as maximum day factor. A constant value of 1.3 is adopted as maximum day factor for all of the villages.

Figure 5.7 shows the distribution of water demand in each Kebeles of the Woreda. The minimum and maximum water demand for Kebeles is 276 M^3/day and 1,897 M^3/day respectively. The overall water demand for the projected population in the Bule Hora Woreda is 38,610 M^3/day.

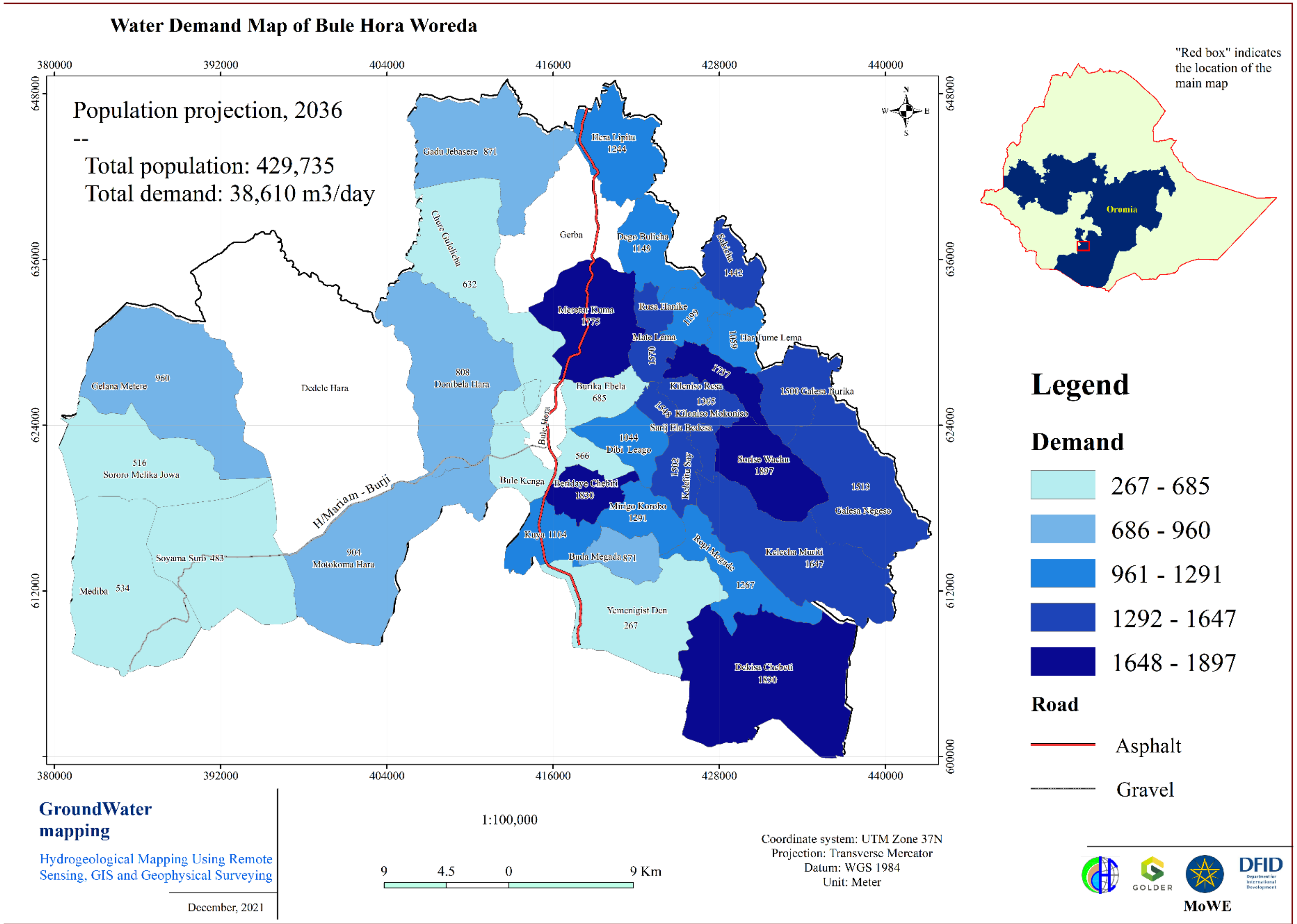


Figure 5.7. Map of water demand (M^3/day) for Bule Hora Woreda.

5.1.5. Proposed Target Sites

Four target sites are identified and proposed within the woreda based on the identified groundwater potential zones, the productivity of the hydro-stratigraphic units with their expected optimum borehole yield, proximity to beneficiaries and population density. With further discussion and consultation with stakeholders, two priority sites will be selected for further hydrogeological and geophysical investigations in phase III. The following are the four proposed sites:

Target Site-I:

This target site is in the central part of the woreda. It is situated in the identified very high potential zones. This target site mainly falls on volcanic rocks.

Target Site-II:

This target site is in the south-central part of the woreda. It is situated in the identified very high groundwater potential zones. This target site mainly falls on volcanic rocks.

Target Site-III:

This target site is in the west central part of the woreda. It is situated in the identified very high groundwater potential zones. This target site mainly falls on volcanic rocks.

Target Site-IV:

This target site is located in the northern peripheral part of the woreda. It is situated in the identified very high groundwater potential zones. This target site mainly falls on Quaternary deposit underlain by volcanic and basement rocks.

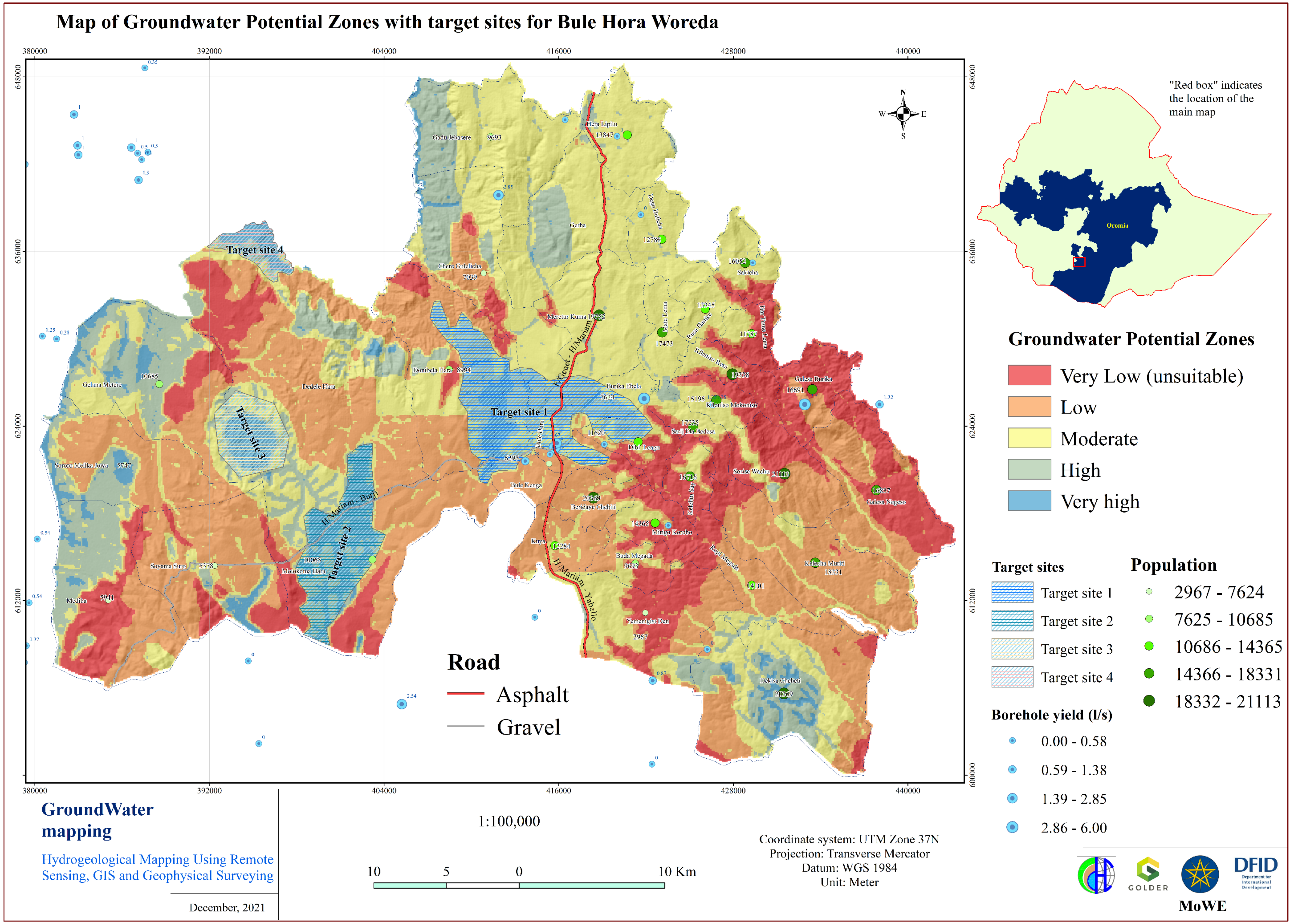


Figure 5.8. Map of groundwater potential zones with selected target sites for Bule Hora Woreda

5.1.6. Conceptual hydrogeological model of Bule Hora Woreda

Hydrogeological conceptual models are collections of hypotheses based on geological structural and geomorphological evidence and existing wells lithologic logs to describe and understand the groundwater occurrence, localization and movement beneath the ground surface. The purpose of the hydrogeological model across inferred groundwater flow direction is to reflect the prototype of regional groundwater flow system into of the two priority sites selected for further study in phase III.

Due to proximity to the Main Ethiopian Rift, rock units are dislocated and placed in juxtaposition against each other. This region has a compartmentalized groundwater flow system constrained by geological structures and topography. Groundwater gets recharge mainly from local rain that falls on central and a southern surrounding highland with expected lateral inflow from adjacent highlands. Groundwater flow direction is generally towards north towards Lake Abaya and central lowlands through fractured volcanic rocks. Hydrogeological conceptual model for Bule Hora Woreda will be prepared based on the converging evidence of secondary data including digital elevation model (DEM), geological and hydrogeological maps and structures, lithological well logs, ones the target sites are selected out of the proposed ones during stakeholders' consultation workshop. The conceptual hydrogeological models for this woreda to be constructed along/across groundwater flow path will be produced after stake holder consultation workshop to select priority target sites for further hydrogeological characterization. The conceptual hydrogeological model summarizes what is known about the hydrogeological system and thereby provides a framework for hydrogeological system of the target sites in the woreda including the major groundwater flow zone (inflow, groundwater flow paths, inferred depth, and outflow) and groundwater table and groundwater condition of Bule Hora woreda using existing data of spring and boreholes.

5.2. Mirab Abaya Woreda

The four thematic layers which were integrated for groundwater potential mapping in Mirab Abaya Woreda are summarized in table 5-4 below. The notes on the description of each thematic layers including classification of potential zones, validation with borehole and scheme datasets, population projection, water demand and selected target sites presented in the sub-sections.

Table 5-4. Assigned and normalized weights for the individual features of the four thematic layers for groundwater potential zoning in Mirab Abaya Woreda

Class	Class interval	Class Weight	Pixel count	Area (Km2)	Area (%)	Weight	Groundwater propsect
	Lineament layer						
1	0 - 0.092	8	6756	67560	11.0	0.21	Very low
2	0.093 - 0.19	14	13618	136180	22.1		Low
3	0.2 - 0.281	18	18179	181790	29.5		Moderate
4	0.29 - 0.36	24	15957	159570	25.9		High

5	0.37 - 0.50	36	7174	71740	11.6		Very high
	Topographic Wetness Index (TWI) layer						
1	4.59 - 7.12	8	21615	216150	35.0	0.27	Very low
2	7.13 – 8.92	14	21181	211810	34.3		Low
3	8.93 - 11.1	18	11470	114700	18.6		Moderate
4	11.2 – 14.1	24	5388	53880	8.7		High
5	14.2 – 23.0	36	2031	20310	3.3		Very high
	Recharge layer						
1	67.1 – 87	8	7315	73150	11.9	0.05	Very low
2	87.1 – 100	14	16878	168780	27.5		Low
3	101 – 110	18	17212	172120	28.1		Moderate
4	111 – 122	24	12704	127040	20.7		High
5	123 – 143	36	7172	71720	11.7		Very high
	Lithology layer						
1	Basement rocks of different kinds	12	3736	37360	6.1	0.46	Poor
2	Basic volcanic and pyroclastic rock units	32	34261	342610	55.6		Good
3	Quaternary sediment and lacustrine deposits	56	23572	235720	38.3		Very good

5.2.1. Integration of Thematic Layers for Groundwater Potential Zoning

The details of geology, rainfall, lineament density, geomorphology, land slope, soil type, land use/land cover, groundwater depth and drainage density together with their spatial distribution in Mirab Abaya woreda are presented below:

I. Geology/lithology

In general, most parts of Mirab Abaya woreda are mapped as volcanic rocks underlain at places with Quaternary sediment deposits. Quaternary deposits of alluvial and lacustrine sediments are mostly found in the eastern part of the woreda along the Abaya Lake shore. Whereas rhyolites outcropped as localized ridges in the central parts of the woreda.

However, the lithological units found in the woreda area are further classified into three major groups based on their significances to groundwater occurrence and productivity using borehole yield a.

- Quaternary sediments and lacustrine deposits,
- Basic volcanics, dominantly basalts and basalt flows,
- Rhyolitic and trachytic lava flows and plugs.

Usually, massive volcanic rocks devoid of primary porosity have little influence on groundwater availability. In this case secondary porosity is very important through the development of weathered regolith, and fractured bedrock units, which form potential groundwater zones. Hence, based on the presence and nature of the weathered regolith units and fracture systems, appropriate weights are assigned to the different lithological units in the study area. The weightage (Figure 5.9) in terms of increasing groundwater potentiality is in the order of poor productivity of Rhyolitic and trachytic lava flows and plugs (0.12), moderate productivity of volcanic rocks (0.32) and high productivity Quaternary deposits (0.56).

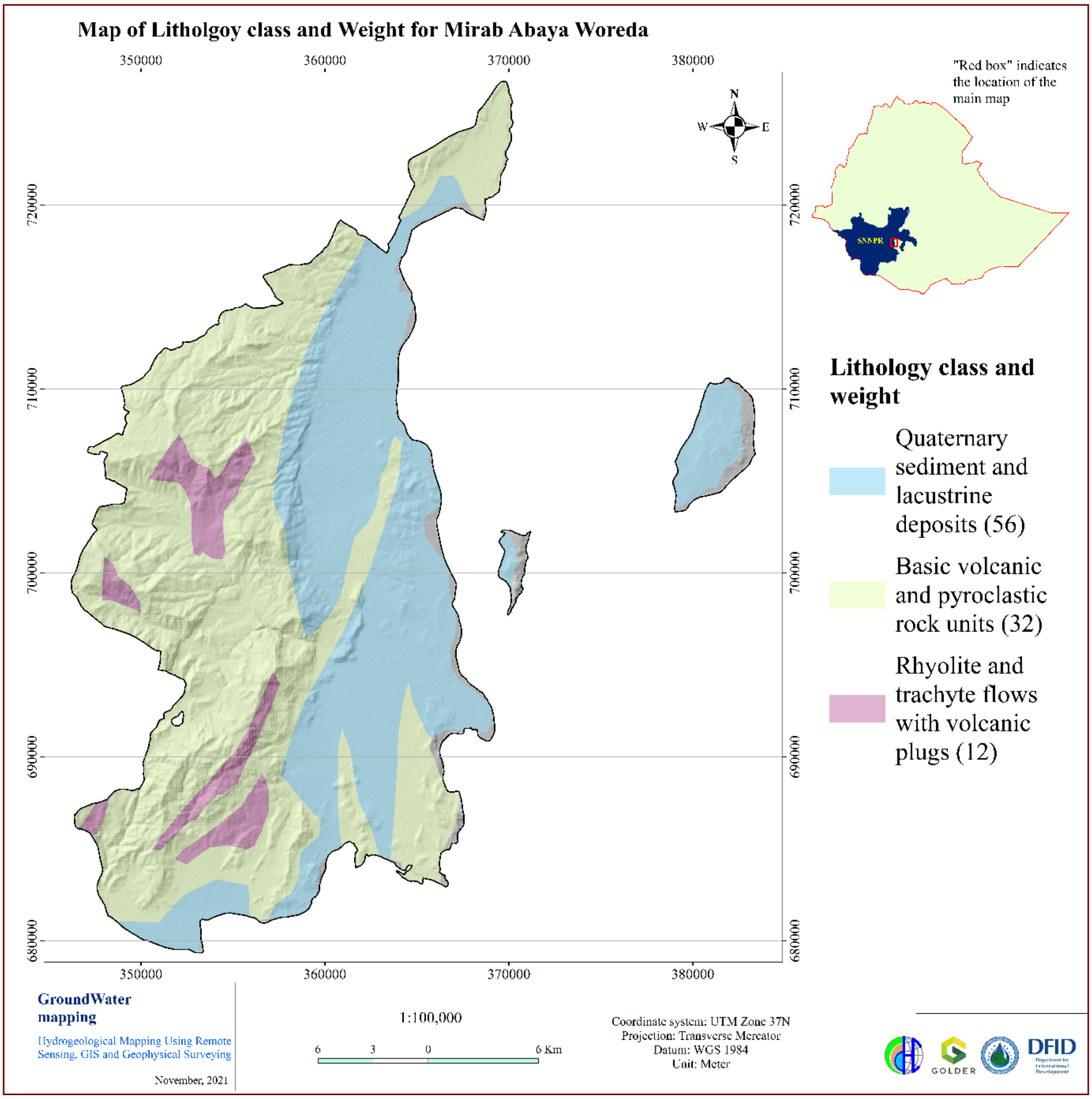


Figure 5.9. Map of lithology class and weight for Mirab Abaya Woreda

II. Lineaments and lineament density

The study area is highly affected by lineaments and/or fractures consequent to a number of tectonic activities in the past. Two prominent directions identified are NE-SW and E-W trending lineaments at woreda scale. Usually, lineament density map is a measure of quantitative length of linear feature per unit area which can indirectly reveal the groundwater potentials as the presence of lineaments usually denotes a permeable zone. For most of the study area, the lineament density varies from less than 0.092 km/Km2 to 0.5 km/Km2 (Figure 5-10). Since lineaments are masked by recent deposits along the Lake Abaya shore, their impact on ground water occurrence is vivid in that particular area. Higher lineament density of 0.29 – 0.50 km/Km2) is obtained for the areas towards mountain but areas along side of the lake shore covered with sediments have low lineament density (<0.29 km/Km2).

Thus, areas with higher lineament density are regarded as good for groundwater development. Consequently, higher weightage of 0.36 was assigned to area with high density of lineaments, while a low weightage of 0.08 was assigned to areas with low lineament density (Figure 5.10).

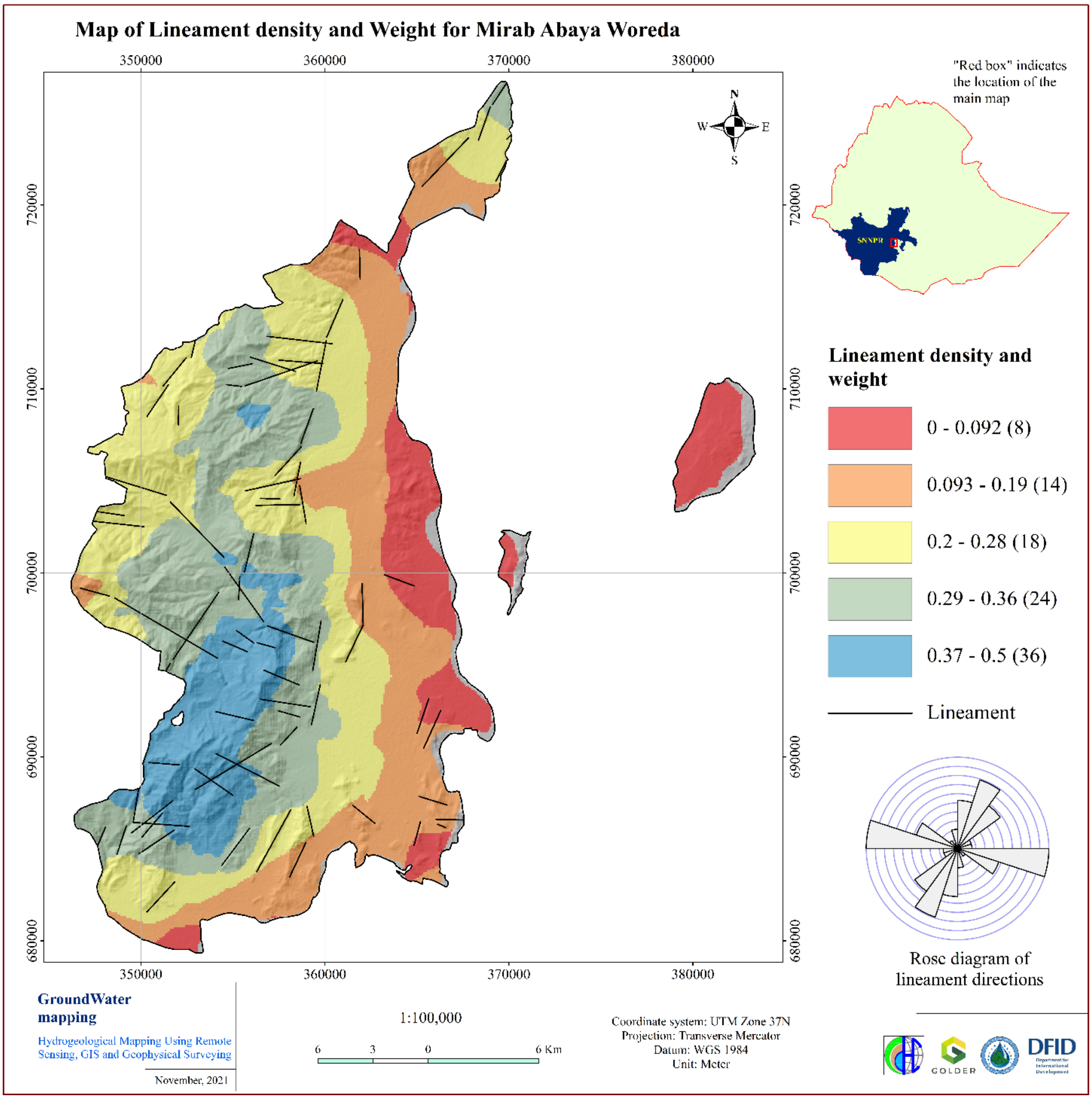


Figure 5.10. Map of lineament density and weight for Mirab Abaya Woreda

III. Topographic Wetness Index (TWI)

In this study area, the TWI value ranges between 4.59 and 23. A closer look at the classification revealed that most elevated areas and drainage systems with steep slopes have relatively lower TWI value while the low lying areas and drainage systems with gentle and flat slopes have relatively higher wetness index value where runoff from highlands flow and accumulates mostly. Therefore, an area with higher value of TWI has good prospect for groundwater occurrence and flow, and accordingly high weightage value (0.36) was assigned to this class. Whereas, areas with lowest TWI value are steep slopes which triggers runoff were considered with low groundwater prospect and given low weightage value of 0.08 (Figure 5.11).

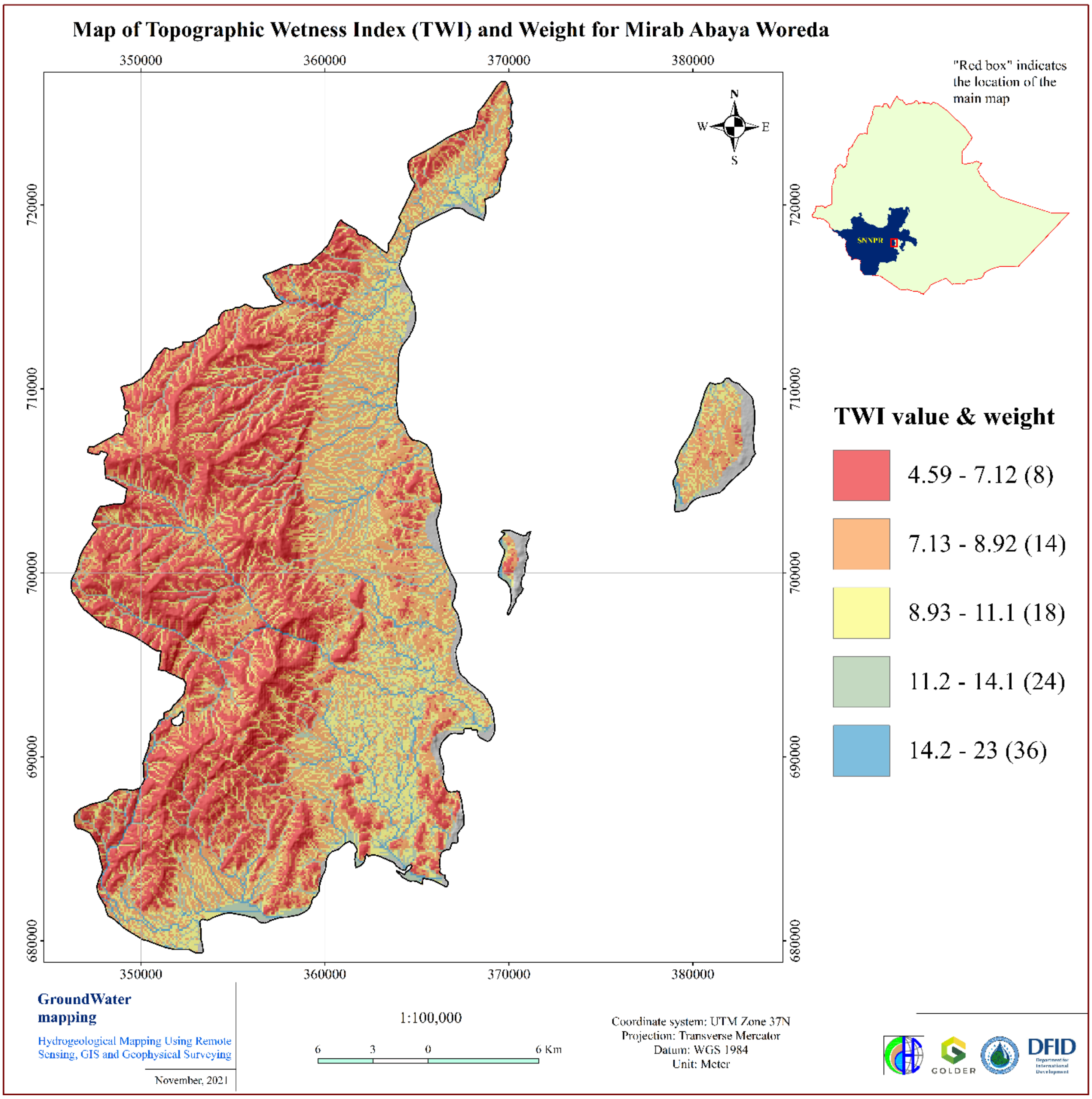


Figure 5.11. Map of topographic wetness index (TWI) and weight for Mirab Abaya Woreda

IV. Recharge

The 10 years spatial annual recharge rate distribution in the Mirab Abaya woreda ranges from 67.5 to 143 mm suggesting groundwaters in most part of the woreda area having volcanic rocks and Quaternary sediments outcrops receive high amount of recharge while areas underlain by rhiyolits and trachytes forming ridges have relatively low recharge amount. Accordingly, areas with higher and moderate amount of recharge have weightage factor of 0.36 and 0.24, respectively signifying very good and moderate groundwater potential respectively while areas with the lowest amount of recharge have weightage factor of 0.08, suggesting poor groundwater potentiality. A closer look at the recharge thematic map (Figure 5.12) revealed that most of the western elevated parts of the woreda have relatively low recharge (<130 mm/y). Significant portion of the area is characterized by moderate to high recharge amount (>130 mm/yr).

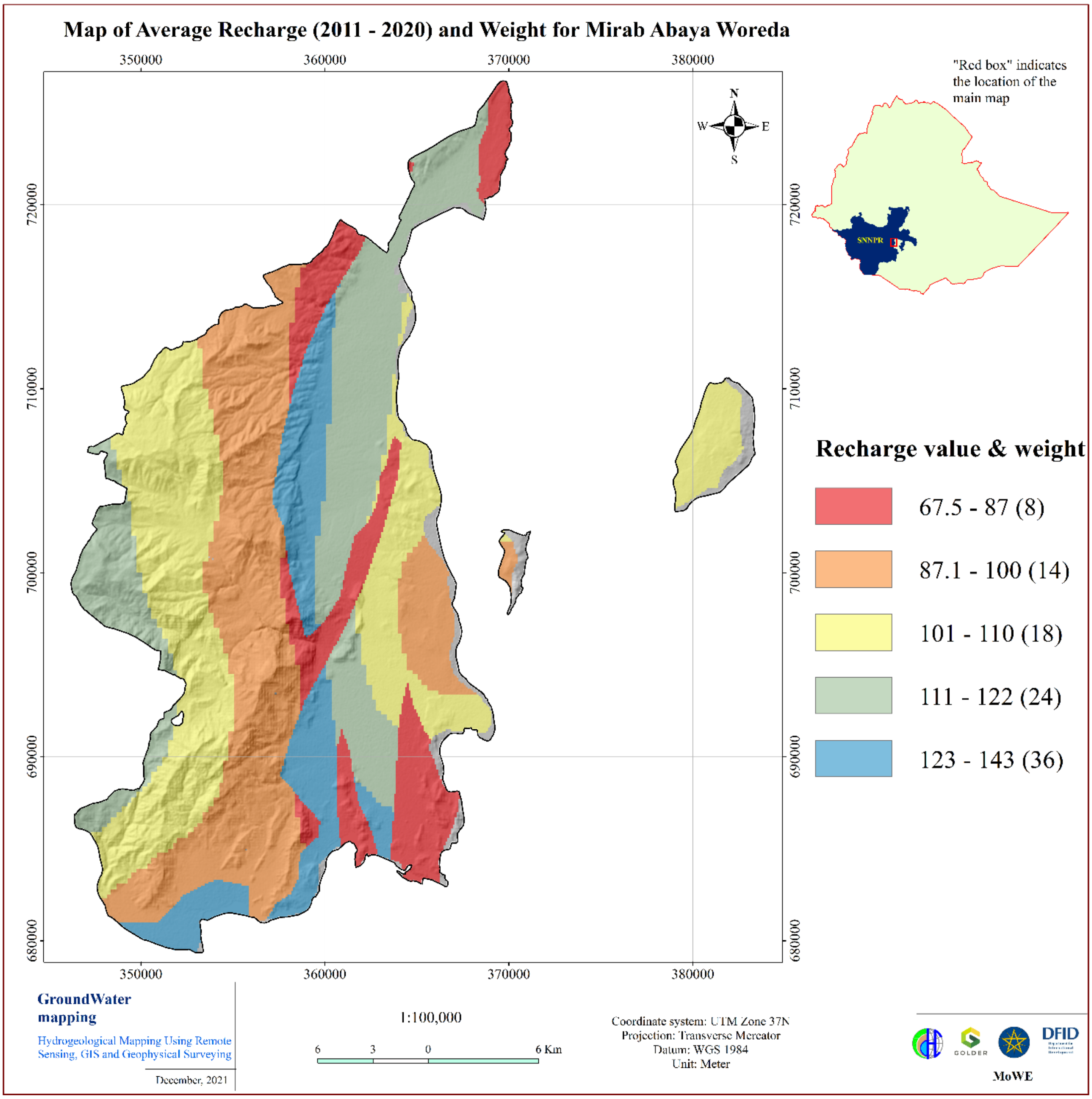


Figure 5.12. Map of average recharge (2011 – 2020) in millimeters and weight for Mirab Abaya Woreda

5.2.2. Classification of Groundwater Potential Zones

The hydrogeological system of Mirab Abaya woreda is comprised of four main lithological units as Quaternary deposits, basic volcanic rock units (basalts), rhiyolits and trachytes with volcanic plugs and Quaternary sediments. At regional scale, Quaternary deposits form extensive and moderately productive aquifers. Within the domain of Mirab Abaya woreda, theses, Quaternary deposits form aquifers with very high groundwater potential.

At regional scale, volcanic rocks form extensive and moderately productive aquifer. However, at local scale, within the domain of Mirab Abaya woreda, due to the geomorphic setup, the volcanic rocks form moderately productive aquifer as revealed from existing borehole yields.

Hydrogeological data from water point inventory, hydro-chemical data and geophysical investigation outcome of the next phase will help to improve the understanding of hydrogeological frame work of the area.

On the basis of the assignment and normalized weighting of the individual features of the thematic layers, a potential groundwater map was produced (Figure 5.13). The potential groundwater zones (PGZ) of Mirab Abaya woreda revealed five distinct zones, namely very low (unsuitable), low, moderate, high and very high zones whose distribution and extents are presented in Table 5.5.

The potential map gives a quick assessment of the occurrence of groundwater resources in the study area. The groundwater potential map revealed that most parts of the elevated areas towards the western part of the Mirab Abaya Woreda generally have low groundwater potential while significant areas along the Lake Abaya shore exhibits high to very high groundwater potential. Generally high to very high groundwater potentiality of the study area is a confirmation of generally moderate to high productive aquifers of Quaternay sediment deposits underlain by basic volcanic rocks, whereas low groundwater potential areas have an indication of limited aquifers capabilities of mountain forming volcanic rocks in the area.

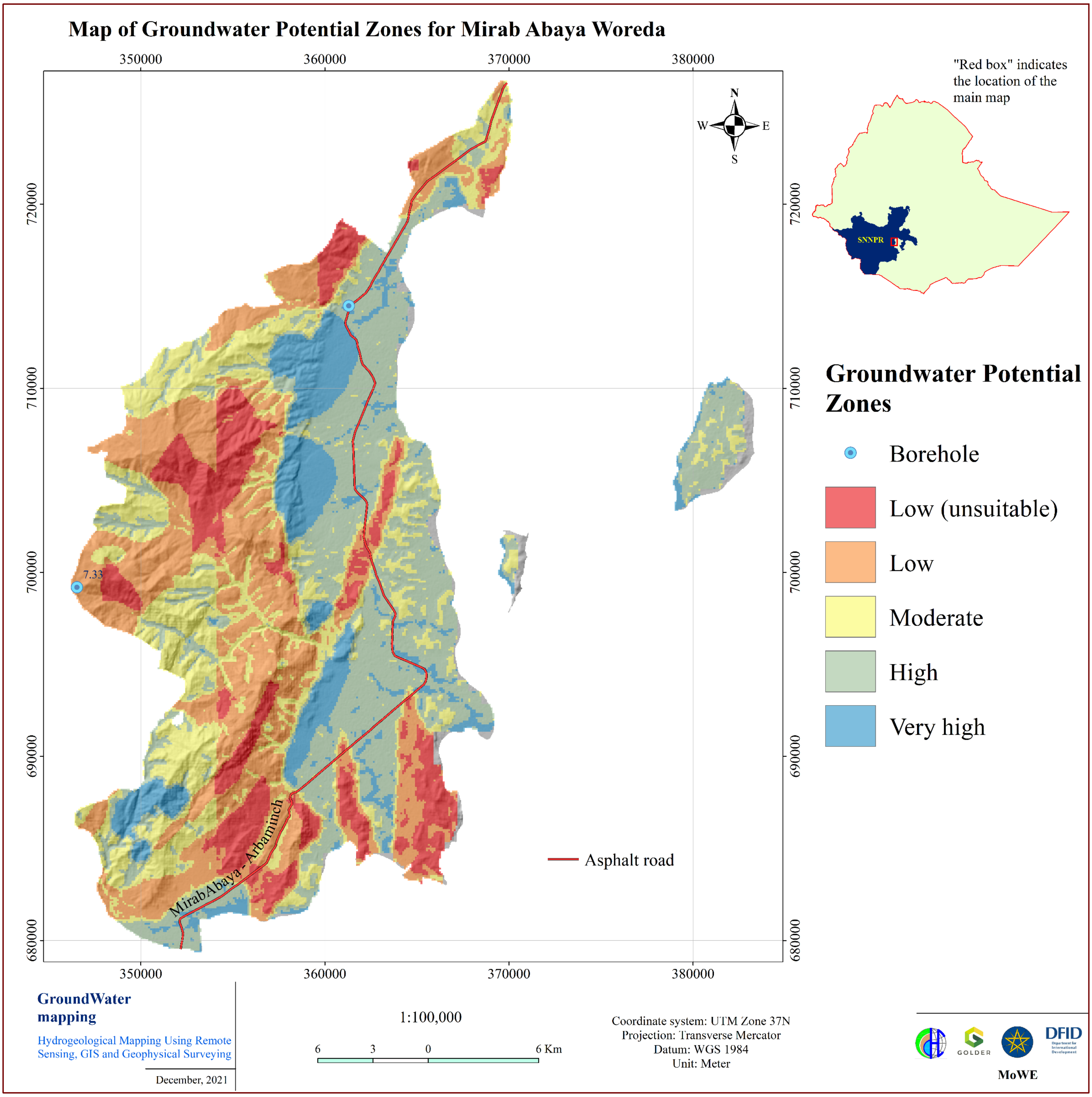


Figure 5.13. Map of groundwater potential zones showing five zones identified by the GIS overlay analysis in Mirab Abaya Woreda

Furthermore, a closer assessment of the groundwater potential map revealed that the distribution is more or less is a reflection of the geology and topographic wetness index. Areas underlain by recent Quaternary deposits especially in the dominant eastern part along the lake shore forming alluvial fans underlain by Quaternary lava flows have very high groundwater potential. Likewise, small part of the area towards western periphery of the woreda are also characterized by relatively plain land with flat slope having higher recharge amount due to the presence of dense lineaments and apparently deep fracturing and weathering have high groundwater potential. On the other hand, areas underlain by rhiyolites and trachytes with basaltic mountain chains in the majority of the woreda areas are characterized dotted ridges and steep slopes, lower recharge and lineament densities, exhibit low groundwater potential. Moreover, low drainage densities, steep slopes and predominance of rhiyolites can be attributed to the observed poor groundwater potentials at the most central parts of the woreda. Summary of the groundwater potential zones identified in the Mirab Abaya woreda is presented in the table below (Table 5-5).

Table 5-5. Classification of groundwater potential zones and coverage areas alongside the respective yield categories in Mirab Abaya Woreda

Class	Class interval	Pixel count	Area (Km2)	Area (%)	Well yield (l/s)	Groundwater prospect
1	132 – 174.94	7610	76100	12.3	-	Very low
2	174.95 – 197.88	16400	164000	26.5	-	Low
3	197.89 – 215.53	13275	132750	21.5	7.33	Moderate
4	215.54 – 232.59	17627	176270	28.5	7-8	High
5	232.60 - 282	6904	69040	11.2	>8 l/s	Very high

5.2.3. Validation with Borehole Yield Data

In order to validate the classification of the groundwater potential zones as revealed by the GIS based groundwater potential map, data on existing wells (outside of the woreda boundary, in a similar geohydrologic environment) were collected for over 20 boreholes most of them are from Arba Minch town and its surroundings.

The borehole data were superimposed on the groundwater potential map in the whole synoptic view and groundwater potential zones were evaluated. As far as the secondary data we have is concerned, the yields of the deep boreholes in the woreda and Arba Minch area vary from 2 to 8 lit/sec. The occurrence of relatively high yield wells is associated with high Quaternary sediments underlain by volcanic rocks; dominantly basalt flows. This is also consistent with the low, moderate, high and very high groundwater potential classification of the GIS map for these rocks unit.

The validation clearly highlights the efficiency of the integrated RS and GIS methods employed in this study as useful modern approach for proper groundwater resource evaluation and sustainable

groundwater development. Nonetheless, the groundwater potential zonation map presented here can be applied only for further study as it provides a quick prospective guide for groundwater study in the area.

3.1.1. Population projection and water demand

3.1.1.1. Population

It is essential that the water supply system is designed to meet the requirements of the population expected to be living in the community at the end of design period by taking into account the design period and annual growth rate. Hence in order to avoid or minimize the aforementioned population related risks, efforts are made to review & justify the credibility of the available population data and growth rate figures.

Population projection is made making use of the geometric growth rate method by using the base population figure estimated by the central statistical Authority. The CSA has set average growth rates for urban and rural areas of the country varying at different times during the design period as shown in the table below. Accordingly, these values are adopted in forecasting future population of the town.

Table 5-6 CSA Rural Population Growth Rates

Rural Population Projection Growth Rate of Regions: 2008-2037						
YEAR / Growth Rate % (Rural)	2008-2012	2013-2017	2018-2022	2023-2027	2028-2032	2033-2037
Oromia Region	2.74	2.54	2.29	2.03	1.8	1.56
SNNP Region	2.49	2.37	2.31	2.03	1.82	1.57
Somali Region	2.75	2.63	2.35	2.05	1.89	1.83
Gambela Region	3.52	3.1	3.13	2.76	2.46	2.31

Source: CSA Population Projection for Ethiopia 2007-2037, Addis Ababa July 2013

Geometric method forecasting formula

$$P = Po\,(1 + r)^{n}$$

Where P – projected population
Po – current population
n – Number of years for projection
r – Population growth rate

The population of Mirab Abaya Woreda has been projected forward until 2036 using the projected scale of Southern Nation Nationalities and Peoples Regional State. The minimum and maximum population in the Woreda is 1555 and 12,387 respectively. The total population of the Mirab Abaya Woreda in 2036 is going to be 137,654. Figure 5.14 presents the projected population for each kebele in the Woreda

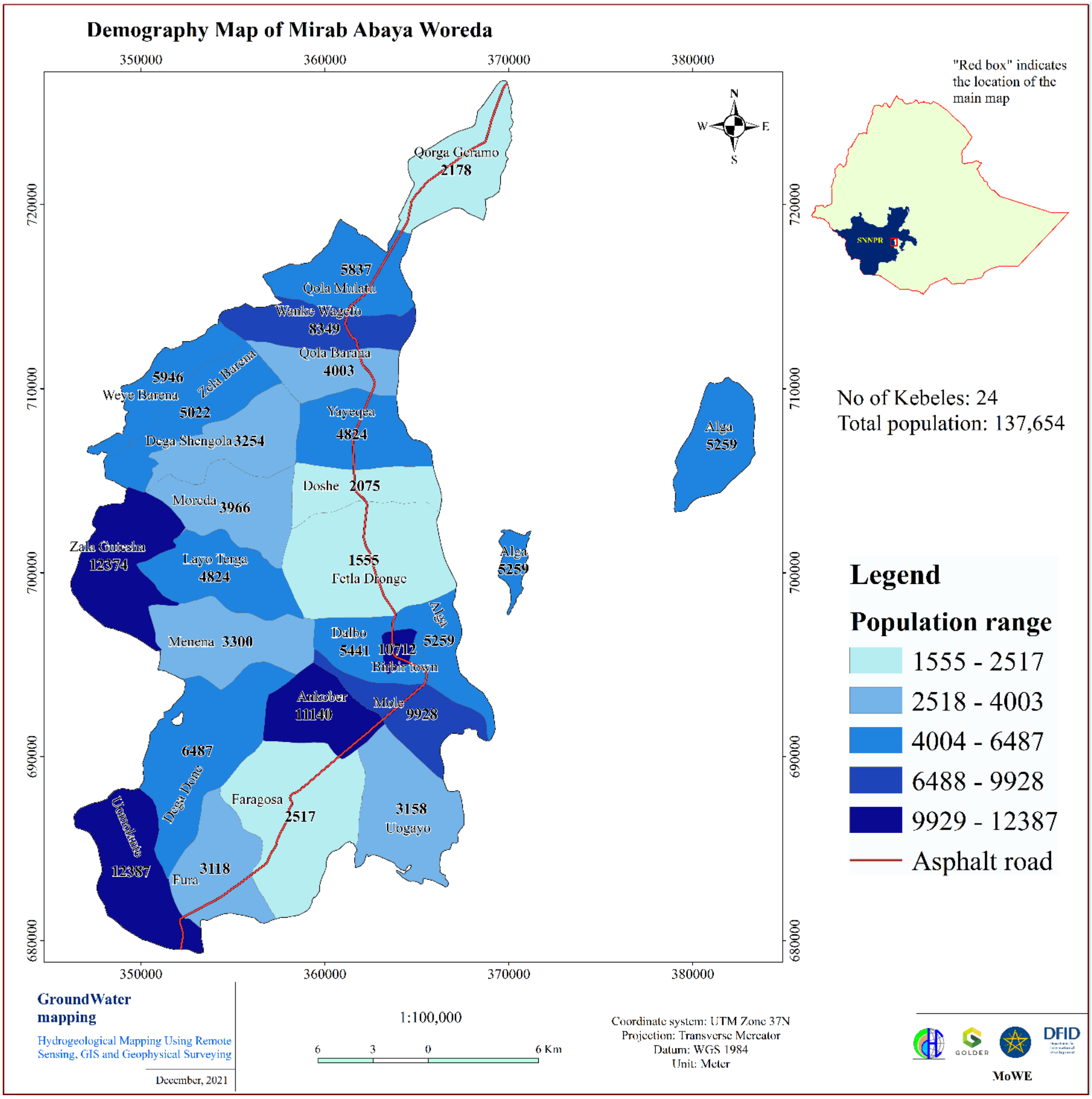


Figure 5.14 Map of projected population (2036) for Mirab Abaya Woreda.

3.1.1.2. Water Demand Projection

Projected Water Demand

Estimating water demands mainly depends on the size of the population to be served, their standard of living and activities. To make the demand projection reliable and suitable for rural areas it is better to classify in details as domestic and non-domestic demands.

Domestic Water Demand

Domestic water demand is the amount of water needed for drinking, food preparation, washing, cleaning, bathing and other miscellaneous domestic purposes. The amount of water used for domestic purposes greatly depends on the lifestyle, living standard, and climate, mode of service and affordability of the users.

Domestic water demand service can be categorized according to the level of service to be provided and amount of per capita water required satisfying the demand served by the level of service. Modes of services used for our projection are classified into four categories, namely: -

- Traditional Source users (TSU)
- Public tap users (PTU)
- Yard connections and Neighbourhood (shared) connections (YCO) & (YCS)
- House tap connections (HTU)

In projecting the domestic water demand, the following procedures were followed:

- Determining population percentage distribution by mode of service and its future projection
- Establishment of per capita water demand by purpose for each mode of service;
- Projected consumption by mode of service;
- Adjustment for climate;
- Adjustment due to socio-economic conditions.

After considering the necessary mode of services, per-capita demand and applying the adjustment factors the domestic demand for the corresponding year and population has been calculated.

Non-Domestic Water Demand

Non-domestic water demand was also determined systematically. We have classified it into three major categories based on our projection:

- Institutional water demands (Public and governmental);
- Commercial water demand;
- Livestock water demand

N.B: - The use of a reliable base population figure is very important for optimizing the water sources but adopting 2007 CSA data as a base population has real impact on the projection so to compensate some unforeseen situation like migration and unplanned rural town growth. To compensate for such

- To estimate the demand of public institutions and commercial services we have adopted 15% - 20% of the domestic demand for our consumption.
- The demand for livestock watering adopted in the projection is 10% -15% of the domestic demand.

Total Average daily day demand

The average daily day demand is taken to be the sum of domestic demands and non-domestic demand. The water demand in a day varies with time according to the consumer's life style. It is the total sum of adjusted domestic, public and livestock demand.

Maximum Day Demand

The maximum day demand is the highest demand of any one 24 hour period over any specific year. It represents the change in demand with season. This demand is used to design source capacity. The deviation of consumption from the average day demand is taken care of as per the maximum daily coefficient figures. Usually a value from1.1 to 1.3 is adopted as maximum day factor. A constant value of 1.3 is adopted as maximum day factor for all of the villages.

Figure 5.15 shows the distribution of water demand in each Kebeles of the Woreda. The minimum and maximum water demand for Kebeles is 140 M^3/day and 1,113 M^3/day respectively. The overall water demand for the projected population in the Mirab Abaya Woreda is 12,367 M^3/day.

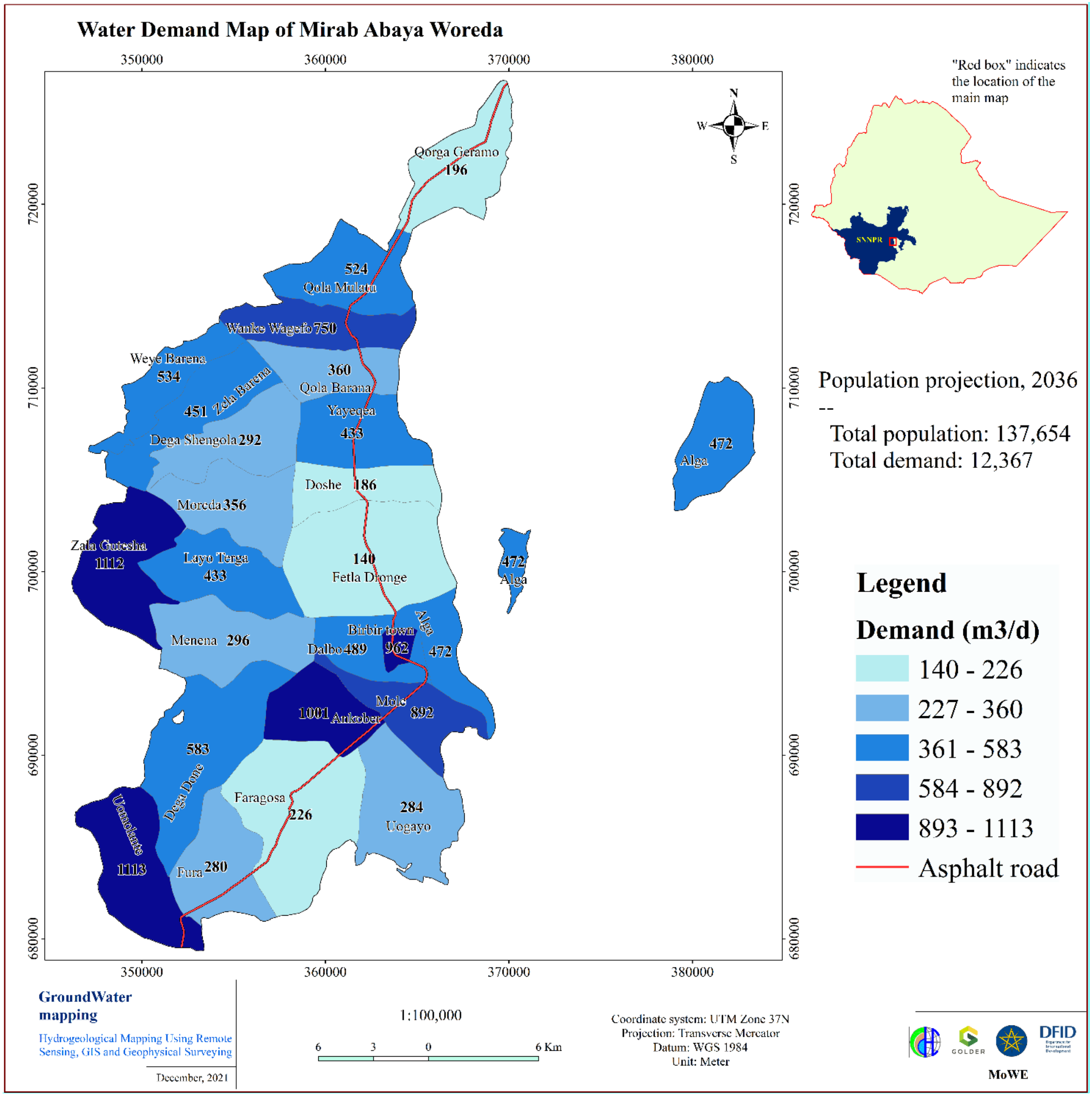


Figure 5.15: Map of water demand (M^3/day) for Mirab Abaya Woreda.

5.2.4. Propsed Target Sites

Four target sites are identified and proposed within the woreda based on the identified groundwater potential zones, the productivity of the hydrostratigraphic units with their expected optimum borehole yield, proximity to beneficiaries and population density. With further discussion and consultation with stakeholders, two priority sites will be selected for further hydrogeological and geophysical investigations in phase III. The following are the four proposed sites (Figure5.16).

Target Site-I:

This target site is located in the south estern part of the woreda along the lake shore. It is situated in the identified very high groundwater potential zone. This target site is mainly underlain by Quaternary sediment deposits underlain by volcanic rocks dominantly composed of basalt flows.

Target Site-II:

This target site is located in the western part of the woreda towards the mountain foot. It is situated in the identified moderate groundwater potential zone. This target site is mainly underlain by Quaternary sediment deposits underlain by volcanic rocks dominantly composed of basalt flows.

Target Site-III:

This target site is located in the north estern part of the woreda along the lake shore. It is situated in the identified very high groundwater potential zone. This target site is mainly underlain by Quaternary sediment deposits underlain by volcanic rocks dominantly composed of basalt flows.

Target Site-IV:

This target site is located in the southern periphery of the woreda along the lake shore. It is situated in the identified very high groundwater potential zone. This target site is mainly underlain by Quaternary sediment deposits underlain by volcanic rocks dominantly composed of basalt flows.

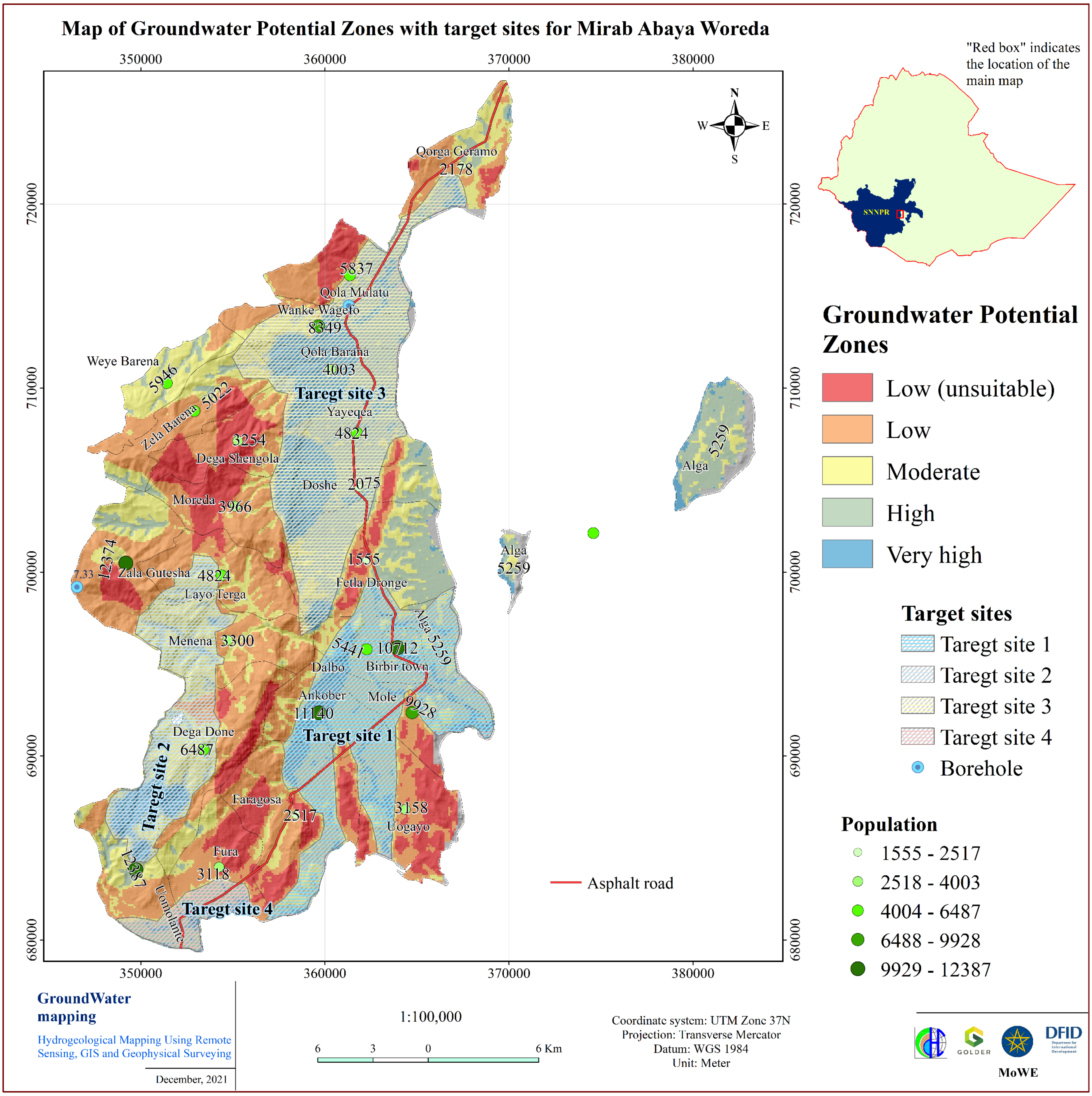


Figure 5.16. Map of groundwater potential zones with selected target sites for Mirab Abaya Woreda

5.2.5. Conceptual hydrogeological model of Mirab Abaya Woreda

Hydrogeological conceptual models are collections of hypotheses based on geological structural and geomorphological evidences and existing wells lithologic logs to describe and understand the groundwater occurrence, localization and movement beneath the ground surface. The purpose of the hydrogeological model across/along inferred groundwater flow direction is to reflect the prototype of regional groundwater flow system in the two priority sites selected for further study in phase III.

Due to proximity to the Main Ethiopian Rift, rock units are dislocated and placed in jackstapostion against each other. This region has a compartimentalized groundwater flow system constrained by geological structres and topography. Groundwater gets recharge mainly from local rain that falls on central and a northwestern surrounding highland with expected lateral inflow from adjacent highlands. Groundwater flow direction is generally towards east in the general direction of surface water flow to Lake Abaya through alluvial plain and fractured volcanic rocks. Development of the hydrogeological conceptual model of the Mirab Abaya Woreda will be prepared based on the converging evidence of secondary data including digital elevation model (DEM), geological and hydrogeological maps and structures, lithological well logs of wells in the area. Two target sites will be selected out of the proposed ones. The conceptual hydrogeological models for this woreda to be constructed along/across groundwater flow path will be produced after stake holder consultation workshop to select priority target sites for further hydrogeological characterization. The conceptual hydrogeological model summarizes what is known about the hydrogeological system and thereby provides a framework for hydrogeological system of the target sites in the woreda including the major groundwater flow zone (inflow, groundwater flow paths, inferred depth, and outflow) and groundwater table and groundwater condition of Mirab Abaya woreda using existing data of spring and boreholes.

5.3. Konso Woreda

The four thematic layers which were integrated for groundwater potential mapping in Konso Woreda are summarized in Table 5.7 below. The notes on the description of each thematic layers including classification of potential zones, validation with borehole and scheme datasets, population projection, water demand and selected target sites presented in the sub-sections.

Table 5-7. Assigned and normalized weights for the individual features of the four thematic layers for groundwater potential zoning in Konso Woreda

Class	Class interval	Class Weight	Pixel count	Area (Km2)	Area (%)	Weight	Groundwater propsect
	Lineament layer						
1	0 - 0.058	8	47478	474780	20.8		Very low
2	0.58 - 0.13	14	76434	764340	33.6		Low

3	0.14 - 0.21	18	65266	652660	28.7	0.21	Moderate
4	0.22 - 0.32	24	30444	304440	13.4		High
5	0.33 - 0.51	36	8132	81320	3.6		Very high
	Topographic Wetness Index (TWI) layer						
1	4.62 - 7.35	8	89525	895250	39.3	0.27	Very low
2	7.36 – 9.29	14	80044	800440	35.1		Low
3	9.30 - 11.9	18	38178	381780	16.8		Moderate
4	12.00 – 16.1	24	16114	161140	7.1		High
5	16.2 – 24.5	36	3893	38930	1.7		Very high
	Recharge layer						
1	14.1 – 45	8	107198	1071980	47.2	0.05	Very low
2	45.1 – 80	14	14741	147410	6.5		Low
3	80 – 105	18	38645	386450	17.0		Moderate
4	106 – 135	24	44169	441690	19.4		High
5	136 – 175	36	22591	225910	9.9		Very high
	Lithology layer						
1	Phonolite and rhyolite	11	8766	87660	3.8	0.46	
2	Basement rocks of different kinds	17	95423	954230	41.9		Poor
3	Basic volcanic and pyroclastic rock units	30	59850	598500	26.3		Good
4	Quaternary sediment and lacustrine deposits	42	63666	636660	28.0		Very good

5.3.1. Integration of Thematic Layers for Groundwater Potential Zoning

The details of geology, rainfall, lineament density, geomorphology, land slope, soil type, land use/land cover, groundwater depth and drainage density together with their spatial distribution in Konso woreda are presented below:

I. Geology/lithology

In general, most parts of Konso woreda are underlain by basement complexes of intrusive granitic and gneissic rocks. Quaternary deposits of alluvial and lacustrine sediments are mostly found western part of the woreda. Whereas, the basement rocks outcropped at the central and eastern parts of the woreda.

However, the lithological units found in the woreda area are further classified into three major groups based on their significances to groundwater occurrence and productivity using borehole yield a.

- Quaternary alluvium and lacustrine deposits,
- Basalt and pyroclastic deposits,

- Basement rocks of granitic and gneissic rocks overlain and
- Phonolites and rhiyolites

The crystalline basement and volcanic rocks underlain by Quaternary sediment are the main lithologic framework of the Konso woreda (Figure 5-17).

Usually, massive unfractured lithologic units in basement complex settings have little influence on groundwater availability except in cases with secondary porosity through the development of weathered regolith, and fractured bedrock units, which form potential groundwater zones. Hence, on the basis of the presence and nature of the weathered regolith units and fracture systems, appropriate weights are assigned to the different lithological units in the study area. The weightage (Figure 5.17) in terms of increasing groundwater potentiality is in the order of poor productivity of basement rocks and phonolites and rhiyolites (0.11-0.16), moderate productivity of volcanic rocks (0.30) and high productivity Quaternary deposites (0.42).

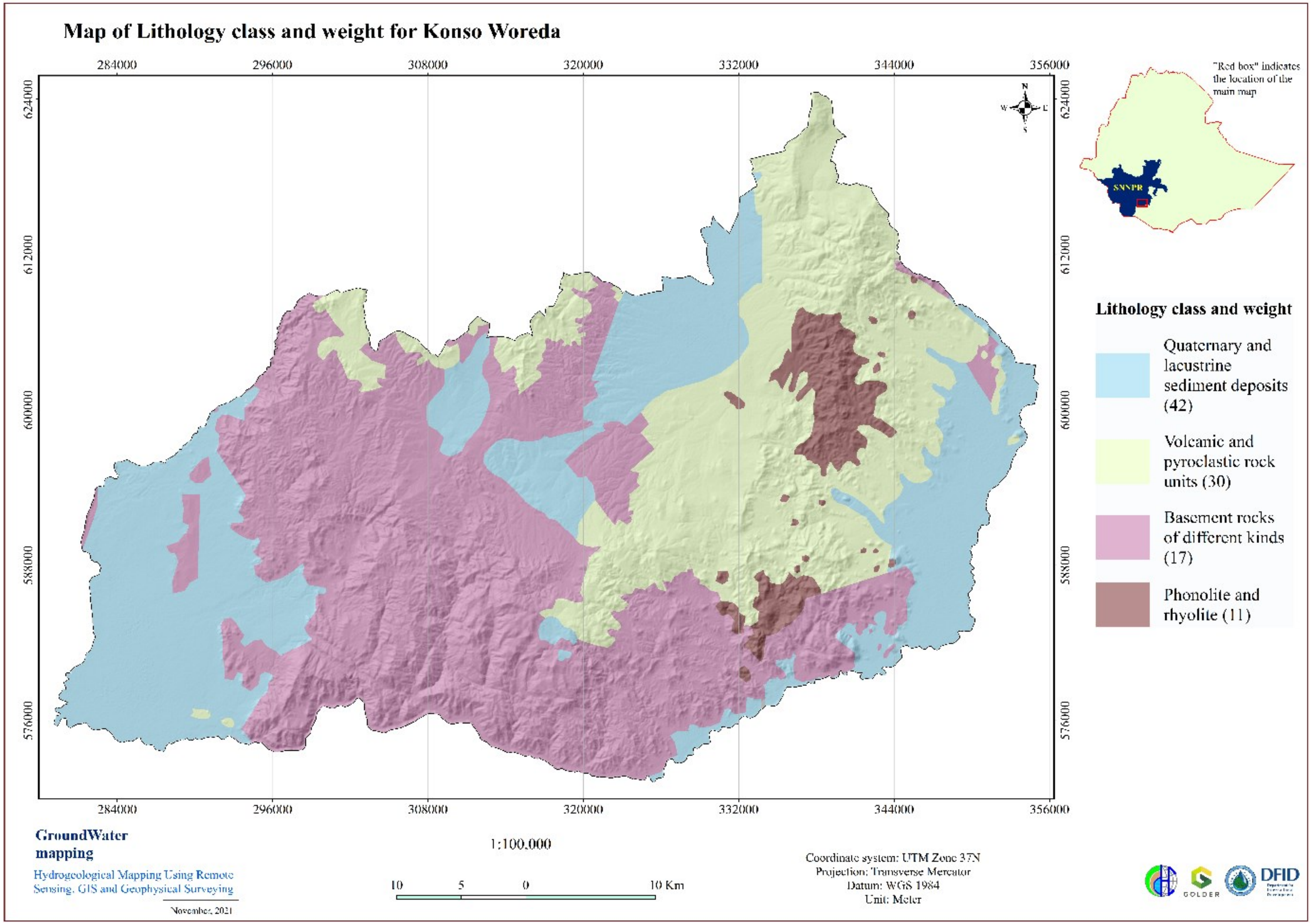


Figure 5.17. Map of lithology class and weight for Konso Woreda

II. Lineaments and lineament density

The study area is highly affected by lineaments and/or fractures consequent to a number of tectonic activities in the past. Two prominent directions identified are NW-SE and NE–SW trending lineaments. Usually, lineament density map is a measure of quantitative length of linear feature per unit area which can indirectly reveal the groundwater potentials as the presence of lineaments usually denotes a permeable zone. For most of the study area, the lineament density varies from less than 0.058 km/Km2 to 0.51 km/Km2 (Figure 5.18). Though the lineaments are widespread across the study area, however, the distribution of lineaments suggests geologic control with areas underlain by crystalline basement complex associated with quaternary sediments having relatively higher lineament density of 0.22 – 0.51 km/Km2) compared with areas underlain by volcanic rocks of (< 0.22 km/Km2).

Thus, areas with higher lineament density are regarded as good for groundwater development. Consequently, higher weightage of 0.36 was assigned to area with high density of lineaments, while a low weightage of 0.08 was assigned to areas with low lineament density (Figure 5.18).

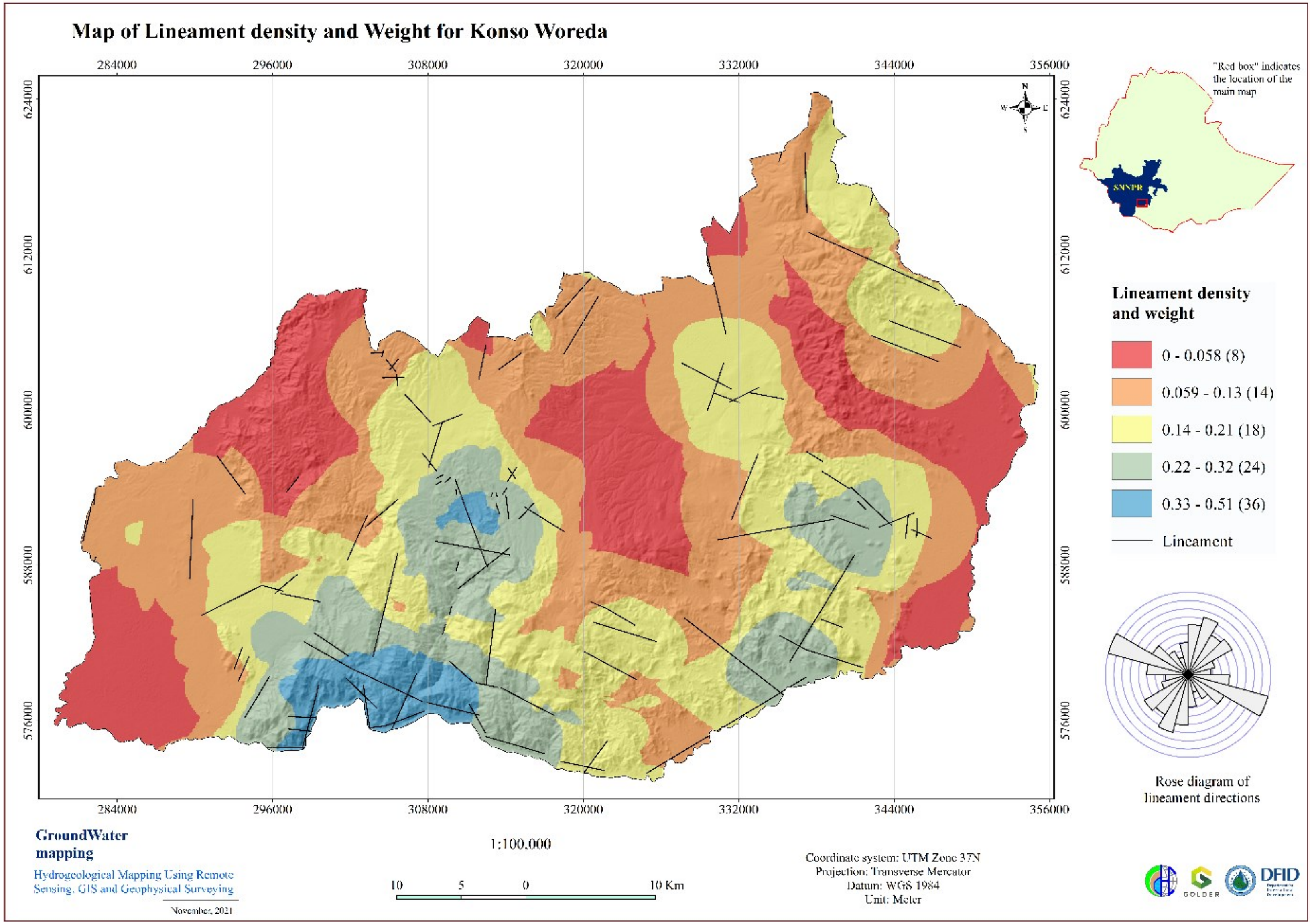


Figure 5.18. Map of lineament density and weight for Konso Woreda

III. Topographic Wetness Index (TWI)

In this study area, the TWI value ranges between 4.62 and 24.5. A closer look at the classification revealed that most the high elevated areas and drainage systems with steep slopes have relatively lower TWI value while the low lying areas and drainage systems with gentle and flat slopes have relatively higher wetness index value where runoff waters from highlands flow and accumulates mostly. Therefore, an area with higher value of TWI has good prospect for groundwater occurrence and flow, and accordingly high weightage value (0.36) was assigned to this class. Whereas, areas with lowest TWI value are steep slopes which triggers runoff were considered with low groundwater prospect and given low weightage value of 0.08 (Figure 5-19).

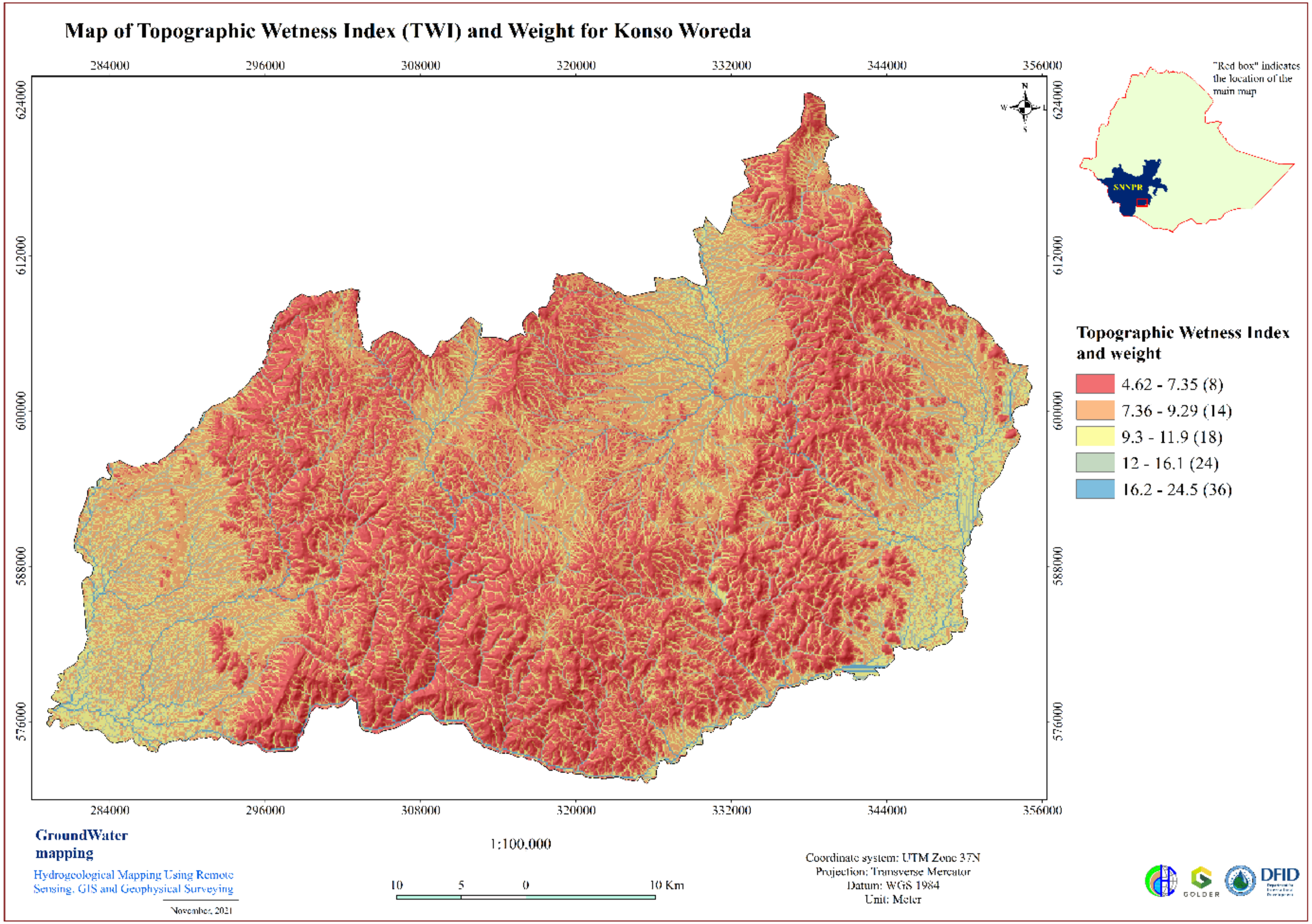


Figure 5.19. Map of topographic wetness index (TWI) and weight for Konso Woreda

IV. Recharge

The 10 years spatial annual recharge rate distribution in the Konso woreda ranges from 14.1 to 175 mm/y suggesting groundwaters in most part of the woreda area underlain by basement complex receive low amount of recharge while areas underlain by volcanic rocks and quaternary sediments have relatively higher recharge amount (Figure 5.20). Accordingly, areas with higher and moderate amount of recharge have weightage factor of 0.46 and 0.24, respectively signifying very good and moderate groundwater potential respectively while areas with the lowest amount of recharge have weightage factor of 0.08, suggesting poor groundwater potentiality. A closer look at the recharge thematic map (Figure 5.20) revealed that most of the western low-lying parts and north central parts of the woreda have relatively higher recharge (> 130 mm/y). Generally, the study area is characterized with very low to low mean annual recharge amount, whereas dominant part of the areas at center and southern parts have low mean annual recharge amount (<130 mm).

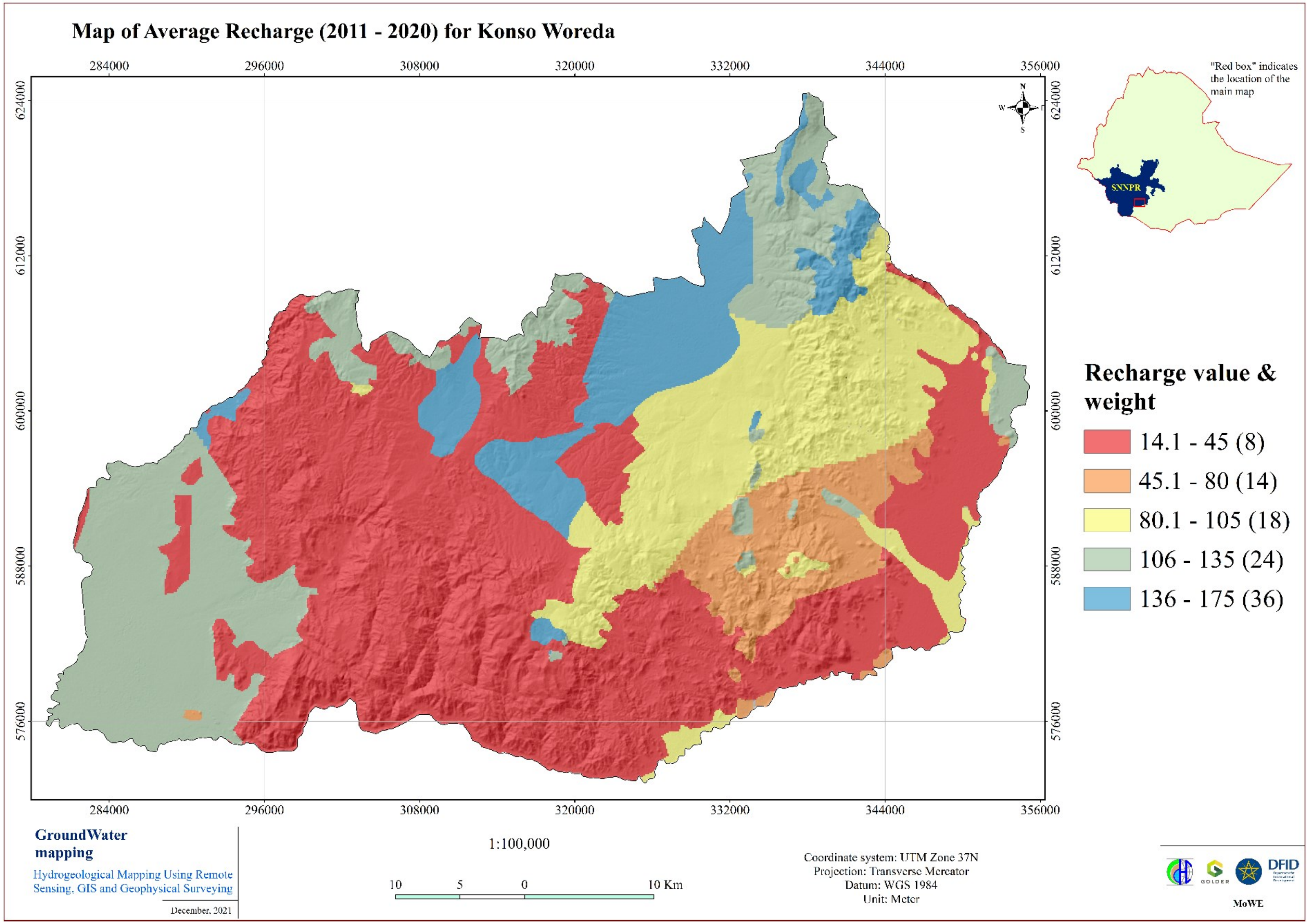


Figure 5.20. Map of yearly recharge (mm/year) and weight for Konso Woreda

5.3.2. Classification of Groundwater Potential Zones

The hydrogeological system of Konso woreda is comprised of four main lithological units as Quaternary deposits, different volcanic rocks, Phonolites and rhiyolits and Crystalline basement rocks. At regional scale, Quaternary deposits form extensive and moderately productive aquifers. Within the domain of Konso woreda, theses, Quaternary deposits form aquifers with high groundwater potential.

At regional scale, volcanic rocks form extensive and moderately productive. However, at local scale, within the domain of Konso woreda, due to the geomorphic setup, the volcanic rocks form moderately productive aquifer as revealed from existing borehole yields.

Only the upper weathered and slightly fractured part of the crystalline basement rocks along lineamnets and faults have potential to store groundwater at shallow depth. Weathered and slightly fractured Crystaline basement rocks with overlying Quaternary deposit form major potential aquifer within the domain of Konso Special Woreda along lineament and fault lines and associated plains.

Hydrogeological data from water point inventory, hydro-chemical data and geophysical investigation outcome of the next phase will help to improve the understanding of hydrogeological frame work of the area.

On the basis of the assignment and normalized weighting of the individual features of the thematic layers, a potential groundwater map was produced (Figure 5.21). The potential groundwater zones (PGZ) of Konso Special woreda revealed four distinct zones, namely low (unsuitable), moderate, high and very high zones whose distribution and extents are presented in Table 5.6.

The potential map, as presented in Figure 5.21, gives a quick assessment of the occurrence of groundwater resources in the study area. The groundwater potential map revealed that most elevated areas central parts of the Konso Woreda generally have low potential while significant areas at northern, eastern and western peripheries generally exhibits high to very high potentials. Generally high to very high groundwater potentiality of the study area is a confirmation of generally moderate to high productive aquifers of Quaternay alluvial and lacustrine deposits, whereas low groundwater potential areas have an indication of limited aquifers capabilities of basement complex terrain.

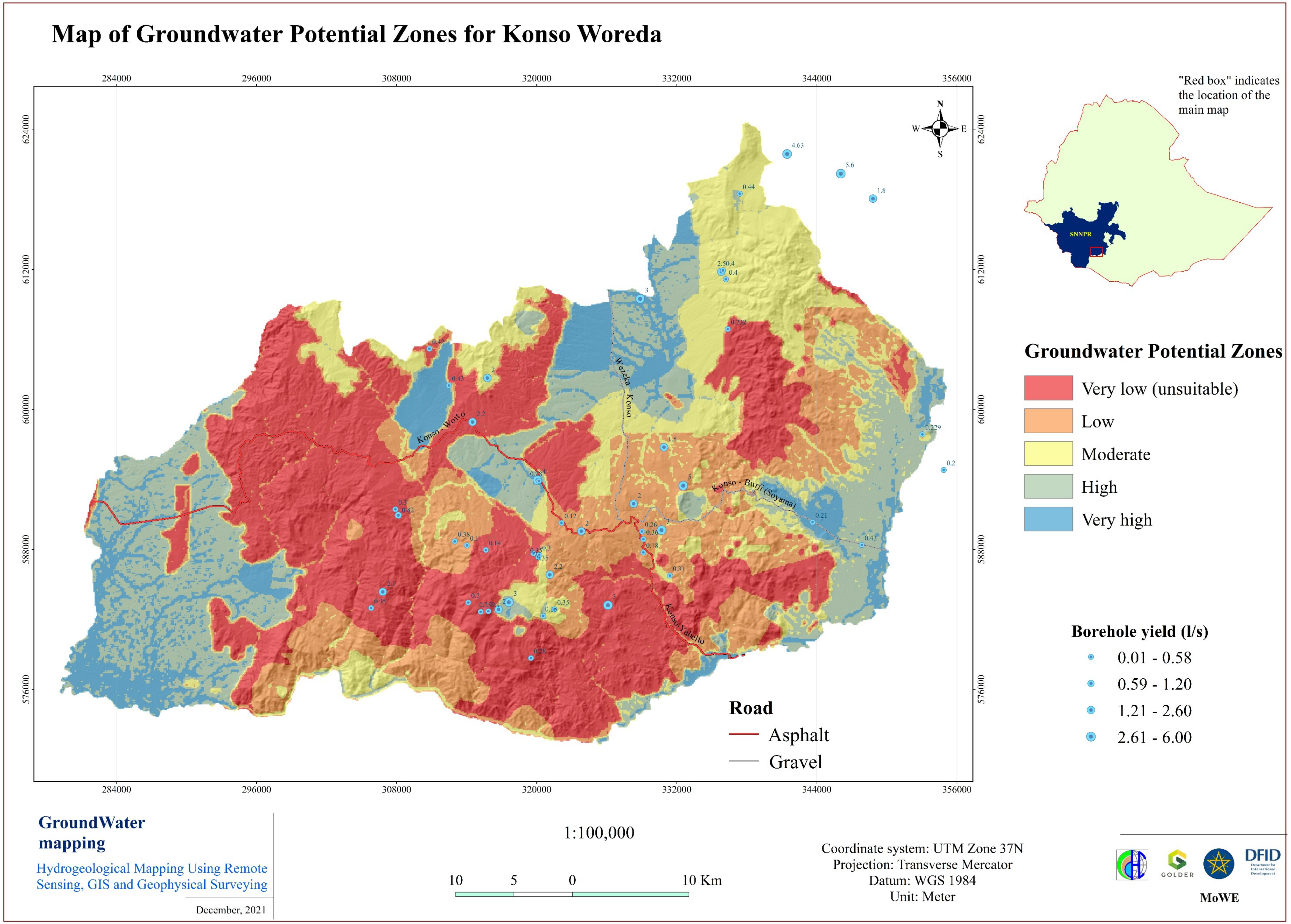


Figure 5.21. Map of groundwater potential zones showing five zones identified by the GIS overlay analysis in Konso Woreda

Furthermore, a closer assessment of the groundwater potential map revealed that the distribution is more or less a reflection of the geology and lineament density in addition to the topographic wetness index control. Areas underlain by recent quaternary deposits especially in the northern, extreme east, west of the woreda which are characterized by relatively plain land with flat slope having higher recharge amount due to the presence of dense lineaments and apparently deep fracturing and weathering have high and very high groundwater potential. On the other hand, areas underlain by crystalline basement complexes in the majority of the woreda areas are characterized by small ridges and steep slopes, lower recharge and lineament densities, exhibit low groundwater potential while areas underlain by massive basement rocks low groundwater potential. Moreover, low drainage densities and predominance of crystalline rock outcrops can be attributed to the observed poor groundwater potentials at the most central parts of the woreda. Summary of the groundwater potential zones identified in the Konso woreda is presented in the table below (Table 5.8).

Table 5-8. Classification of groundwater potential zones and coverage areas alongside the respective yield categories in Konso Woreda

Class	Class interval	Pixel count	Area (Km2)	Area (%)	Well yield (l/s)	Groundwater prospect
1	100 – 148.7	78494	784940	34.5	0.12 – 2.0	Very low
2	148.8 – 175.2	46016	460160	20.2	0.12 - 2.1	Low
3	175.3 – 201.8	39114	391140	17.2	0.12 – 5.0	Moderate
4	201.9 – 226.9	41371	413710	18.2	2.1 - 5.0	High
5	227 – 288.1	22759	227590	10.0	2.1 - 6.0	Very high

5.3.3. Validation with Borehole Yield Data

In order to validate the classification of the groundwater potential zones as revealed by the GIS based groundwater potential map, data on existing wells (yield) were collected for over 33 dug and drilled wells in and around Konso Special woreda. Since the wells were dug/drilled for water supply purpose without proper pumping test, they lack necessary information about aquifer properties and most of them have even no proper well yield information.

The available dug well and borehole data were superimposed on the groundwater potential map and numbers of wells with different yield ranges for different groundwater potential zones were crudely evaluated. As far as the secondary data we have is concerned, the yields of the deep drilled boreholes in the woreda and its surrounding areas vary from 0.2 to 5.6 lit/sec (Figure 5.21). As shown in the same figure, the occurrence of relatively high yield wells is associated with high lineament zone and Quaternary sediments underlain by volcanic rocks. This is also consistent with the low, moderate, high and very high groundwater potential classification of the GIS map for these rocks unit.

The validation clearly highlights the efficiency of the integrated RS and GIS methods employed in this study as useful modern approach for proper groundwater resource evaluation and sustainable

groundwater development. Nonetheless, the groundwater potential zonation map presented here can be applied only for further by providing quick prospective guides for groundwater in such complex basement dominated area.

3.1.2. Population projection and water demand

3.1.2.1. Population

It is essential that the water supply system is designed to meet the requirements of the population expected to be living in the community at the end of design period by taking into account the design period and annual growth rate. Hence in order to avoid or minimize the aforementioned population related risks, efforts are made to review & justify the credibility of the available population data and growth rate figures.

Population projection is made making use of the geometric growth rate method by using the base population figure estimated by the central statistical Authority. The CSA has set average growth rates for urban and rural areas of the country varying at different times during the design period as shown in the table below. Accordingly these values are adopted in forecasting future population of the town.

Table 5-9 CSA Rural Population Growth Rates

Rural Population Projection Growth Rate of Regions: 2008-2037						
YEAR / Growth Rate % (Rural)	2008-2012	2013-2017	2018-2022	2023-2027	2028-2032	2033-2037
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Source: CSA Population Projection for Ethiopia 2007-2037, Addis Ababa July 2013

Geometric method forecasting formula

$$P=Po\,(1 + r)^{n}$$

Where P – projected population
Po – current population
n – Number of years for projection
r – Population growth rate

The population of Konso Woreda has been projected forward until 2036 using the projected scale of Southern Nation Nationalities and Peoples Regional State. The minimum and maximum population in the Woreda is 2336 and 21331 respectively. The total population of the Konso Woreda in 2036 is going to be 400,759. Figure 5.22 presents the projected population for each kebele in the Woreda.

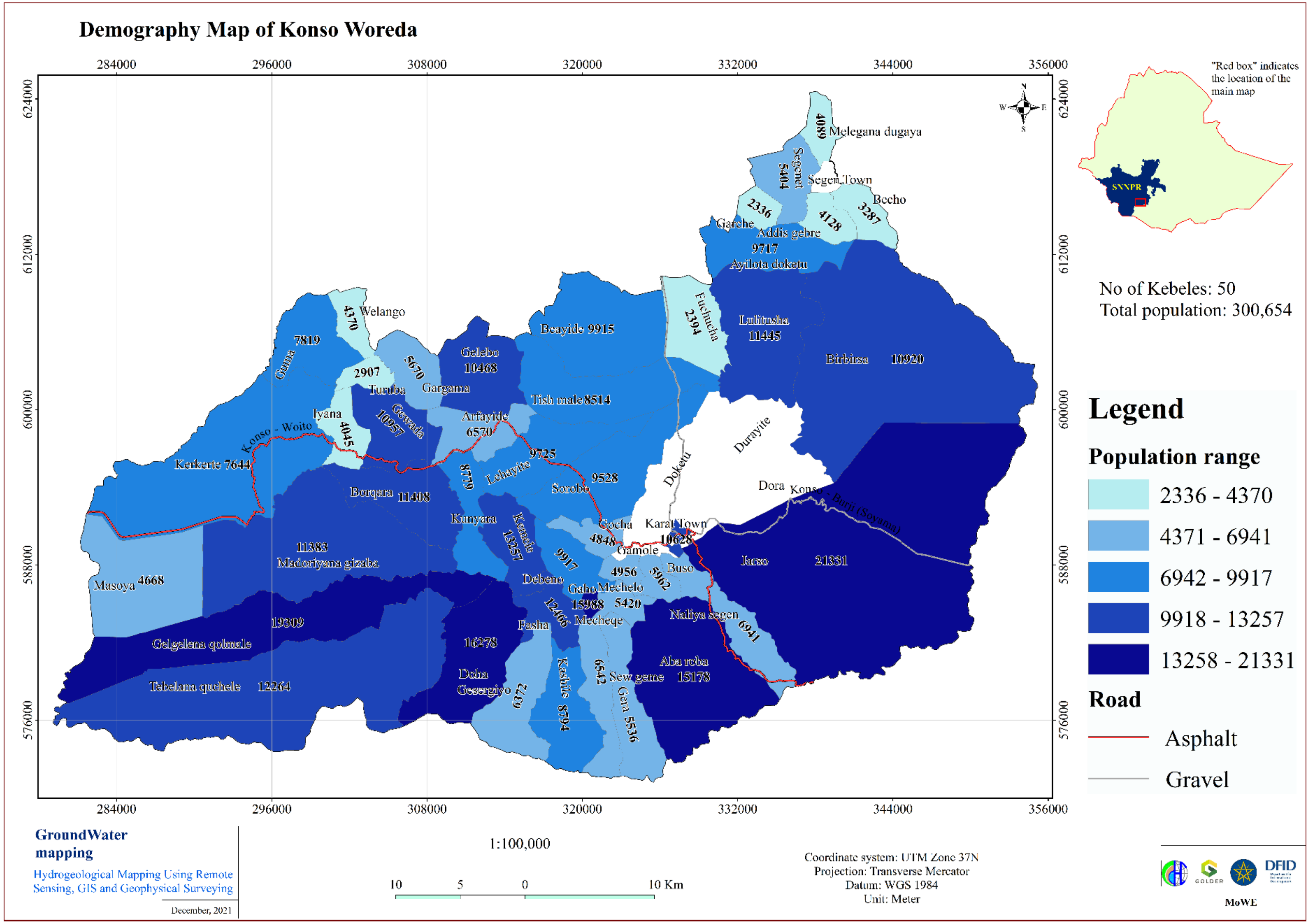

Figure 5.22: Map of projected population (2036) for Konso Woreda.

3.1.2.2. Water Demand Projection

Projected Water Demand

Estimating water demands mainly depends on the size of the population to be served, their standard of living and activities. To make the demand projection reliable and suitable for rural areas it is better to classify in details as domestic and non-domestic demands.

Domestic Water Demand

Domestic water demand is the amount of water needed for drinking, food preparation, washing, cleaning, bathing and other miscellaneous domestic purposes. The amount of water used for domestic purposes greatly depends on the lifestyle, living standard, and climate, mode of service and affordability of the users.

Domestic water demand service can be categorized according to the level of service to be provided and amount of per capita water required satisfying the demand served by the level of service. Modes of services used for our projection are classified into four categories, namely: -

- Traditional Source users (TSU)
- Public tap users (PTU)
- Yard connections and Neighbourhood (shared) connections (YCO) & (YCS)
- House tap connections (HTU)

In projecting the domestic water demand, the following procedures were followed:

- Determining population percentage distribution by mode of service and its future projection
- Establishment of per capita water demand by purpose for each mode of service;
- Projected consumption by mode of service;
- Adjustment for climate;
- Adjustment due to socio-economic conditions.

After considering the necessary mode of services, per-capita demand and applying the adjustment factors the domestic demand for the corresponding year and population has been calculated.

Non-Domestic Water Demand

Non-domestic water demand was also determined systematically. We have classified it into three major categories based on our projection:

- Institutional water demands (Public and governmental);
- Commercial water demand;
- Livestock water demand

N.B: - The use of a reliable base population figure is very important for optimizing the water sources but adopting 2007 CSA data as a base population has real impact on the projection so to compensate some unforeseen situation like migration and unplanned rural town growth. To compensate for such

- To estimate the demand of public institutions and commercial services we have adopted 15% - 20% of the domestic demand for our consumption.
- The demand for livestock watering adopted in the projection is 10% -15% of the domestic demand.

Total Average daily day demand

The average daily day demand is taken to be the sum of domestic demands and non-domestic demand. The water demand in a day varies with time according to the consumer's life style. It is the total sum of adjusted domestic, public and livestock demand.

Maximum Day Demand

The maximum day demand is the highest demand of any one 24 hour period over any specific year. It represents the change in demand with season. This demand is used to design source capacity. The deviation of consumption from the average day demand is taken care of as per the maximum daily coefficient figures. Usually a value from1.1 to 1.3 is adopted as maximum day factor. A constant value of 1.3 is adopted as maximum day factor for all of the villages.

Figure 5.23 shows the distribution of water demand in each Kebeles of the Woreda. The minimum and maximum water demand for Kebeles is 210 M^3/day and 1916 M^3/day respectively. The overall water demand for the projected population in the Konso Woreda is 36,004 M^3/day.

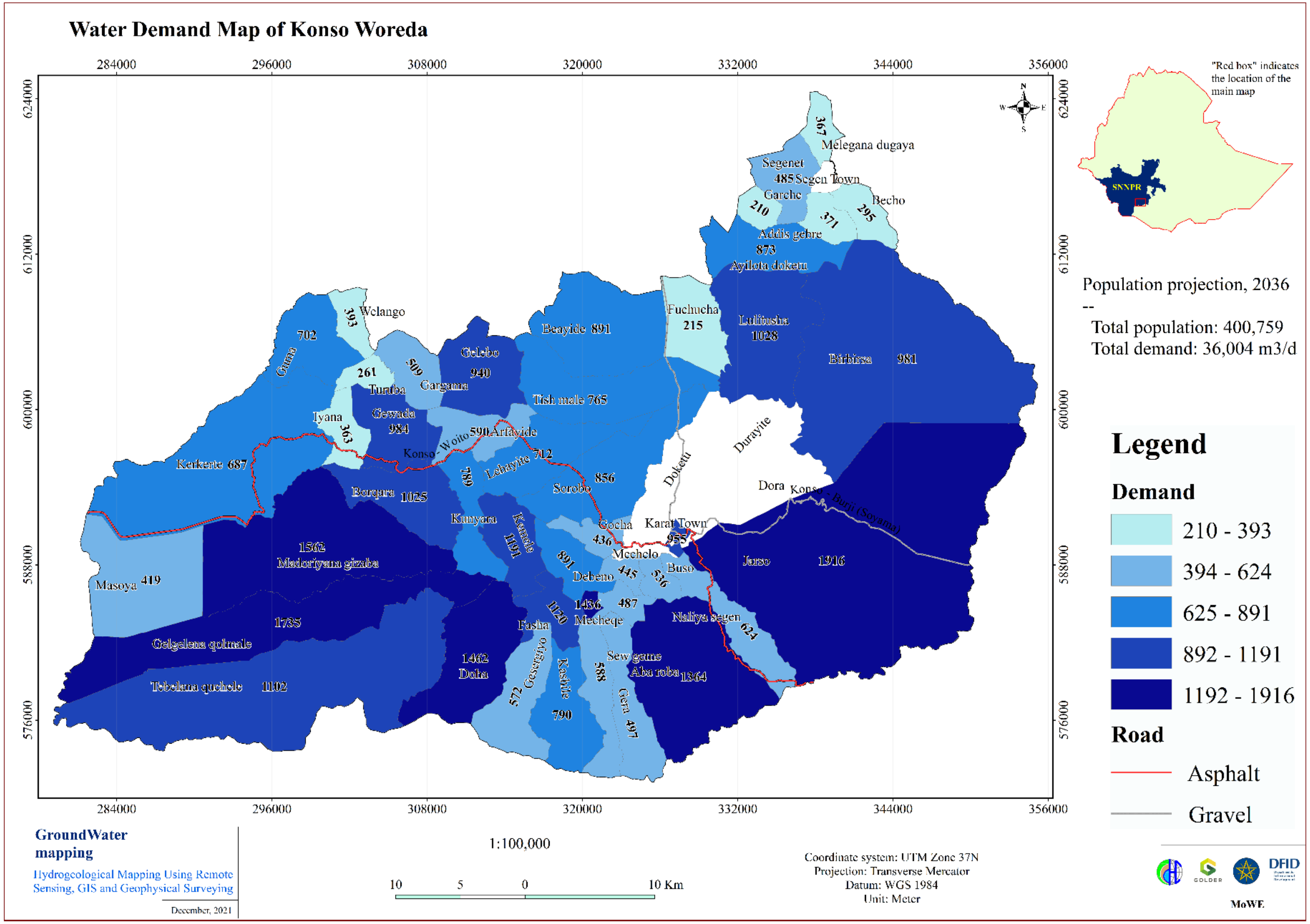

Figure 5.23: Map of water demand (M^3/day) for Konso Woreda.

5.3.4. Propsed Target Sites

Four target sites are identified and proposed within the woreda based on the identified groundwater potential zones, the productivity of the hydrostratigraphic units with their expected optimum borehole yield, proximity to beneficiaries and population density. With further discussion and consultation with stakeholders, two priority sites will be selected for further hydrogeological and geophysical investigations in phase III. The following are the four proposed sites (Figure 5.24):

Target Site-I:

This target site is located in the northern part of the woreda. It is situated in the identified very high potential zones. This target site is mainly underlain by quaternary recent deposits of alluvial and lacustrine sediments underlain by volcanic rocks.

Target Site-II:

This target site is located in the easternpart of the woreda. It is situated mainly in the identified high groundwater potential zones. This target site is mainly underlain by quaternary recent deposits of alluvial and lacustrine sediments underlain by volcanic rocks.

Target Site-III:

This target site is located northwestern part of the woreda. It is situated mainly in the identified moderate groundwater potential zone. This target site is mainly underlain Quaternary sediments underlain by basement rocks.

Target Site-IV:

This target site is located western part of the woreda. It is situated mainly in the identified moderate to high groundwater potential zone. This target site is mainly underlain by Quaternary sediment, weathered regolith of granitic rocks and associated fractured basement rocks.

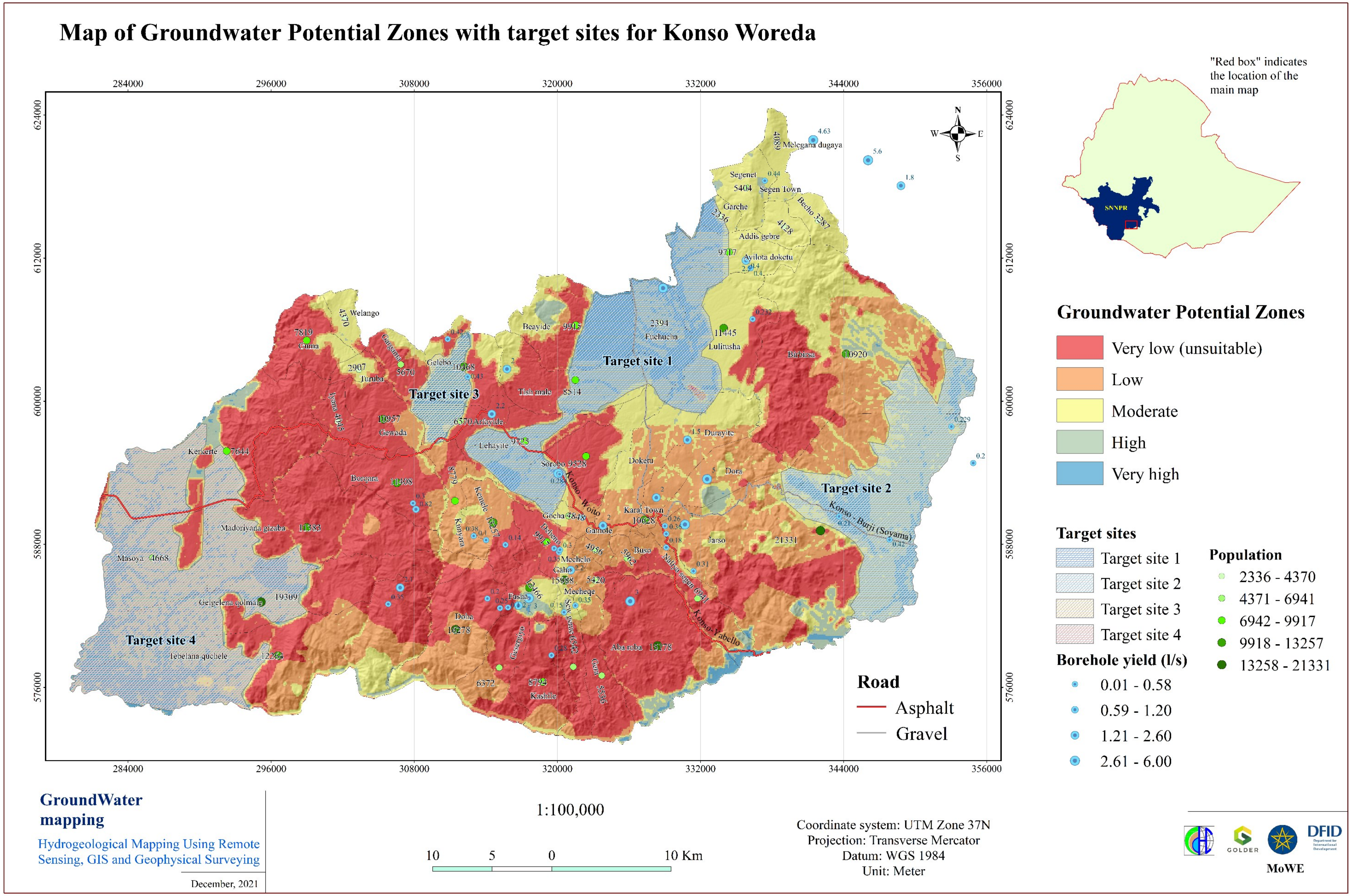

Figure 5.24. Map of groundwater potential zones with selected target sites in Konso Woreda

5.3.5. Conceptual hydrogeological model of Konso Woreda

Hydrogeological conceptual models are collections of hypotheses based on geological structural and geomorphological evidences and existing wells lithologic logs to describe and understand the groundwater occurrence, localization and movement beneath the ground surface. The purpose of the hydrogeological model across/along inferred groundwater flow direction is to reflect the prototype of regional groundwater flow system in the two priority sites selected for further study in phase III.

Due to proximity to the Main Ethiopian Rift, rock units are dislocated and placed in jackstapostion against each other. This region has a compartimentalized groundwater flow system constrained by geological structres and topography. Groundwater gets recharge mainly from local rain that falls on central and a northeast surrounding highland with expected lateral inflow from northwest adjacent highlands. Groundwater flow direction is generally towards south east in the general direction of Woyito River flow and central lowlands through alluvial plain and fractured basement rocks. Development of the hydrogeological conceptual model of the Konso Special Woreda will be prepared based on the converging evidence of secondary data including digital elevation model (DEM), geological and hydrogeological maps and structures, lithological well logs of wells in the area. The target sites will be selected out of the proposed ones. The conceptual hydrogeological models for this woreda to be constructed along/across groundwater flow path will be produced after stake holder consultation workshop to select priority target sites for further hydrogeological characterization. The conceptual hydrogeological model summarizes what is known about the hydrogeological system and thereby provides a framework for hydrogeological system of the target sites in the woreda including the major groundwater flow zone (inflow, groundwater flow paths, inferred depth, and outflow) and groundwater table and groundwater condition of Konso Special woreda using existing data of spring, river and boreholes.

5.4. Kochere Woreda

The four thematic layers which were integrated for groundwater potential mapping in Kochere Woreda are summarized in table 3-10 below. The notes on the description of each thematic layers including classification of potential zones, validation with borehole and scheme datasets, population projection, water demand and selected target sites presented in the sub-sections.

Table 5-10. Assigned and normalized weights for the individual features of the four thematic layers for groundwater potential zoning in Kochere Woreda

Class	Class interval	Class Weight	Pixel count	Area (Km2)	Area (%)	Weight	Groundwater propsect
	Lineament layer						
1	0 - 0.11	8	1404	14040	6.2	0.21	Very low
2	0.12 - 0.19	14	5011	50110	22.2		Low
3	0.20 - 0.24	18	6055	60550	26.8		Moderate
4	0.25 - 0.30	24	4896	48960	21.7		High
5	0.31 - 0.38	36	5221	52210	23.1		Very high
	Topographic Wetness Index (TWI) layer						
1	4.7 – 7.1	8	10148	101480	44.9	0.27	Very low
2	7.11 – 8.63	14	7695	76950	34.1		Low
3	8.64 – 11	18	3112	31120	13.8		Moderate
4	11.1 – 14.3	24	1172	11720	5.2		High
5	14.4 – 21.7	36	460	4600	2.0		Very high
	Recharge layer						
1	57.8 – 120	8	7082	70820	31.7	0.05	Very low
2	121 – 130	14	8892	88920	39.8		Low
3	131 – 135	18	2449	24490	11.0		Moderate
4	136 – 142	24	2679	26790	12.0		High
5	143 – 152	36	1233	12330	5.5		Very high
	Lithology layer						
2	Basic volcanic and pyroclastic rock units	70	18416	184160	82.10	0.46	High
3	Rhyolite and trachyte	30	4014	40140	17.90		Low

5.4.1. Integration of Thematic Layers for Groundwater Potential Zoning

The details of geology, rainfall, lineament density, geomorphology, land slope, soil type, land use/land cover, groundwater depth and drainage density together with their spatial distribution in Kochere woreda are presented below:

I. Geology/lithology

In general, most parts of Kochere woreda are underlain by basic volcanic rocks dominantly composed of basalts. Rhiyolits and trachytes with plugs are mostly found in the central part of the woreda. Quaternary deposits are found in very small part of the area.

However, the lithological units found in the woreda area are further classified into three major groups based on their significances to groundwater occurrence and productivity using borehole yield a.

- Basic volcanic rocks odominantly composed of basalts,
- Rhyolitic and trachytic lava flows and plugs,
- Quaternary alluvium and lacustrine deposits,

Usually, massive unfractured lithologic units having low primary porosity in volcanic teraain have little influence on groundwater availability except in cases with secondary porosity through the development of weathered regolith, and fractured bedrock units, which form potential groundwater zones. Hence, on the basis of the presence and nature of the weathered regolith units and fracture systems, appropriate weights are assigned to the different lithological units in the study area. The weightage (Figure 5.25) in terms of increasing groundwater potentiality is in the order of low productivity of rhiyolites, trachyts and and plugs (0.11), high productivity of basic volcanic rocks dominantly composed of basalts (0.7).

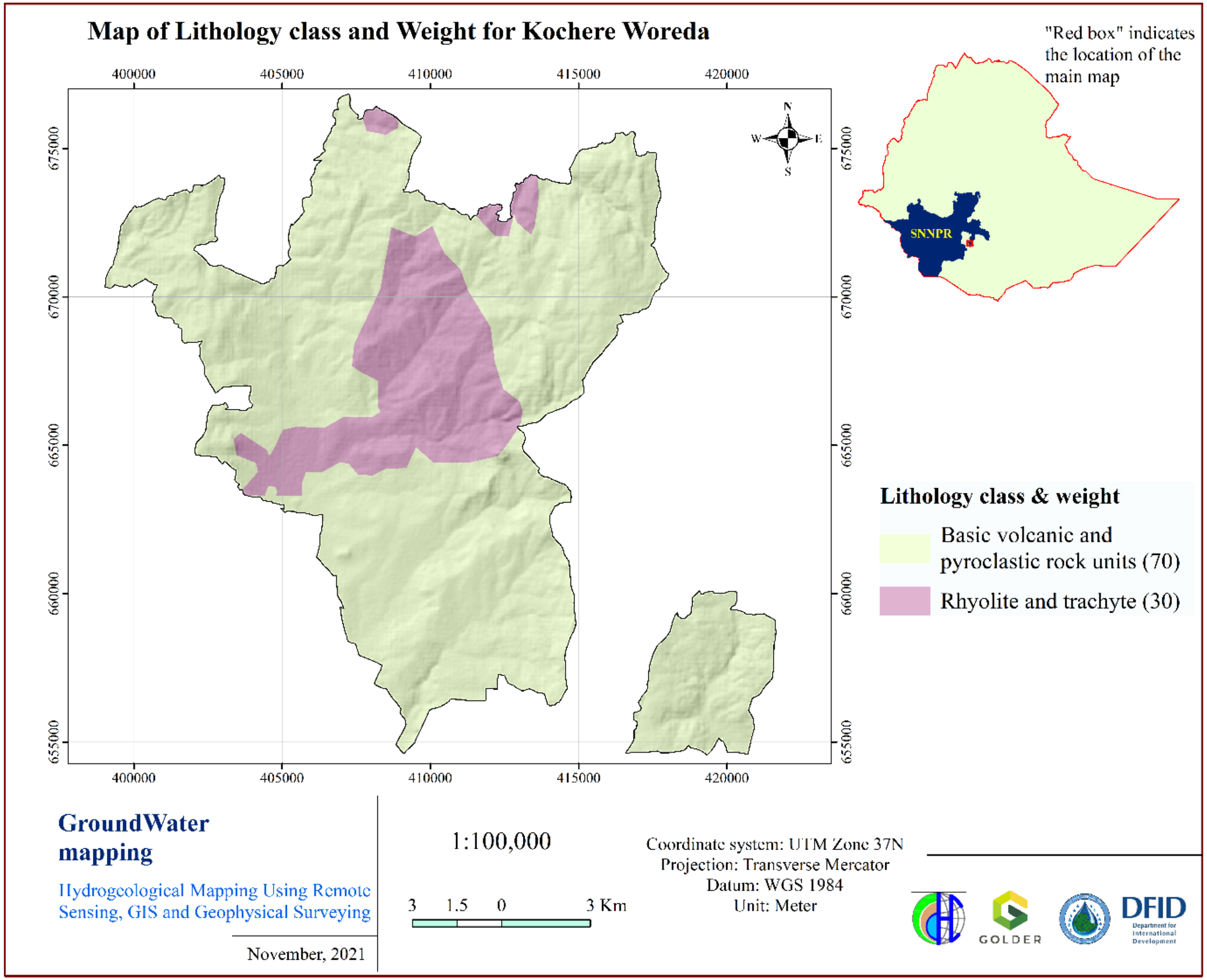

Figure 5.25: Map of lithology class and weight for Kochere Woreda

II. Lineaments and lineament density

The study area is highly affected by lineaments and/or fractures consequent to a number of tectonic activities in the past. Two prominent directions identifiedin the area are NNE-SSW and E–W trending lineaments. Usually, lineament density map is a measure of quantitative length of linear feature per unit area which can indirectly reveal the groundwater potentials as the presence of lineaments usually denotes a permeable zone. For most of the study area, the lineament density varies from less than 0.11 km/Km2 to 0.38 km/Km2 (Figure 5.26). Though the lineaments are widespread across the study area, however, the distribution of lineaments suggests geologic control within the areas underlain by basic volcanic rocks of 0.2 – 0.38 km/Km2 compared with areas underlain by rhiyolites and trachytes with volcanic plugs (< 0.2 km/Km2).

Thus, areas with higher lineament density are regarded as good for groundwater development. Consequently, higher weightage of 0.36 was assigned to area with high density of lineaments, while a low weightage of 0.08 was assigned to areas with low lineament density (Figure 5.26).

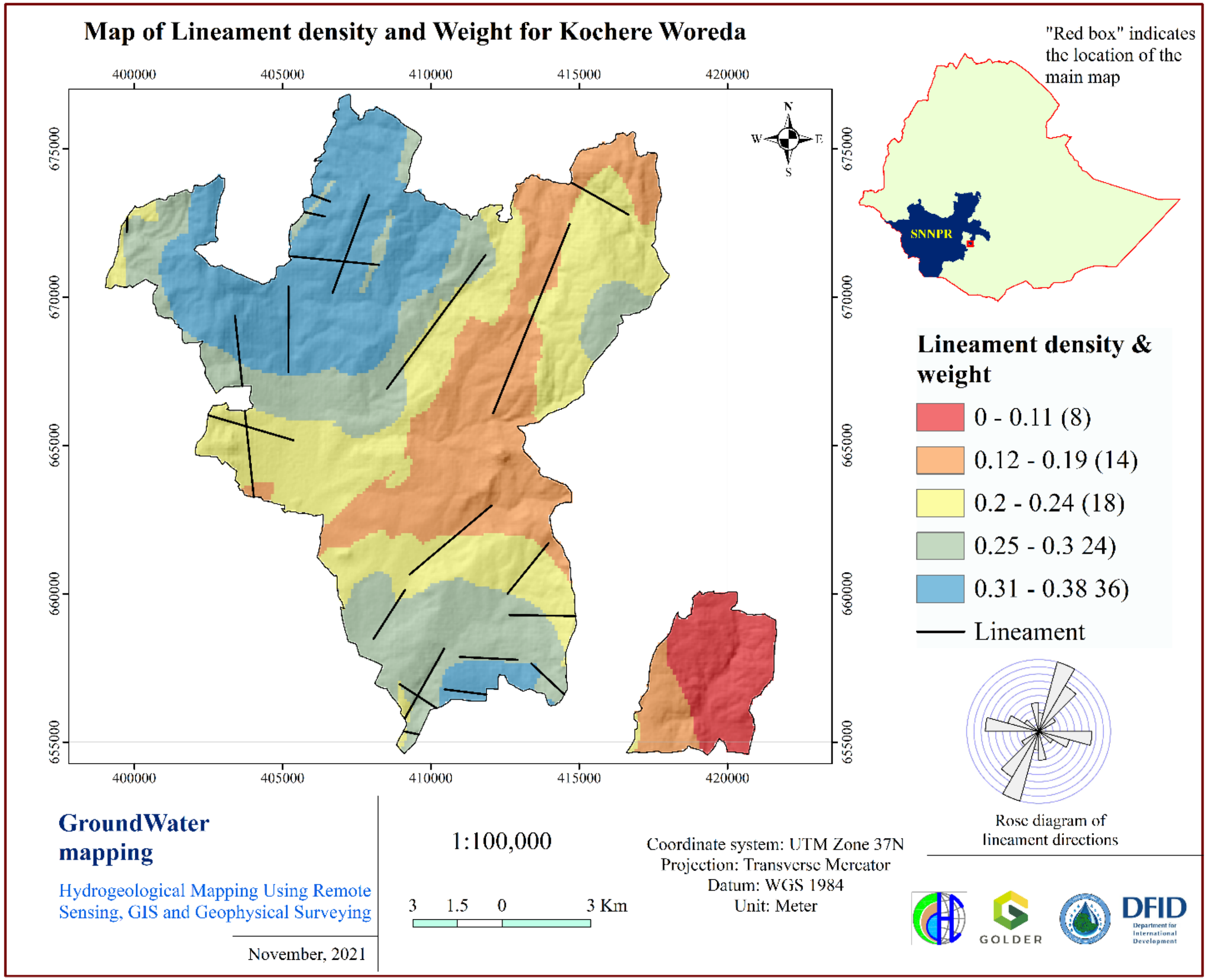

Figure 5.26:- Map of lineament density and weight for Kochere Woreda

III. Topographic Wetness Index (TWI)

In this study area, the TWI value ranges between 4.62 and 24.5. A closer look at the classification revealed that most the high elevated areas and drainage systems with steep slopes have relatively lower TWI value while the low lying areas and drainage systems with gentle and flat slopes have relatively higher wetness index value where runoff waters from highlands flow and accumulates mostly. Therefore, an area with higher value of TWI has good prospect for groundwater occurrence and flow, and accordingly high weightage value (0.36) was assigned to this class. Whereas, areas with lowest TWI value are steep slopes which triggers runoff were considered as low groundwater prospect and given low weightage value of 0.08 (Figure 5.27).

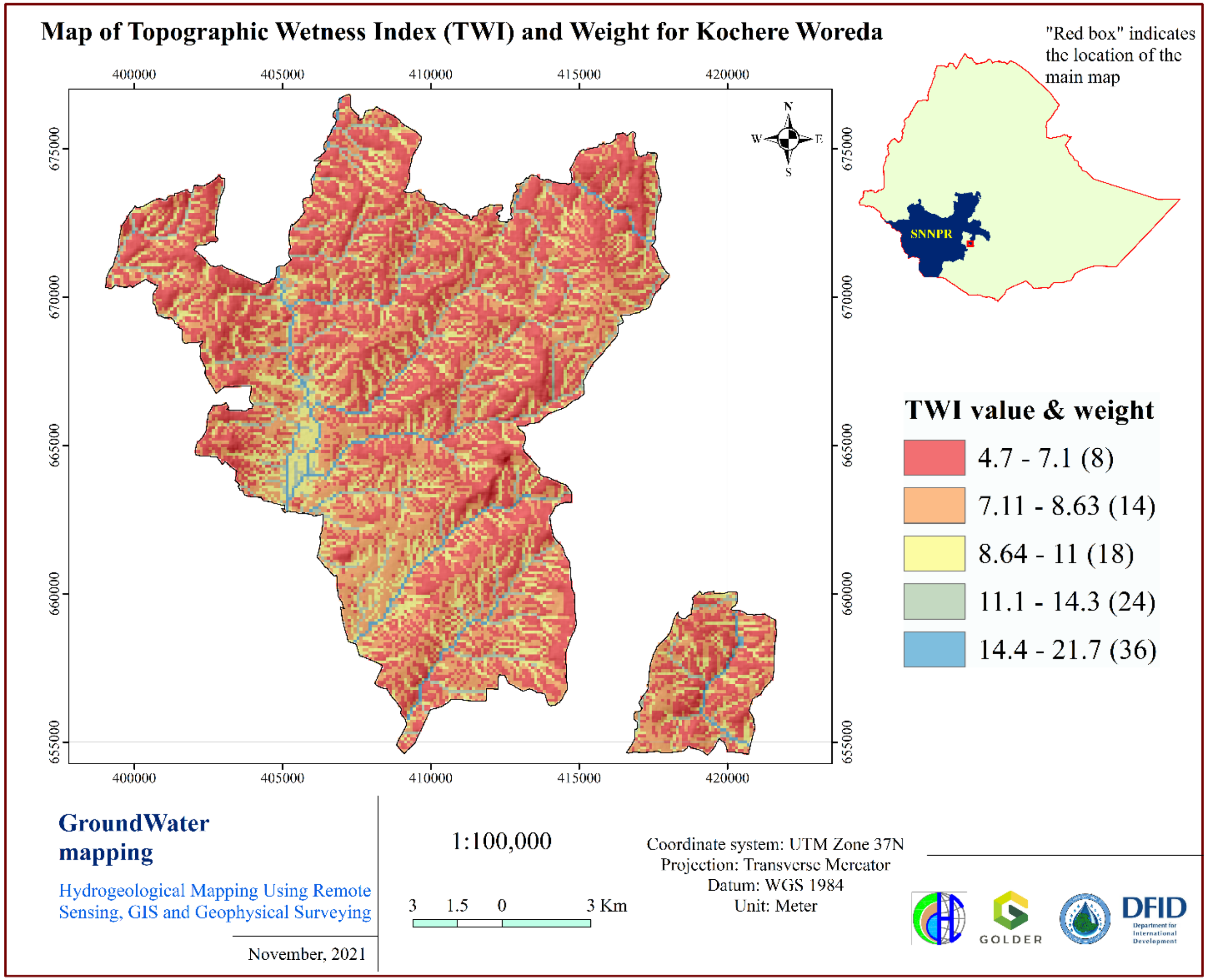

Figure 5.27:- Map of topographic wetness index (TWI) and weight for Kochere Woreda

IV. Recharge

The 10 years spatial annual recharge rate distribution in Kochere woreda ranges from 57.5.6 to 152 mm suggesting groundwater systems in most part of the woreda area underlain by fractured and weathered basic volcanic rocks receive high amount of recharge while areas underlain by massive volcanic rocks have relatively low recharge amount (Figure 5.28). Accordingly, areas with higher and moderate amount of recharge have weightage factor of 0.36 and 0.24, respectively signifying very good and moderate groundwater potential respectively while areas with the lowest amount of recharge have weightage factor of 0.08, suggesting poor groundwater potentiality. A closer look at the recharge thematic map (Figure 5.28) revealed that most of the central low-lying parts and north eastern parts of the woreda have relatively higher recharge (> 147 mm/y). Generally, the study area is characterized moderate mean annual recharge amount.

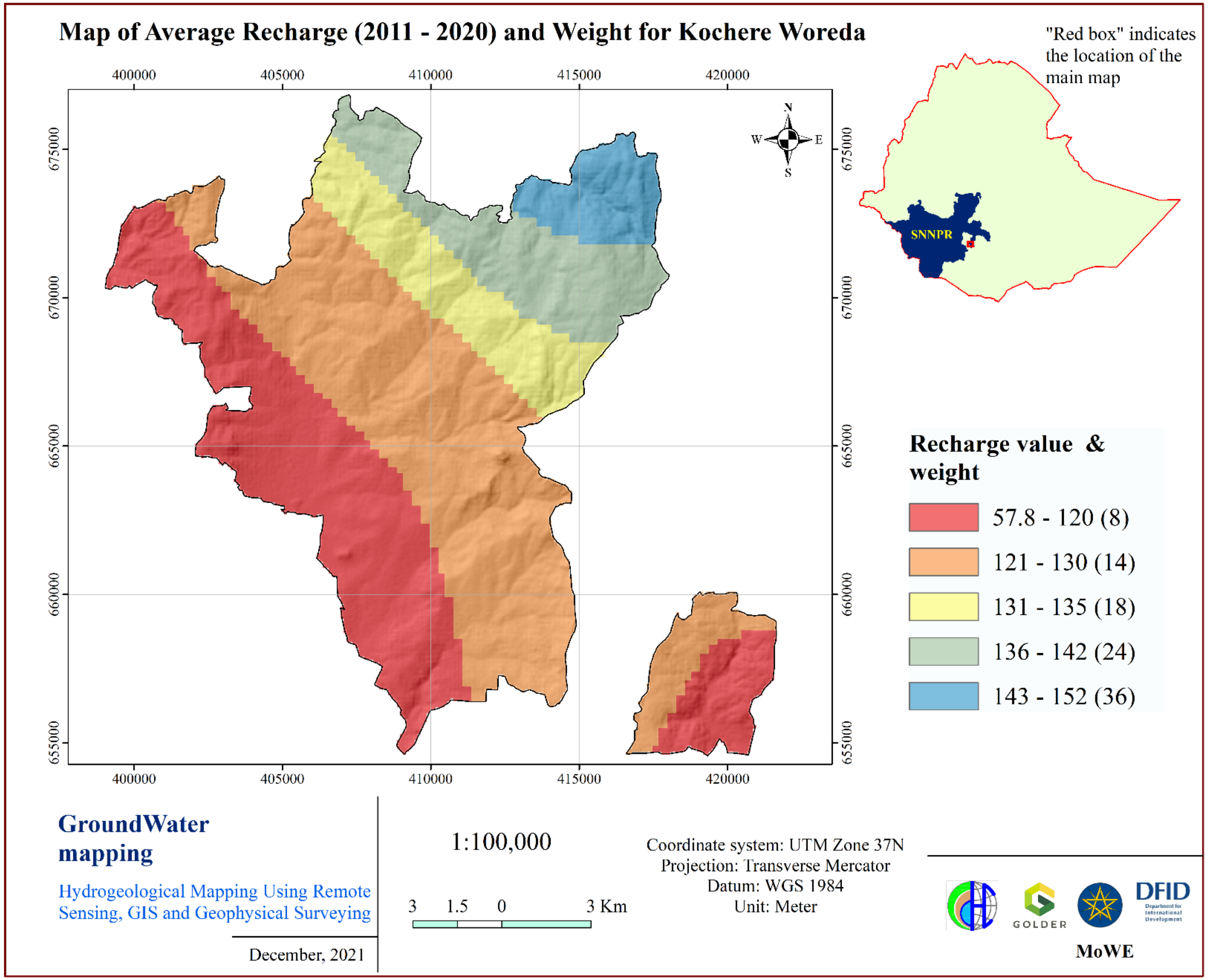

Figure 5.28: Map of average recharge (2011-2020) and weight for Kochere Woreda

5.4.2. Classification of Groundwater Potential Zones

The hydrogeological system of Kochere woreda is comprised of two main lithological units as basic volcanic rocks and rhiyolits and trachyte volcanic rocks with plugs. At regional scale, basic volcanics form moderately productive aquifers. Within the domain of Kochere woreda, theses, basic volcanics form aquifers with high groundwater potential.

At regional scale, volcanic rocks form extensive and moderately productiveaquifer. However, at local scale, within the domain of Kochere woreda, due to the geomorphic setup, acidic volcanic rocks form low potential aquifer.

Hydrogeological data from water point inventory, hydro-chemical data and geophysical investigation outcome of the next phase will help to improve the understanding of hydrogeological frame work of the area.

On the basis of the assignment and normalized weighting of the individual features of the thematic layers, a potential groundwater map was produced (Figure 5.29). The potential groundwater zones (PGZ) of Kochere woreda revealed two distinct zones, namely low (unsuitable) and very high zones whose distribution and extents are presented in Table 5.11.

The groundwater potential map gives a quick assessment of the occurrence of groundwater resources in the study area. The groundwater potential map revealed that most elevated areas in the central parts of the Kochere Woreda generally have low potential while dominant parts of the area elsewhere generally exhibits very high groundwater potentials. Generally, very high groundwater potentiality of the study area is a confirmation of highly productive aquifers basic volcanics in the area.

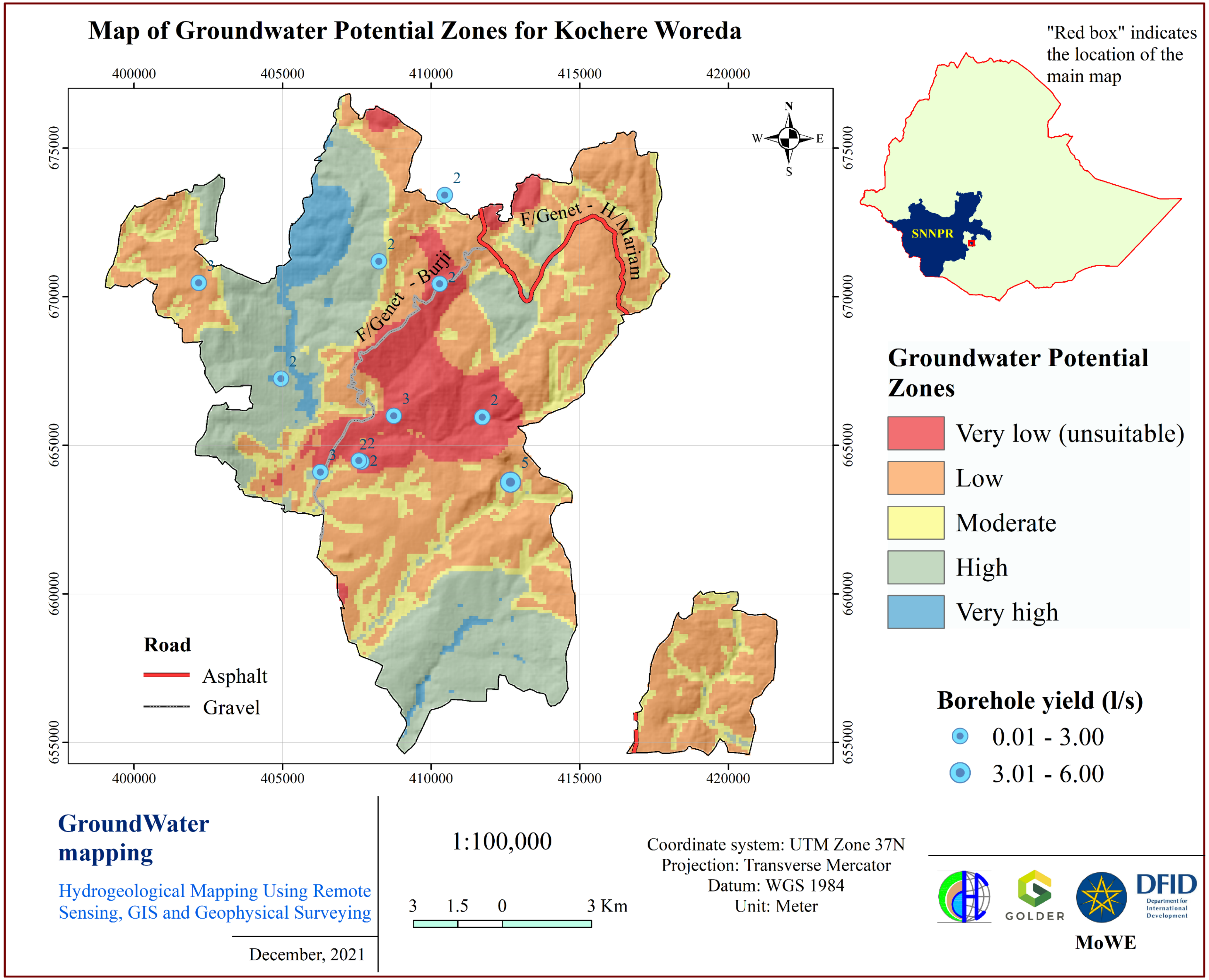

Figure 5.29:- Map of groundwater potential zones showing five zones identified by the GIS overlay analysis in Kochere Woreda

Furthermore, a closer assessment of the groundwater potential map revealed that the distribution is more or less a reflection of the geology and lineament density in addition to the topographic wetness index control. Areas underlain by basic volcanics are characterized by relatively plain land with flat slope having higher recharge amount due to the presence of lineaments and apparently deep fracturing and weathering have very high groundwater potential. Summary of the groundwater potential zones identified in Kochere woreda is presented in the table below (Table 5.11).

Table 5-11:- Classification of groundwater potential zones and coverage areas alongside the respective yield categories in Kochere Woreda

Class	Class interval	Pixel count	Area (Km2)	Area (%)	Well yield (l/s)	Groundwater prospect
1	117 - 167.12	2697	26970	11.9	-	Very low
2	167.13 - 186.4	9370	93700	41.5	0.4 – 1.0	Low
3	186.41 - 201.27	3641	36410	16.1	0.4 – 5.0	Moderate
4	201.28 - 223.3	5970	59700	26.4	0.5 – 5.0	High
5	223.31 - 257.44	909	9090	4.0	0.7 – 5.0	Very high

5.4.3. Validation with Borehole Yield Data

In order to validate the classification of the groundwater potential zones as revealed by the GIS based groundwater potential map, data on existing wells (yield) were collected for over 65 boreholes in and around the woreda area.

The borehole data were superimposed on the groundwater potential map and numbers of wells with different yield ranges for different groundwater potential zones were evaluated. As far as the secondary data obtained is concerned, the yields of the boreholes in the woreda and its surrounding areas vary from 0.5 to 5 lit/sec (Figure 5.29). As shown in the same figure, the occurrence of relatively high yield wells is associated with high lineament zone and volcanic rocks of basic composition. This is also consistent with the low and very high groundwater potential classification of the GIS map for these rocks unit.

The validation clearly highlights the efficiency of the integrated RS and GIS methods employed in this study as useful modern approach for proper groundwater resource evaluation and sustainable groundwater development. Nonetheless, the groundwater potential zonation map presented here can be applied only for further by providing quick prospective guides for groundwater in such tectonically disturbed area.

3.1.3. Population projection and water demand

3.1.3.1. Population

It is essential that the water supply system is designed to meet the requirements of the population expected to be living in the community at the end of design period by taking into account the design period and annual growth rate. Hence in order to avoid or minimize the aforementioned population related risks, efforts are made to review & justify the credibility of the available population data and growth rate figures.

Population projection is made making use of the geometric growth rate method by using the base population figure estimated by the central statistical Authority. The CSA has set average growth rates for urban and rural areas of the country varying at different times during the design period as shown in the table below. Accordingly, these values are adopted in forecasting future population of the town.

Table 5-12 CSA Rural Population Growth Rates

Rural Population Projection Growth Rate of Regions: 2008-2037						
YEAR / Growth Rate % (Rural)	2008-2012	2013-2017	2018-2022	2023-2027	2028-2032	2033-2037
Oromia Region	2.74	2.54	2.29	2.03	1.8	1.56
SNNP Region	2.49	2.37	2.31	2.03	1.82	1.57
Somali Region	2.75	2.63	2.35	2.05	1.89	1.83
Gambela Region	3.52	3.1	3.13	2.76	2.46	2.31

Source: CSA Population Projection for Ethiopia 2007-2037, Addis Ababa July 2013

Geometric method forecasting formula

$$P = Po (1 + r)^n$$

Where
P – projected population
Po – current population
n – Number of years for projection
r – Population growth rate

The population of Kochere Woreda has been projected forward until 2036 using the projected scale of Southern Nation Nationalities and Peoples Regional State. The minimum and maximum population in the Woreda is 3551 and 18562 respectively. The total population of the Kochere Woreda in 2036 is going to be 204,594. Figure 5.30 presents the projected population for each kebele in the Woreda.

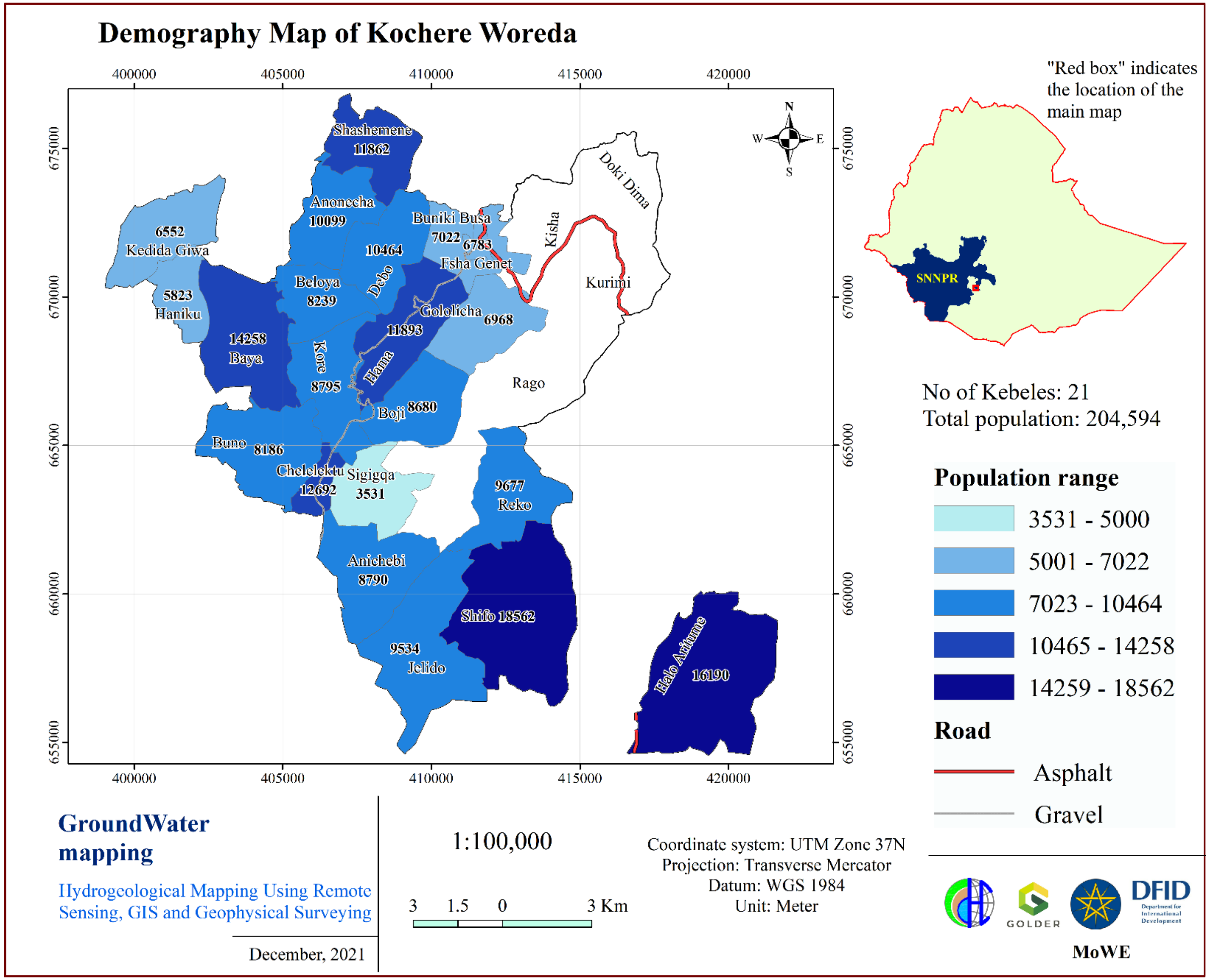

Figure 5.30: Map of projected population (2036) for Kochere Woreda.

3.1.3.2. Water Demand Projection

Projected Water Demand

Estimating water demands mainly depends on the size of the population to be served, their standard of living and activities. To make the demand projection reliable and suitable for rural areas it is better to classify in details as domestic and non-domestic demands.

Domestic Water Demand

Domestic water demand is the amount of water needed for drinking, food preparation, washing, cleaning, bathing and other miscellaneous domestic purposes. The amount of water used for domestic purposes greatly depends on the lifestyle, living standard, and climate, mode of service and affordability of the users.

Domestic water demand service can be categorized according to the level of service to be provided and amount of per capita water required satisfying the demand served by the level of service. Modes of services used for our projection are classified into four categories, namely: -

- Traditional Source users (TSU)
- Public tap users (PTU)
- Yard connections and Neighbourhood (shared) connections (YCO) & (YCS)
- House tap connections (HTU)

In projecting the domestic water demand, the following procedures were followed:

- Determining population percentage distribution by mode of service and its future projection
- Establishment of per capita water demand by purpose for each mode of service;
- Projected consumption by mode of service;
- Adjustment for climate;
- Adjustment due to socio-economic conditions.

After considering the necessary mode of services, per-capita demand and applying the adjustment factors the domestic demand for the corresponding year and population has been calculated.

Non-Domestic Water Demand

Non-domestic water demand was also determined systematically. We have classified it into three major categories based on our projection:

- Institutional water demands (Public and governmental);
- Commercial water demand;
- Livestock water demand

N.B:- The use of a reliable base population figure is very important for optimizing the water sources but adopting 2007 CSA data as a base population has real impact on the projection so to compensate some unforeseen situation like migration and unplanned rural town growth. To compensate for such

- To estimate the demand of public institutions and commercial services we have adopted 15% - 20% of the domestic demand for our consumption.
- The demand for livestock watering adopted in the projection is 10% -15% of the domestic demand.

Total Average daily day demand

The average daily day demand is taken to be the sum of domestic demands and non-domestic demand. The water demand in a day varies with time according to the consumer's life style. It is the total sum of adjusted domestic, public and livestock demand.

Maximum Day Demand

The maximum day demand is the highest demand of any one 24-hour period over any specific year. It represents the change in demand with season. This demand is used to design source capacity. The deviation of consumption from the average day demand is taken care of as per the maximum daily coefficient figures. Usually a value from1.1 to 1.3 is adopted as maximum day factor. A constant value of 1.3 is adopted as maximum day factor for all of the villages.

Figure 5.31 shows the distribution of water demand in each Kebeles of the Woreda. The minimum and maximum water demand for Kebeles is 317 M^3/day and 11,668 M^3/day respectively. The overall water demand for the projected population in the Kochere Woreda is 18,381 M^3/day.

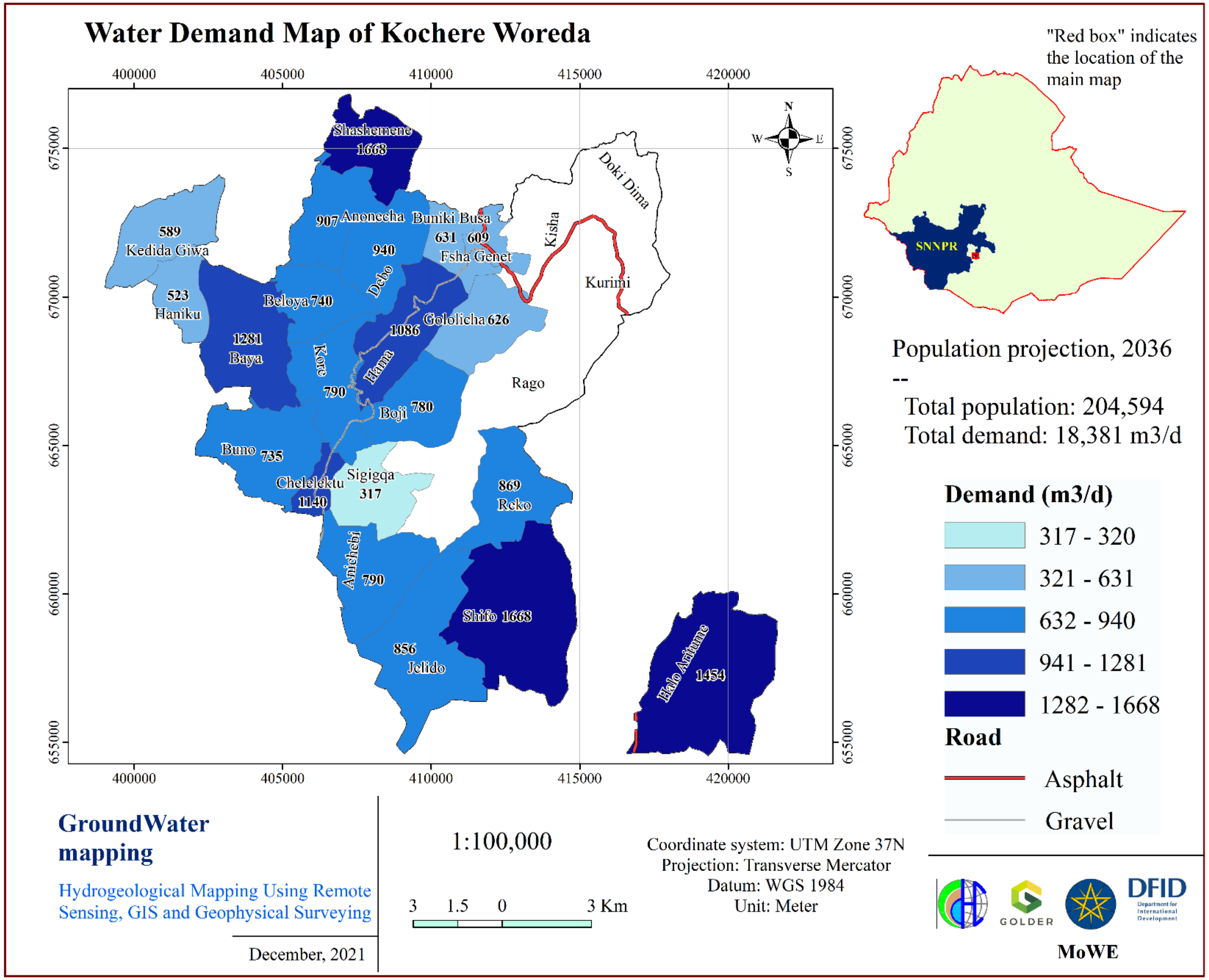

Figure 5.31: Map of water demand (M^3/day) for Kochere Woreda.

5.4.4. Propsed Target Sites

Four target sites are identified and proposed within the woreda based on the identified groundwater potential zones, the productivity of the hydrostratigraphic units with their expected optimum borehole yield, proximity to beneficiaries and population density. With further discussion and consultation with stakeholders, two priority sites will be selected for further hydrogeological and geophysical investigations in phase III. The following are the four proposed sites (Figure5.32):

Target Site-I:

This target site is located in the western part of the woreda. It is situated in the identified very high groundwater potential zones. This target site is mainly underlain by volcanic rocks.

Target Site-II:

This target site is located in the southern part of the woreda. It is situated in the identified very high groundwater potential zones. This target site is mainly underlain by volcanic rocks.

Target Site-III:

This target site is located in the south eastern part of the woreda. It is situated in the identified very high groundwater potential zones. This target site is mainly underlain by volcanic rocks.

Target Site-IV:

This target site is located in the eastern part of the woreda. It is situated in the identified very high groundwater potential zones.This target site is mainly underlain by volcanic rocks.

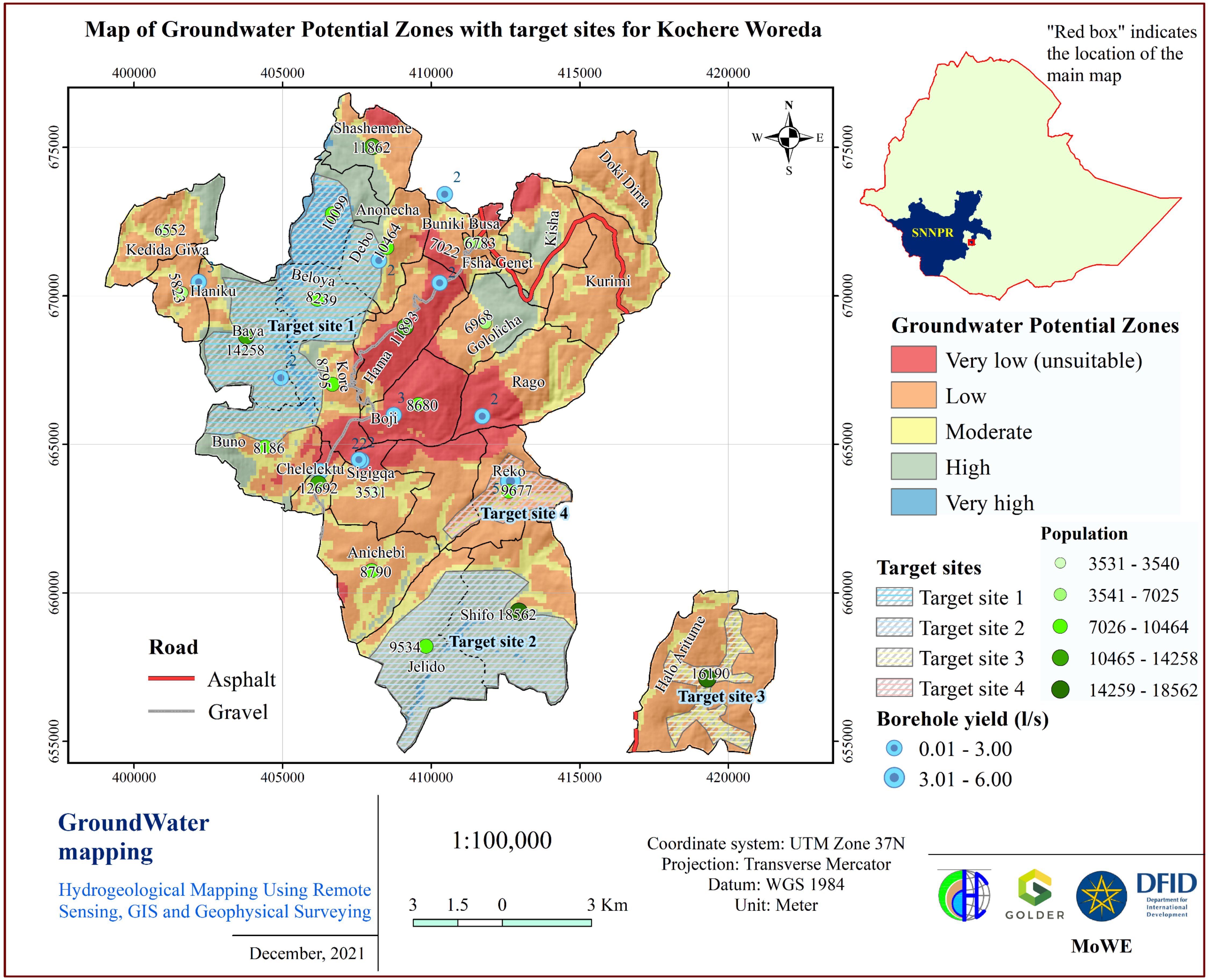

Figure 5.32:- Map of groundwater potential zones with selected target sites in Kochere Woreda

5.4.5. Conceptual hydrogeological model of Kochere Woreda

Hydrogeological conceptual models are collections of hypotheses based on geological structural and geomorphological evidences and existing wells lithologic logs to describe and understand the groundwater occurrence, localization and movement beneath the ground surface. The purpose of the hydrogeological model across/along inferred groundwater flow direction is to reflect the prototype of regional groundwater flow system in the two priority sites selected for further study in phase III.

Due to its location in the Main Ethiopian Rift, rock units are dislocated and placed in jackstapostion against each other. This region has a compartimentalized groundwater flow system constrained by geological structres and topography. Groundwater gets recharge mainly from local rain that falls on central and a northeast surrounding highland with expected lateral inflow from north. Groundwater flow direction is generally towards south in the general direction of Gelana River through fractured volcanic rocks. Development of the hydrogeological conceptual model of the Kochre Woreda will be prepared based on the converging evidence of secondary data including digital elevation model (DEM), geological and hydrogeological maps and structures, lithological well logs of wells in the area. The target sites will be selected out of the proposed ones. The conceptual hydrogeological models for this woreda to be constructed along/across groundwater flow path will be produced after stake holder consultation workshop to select priority target sites for further hydrogeological characterization. The conceptual hydrogeological model summarizes what is known about the hydrogeological system and thereby provides a framework for hydrogeological system of the target sites in the woreda including the major groundwater flow zone (inflow, groundwater flow paths, inferred depth, and outflow) and groundwater table and groundwater condition of Kochere woreda using existing data of spring and boreholes.

5.5. Kemba Woreda

The four thematic layers which were integrated for groundwater potential mapping in Kemba Woreda are summarized in table 5.13 below. The notes on the description of each thematic layers including classification of potential zones, validation with borehole and scheme datasets, population projection, water demand and selected target sites presented in the sub-sections.

Table 5-13. Assigned and normalized weights for the individual features of the four thematic layers for groundwater potential zoning in Bule Hora Woreda

Class	Class interval	Class Weight	Pixel count	Area (Km2)	Area (%)	Weight	Groundwater prospect
	Lineament layer						
1	0 - 0.075	8	16759	167590	14.3	0.21	Very low
2	0.076 - 0.14	14	26632	266320	22.8		Low
3	0.15 - 0.2	18	32059	320590	27.4		Moderate
4	0.21 - 0.27	24	23153	231530	19.8		High

5	0.28 - 0.37	36	18264	182640	15.6		Very high
	Topographic Wetness Index (TWI) layer						
1	4.55 – 7.04	8	42671	426710	36.5	0.27	Very low
2	7.05 – 8.82	14	42112	421120	36.0		Low
3	8.83 - 11.2	18	21083	210830	18.0		Moderate
4	11.3 – 15.1	24	8774	87740	7.5		High
5	15.2 – 22.7	36	2227	22270	1.9		Very high
	Recharge layer						
1	29.2 – 42	8	20209	202090	17.4	0.05	Very low
2	42.1 – 127	14	46662	466620	40.2		Low
3	128 – 147	18	22107	221070	19.0		Moderate
4	148 – 172	24	20312	203120	17.5		High
5	173 – 201	36	6867	68670	5.9		Very high
	Lithology layer						
2	Basement rocks of different kinds	12	20702	207020	17.8	0.46	Poor
3	Basic volcanic and pyroclastic rock units	32	66333	663330	57.0		Good
5	Quaternary sediment and lacustrine deposits	56	29407	294070	25.3		Very good

5.5.1. Integration of Thematic Layers for Groundwater Potential Zoning

The details of geology, rainfall, lineament density, geomorphology, land slope, soil type, land use/land cover, groundwater depth and drainage density together with their spatial distribution in Kemba woreda are presented below:

I. Geology/lithology

In general, the area southeast and north central parts of Kemba woreda are underlain by basement rocks. Basic volcanic rocks outcrop in the northern mountainous and mountain foot. Rhyolite and trachyte flows outcropped in the central east west belt of the woreda. Quaternary sediments outcrop in the elongated plain in the western part of the woreda.

However, the lithological units found in the woreda area are further classified into three major groups based on their significances to groundwater occurrence and productivity using borehole yield information available in the synoptic view.

- Quaternary alluvium and lacustrine deposits,
- Basalt, rhyolite and trachyte flows,
- Basement rocks

The crystalline basement and volcanic rocks (basalts, rhiyolites and trachyte flows) underlain by Quaternary sediment are the main lithologic framework of Kemba woreda (Figure 5.33).

Usually, massive unfractured lithologic units in basement and volcanic rock settings have little influence on groundwater availability except in cases with secondary porosity through the development of weathered regolith, and fractured bedrock units, which form potential groundwater zones. Hence, on the basis of the presence and nature of the weathered regolith units and fracture systems, appropriate weights are assigned to the different lithological units in the study area. The weightage (Figure 5.33) in terms of increasing groundwater potentiality is in the order of poor productivity of basement rocks (0.12), moderate productivity of volcanic rocks (0.32) and high productivity of Quaternary deposites (0.42).

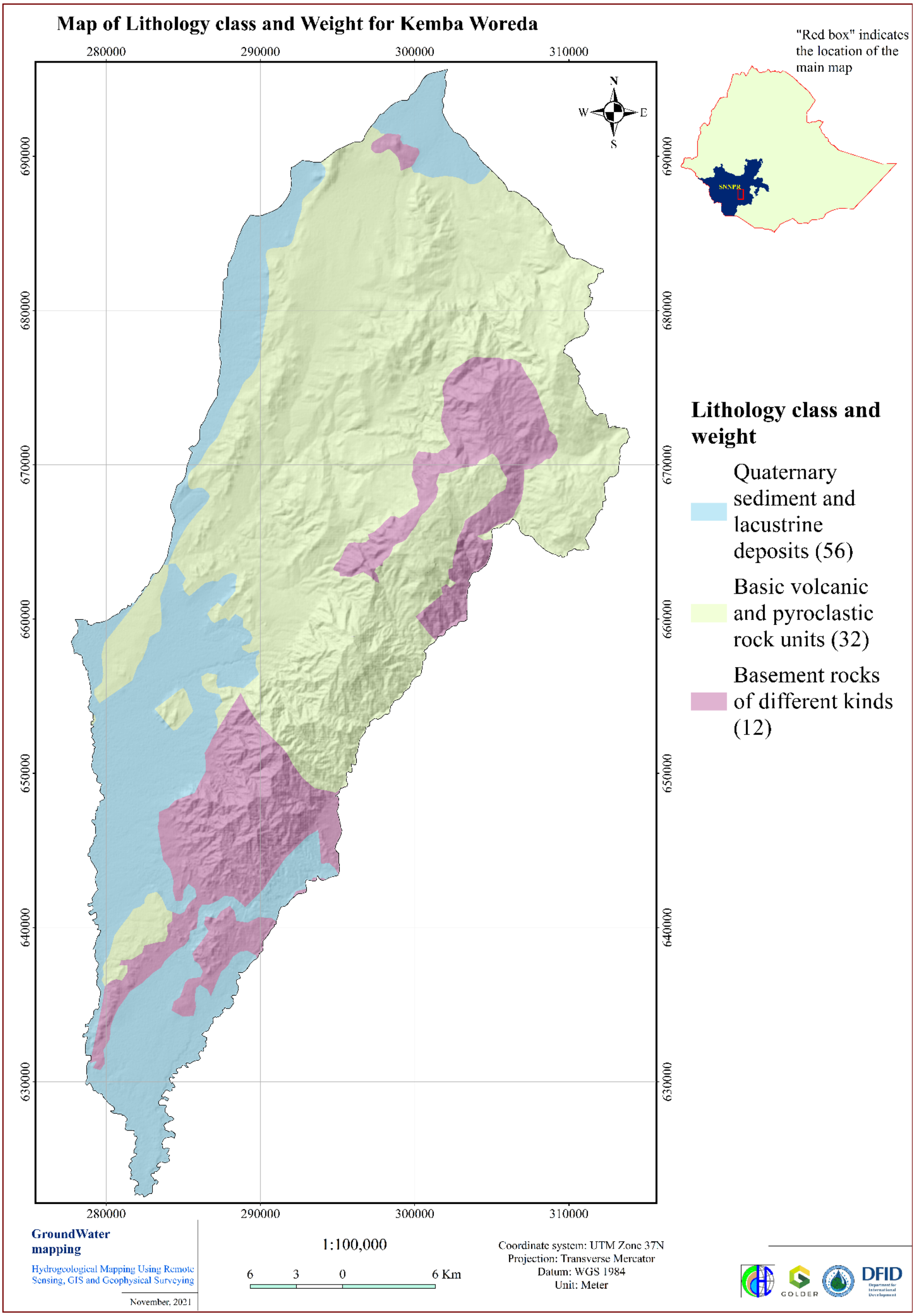

Figure 5.33. Map of lithology class and weight for Kemba Woreda

II. Lineaments and lineament density

The study area is highly affected by lineaments and/or fractures consequent to a number of tectonic activities in the past. Two prominent directions identified are NNE-SSW and NW–SE trending lineaments. Usually, lineament density map is a measure of quantitative length of linear feature per unit area which can indirectly reveal the groundwater potentials as the presence of lineaments usually denotes a permeable zone. For most of the study area, the lineament density varies from less than 0.075 km/Km2 to 0.37 km/Km2 (Figure 5-34). Lineament density is in the central part where the rock units are dominantly basalts and basement complex where there is higher lineament density of 0.21 – 0.37 km/Km2) compared with areas underlain by other rocks unit's o (< 0.21 km/Km2).

Thus, areas with higher lineament density are regarded as good for groundwater development provided that the land slope is gentle or flat. Consequently, higher weightage of 0.36 was assigned to area with high density of lineaments, while a low weightage of 0.08 was assigned to areas with low lineament density (Figure 5.34).

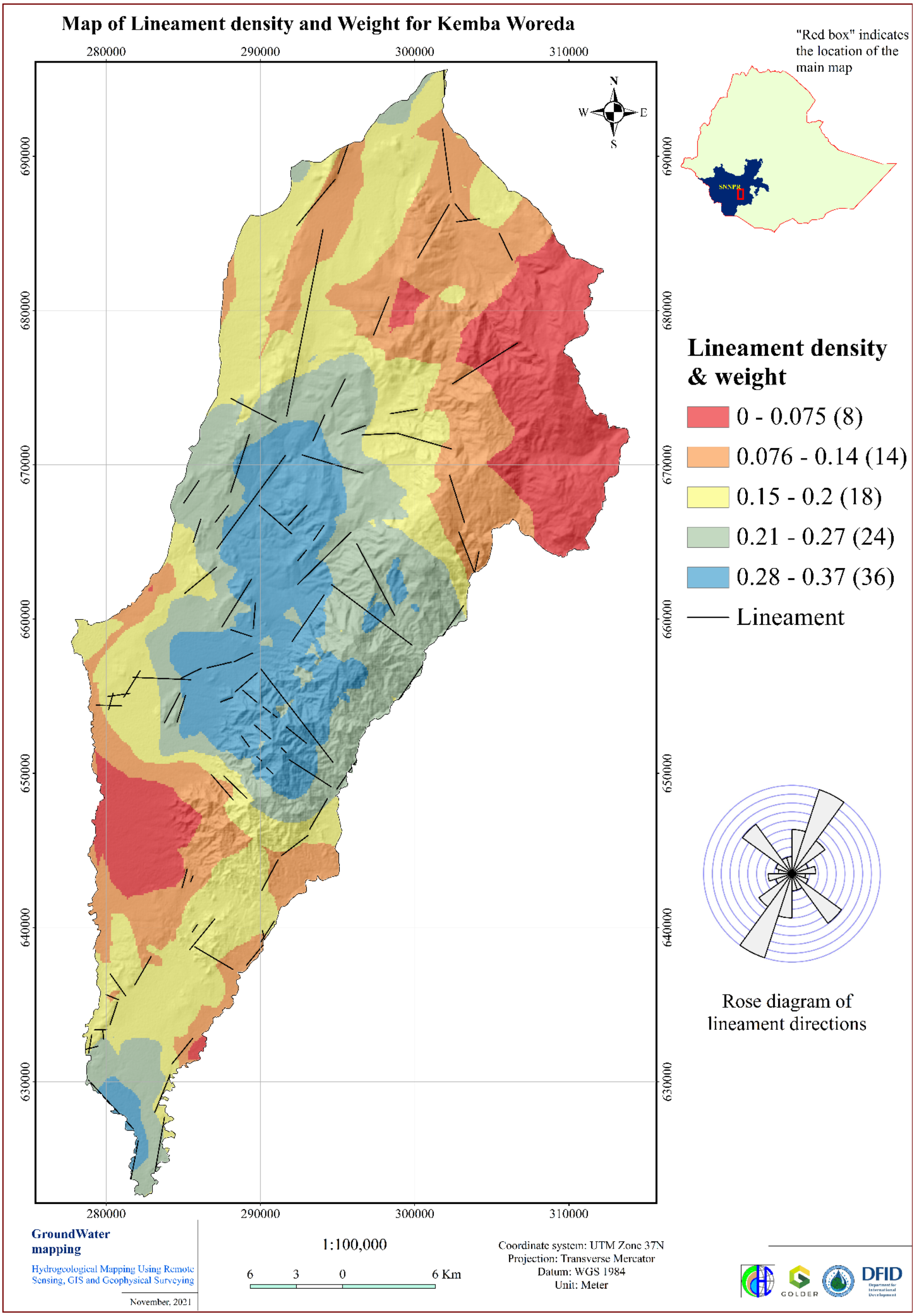

Figure 5.34. Map of lineament density and weight for Kemba Woreda

III. Topographic Wetness Index (TWI)

In this study area, the TWI value ranges between 4.62 and 24.5. A closer look at the classification revealed that most of the elevated areas and drainage systems with steep slopes have relatively lower TWI value while the low-lying areas and drainage systems with gentle and flat slopes have relatively higher wetness index value where runoff waters from highlands flow and accumulates mostly. Therefore, an area with higher value of TWI has good prospect for groundwater occurrence and flow, and accordingly high weightage value (0.36) was assigned to this class. Whereas areas with lowest TWI value are steep slopes which triggers runoff were considered with low groundwater prospect and given low weightage value of 0.08 (Figure 5.35).

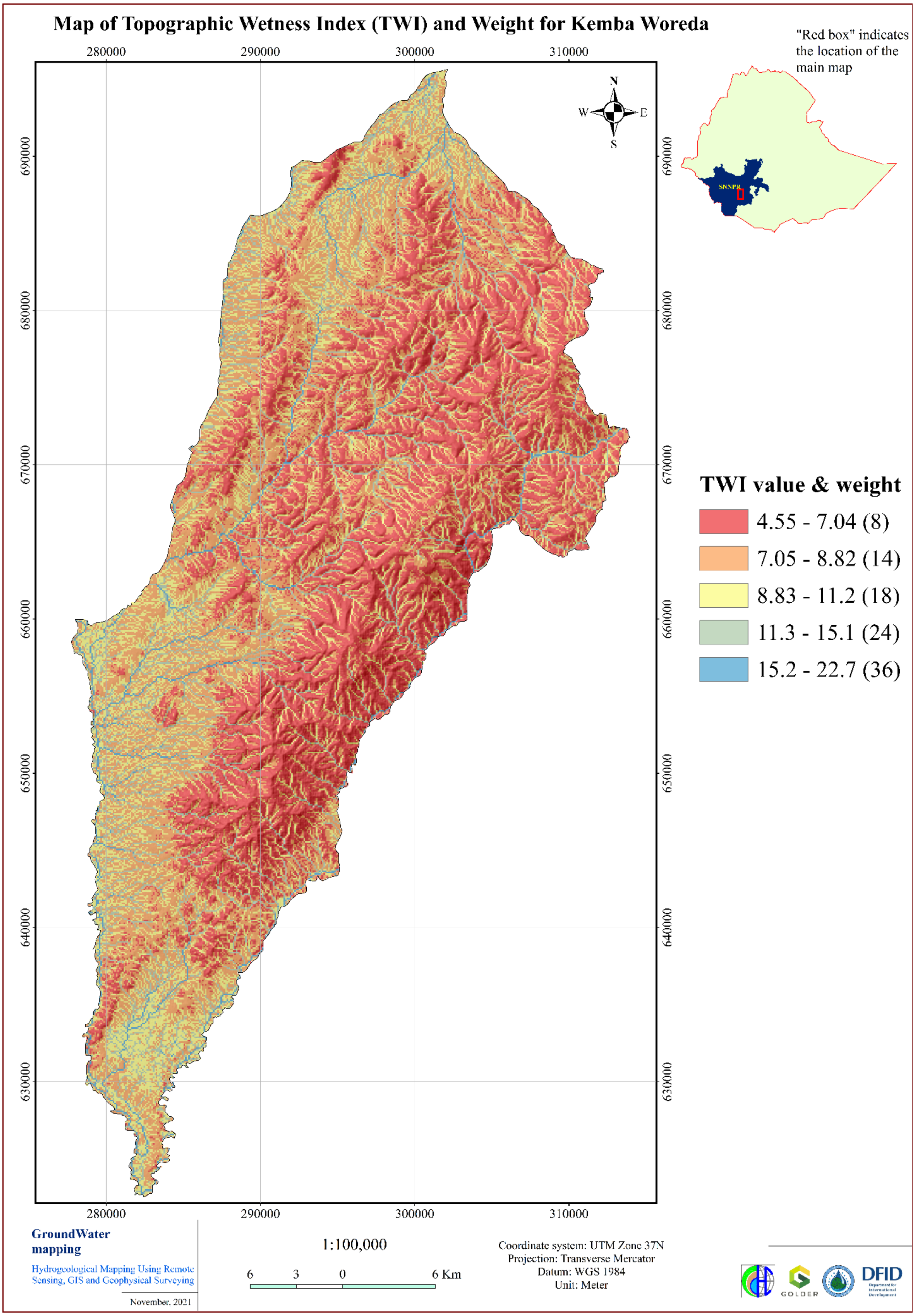

Figure 5.35. Map of topographic wetness index (TWI) and weight for Kemba Woreda

IV. Recharge

The 10 years spatial average annual recharge rate distribution in the Kemba Woreda ranges from 29.2 to 201 mm. The lower values coincide with basement lithology and the higher values coincide with volcanic rock units and Quaternary sediments suggesting groundwaters in most part of the woreda area underlain by basement complex receive low amount of recharge while areas underlain by volcanic rocks and Quaternary sediments have relatively higher recharge amount (Figure 5.36). Accordingly, areas with higher and moderate amount of recharge have weightage factor of 0.36 and 0.24, respectively signifying very good and moderate groundwater potential respectively while areas with the lowest amount of recharge have weightage factor of 0.8, suggesting poor groundwater potentiality. A closer look at the recharge thematic map (Figure 5.36) revealed that most of the western low-lying parts and north central parts of the woreda have relatively higher recharge (> 173 mm). Generally, the central part of the woreda domain is characterized with very low to low average recharge amount (42.1 – 127), whereas dominant part of the areas at center and southern parts has moderate mean annual recharge amount (148-172 mm).

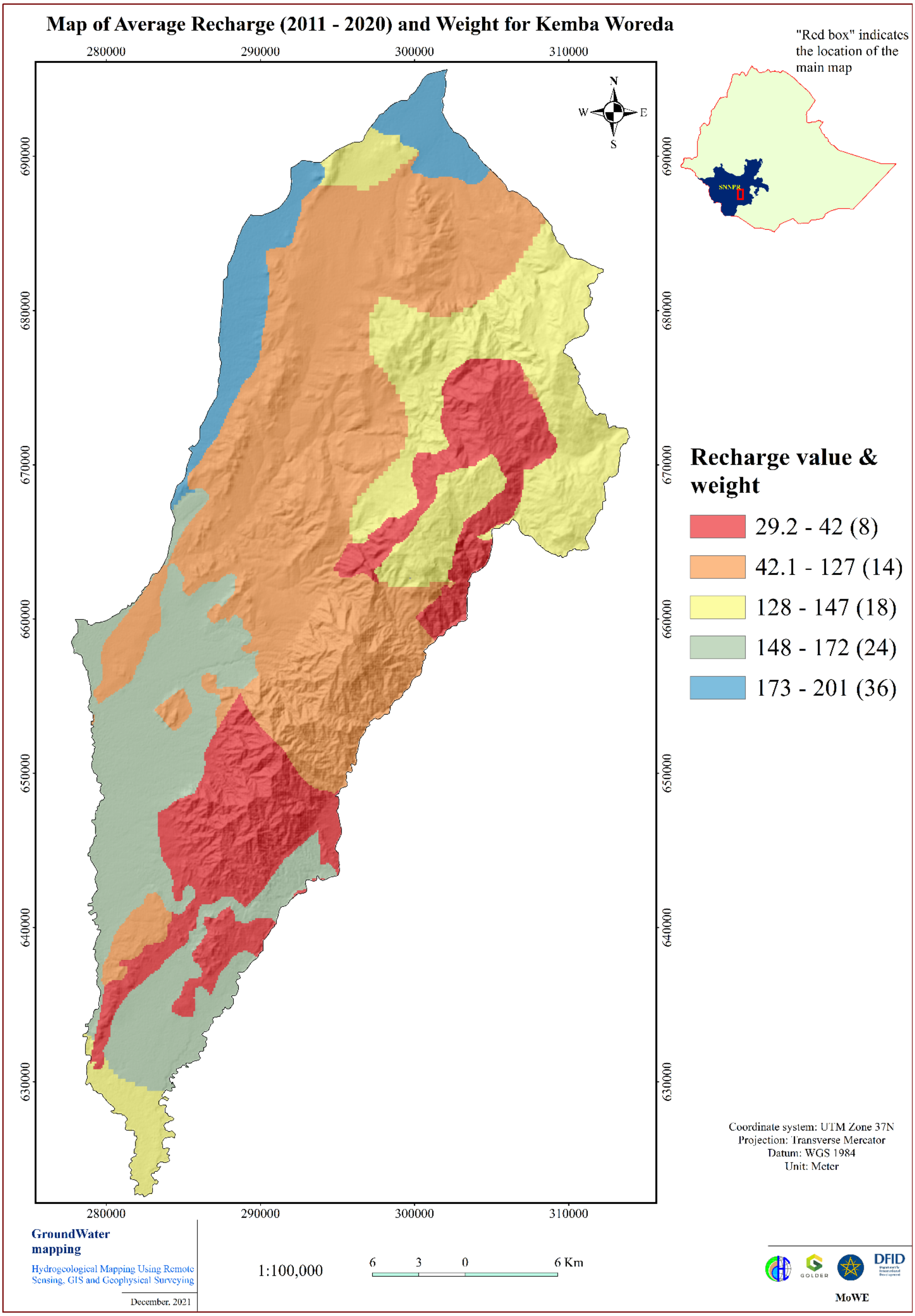

Figure 5.36. Map of average recharge (2011 – 2020) in millimeters and weight for Kemba Woreda

5.5.2. Classification of Groundwater Potential Zones

The hydrogeological system of Kemba woreda is comprised of four main lithological units as Quaternary deposits, different volcanic rocks, Phonolites and rhyolite and Crystalline basement rocks. At regional scale, Quaternary deposits form extensive and moderately productive aquifers. Within the domain of Kemba woreda, theses, Quaternary deposits form aquifers with high groundwater potential.

At regional scale, volcanic rocks form extensive and moderately productive aquifer. However, at local scale, within the domain of Kemba woreda, due to the geomorphic setup, the volcanic rocks form moderately productive aquifer as revealed from existing borehole yields found in a similar geohydrologic system outside the woreda.

Only the upper weathered and slightly fractured part of the crystalline basement rocks along lineamnets and faults have potential to store groundwater at shallow depth. Weathered and slightly fractured Crystaline basement rocks with overlying Quaternary deposit form major potential aquifer within the domain of Kemba Woreda along lineament and fault lines and associated plains.

Hydrogeological data from water point inventory, hydro-chemical data and geophysical investigation outcome of the next phase will help to improve the understanding of hydrogeological frame work of the area.

On the basis of the assignment and normalized weighting of the individual features of the thematic layers, a potential groundwater map was produced (Figure 5.37). The potential groundwater zones (PGZ) of Kemba woreda revealed five distinct zones, namely very low (unsuitable), low, moderate, high and very high zones whose distribution and extents are presented in Table 5.14.

The groundwater potential map gives a quick assessment of the occurrence of groundwater resources in the study area. It also revealed that most elevated areas in the central parts of Kemba Woreda generally have low potential while significant areas in the west, northern and wsouthern peripheral parts generally exhibits high to very high groundwater potentials. Generally high to very high groundwater potentiality of the study area is a confirmation of generally moderate to high productive aquifers of Quaternay sediments underlain by volcanic rocks, whereas very low to low groundwater potential areas have an indication of limited aquifers capabilities of basement complex and elevated volcanic rock mountains.

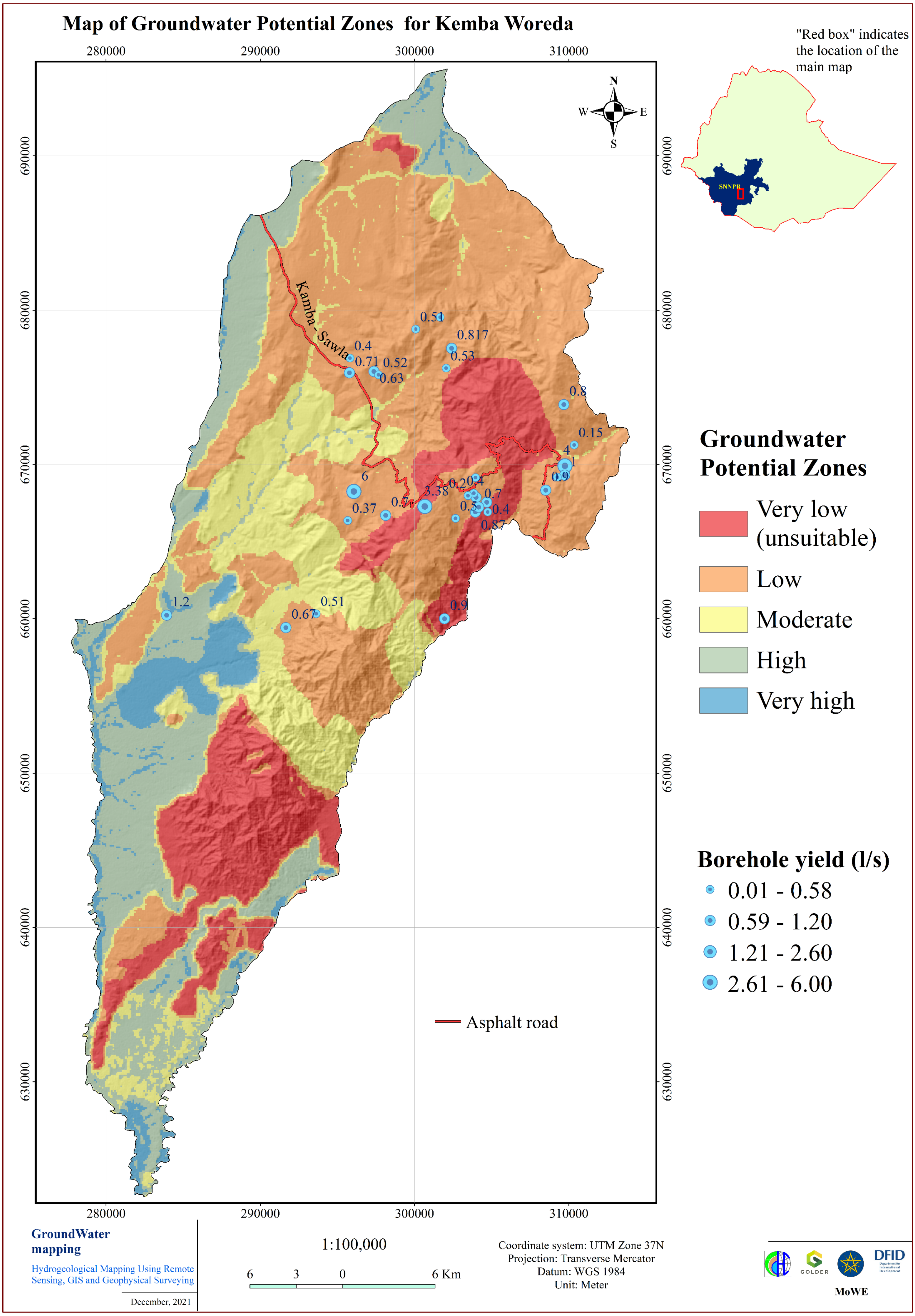

Figure 5.37. Map of groundwater potential zones showing five zones identified by the GIS overlay analysis in Kemba Woreda

Furthermore, a closer assessment of the groundwater potential map revealed that the distribution is a reflection of the geology and lineament density in addition to the topographic wetness index control. Areas underlain by Quaternary deposits especially in the west, north, extreme east of the woreda which are characterized by relatively plain land with flat slope having higher recharge amount have high and very high groundwater potential. On the other hand, areas underlain by crystalline basement complexes in the majority of the woreda areas and volcanic rocks forming mountains and small ridges and steep slopes exhibit low groundwater potential. Moreover, low drainage densities and predominance of crystalline rock outcrops can be attributed to the observed poor groundwater potentials at the most central parts of the woreda. Summary of the groundwater potential zones identified in the Kemba woreda is presented in the table below (Table 5.14).

Table 5-14. Classification of groundwater potential zones and coverage areas alongside the respective yield categories in Kemba Woreda

Class	Class interval	Pixel count	Area (Km2)	Area (%)	Well yield (l/s)	Groundwater prospect
1	132 - 160.72	19347	193470	16.6	< 0.4	Very low
2	160.73 - 197.56	49709	497090	42.6	0.58 – 0.9	Low
3	197.57 - 224.41	20797	207970	17.8	0.7 - 6	Moderate
4	224.42 - 249.39	21027	210270	18.0	0.7 - 6	High
5	249.4 - 291.22	5823	58230	5.0	1.5 - 10	Very high

5.5.3. Validation with Borehole Yield Data

To validate the classification of the groundwater potential zones as revealed by the GIS based groundwater potential map, data on existing wells (yield) were collated for over 50 boreholes in and around the study woreda area.

The borehole data were superimposed on the groundwater potential map and numbers of wells with different yield ranges for different groundwater potential zones were evaluated. As far as the secondary data obtained within the woreda domain and outside is concerned, the yields of the deep boreholes in the woreda and its surrounding areas vary from 0.2 to 10 lit/sec (Figure 5.37). As shown in the same figure, the occurrence of relatively high yield wells is associated with high lineament zone and Quaternary sediments underlain by volcanic and /basement rocks. These are also consistent with the low, moderate, high, and very high groundwater potential classification of the GIS map for area.

The validation clearly highlights the efficiency of the integrated RS and GIS methods employed in this study as useful modern approach for proper groundwater resource evaluation and sustainable groundwater development. Nonetheless, the groundwater potential zonation map presented here can be applied only for further by providing quick prospective guides for groundwater in such complex basement dominated area.

5.5.4. Population projection and water demand

5.5.4.1. Population

It is essential that the water supply system is designed to meet the requirements of the population expected to be living in the community at the end of design period by taking into account the design period and annual growth rate. Hence in order to avoid or minimize the aforementioned population related risks, efforts are made to review & justify the credibility of the available population data and growth rate figures.

Population projection is made making use of the geometric growth rate method by using the base population figure estimated by the central statistical Authority. The CSA has set average growth rates for urban and rural areas of the country varying at different times during the design period as shown in the table below. Accordingly, these values are adopted in forecasting future population of the town.

Table 5-15 CSA Rural Population Growth Rates

Rural Population Projection Growth Rate of Regions: 2008-2037						
YEAR / Growth Rate % (Rural)	2008-2012	2013-2017	2018-2022	2023-2027	2028-2032	2033-2037
Oromia Region	2.74	2.54	2.29	2.03	1.8	1.56
SNNP Region	2.49	2.37	2.31	2.03	1.82	1.57
Somali Region	2.75	2.63	2.35	2.05	1.89	1.83
Gambela Region	3.52	3.1	3.13	2.76	2.46	2.31

Source: CSA Population Projection for Ethiopia 2007-2037, Addis Ababa July 2013

Geometric method forecasting formula

$$P=Po\,(1+r)^{n}$$

Where P – projected population
Po – current population
n – Number of years for projection
r – Population growth rate

The population of Kemba Woreda has been projected forward until 2036 using the projected scale of Southern Nation Nationalities and Peoples Regional State. The minimum and maximum population in the Woreda is 3,149 and 17,721 respectively. The total population of the Kemba Woreda in 2036 is going to be 208,783. Figure 5.38 presents the projected population for each kebele in the Woreda.

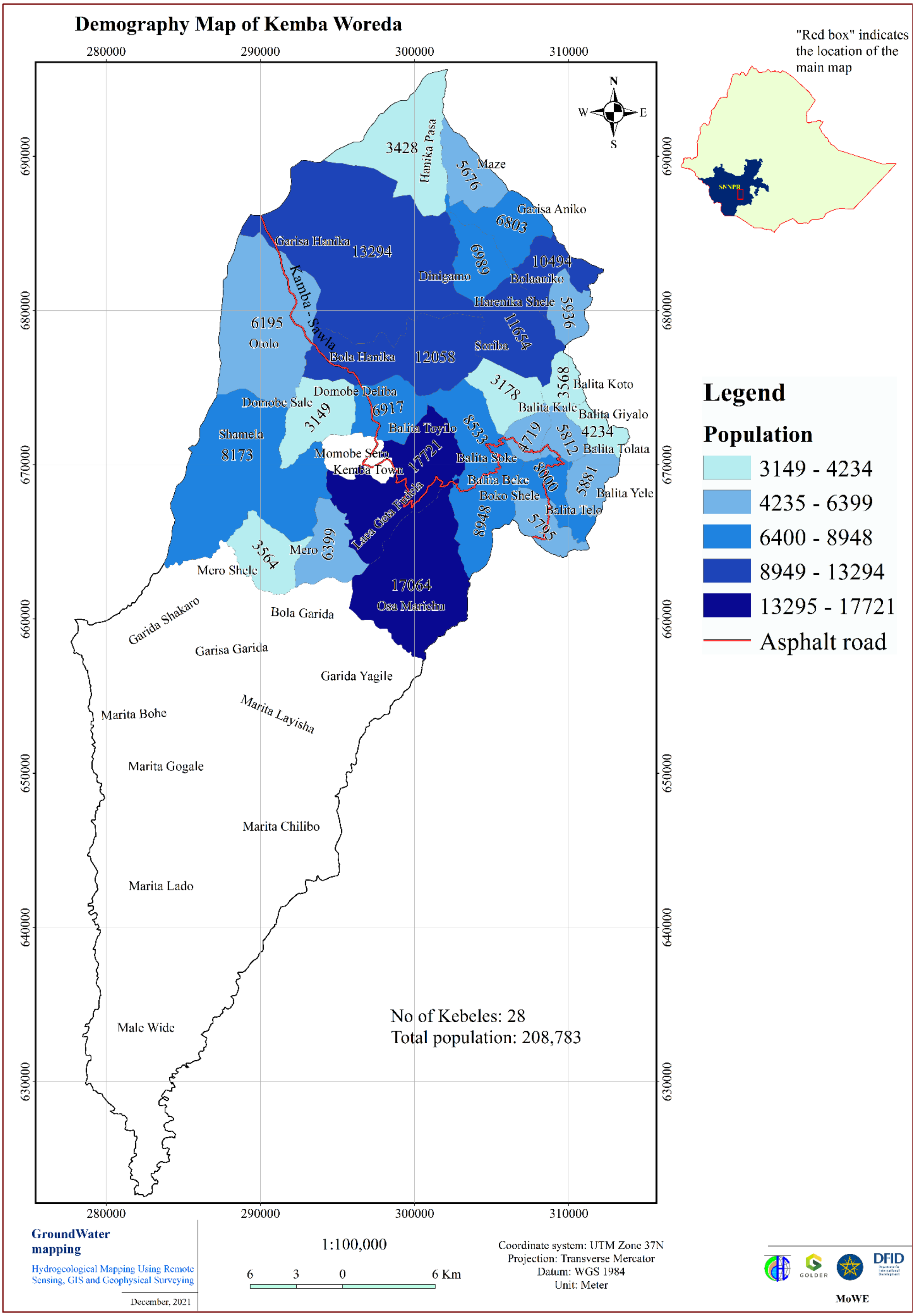

Figure 5.38: Map of projected population (2036) for Kemba Woreda.

5.5.4.2. Water Demand Projection

Projected Water Demand

Estimating water demands mainly depends on the size of the population to be served, their standard of living and activities. To make the demand projection reliable and suitable for rural areas it is better to classify in details as domestic and non-domestic demands.

Domestic Water Demand

Domestic water demand is the amount of water needed for drinking, food preparation, washing, cleaning, bathing and other miscellaneous domestic purposes. The amount of water used for domestic purposes greatly depends on the lifestyle, living standard, and climate, mode of service and affordability of the users.

Domestic water demand service can be categorized according to the level of service to be provided and amount of per capita water required satisfying the demand served by the level of service. Modes of services used for our projection are classified into four categories, namely: -

- Traditional Source users (TSU)
- Public tap users (PTU)
- Yard connections and Neighbourhood (shared) connections (YCO) & (YCS)
- House tap connections (HTU)

In projecting the domestic water demand, the following procedures were followed:

- Determining population percentage distribution by mode of service and its future projection
- Establishment of per capita water demand by purpose for each mode of service;
- Projected consumption by mode of service;
- Adjustment for climate;
- Adjustment due to socio-economic conditions.

After considering the necessary mode of services, per-capita demand and applying the adjustment factors the domestic demand for the corresponding year and population has been calculated.

Non-Domestic Water Demand

Non-domestic water demand was also determined systematically. We have classified it into three major categories based on our projection:

- Institutional water demands (Public and governmental);
- Commercial water demand;
- Livestock water demand

N.B:- The use of a reliable base population figure is very important for optimizing the water sources but adopting 2007 CSA data as a base population has real impact on the projection so to compensate some unforeseen situation like migration and unplanned rural town growth. To compensate for such

- To estimate the demand of public institutions and commercial services we have adopted 15% - 20% of the domestic demand for our consumption.
- The demand for livestock watering adopted in the projection is 10% -15% of the domestic demand.

Total Average daily day demand

The average daily day demand is taken to be the sum of domestic demands and non-domestic demand. The water demand in a day varies with time according to the consumer's life style. It is the total sum of adjusted domestic, public and livestock demand.

Maximum Day Demand

The maximum day demand is the highest demand of any one 24 hour period over any specific year. It represents the change in demand with season. This demand is used to design source capacity. The deviation of consumption from the average day demand is taken care of as per the maximum daily coefficient figures. Usually a value from1.1 to 1.3 is adopted as maximum day factor. A constant value of 1.3 is adopted as maximum day factor for all of the villages.

Figure 5.39 shows the distribution of water demand in each Kebeles of the Woreda. The minimum and maximum water demand for Kebeles is 280 M^3/day and 1,577 M^3/day respectively. The overall water demand for the projected population in the Amaro Woreda is 18,580 M^3/day.

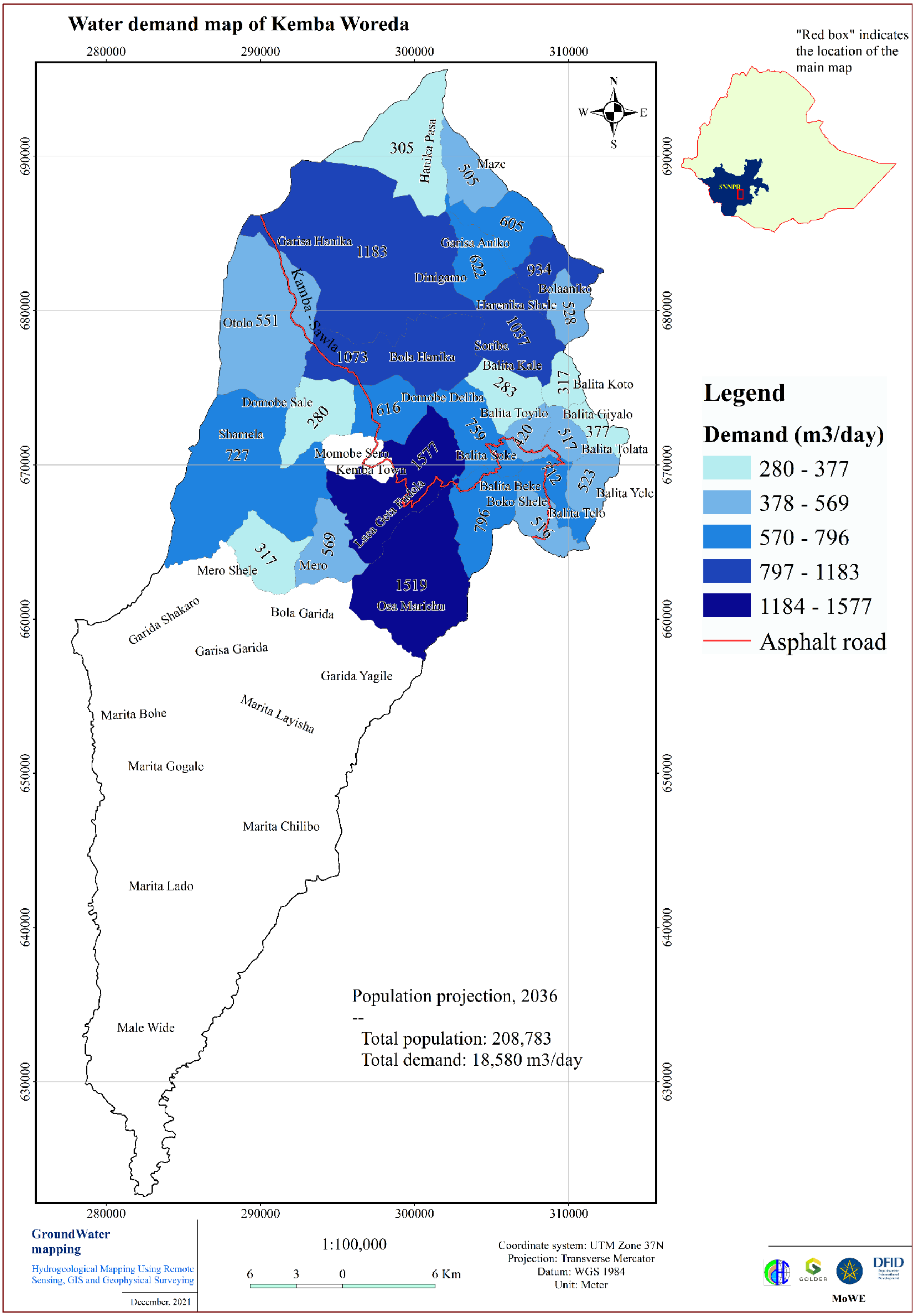

Figure 5.39: Map of water demand (M^3/day) for Kemba Woreda.

5.5.5. Proposed Target Sites

Four target sites are identified and proposed within the woreda based on the identified groundwater potential zones, the productivity of the hydrostratigraphic units with their expected optimum borehole yield, proximity to beneficiaries and population density. With further discussion and consultation with stakeholders, two priority sites will be selected for further hydrogeological and geophysical investigations in phase III. The following are the four proposed sites (Figure 5.40):

Target Site-I:

This target site is in the western central part of the woreda. It is situated in the identified high to very high groundwater potential zones. This target site falls mainly on volcanic rocks.

Target Site-II:

This target site is in the southwestern part of the woreda. It is situated in the identified high to very high groundwater potential zones. This target site falls mainly on Quaternary sediments underlain by volcanic/basement rocks.

Target Site-III:

This target site is in the northern periphery of the woreda. It is situated in the identified moderate to high groundwater potential zones. This target site falls mainly on Quaternary sediments underlain by volcanic rocks.

Target Site-IV:

This target site is in the southern periphery of the woreda. It is situated in the identified high to very high groundwater potential zones. This target site falls mainly on Quaternary sediments underlain by basement rocks.

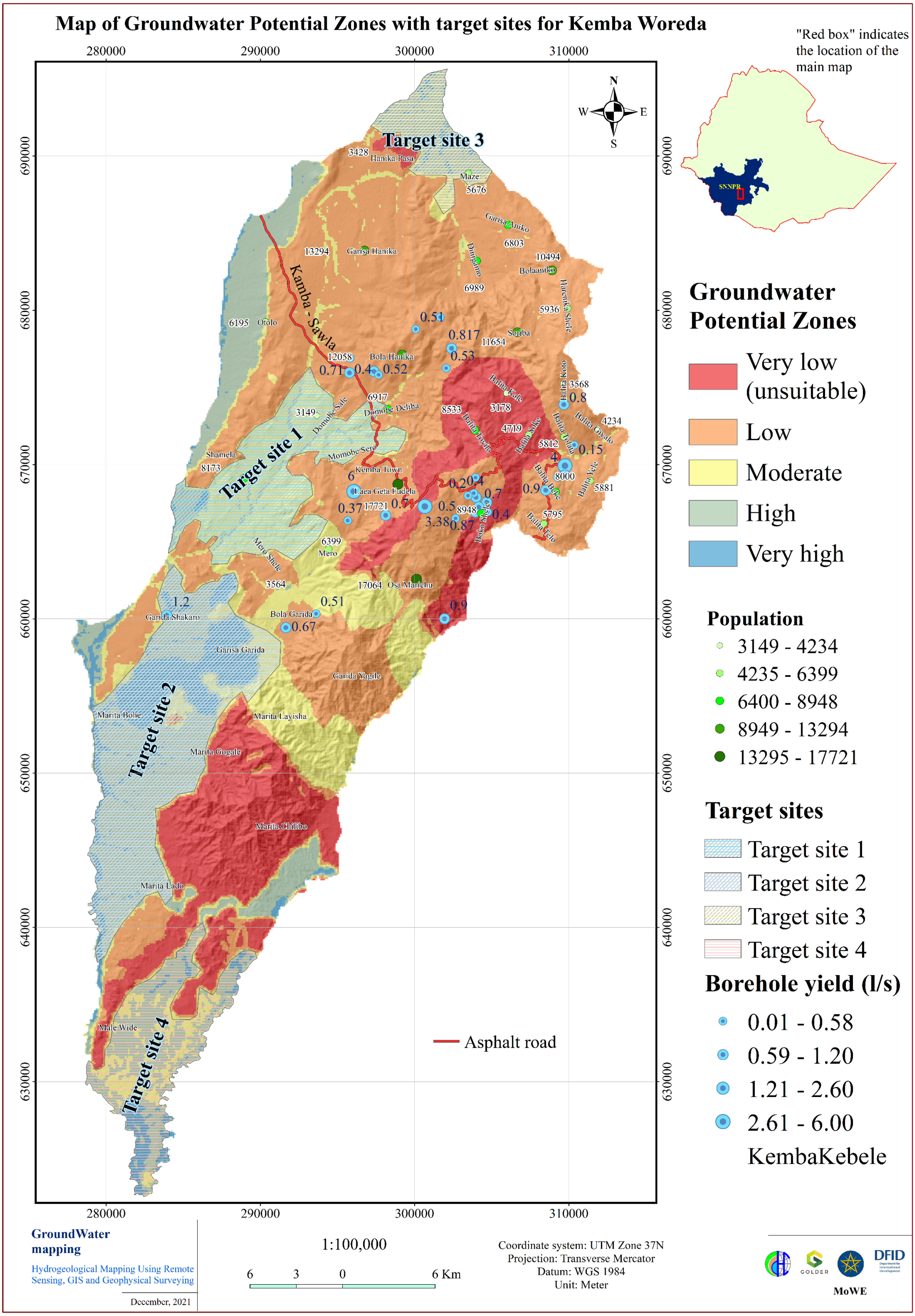

Figure 5.40. Map of groundwater potential zones with selected target sites in Kemba Woreda

5.5.6. Conceptual hydrogeological model of Kemba Woreda

Hydrogeological conceptual models are collections of hypotheses based on geological structural and geomorphological evidences and existing wells lithologic logs to describe and understand the groundwater occurrence, localization and movement beneath the ground surface. The purpose of the hydrogeological model across/along inferred groundwater flow direction is to reflect the prototype of regional groundwater flow system in the two priority sites selected for further study in phase III.

Due to proximity to the Main Ethiopian Rift, rock units are dislocated and placed in jackstapostion against each other. This region has a compartimentalized groundwater flow system constrained by geological structres and topography. Groundwater gets recharge mainly from local rain that falls on central and a northeast surrounding highland with expected lateral inflow from northwest adjacent highlands. Groundwater flow direction is dominantly towards south in the general direction of Woyito River flow and central lowlands through alluvial plain and fractured volcanic and basement rocks.

Development of the hydrogeological conceptual model of the Kemba Woreda will be prepared based on the converging evidence of secondary data including digital elevation model (DEM), geological and hydrogeological maps and structures, lithological well logs of wells in the area. The target sites will be selected out of the proposed ones. The conceptual hydrogeological models for this woreda to be constructed along/across groundwater flow path will be produced after stake holder consultation workshop to select priority target sites for further hydrogeological characterization. The conceptual hydrogeological model summarizes what is known about the hydrogeological system and thereby provides a framework for hydrogeological system of the target sites in the woreda including the major groundwater flow zone (inflow, groundwater flow paths, inferred depth, and outflow) and groundwater table and groundwater condition of Kemba woreda using existing data of spring, river and boreholes.

5.6. Burji Woreda

The four thematic layers which were integrated for groundwater potential mapping in Burji Woreda are summarized in Table 5.16 below. The notes on the description of each thematic layers including classification of potential zones, validation with borehole and scheme datasets, population projection, water demand and selected target sites presented in the sub-sections.

Table 5-16. Assigned and normalized weights for the individual features of the four thematic layers for groundwater potential zoning in Burji Woreda

Class	Class interval	Class Weight	Pixel count	Area (Km2)	Area (%)	Weight	Groundwater prospect
	Lineament layer						
1	0.0 -0.11	8	23707	237070	20.9		Very low
2	0.12 – 0.18	14	29021	290210	25.6		Low
3	0.19 – 0.24	18	27709	277090	24.4	0.21	Moderate

4	0.25 – 0.31	24	21178	211780	18.6		High
5	0.32 – 0.44	36	11970	119700	10.5		Very high
	Topographic Wetness Index (TWI) layer						
1	4.47 – 7.26	8	46884	468840	41.3		Very low
2	7.26 – 9.15	14	40540	405400	35.7		Low
3	9.15 – 11.87	18	17657	176570	15.5	0.27	Moderate
4	11.88 – 16.1	24	7224	72240	6.4		High
5	16.11 – 23.73	36	1280	12800	1.1		Very high
	Recharge layer						
1	20.7 – 35	8	71795	717950	63.6		Very low
2	35.1 – 70	14	20039	200390	17.8		Low
3	70.1 – 115	18	14744	147440	13.1	0.05	Moderate
4	116 – 140	24	3558	35580	3.2		High
5	141 – 165	36	2702	27020	2.4		Very high
	Lithology layer						
2	Basement rocks of different kinds	12	70463	704630	62.4	0.46	Poor
3	Volcanic and pyroclastic rock units	32	14788	147880	13.1		Good
4	Quaternary sediment and lacustrine deposits	56	27691	276910	24.5		Very good

5.6.1. Integration of Thematic Layers for Groundwater Potential Zoning

The details of geology, rainfall, lineament density, geomorphology, land slope, soil type, land use/land cover, groundwater depth and drainage density together with their spatial distribution in Burji Special woreda are presented below:

I. Geology/lithology

In general, most parts of Burji Special woreda are underlain by basement complexes and volcanic rocks. Quaternary deposits of alluvial and lacustrine sediments are mostly found in the central and eastern periphery of the woreda.

However, the lithological units found in the woreda area are further reclassified into three major groups based on their significances to groundwater occurrence and productivity using borehole yield analysis in particular.

- Recent Quaternary alluvium and lacustrine deposits,
- Volcanic and pyroclastic rock units,

- Basement rocks of different kinds
- Phonolites and rhiyolits.

The crystalline basement rocks are the main lithologic framework of the Burji Special. Basic volcanic and pyroclastic rock cover significant part of the area followed by Quaternary alluvium sediments and lacustrine deposits (Figure 5.41).

Usually, massive unfractured lithologic units in volcanic and basement complex settings have little influence on groundwater availability except in cases with secondary porosity through the development of fault and weathered overburden, and fractured bedrock units, which form potential groundwater zones. Hence, on the basis of the presence and nature of the weathered regolith units, faulting and fracture systems, appropriate weights are assigned to the different lithological units in the study area (Fig 5.41).

The weightage in terms of increasing groundwater potentiality is in the order of poor productivity of basement rocks and phonolit (0.12) \ moderate productivity of volcanic rocks (0.32) \ high productivity of alluvial/lacustrine sediments (0.56).

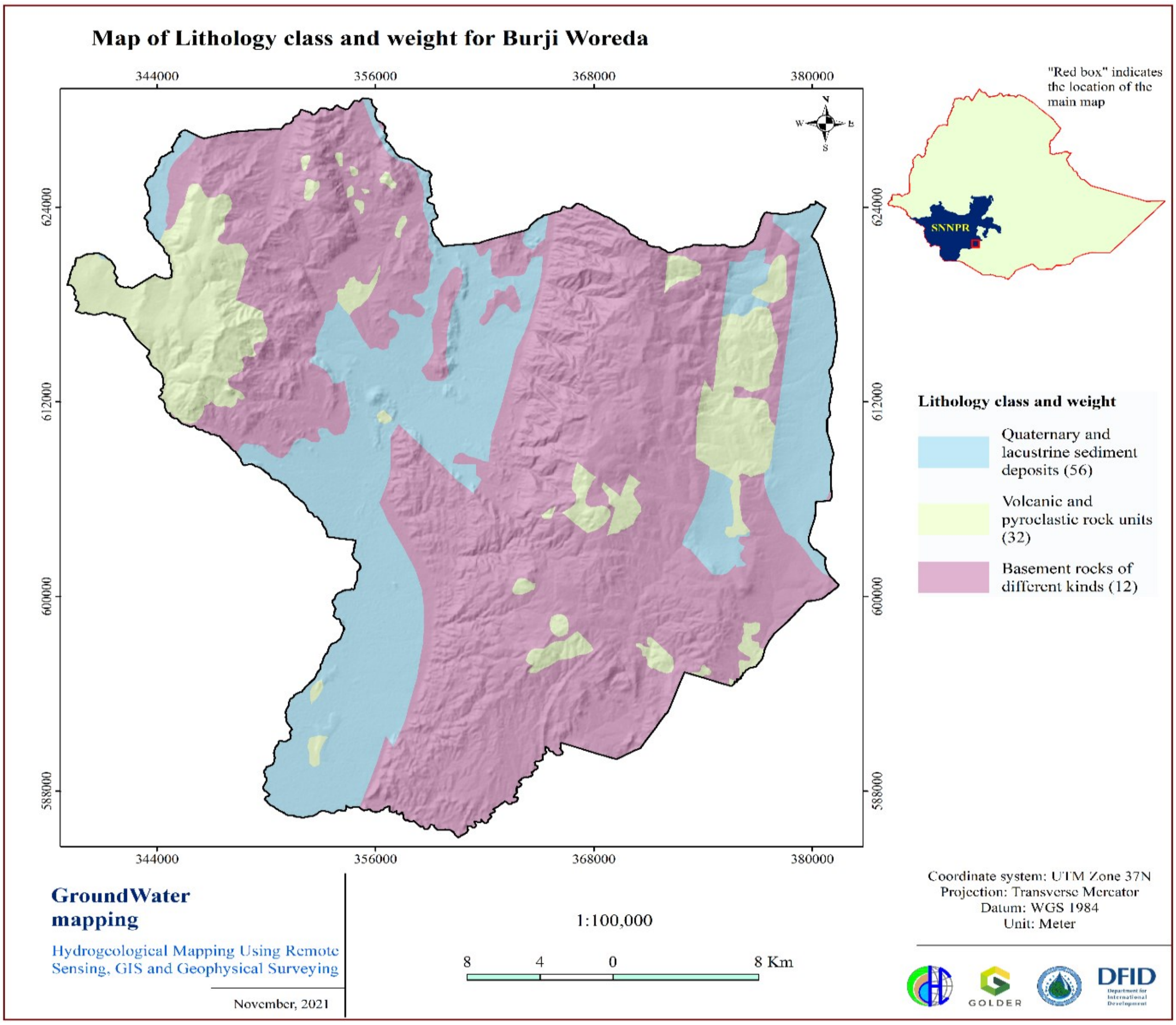

Figure 5.41: Map of lithology class and weight for Burji Woreda

II. Lineaments and lineament density

The study area is moderately affected by lineaments and/or fractures consequent to tectonic activities in the past. The prominent directions identified within the woreda domain is nearly NNW-SSE trending. Usually, lineament density map is a measure of quantitative length of linear feature per unit area which can indirectly reveal the groundwater potentials as the presence of lineaments usually denotes a permeable zone. For most of the woreda, the lineament density varies from less than 0.11 km/Km2 to 0.44 km/Km2 (Figure 5.42).

Though the lineaments are widespread across the study area, however, the distribution of lineaments suggests geologic control with areas underlain by crystalline basement complex associated with Quaternary sediments having relatively higher lineament density of 0.25 – 0.44 km/Km2 compared with areas marked with basement rocks (< 0.25 km/Km2).

Thus, areas with higher lineament density are regarded as good for groundwater development, of course after further hydrogeological study. Consequently, higher weightage of 0.36 was assigned to area with high density of lineaments, while a low weightage of 0.8 was assigned to areas with low lineament density (Figure 5.42).

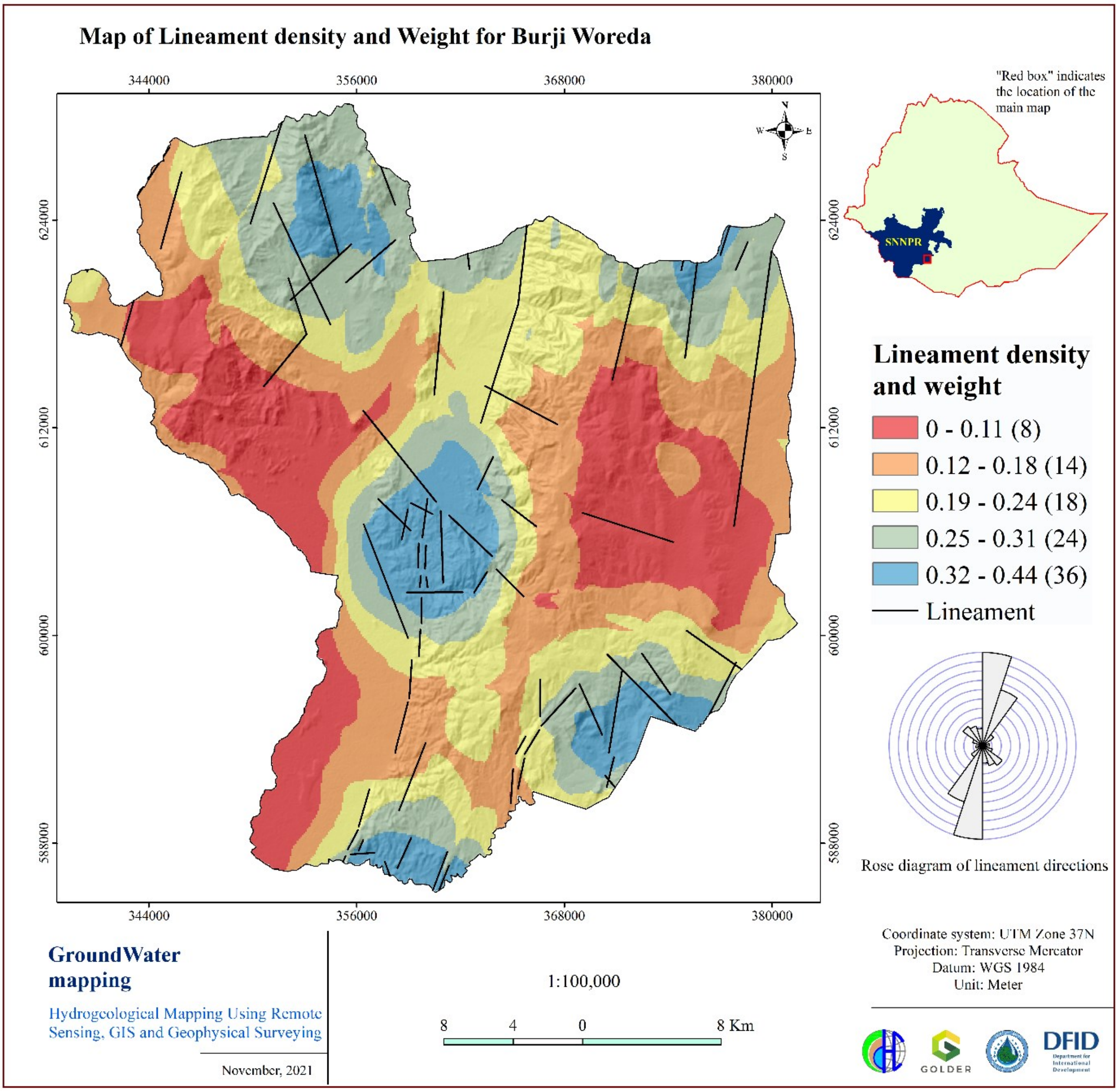

Figure 5.42: Map of lineament density and weight for Burji Woreda

III. Topographic Wetness Index (TWI)

In this study area, the TWI value ranges between 4.47 and 23.73. A closer look at the classification revealed that most elevated areas and drainage systems with steep slopes have relatively lower TWI value while the low lying areas and drainage systems with gentle and flat slopes close to Segen River bank areas in the cental part in particular have relatively higher wetness index value where runoff waters from highlands flow and accumulates mostly. Therefore, an area with higher value of TWI has good prospect for groundwater occurrence and flow, and accordingly high weightage value (0.36) was assigned to this class. Whereas, as shown in the figure below (Figure 5.43), areas with lowest TWI value are steep slopes which triggers runoff were considered with low groundwater prospect and given low weightage value (0.8).

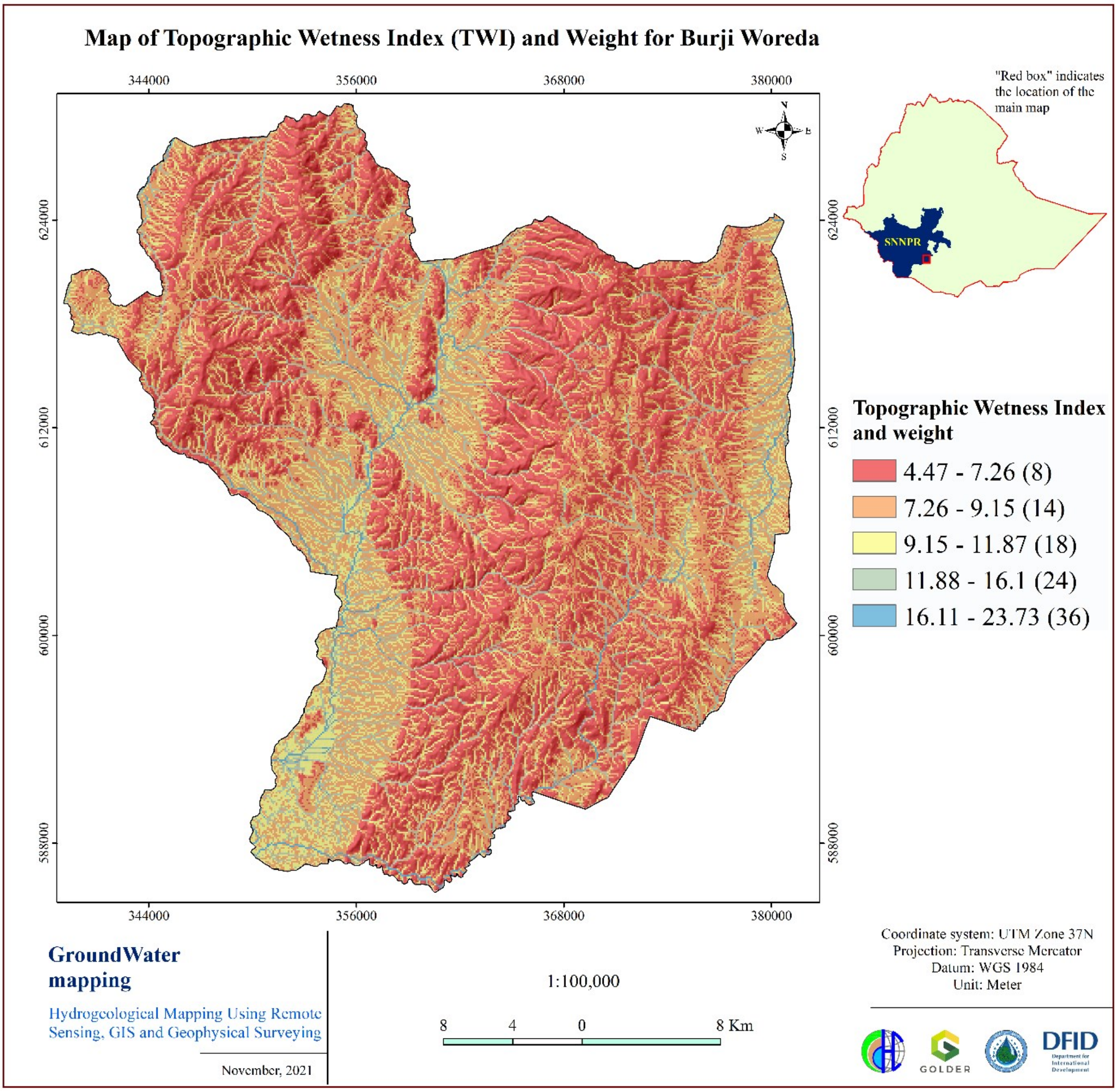

Figure 5.43: Map of topographic wetness index (TWI) and weight for Burji Woreda

IV. Recharge

The 10 years spatial annual recharge rate distribution in the Burji Special woreda ranges from 20.7 to 165 mm/y suggesting groundwaters in most part of the woreda area underlain by basement complex receive low amount of recharge while areas underlain Quaternary sediments have relatively higher recharge amount (Figure 5.44). Accordingly, areas with higher and moderate amount of recharge have weightage factor of 0.36 and 0.24, respectively signifying very good and moderate groundwater potential while areas with the lowest amount of recharge have weightage factor of 0.08, suggesting poor groundwater potentiality. A closer look at the recharge thematic map revealed that most of the central along Segen River bank and western low-lying parts of the woreda have relatively higher recharge (>112 mm/y). Generally, the study area is characterized with very low to low mean annual recharge amount, whereas only limited areas at western and central parts have moderate to high mean annual recharge amount (112.2-190.2mm).

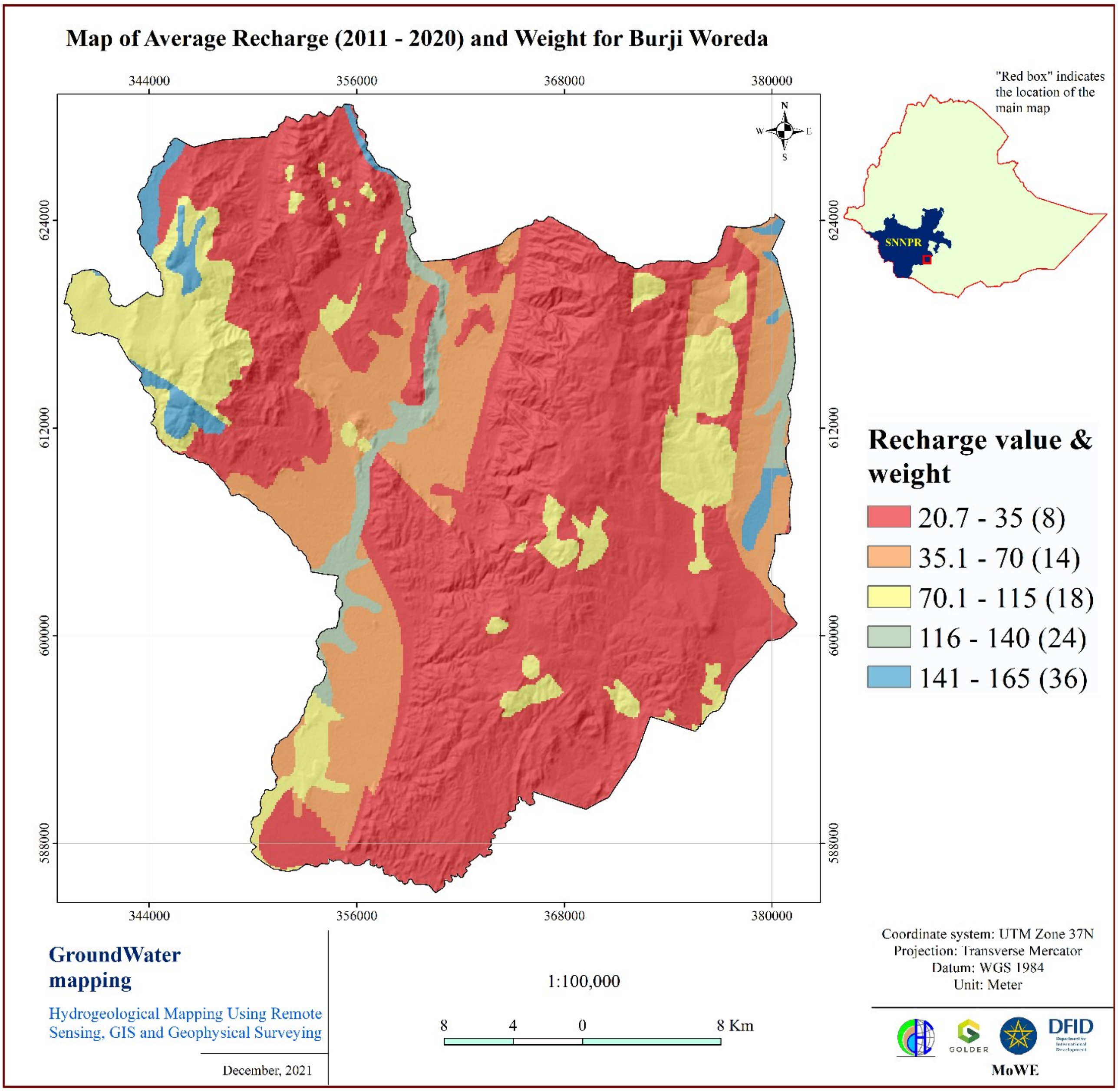

Figure 5.44: Map of yearly (mm/year) recharge and weight for Burji Woreda

5.6.2. Classification of Groundwater Potential Zones

The hydrogeological system of Burji woreda is comprised of four main lithological units as Quaternary deposits, different volcanic rocks, Phonolites and rhiyolits and Crystalline basement rocks. At regional scale, Quaternary deposits form extensive and moderately to highly productive aquifers. Within the domain of Burji Special woreda, these Quaternary deposits form aquifers with high groundwater potential.

At regional scale, volcanic rocks form extensive and moderately productive. However, at local scale, within the domain of Burji Special woreda, due to the geomorphic setup, the volcanic rocks form moderately productive aquifer as revealed from existing borehole yields.

Only the upper weathered and slightly fractured part of the crystalline basement rocks along lineamnets and faults have potential to store groundwater at shallow depth. Weathered and slightly fractured Crystaline basement rocks with overlying Quaternary deposit form major potential aquifer within the domain of Burji Special Woreda along lineament and fault lines and associated plains.

Hydrogeological data from water point inventory, hydro-chemical data and geophysical investigation outcome of the next phase will help to improve the understanding of hydrogeological frame work of the area.

On the basis of the assignment and normalized weighting of the individual features of the thematic layers, a potential groundwater map was produced (Figure 5.45). The potential groundwater zones (PGZ) of Burji Special woreda revealed four distinct zones, namely low (unsuitable), moderate, high and very high zones whose distribution and extents are presented in Table 5.17.

The groundwater potential map, as presented in Figure 5.45, gives a quick assessment of the occurrence of groundwater resources in the study area. The groundwater potential map revealed that most elevated areas central parts of the Burji Woreda generally have low potential while significant areas at northern, eastern and western peripheries generally exhibits high to very high potentials. Generally high to very high groundwater potentiality of the study area is a confirmation of generally moderate to high productive aquifers of Quaternay alluvial and lacustrine deposits, whereas low groundwater potential areas have an indication of limited aquifers capabilities of basement basement complex terrain.

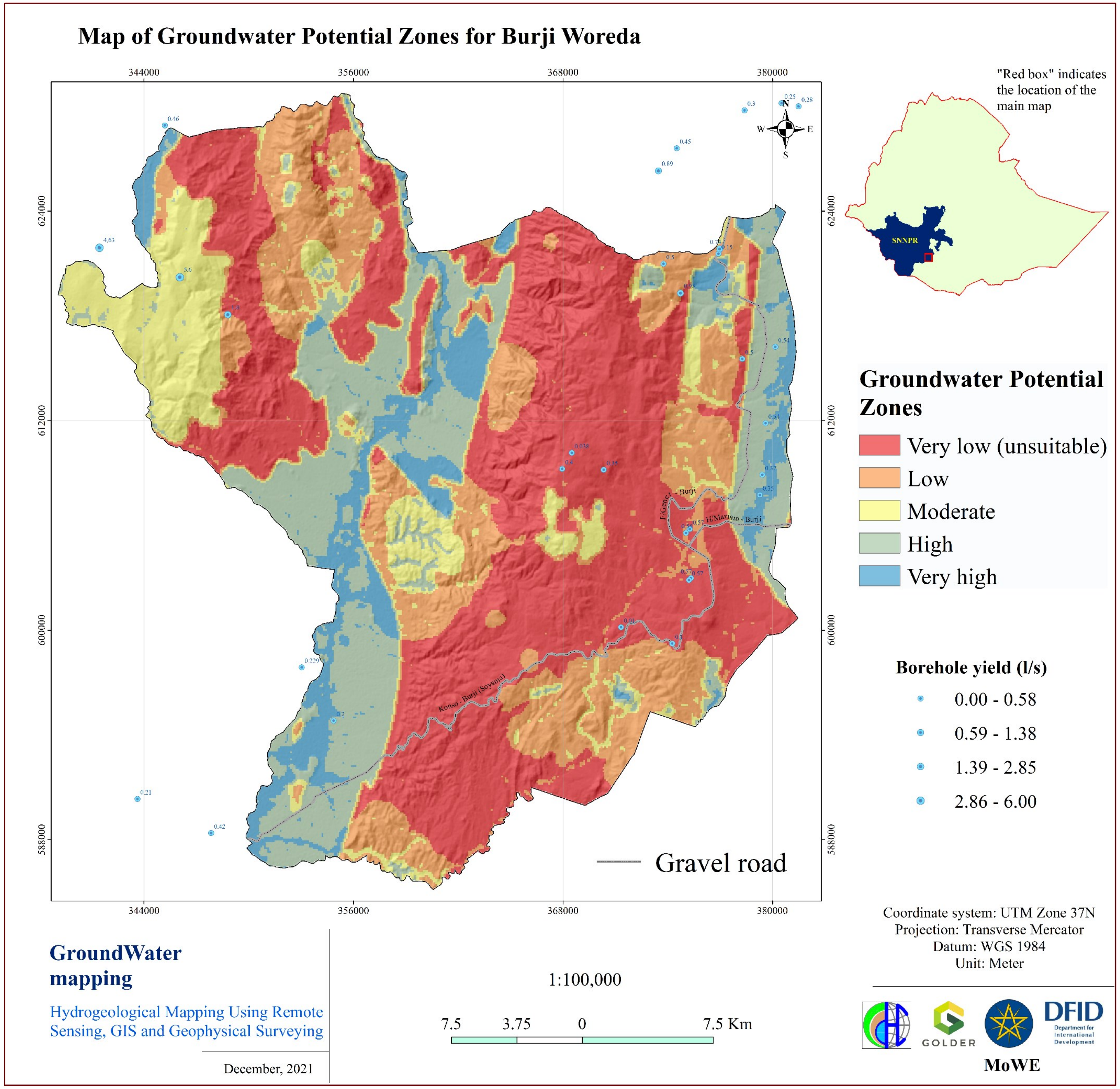

Figure 5.45: Map of groundwater potential zones showing five zones identified by the GIS overlay analysis in Burji Woreda

5.6.3. Validation with Borehole Yield Data

In order to validate the classification of the groundwater potential zones as revealed by the GIS based groundwater potential map, data on existing wells (yield) were collected for over 33 dug and drilled wells in and around Burji Special woreda. Since the wells were dug/drilled for water supply purpose without proper pumping test, they lack necessary information about aquifer properties and most of them have even no proper well yield information.

The borehole data were superimposed on the groundwater potential map and numbers of wells with different yield ranges for different groundwater potential zones were evaluated. Generally, the yields of the deep boreholes in the study area vary from 1.8 to 6 lit/sec in very high potential zones and it is less than 0.5 l/s else where.

The validation clearly highlights the efficiency of the integrated RS and GIS methods employed in this study as useful modern approach for proper groundwater resource evaluation and sustainable groundwater development. Nonetheless, the groundwater potential zonation presented here can be applied only for regional studies not for direct application for groundwater development. As it provides quick prospective guides for preliminary groundwater exploration in such basement and volcanic teraains overlain by Quaternary sediments, it highly recommeneded to start groundwater exoloration with this approach. Site selection for groundwater development should take into consideration other site-specific conventional ground-study methods.

Table 5-17. Classification of groundwater potential zones and coverage areas alongside the respective yield categories in Burji Woreda

Class	Class interval	Pixel count	Area (Km2)	Area (%)	Well yield (l/s)	Groundwater prospect
1	132-148.98	46584	465840	41.2	0.12 – 0.5	Very low
2	148.99-172.53	24038	240380	21.3	0.12 - 2.1	Low
3	172.54-194.44	13878	138780	12.3	0.12 – 3.0	Moderate
4	194.45-217.99	19910	199100	17.6	2.1 – 4.63	High
5	218-271.67	8539	85390	7.6	2.1 - 6.0	Very high

5.6.4. Population projection and water demand

3.1.1.1. Population

It is essential that the water supply system is designed to meet the requirements of the population expected to be living in the community at the end of design period by taking into account the design period and annual growth rate. Hence in order to avoid or minimize the aforementioned population related risks, efforts are made to review & justify the credibility of the available population data and growth rate figures.

Population projection is made making use of the geometric growth rate method by using the base population figure estimated by the central statistical Authority. The CSA has set average growth rates for urban and rural areas of the country varying at different times during the design period as shown in the table below. Accordingly, these values are adopted in forecasting future population of the town.

Table 5-18 CSA Rural Population Growth Rates

Rural Population Projection Growth Rate of Regions: 2008-2037						
YEAR / Growth Rate % (Rural)	2008-2012	2013-2017	2018-2022	2023-2027	2028-2032	2033-2037
Oromia Region	2.74	2.54	2.29	2.03	1.8	1.56
SNNP Region	2.49	2.37	2.31	2.03	1.82	1.57
Somali Region	2.75	2.63	2.35	2.05	1.89	1.83
Gambela Region	3.52	3.1	3.13	2.76	2.46	2.31

Source: CSA Population Projection for Ethiopia 2007-2037, Addis Ababa July 2013

Geometric method forecasting formula

$$P=Po\,(1 + r)^{n}$$

Where P – projected population
Po – current population
n – Number of years for projection
r – Population growth rate

The population of Burji Woreda has been projected forward until 2036 using the projected scale of Southern Nation Nationalities and Peoples Regional State. The minimum and maximum population in the Woreda is 9 and 8276 respectively. The total population of the Burgi Woreda in 2036 is going to be 90,721. Figure 5.46 presents the projected population for each kebele in the Woreda.

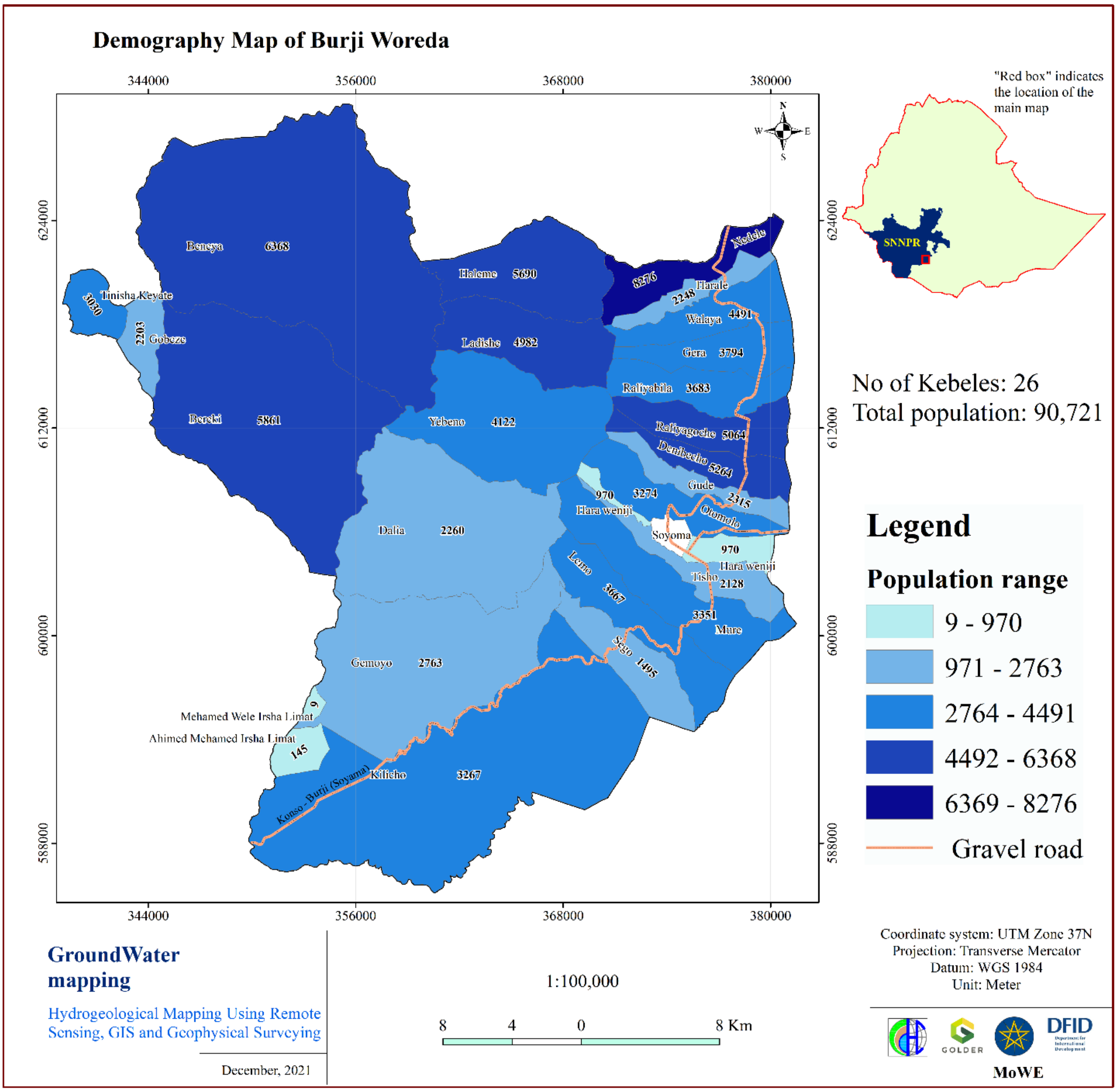

Figure 5.46 Map of projected population (2036) for Burji Woreda.

3.1.1.2. Water Demand Projection

Projected Water Demand

Estimating water demands mainly depends on the size of the population to be served, their standard of living and activities. To make the demand projection reliable and suitable for rural areas it is better to classify in details as domestic and non-domestic demands.

Domestic Water Demand

Domestic water demand is the amount of water needed for drinking, food preparation, washing, cleaning, bathing and other miscellaneous domestic purposes. The amount of water used for domestic purposes greatly depends on the lifestyle, living standard, and climate, mode of service and affordability of the users.

Domestic water demand service can be categorized according to the level of service to be provided and amount of per capita water required satisfying the demand served by the level of service. Modes of services used for our projection are classified into four categories, namely: -

- Traditional Source users (TSU)
- Public tap users (PTU)
- Yard connections and Neighbourhood (shared) connections (YCO) & (YCS)
- House tap connections (HTU)

In projecting the domestic water demand, the following procedures were followed:

- Determining population percentage distribution by mode of service and its future projection
- Establishment of per capita water demand by purpose for each mode of service;
- Projected consumption by mode of service;
- Adjustment for climate;
- Adjustment due to socio-economic conditions.

After considering the necessary mode of services, per-capita demand and applying the adjustment factors the domestic demand for the corresponding year and population has been calculated.

Non-Domestic Water Demand

Non-domestic water demand was also determined systematically. We have classified it into three major categories based on our projection:

- Institutional water demands (Public and governmental);
- Commercial water demand;
- Livestock water demand

N.B: - The use of a reliable base population figure is very important for optimizing the water sources but adopting 2007 CSA data as a base population has real impact on the projection so to compensate some unforeseen situation like migration and unplanned rural town growth. To compensate for such

- To estimate the demand of public institutions and commercial services we have adopted 15% - 20% of the domestic demand for our consumption.
- The demand for livestock watering adopted in the projection is 10% -15% of the domestic demand.

Total Average daily day demand

The average daily day demand is taken to be the sum of domestic demands and non-domestic demand. The water demand in a day varies with time according to the consumer's life style. It is the total sum of adjusted domestic, public and livestock demand.

Maximum Day Demand

The maximum day demand is the highest demand of any one 24-hour period over any specific year. It represents the change in demand with season. This demand is used to design source capacity. The deviation of consumption from the average day demand is taken care of as per the maximum daily coefficient figures. Usually a value from1.1 to 1.3 is adopted as maximum day factor. A constant value of 1.3 is adopted as maximum day factor for all of the villages.

Figure 5.47 shows the distribution of water demand in each Kebeles of the Woreda. The minimum and maximum water demand for Kebeles is 1 M^3/day and 743 M^3/day respectively. The overall water demand for the projected population in the Burji Woreda is 150 M^3/day.

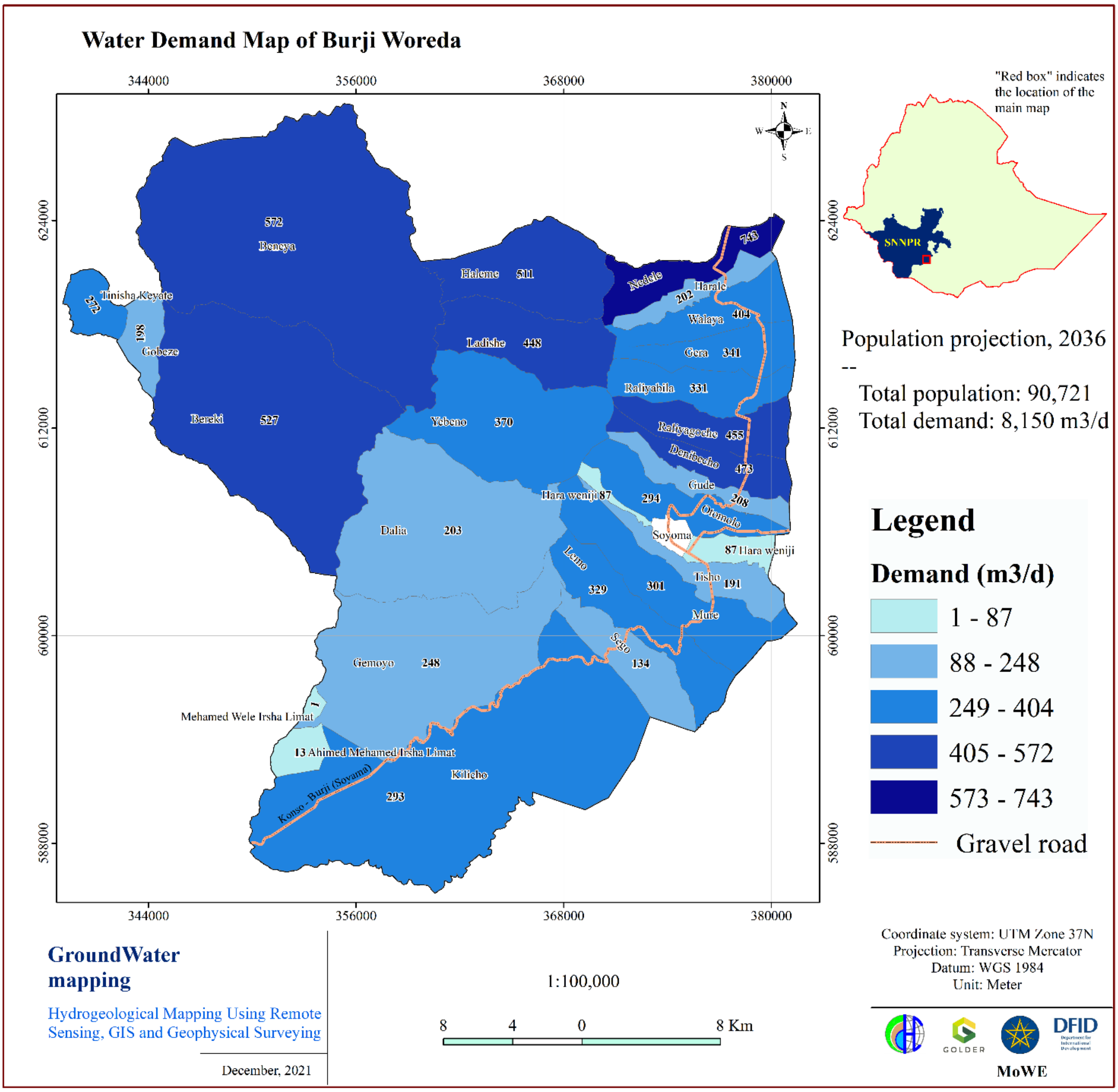

Figure 5.47 Map of water demand (M^3/day) for Burji Woreda.

5.6.5. Propsed Target Sites

Four target sites are identified and proposed within the woreda based on the identified groundwater potential zones, the productivity of the hydrostratigraphic units with their expected optimum borehole yield, proximity to beneficiaries and population density. With further discussion and consultation with stakeholders, two priority sites will be selected for further hydrogeological and geophysical investigations in phase III. The following are the four proposed sites:

Target Site-I:

This target site is located in the northcentral part of the woreda. It is situated in the identified very high groundwater potential zone. This target site is mainly placed on Quaternary sediments and lacustrin deposits underlain by fractured basement rocks.

Target Site-II:

This target site is located in the southwestern part of the woreda. It is situated in the identified very high groundwater potential zone. This target site is mainly placed on Quaternary sediments and lacustrin deposits underlain by fractured basement rocks

Target Site-III:

This target site is located in the estern part of the woreda. It is situated in the identified very high groundwater potential zone. This target site is mainly placed on Quaternary sediments and lacustrin deposits underlain by fractured basement rocks

Target Site-IV:

This target site is located in the northwestern part of the woreda. It is situated in the identified very high groundwater potential zone. This target site is mainly placed on Quaternary sediments and lacustrin deposits underlain by fractured basement rocks.

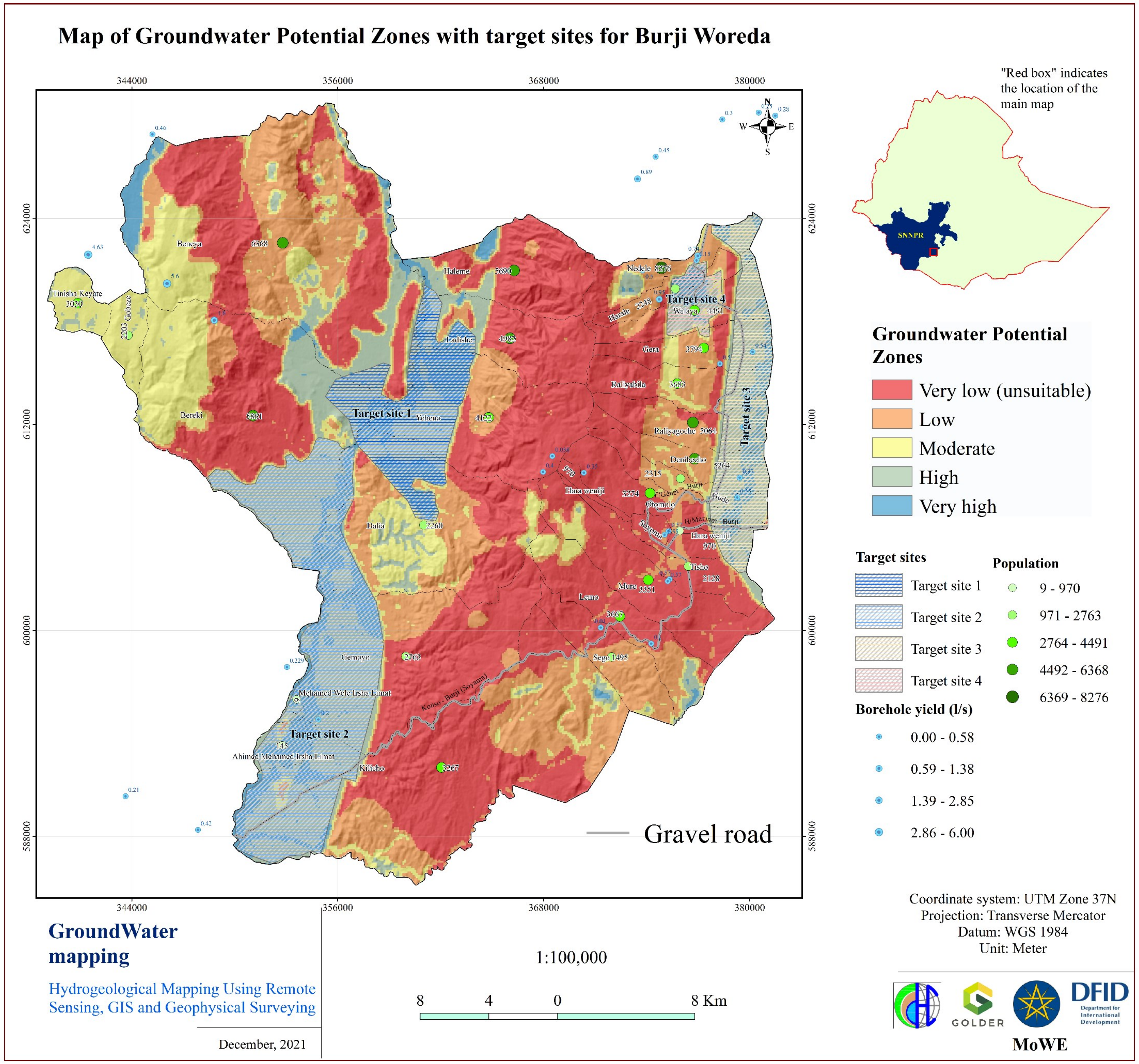

Figure 5.48. Map of groundwater potential zones with selected target sites in Burji Woreda

5.6.6. Conceptual hydrogeological model of Burji Special Woreda

Hydrogeological conceptual models are collections of hypotheses based on geological structural and geomorphological evidences and existing wells lithologic logs to describe and understand the groundwater occurrence, localization and movement beneath the ground surface. The purpose of the hydrogeological model across inferred groundwater flow direction is to reflect the prototype of regional groundwater flow system into of the two priority sites selected for further study in phase III.

Due to proximity to the Main Ethiopian Rift, rock units are dislocated and placed in jackstapostion against each other. This region has a compartimentalized groundwater flow system constrained by geological structres and topography. Groundwater gets recharge mainly from local rain that falls on central and a northern part and surrounding chains of mountains with expected lateral inflow from north adjacent highlands. Groundwater flow direction is expected to follow Segen River flw direction generally towards south and central lowlands through alluvial plain and fractured basement rocks and regolith developed over it. Development of the hydrogeological conceptual model of the Burji Special Woreda will be done based on the converging evidence of secondary data including digital elevation model (DEM), geological and hydrogeological maps and structures, lithological well logs, ones the target sites are selected out of the proposed ones. The conceptual hydrogeological models for this woreda to be constructed along/across groundwater flow path will be produced after stake holder consultation workshop to select priority target sites for further hydrogeological characterization. The conceptual hydrogeological model summarizes what is known about the hydrogeological system and thereby provides a framework for hydrogeological system of the target sites in the woreda taking major groundwater flow zone characteristics (inflow, groundwater flow paths, inferred depth, and outflow) and inferred groundwater table from existing data (spring, river and boreholes.

5.7. Amaro Woreda

The four thematic layers which were integrated for groundwater potential mapping in Amaro Woreda are summarized in Table 5.19 below. The notes on the description of each thematic layers including classification of potential zones, validation with borehole and scheme datasets, population projection, water demand and selected target sites presented in the sub-sections.

Table 5-19. Assigned and normalized weights for the individual features of the four thematic layers for groundwater potential zoning in Amaro Woreda

Class	Class interval	Class Weight	Pixel count	Area (Km2)	Area (%)	Weight	Groundwater propsect
	Lineament layer						
1	0 - 0.053	8	27397	273970	20.2	0.21	Very low
2	0.054 - 0.11	14	33124	331240	24.4		Low
3	0.12 - 0.17	18	38255	382550	28.2		Moderate
4	0.18 - 0.23	24	22261	222610	16.4		High

5	0.24 - 0.34	36	14716	147160	10.8		Very high
	Topographic Wetness Index (TWI) layer						
1	4.44 – 6.68	8	56358	563580	41.5	0.27	Very low
2	6.69 – 8.81	14	45527	455270	33.5		Low
3	8.82 – 11.4	18	22109	221090	16.3		Moderate
4	11.5 – 15.3	24	10025	100250	7.4		High
5	15.4 – 23.3	36	1740	17400	1.3		Very high
	Recharge layer						
1	31.26 – 45.89	8	77606	776060	57.2	0.05	Very low
2	45.90 – 63.70	14	20402	204020	15.0		Low
3	63.71 – 129.2	18	17525	175250	12.9		Moderate
4	129.3 – 154	24	6008	60080	4.4		High
5	154.1 – 193.4	36	14132	141320	10.4		Very high
	Lithology layer						
1	Phonolite and rhyolite	11	899	8990	0.7	0.46	
2	Basement rocks of different kinds	17	79855	798550	58.8		Poor
3	Basic volcanic and pyroclastic rock units	30	22414	224140	16.5		Good
4	Quaternary sediment and lacustrine deposits	42	32561	325610	24.0		Very good

5.7.1. Integration of Thematic Layers for Groundwater Potential Zoning

The details of geology, rainfall, lineament density, geomorphology, land slope, soil type, land use/land cover, groundwater depth and drainage density together with their spatial distribution in Amaro Special Woreda are presented below:

I. Geology/lithology

In general, most parts of Amaro Special Woreda are volcanic dominantly overlain by Quaternary alluvial and elluvial sedments and lacustrine deposits. Quaternary deposits of alluvial and lacustrine sediments are mostly found in the eastern part of the woreda. Whereas, the basement rocks outcropped in the small part in the southern peripheral part of the woreda.

However, the lithological units found in the woreda area are further classified into three major groups based on their significances to groundwater occurrence and productivity using borehole yield.

- Quaternary alluvium and lacustrine deposits,
- Basalt and pyroclastic deposits,
- Basement rocks of granitic and gneissic rocks overlain and
- Phonolites and rhiyolites

The volcanic rocks overlain by Quaternary sediment are the main lithologic framework of the Amaro Special woreda (Figure 5.49). Both Quaternary sediment and volcanic rocks are underlain by Basment rocks in the woreda domain. Usually, massive unfractured lithologic units in basement complex settings have little influence on groundwater availability except in cases with secondary porosity through the development of weathered regolith, and fractured bedrock units, which form potential groundwater zones. Hence, on the basis of the presence and nature of the weathered regolith units and fracture systems, appropriate weights are assigned to the different lithological units in the study area. The weightage (Figure 5.49) in terms of increasing groundwater potentiality is in the order of poor productivity of basement rocks and phonolites and rhiyolites (0.11-0.17), moderate productivity of volcanic rocks (0.30) and high productivity Quaternary deposites (0.42).

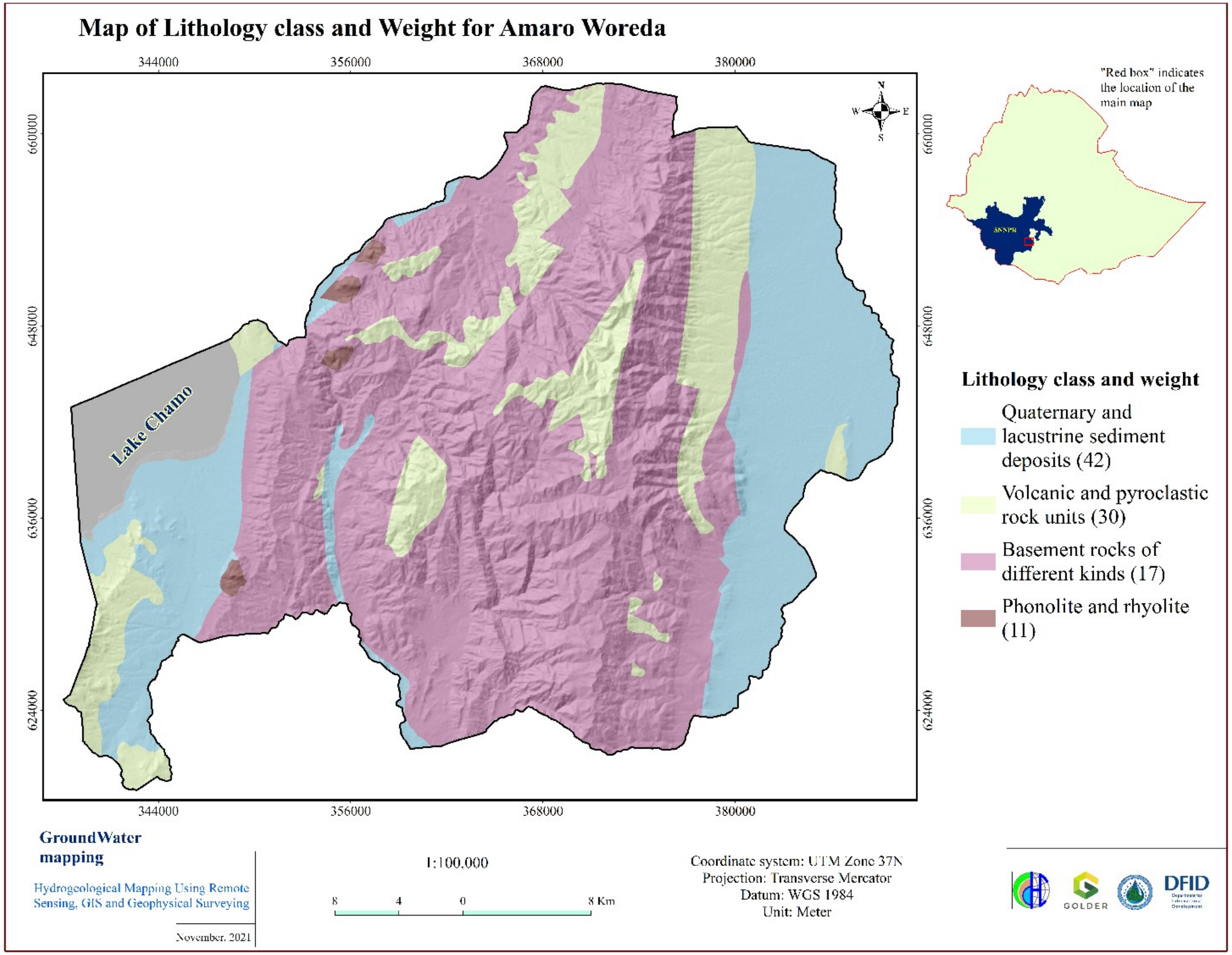

Figure 5.49: Map of lithology class and weight for Amaro Woreda

II. Lineaments and lineament density

The study area is moderatly affected by lineaments and/or fractures consequent to tectonic activities in the past. The prominent directions identified in the area is NNE-SSW trending lineaments. Usually, lineament density map is a measure of quantitative length of linear feature per unit area which can indirectly reveal the groundwater potentials as the presence of lineaments usually denotes a permeable zone. For most of the study area, the lineament density is less than 0.017 km/Km2 (Figure 5.50). Though the lineaments are widespread across the study area, however, the distribution of lineaments suggests geologic control with areas underlain by volcanic rocks associated with quaternary sediments having relatively higher lineament density of 0.18 – 0.34 km/Km2).

Thus, areas with higher lineament density are regarded as good for groundwater development. Consequently, higher weightage of 0.36 was assigned to area with high density of lineaments, while a low weightage of 0.08 was assigned to areas with low lineament density (Figure 5.50).

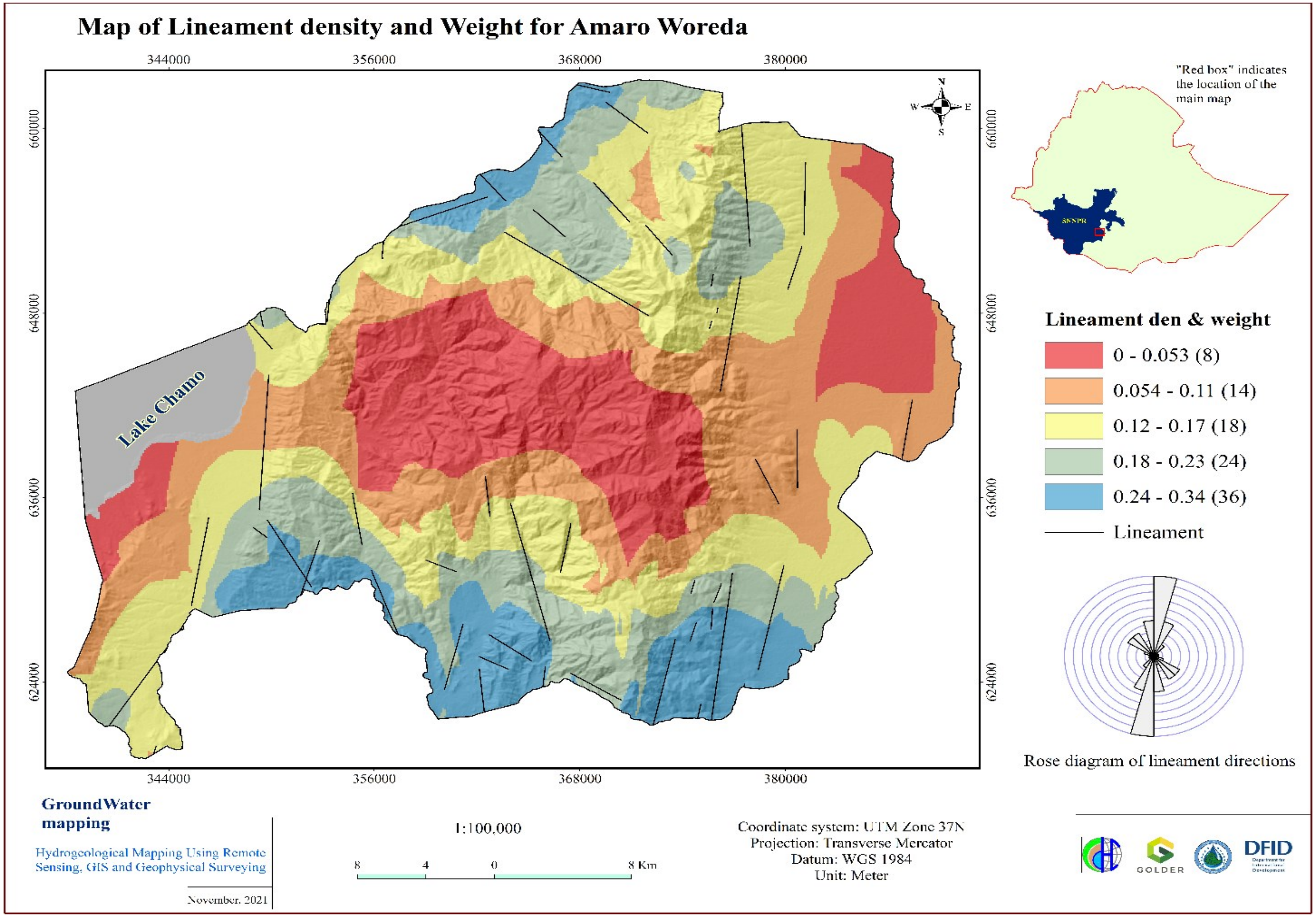

Figure 5.50. Map of lineament density and weight for Amaro Woreda

III. Topographic Wetness Index (TWI)

In this study area, the TWI value ranges between 4.44 and 23.3. A closer look at the classification revealed that most of the elevated areas and drainage systems with steep slopes have relatively lower TWI value while the low lying areas and drainage systems with gentle and flat slopes have relatively higher wetness index value where runoff waters from highlands flow and accumulates mostly in the gentle and flat slopes. Therefore, an area with higher value of TWI has good prospect for groundwater occurrence and flow, and accordingly high weightage value (0.36) was assigned to this class. Whereas, areas with lowest TWI value are steep slopes which triggers runoff were considered with low groundwater prospect and given low weightage value of 0.08 (Figure 5.51).

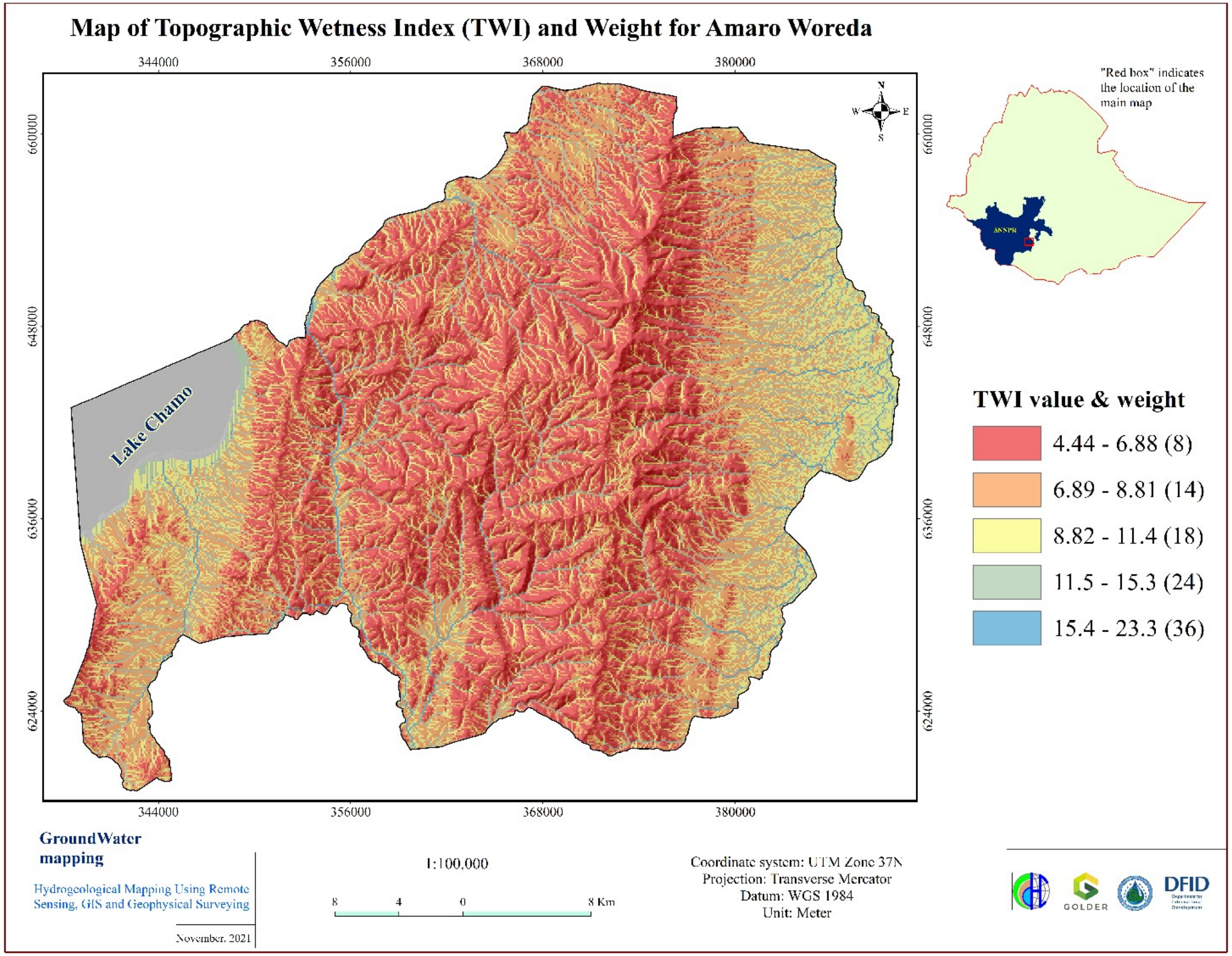

Figure 5.51 Map of topographic wetness index (TWI) and weight for Amaro Woreda

IV. Recharge

The 10 years spatial annual recharge rate distribution in the Amaro Special woreda ranges from 27.2 to 165 mm suggesting groundwaters in most part of the woreda area underlain by volcanic rocks receive moderate amount of recharge while areas underlain by basement rocks receive low recharge. Quaternary sediments have relatively higher recharge amount (Figure 5.52). Accordingly, areas with higher and moderate amount of recharge have weightage factor of 0.36 and 0.24, respectively signifying very good and moderate groundwater potential respectively while areas with the lowest amount of recharge have weightage factor of 0.08, suggesting poor groundwater potentiality. A closer look at the recharge thematic map (Figure 5.52) revealed that most of the western low-lying parts and eastern peripheral parts of the woreda have relatively higher recharge (> 129 mm/y). Generally, the study area is characterized with very low to low mean annual recharge amount, whereas dominant part of the areas at center and southern parts have very low mean annual recharge amount (<63mm).

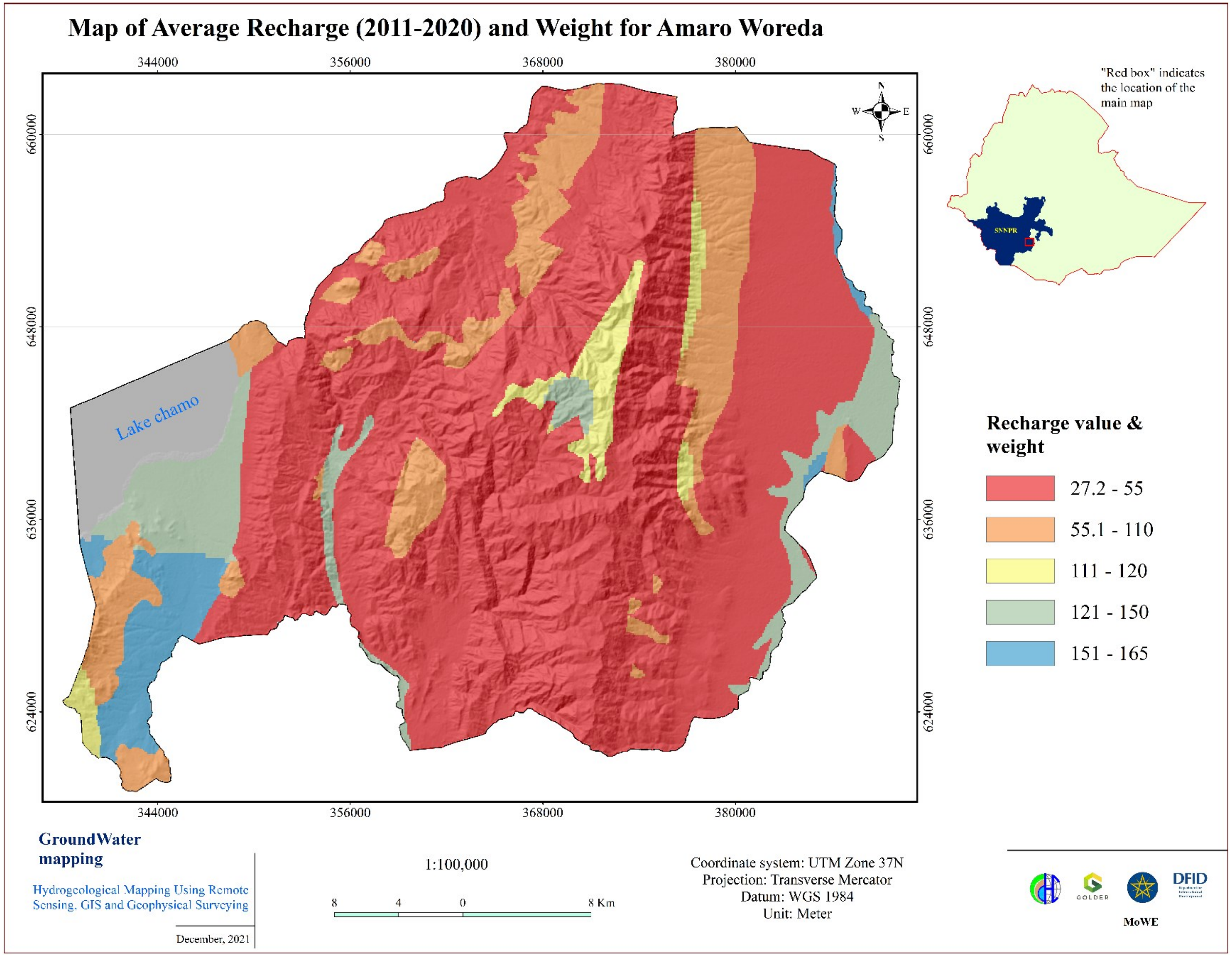

Figure 5.52. Map of yearly (mm/year) recharge and weight for Amaro Woreda

5.7.2. Classification of Groundwater Potential Zones

The hydrogeological system of Amaro Special woreda is comprised of four main lithological units as Quaternary deposits, different volcanic rocks, Phonolites and rhiyolits and Crystalline basement rocks. At regional scale, volcanic rocks and Quaternary deposits form extensive moderately productive aquifers. Within the domain of Amaro woreda, theses, Quaternary deposits form aquifers with high groundwater potential. However, at local scale, within the domain of Amaro Special woreda, due to the geomorphic setup, the volcanic rocks form moderately productive aquifer as revealed from existing borehole yields.

Only the upper weathered and slightly fractured part of the crystalline basement rocks along lineamnets and faults have potential to store groundwater. Weathered and slightly fractured Crystaline basement rocks with overlying Quaternary deposit form moderately potential groundwater storage in small southern part of Amaro Special Woreda along lineament and fault lines and associated plains.

Hydrogeological data from water point inventory, hydro-chemical data and geophysical investigation outcome of the next phase will help to improve the understanding of hydrogeological frame work of the area.

On the basis of the assignment and normalized weighting of the individual features of the thematic layers, a potential groundwater map was produced (Figure 5.53). The potential groundwater zones (PGZ) of Amaro Special woreda revealed five distinct zones, namely very low (unsuitable), low, moderate, high and very high zones whose distribution and extents are presented in figure 5.53 and Table 5.20

The potential map gives a quick assessment of the occurrence of groundwater resources in the study area. The groundwater potential map revealed that most elevated areas in the central parts of the Amaro Special Woreda generally have low potential while significant areas in the east and western peripheries generally exhibits high to very high potentials. Generally high to very high groundwater potentiality of the study area is a confirmation of generally moderate to high productive aquifers of Quaternay deposits, and volcanic aquifers, whereas low groundwater potential areas have an indication of limited aquifers capabilities of volcanic rocks in elevated parts and basement complex terrain.

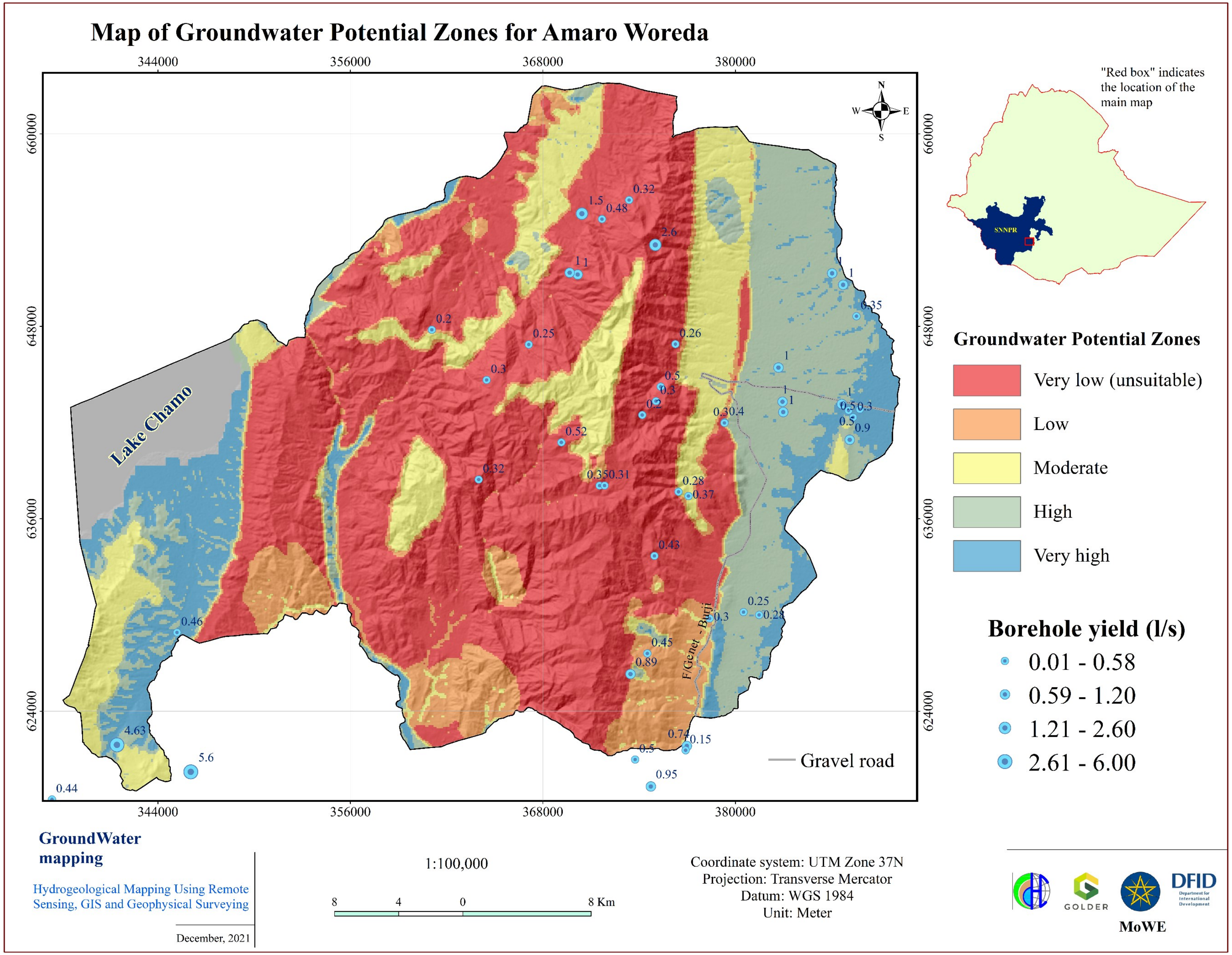

Figure 5.53. Map of groundwater potential zones showing five zones identified by the GIS overlay analysis in Amaro Woreda

Furthermore, a closer assessment of the groundwater potential map revealed that the distribution is more or less a reflection of the geology and lineament density in addition to the topographic wetness index control. Areas underlain by recent quaternary deposits especially in the west and east of the woreda, characterized by relatively plain land with flat slope having higher recharge amount due to the presence of dense lineaments and apparently deep fracturing and weathering have high and very high groundwater potential. On the other hand, small part of the woreda underlain by crystalline basement complexes and mountaneous volcanic terrain with steep slopes, having lower recharge and lineament densities, exhibit low groundwater potential. Moreover, low drainage densities and predominance of volcanic rock outcrops in elevated part can be attributed to the observed poor groundwater potentials at the most central parts of the woreda. Summary of the groundwater potential zones identified in the Amaro woreda is presented in the table below (Table 5.20).

Table 5-20. Classification of groundwater potential zones and coverage areas alongside the respective yield categories in Amaro Woreda

Class	Class interval	Pixel count	Area (Km2)	Area (%)	Well yield (l/s)	Groundwater prospect
1	100 – 147.3	66555	665550	49.0	-	Very low
2	147.4 – 172.0	14892	148920	11.0	0.2 – 1.5	Low
3	172.1 – 194.7	20565	205650	15.1	0.2 – 1.5	Moderate
4	194.8 – 217.3	21411	214110	15.8	1.0 – 2.6	High
5	217.4 – 270.0	12344	123440	9.1	1.0 – 2.6	Very high

5.7.3. Validation with Borehole Yield Data

In order to validate the classification of the groundwater potential zones as revealed by the GIS based groundwater potential map, data on existing wells (yield) were collected for over 44 springs, dug and drilled wells in and around Amaro Special woreda. Since the wells were dug/drilled for water supply purpose without proper pumping test, they lack necessary information about aquifer properties and most of them have even no proper well yield information.

The available dug well and borehole data were superimposed on the groundwater potential map and numbers of wells with different yield ranges for different groundwater potential zones were crudely evaluated. As far as the secondary data we have is concerned, the yields of the deep drilled boreholes in the woreda and its surrounding areas vary from 0.2 to 2.6 lit/sec (Figure 5.53). As shown in the same figure, the occurrence of relatively high yield wells is associated with high lineament zone and Quaternary sediments underlain by volcanic rocks. This is also consistent with very low, low, moderate, high and very high groundwater potential classification of the GIS map for these rocks unit.

The validation clearly highlights the efficiency of the integrated RS and GIS methods employed in this study as useful modern first step approach for proper groundwater resource evaluation and sustainable groundwater development. Nonetheless, the groundwater potential zonation map presented here can be applied only for further by providing quick prospective guides for groundwater in such complex basement dominated area.

5.7.4. Population projection and water demand

5.7.4.1.Population

It is essential that the water supply system is designed to meet the requirements of the population expected to be living in the community at the end of design period by taking into account the design period and annual growth rate. Hence in order to avoid or minimize the aforementioned population related risks, efforts are made to review & justify the credibility of the available population data and growth rate figures.

Population projection is made making use of the geometric growth rate method by using the base population figure estimated by the central statistical Authority. The CSA has set average growth rates for urban and rural areas of the country varying at different times during the design period as shown in the table below. Accordingly these values are adopted in forecasting future population of the town.

Table 5-21 CSA Rural Population Growth Rates

Rural Population Projection Growth Rate of Regions: 2008-2037						
YEAR / Growth Rate % (Rural)	2008-2012	2013-2017	2018-2022	2023-2027	2028-2032	2033-2037
Oromia Region	2.74	2.54	2.29	2.03	1.8	1.56
SNNP Region	2.49	2.37	2.31	2.03	1.82	1.57
Somali Region	2.75	2.63	2.35	2.05	1.89	1.83
Gambela Region	3.52	3.1	3.13	2.76	2.46	2.31

Source: CSA Population Projection for Ethiopia 2007-2037, Addis Ababa July 2013

Geometric method forecasting formula

$$P = Po\,(1 + r)^{n}$$

Where P – projected population
Po – current population
n – Number of years for projection
r – Population growth rate

The population of Amaro Woreda has been projected forward until 2036 using the projected scale of Southern Nation Nationalities and Peoples Regional State. The minimum and maximum population in the Woreda is 1460 and 15,132 respectively. The total population of the Amaro Woreda in 2036 is going to be 258,165. Figure 5.54 presents the projected population for each kebele in the Woreda.

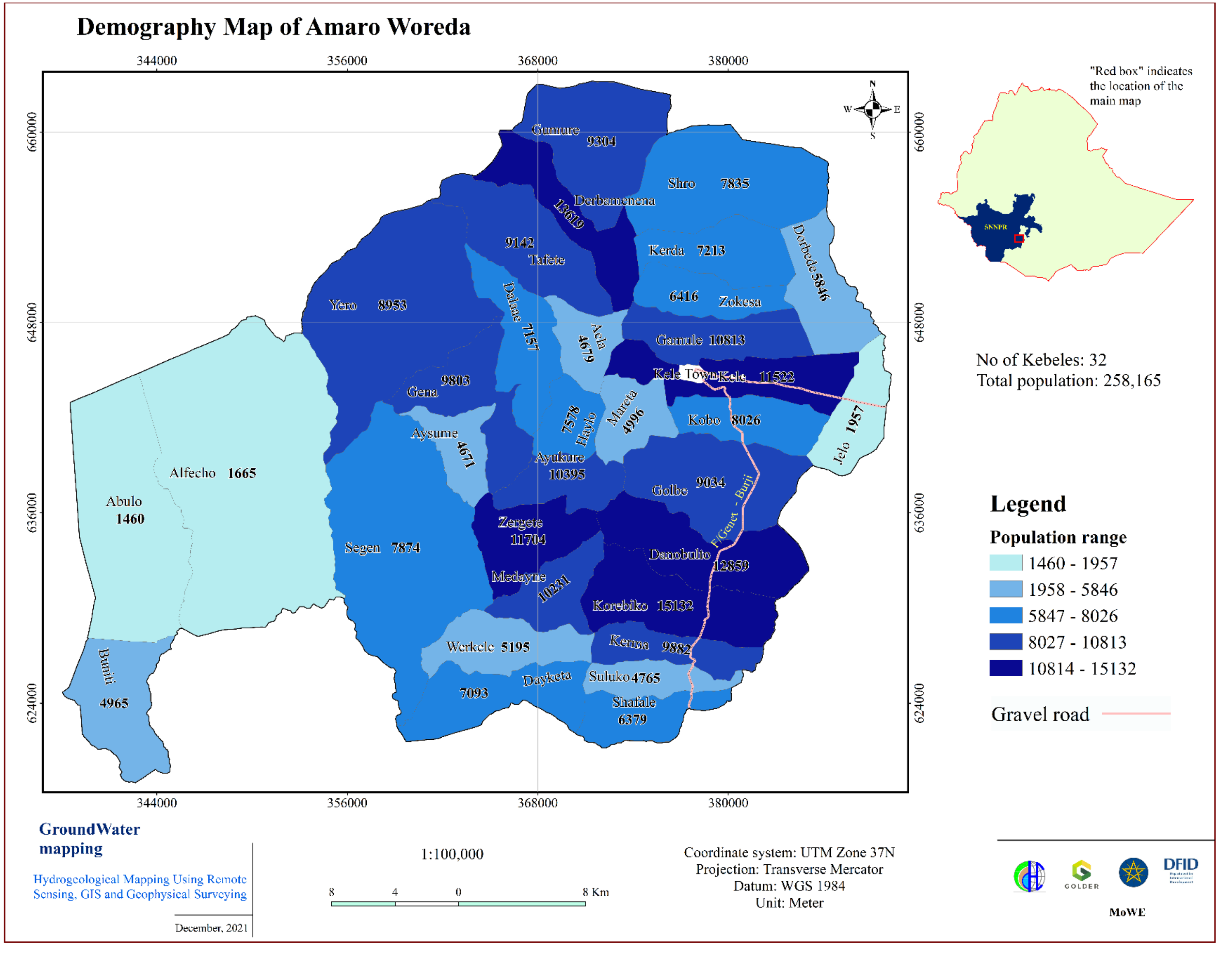

Figure 5.54: Map of projected population (2036) for Amaro Woreda.

5.7.4.2. Water Demand Projection

Projected Water Demand

Estimating water demands mainly depends on the size of the population to be served, their standard of living and activities. To make the demand projection reliable and suitable for rural areas it is better to classify in details as domestic and non-domestic demands.

Domestic Water Demand

Domestic water demand is the amount of water needed for drinking, food preparation, washing, cleaning, bathing and other miscellaneous domestic purposes. The amount of water used for domestic purposes greatly depends on the lifestyle, living standard, and climate, mode of service and affordability of the users.

Domestic water demand service can be categorized according to the level of service to be provided and amount of per capita water required satisfying the demand served by the level of service. Modes of services used for our projection are classified into four categories, namely: -

- Traditional Source users (TSU)
- Public tap users (PTU)
- Yard connections and Neighbourhood (shared) connections (YCO) & (YCS)
- House tap connections (HTU)

In projecting the domestic water demand, the following procedures were followed:

- Determining population percentage distribution by mode of service and its future projection
- Establishment of per capita water demand by purpose for each mode of service;
- Projected consumption by mode of service;
- Adjustment for climate;
- Adjustment due to socio-economic conditions.

After considering the necessary mode of services, per-capita demand and applying the adjustment factors the domestic demand for the corresponding year and population has been calculated.

Non-Domestic Water Demand

Non-domestic water demand was also determined systematically. We have classified it into three major categories based on our projection:

- Institutional water demands (Public and governmental);
- Commercial water demand;
- Livestock water demand

N.B: - The use of a reliable base population figure is very important for optimizing the water sources but adopting 2007 CSA data as a base population has real impact on the projection so to compensate some unforeseen situation like migration and unplanned rural town growth. To compensate for such

- To estimate the demand of public institutions and commercial services we have adopted 15% - 20% of the domestic demand for our consumption.
- The demand for livestock watering adopted in the projection is 10% -15% of the domestic demand.

Total Average daily day demand

The average daily day demand is taken to be the sum of domestic demands and non-domestic demand. The water demand in a day varies with time according to the consumer’s life style. It is the total sum of adjusted domestic, public and livestock demand.

Maximum Day Demand

The maximum day demand is the highest demand of any one 24-hour period over any specific year. It represents the change in demand with season. This demand is used to design source capacity. The deviation of consumption from the average day demand is taken care of as per the maximum daily coefficient figures. Usually a value from1.1 to 1.3 is adopted as maximum day factor. A constant value of 1.3 is adopted as maximum day factor for all of the villages.

Figure 3.55 shows the distribution of water demand in each Kebeles of the Woreda. The minimum and maximum water demand for Kebeles is 131 M^3/day and 1,359 M^3/day respectively. The overall water demand for the projected population in the Amaro Woreda is 23,194 M^3/day.

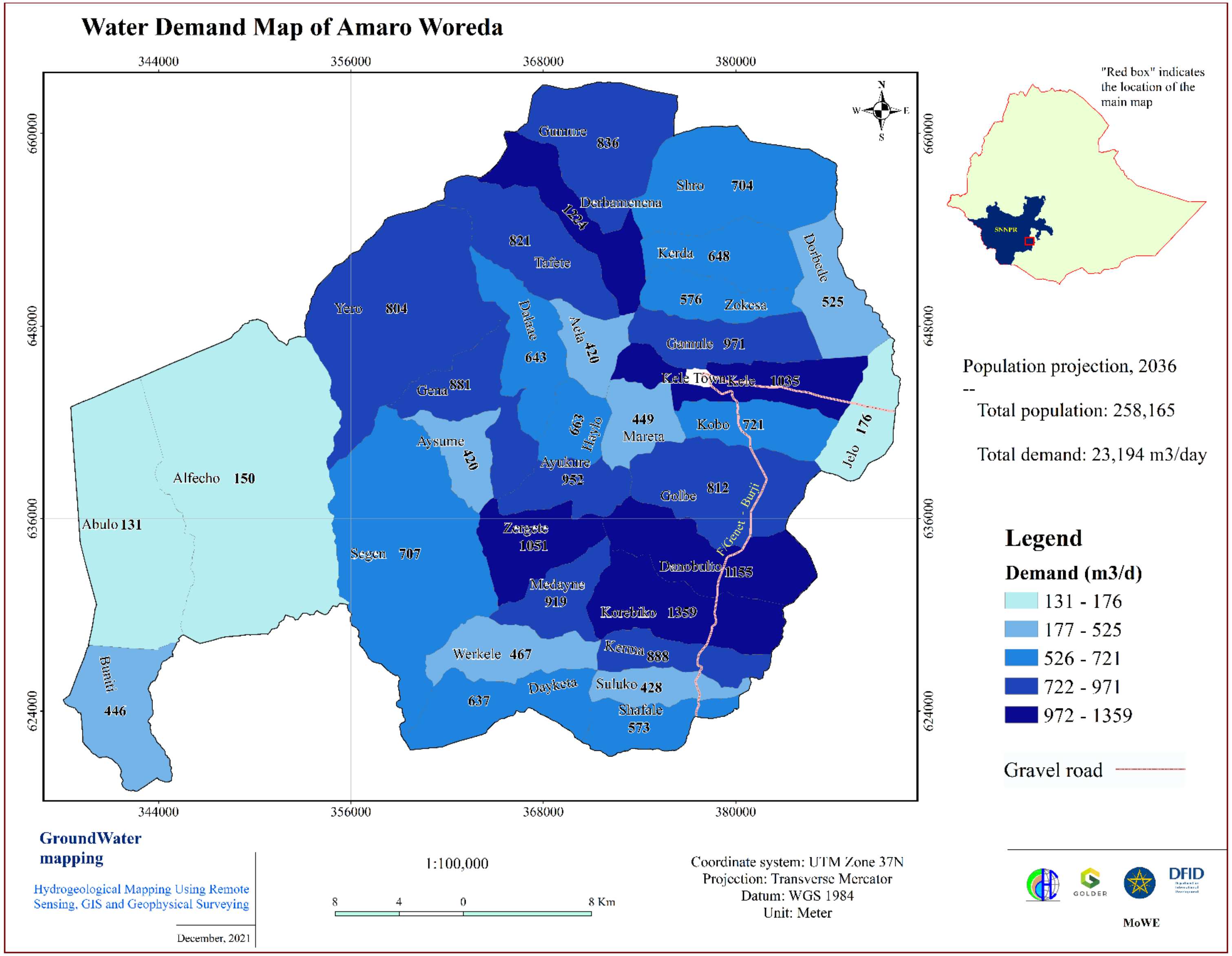

Figure 5.55: Map of water demand (M^3/day) for Amaro Woreda.

5.7.5. Propsed Target Sites

Four target sites are identified and proposed within the woreda based on the identified groundwater potential zones, the productivity of the hydrostratigraphic units with their expected optimum borehole yield, proximity to beneficiaries and population density. With further discussion and consultation with stakeholders, two priority sites will be selected for further hydrogeological and geophysical investigations in phase III. The following are the four proposed sites (Figure 5.56):

Target Site-I:

This target site is located in the eastern part of the woreda. It is situated in the identified very high potential zones. This target site mainly falls on Quaternary recent deposits underlain by volcanic rocks.

Target Site-II:

This target site is located in the Western part of the woreda. It is situated mainly in the identified high groundwater potential zones. This target site mainly falls on Quaternary deposits underlain by volcanic rocks.

Target Site-III:

This target site is located in the central part of the woreda. It is situated mainly in the identified moderate groundwater potential zone. This target site mainly falls on Quaternary sediments underlain by volcanic rocks.

Target Site-IV:

This target site is located in the northwestern part of the woreda. It is situated mainly in the identified moderate groundwater potential zone. This target site mainly falls on Quaternary sediments underlain by volcanic rocks.

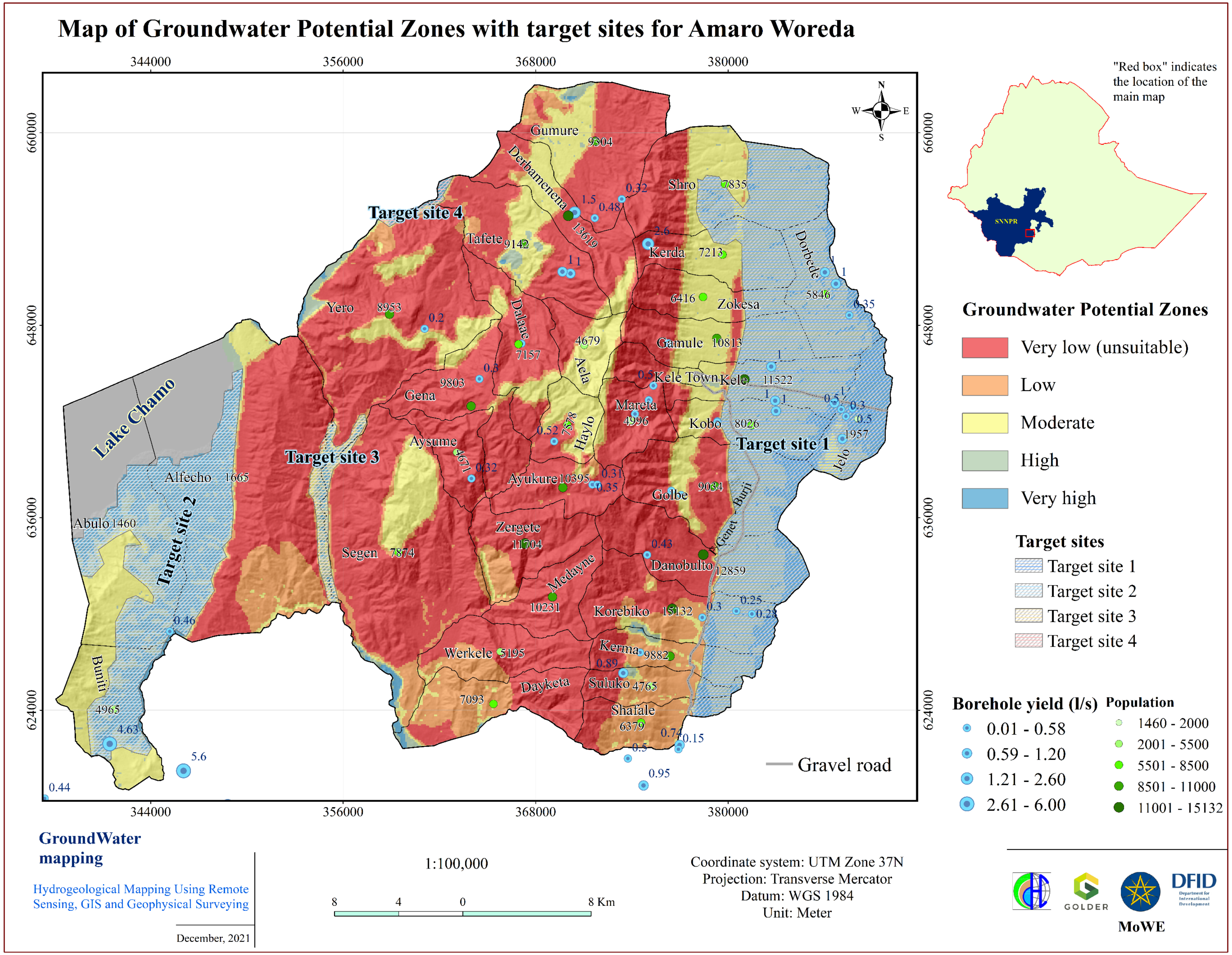

Figure 5.56: Map of groundwater potential zones with selected target sites in Amaro Woreda

5.7.6. Conceptual hydrogeological model of Amaro Special Woreda

Hydrogeological conceptual models are collections of hypotheses based on geological structural and geomorphological evidences and existing wells lithologic logs to describe and understand the groundwater occurrence, localization and movement beneath the ground surface. The purpose of the hydrogeological model across/along inferred groundwater flow direction is to reflect the prototype of regional groundwater flow system in the two priority sites selected for further study in phase III.

Due to proximity to the Main Ethiopian Rift, rock units are dislocated and placed in jackstapostion against each other. This region has a compartimentalized groundwater flow system constrained by geological structres and topography. Groundwater gets recharge mainly from local rain that falls on central and a northeast surrounding highland with expected lateral inflow from central adjacent highlands of volcanic rocks. Groundwater flow direction is generally towards south in the general direction of tributary stream of Segen River flow direction through alluvial plain and fractured volcanic rocks. Development of the hydrogeological conceptual model of the Amaro Special Woreda will be prepared based on the converging evidence of secondary data including digital elevation model (DEM), geological and hydrogeological maps and structures, lithological well logs of wells in the area. The target sites will be selected out of the proposed ones. The conceptual hydrogeological models for this woreda to be constructed along/across groundwater flow path will be produced after stake holder consultation workshop to select priority target sites for further hydrogeological characterization. The conceptual hydrogeological model summarizes what is known about the hydrogeological system and thereby provides a framework for hydrogeological system of the target sites in the woreda including the major groundwater flow zone (inflow, groundwater flow paths, inferred depth, and outflow) and groundwater table and groundwater condition of Amaro Special woreda using existing data of spring, river and boreholes.

5.8. Akobo Woreda

The four thematic layers which were integrated for groundwater potential mapping in Akobo Woreda are summarized in table 5.22 below. The notes on the description of each thematic layers including classification of potential zones, validation with borehole and scheme datasets, population projection, water demand and selected target sites presented in the sub-sections.

Table 5-22. Assigned and normalized weights for the individual features of the four thematic layers for groundwater potential zoning in Akobo Woreda

Theme	Class	Groundwater Prospect	Weight assigned	Normalized weight	Rank	Area (Km2)	Area (%)
Geology/ Lithology, 'GG'	Quaternary flood plain and alluvial fan deposits	Very good	4	0.6	0.40	549.33	30
	Elluvia soil	Good	3	0.40		1477.84	70
Lineament Density,' LD' (Km/Km2)	0 - 0.084	Very poor	1	0.11	0.39	450.61	0.22
	0.084- 0.197	Poor	2	0.19		920.77	0.44
	0.197– 0.328	Moderate	3	0.27		550.81	0.26
	0.328– 0.598	good	4	0.43		158.06	0.08
Topographic Wetness Index, 'TWI'	6.3-10.3	poor	1	0.12	0.15	1089.53	0.52
	10.3 – 12.5	Moderate	2	0.2		631.08	0.30
	12.5 – 15.9	Good	3	0.28		291.34	0.14
	15.9 – 24.17	Very good	4	0.40		68.58	0.03
Recharge, 'GR' (mm/y)	153 – 169	poor	1	0.11	0.06	941.16	0.46
	170 – 191	Moderate	2	0.15		462.8	0.22
	192 – 218	Good	3	0.29		474.55	0.23
	219 – 249	Very good	4	0.45		181.69	0.09

5.8.1. Integration of Thematic Layers for Groundwater Potential Zoning

The details of geology, rainfall, lineament density, geomorphology, land slope, soil type, land use/land cover, groundwater depth and drainage density together with their spatial distribution in Akobo woreda are presented below:

I. Geology/lithology

The major geology of Akobo Woreda are Quaternary elluvials and alluvial deposit.

Elluvials deposits (Qe)

The elluvials deposit is found at the foot of volcanic and basement rock units which are outcrop in small areal coverage in the area in northwestern and southern direction on the woreda (Fig 5.57.). It is derived from basement and volcanic rock units from the surrounding lithology units. Akobo is mainly covered by quaternary eluvium (Qe) sediment which covers an area of 70% of the total woreda. The Alluvium (Qa) form minor subdued topography, filled with silty-clayey sediments dominated by marshy to bogy silty-clays. The alluvial deposit covers small area compared to the eluvium deposit. Some bedding-like structures are developed in the recent alluvial deposits, which are a primary structure noted in alluvial formation layers. These structures are produced based on the horizontal depositions of the layer by sedimentation compactions of transgressed materials (GSE, 2018). Major geological units and its spatial distribution is shown in Figure 5.57.

Quaternary Flood plain and Alluvial fan deposits (Qa)

Large part of the Project area is covered by quaternary flood plain and alluvial deposits with variable thickness in the area. Its outcrop thickens is 2 to 3m towards Akobo river. This unit is mainly represented by silt, sand and gravel which is forming alluvial fan in the area. Its grain size is also different from place to place on the area. From borehole drilled for water supply towards northern direction indicate that the thickness of this unit is variable from 60m to 100m depth and it is underlain by volcanic and basement rock unit. The weightage in terms of increasing groundwater potentiality is in the order of moderate productivity of elluvial (0.4) to high productivity of alluvial/lacustrine sediments (0.6).

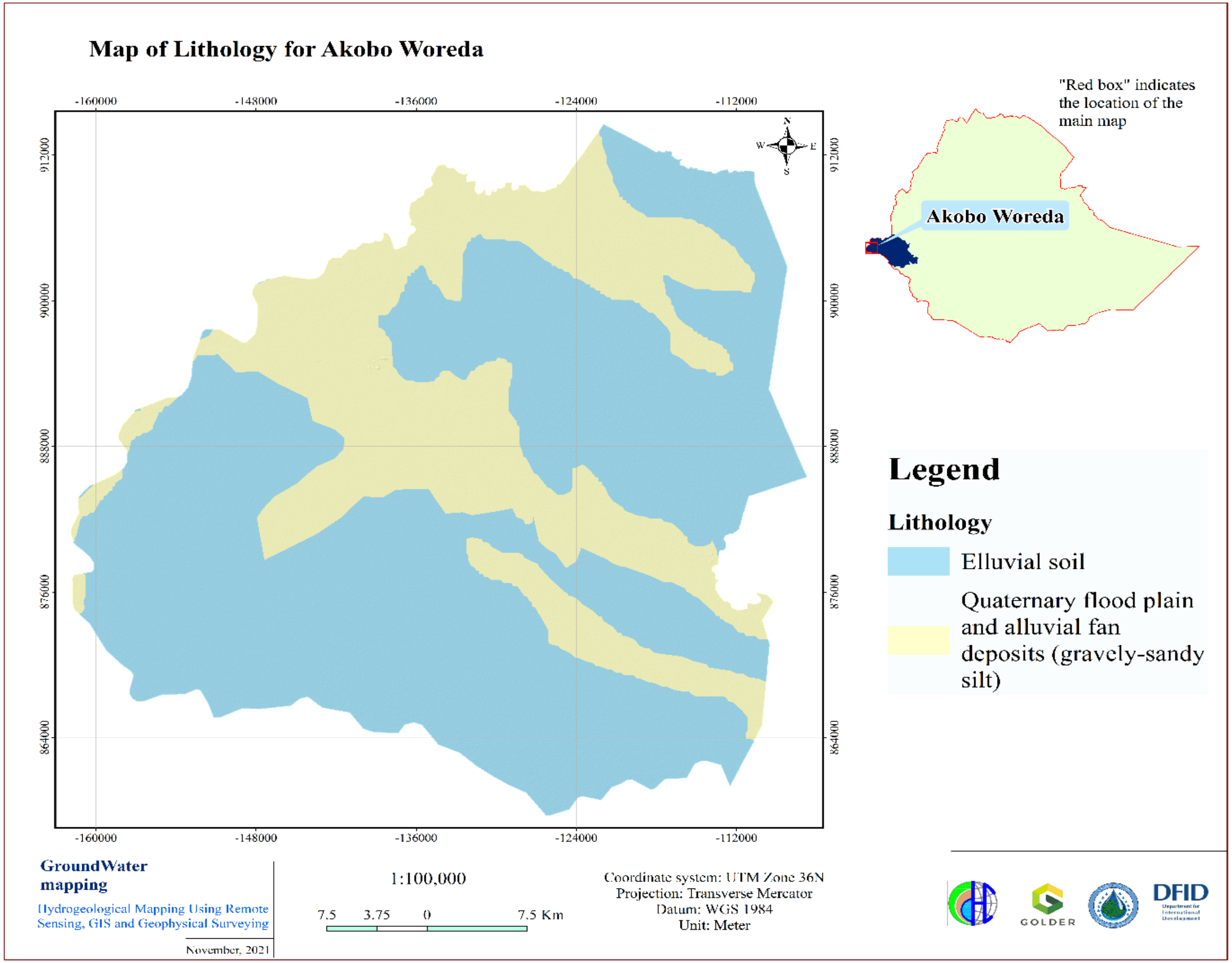

Figure 5.57 Map of lithology class for Akobo Woreda

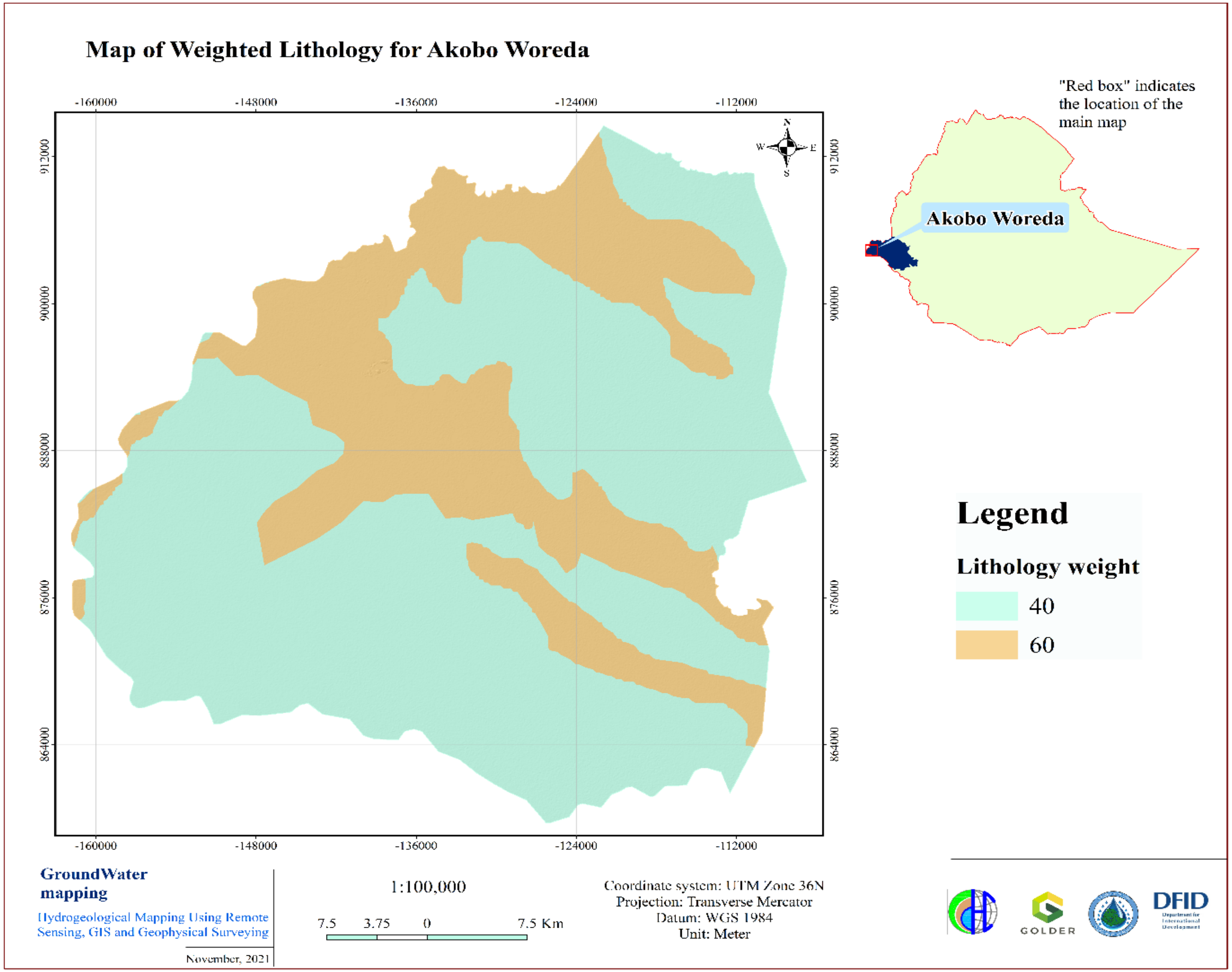

Figure 5.58 Map of weighted lithology class for Akobo Woreda

II. Lineaments and lineament density

Lineaments are manifestation of linear features that can be identified directly on the rock units or from remote sensing data. Lineaments and their intersections play a significant role in the occurrence and movement of groundwater. The presence of lineaments may act as a conduit for groundwater movement which results in increased secondary porosity and, therefore, can serve as groundwater potential zone (Rao, 2006; Prasad et al., 2008). Accordingly, detailed lineaments of the study area were extracted from a mosaicked Cloud Free Images Sentinel-2 selected from the year 2020 to 2021 series combined with geomorphology of the area and mapped using ArcGIS 10.8 software, and subsequently lineament density map was computed in using GIS algorithm and expressed in terms of length of the lineament per unit area (km/Km2).

Some bedding-like structures are developed in the recent alluvial deposits, which are a primary structure noted in alluvial formation layers. These structures are produced based on the horizontal depositions of the layer by sedimentation compactions of transgressed materials (GSE, 2018).

The lineament density varies from less than 0.058 km/Km2 to 0.598 km/Km2 with the central, north, northeast, southeast and south west has relatively high lineament density (Figure 5.59). Though the lineaments are widespread across the study area, however, the distribution of lineaments suggests geologic control with areas covered by Quaternary sediment central area have higher lineament density of 0.17 – 0.6 km/Km2) which is good for groundwater development. Consequently, higher weightage of 0.43 was assigned to area with high density of lineaments, while a low weightage of 0.11 was assigned to areas with low lineament density (Figure 5.59).

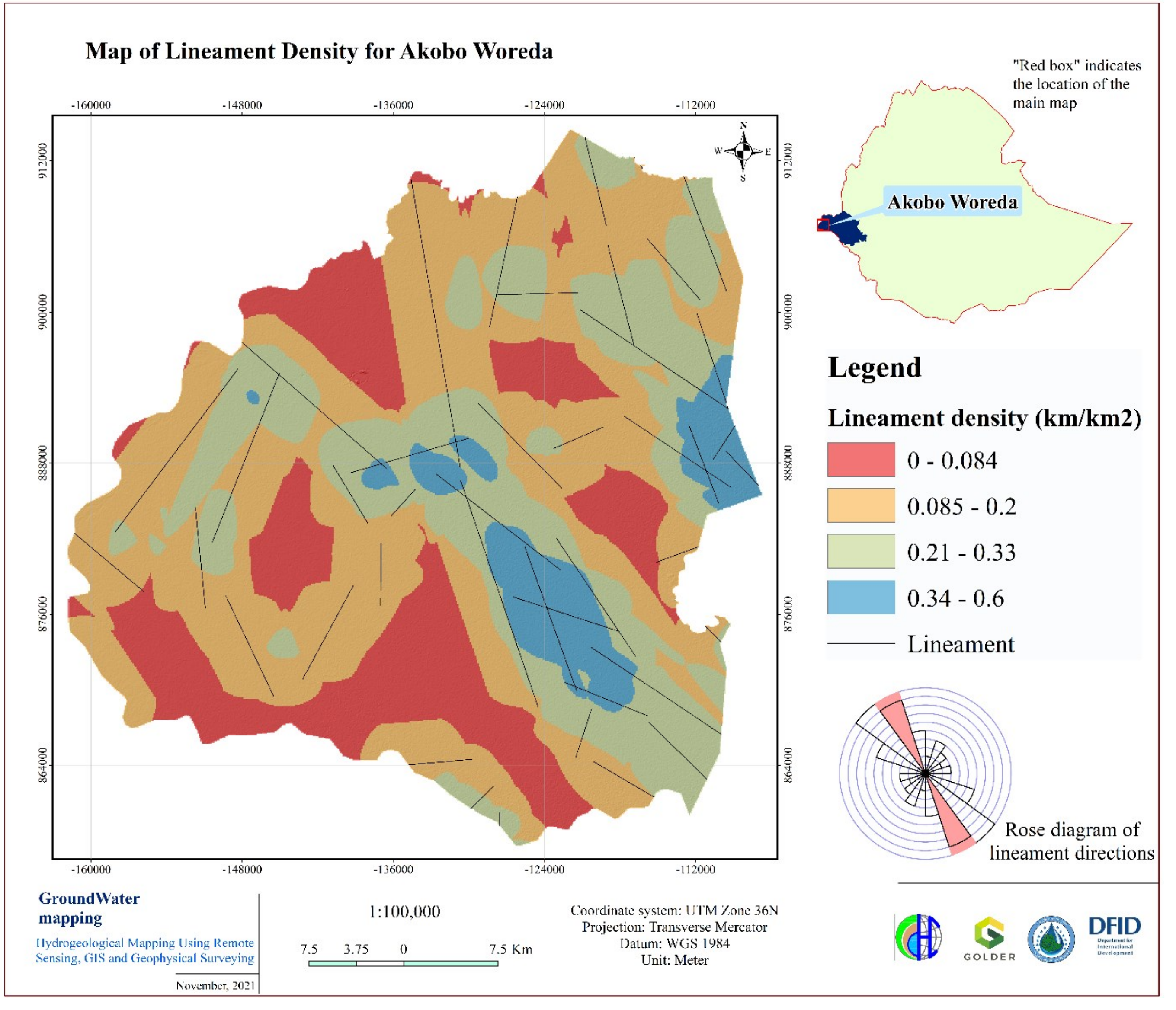

Figure 5.59: Map of lineament density for Akobo Woreda

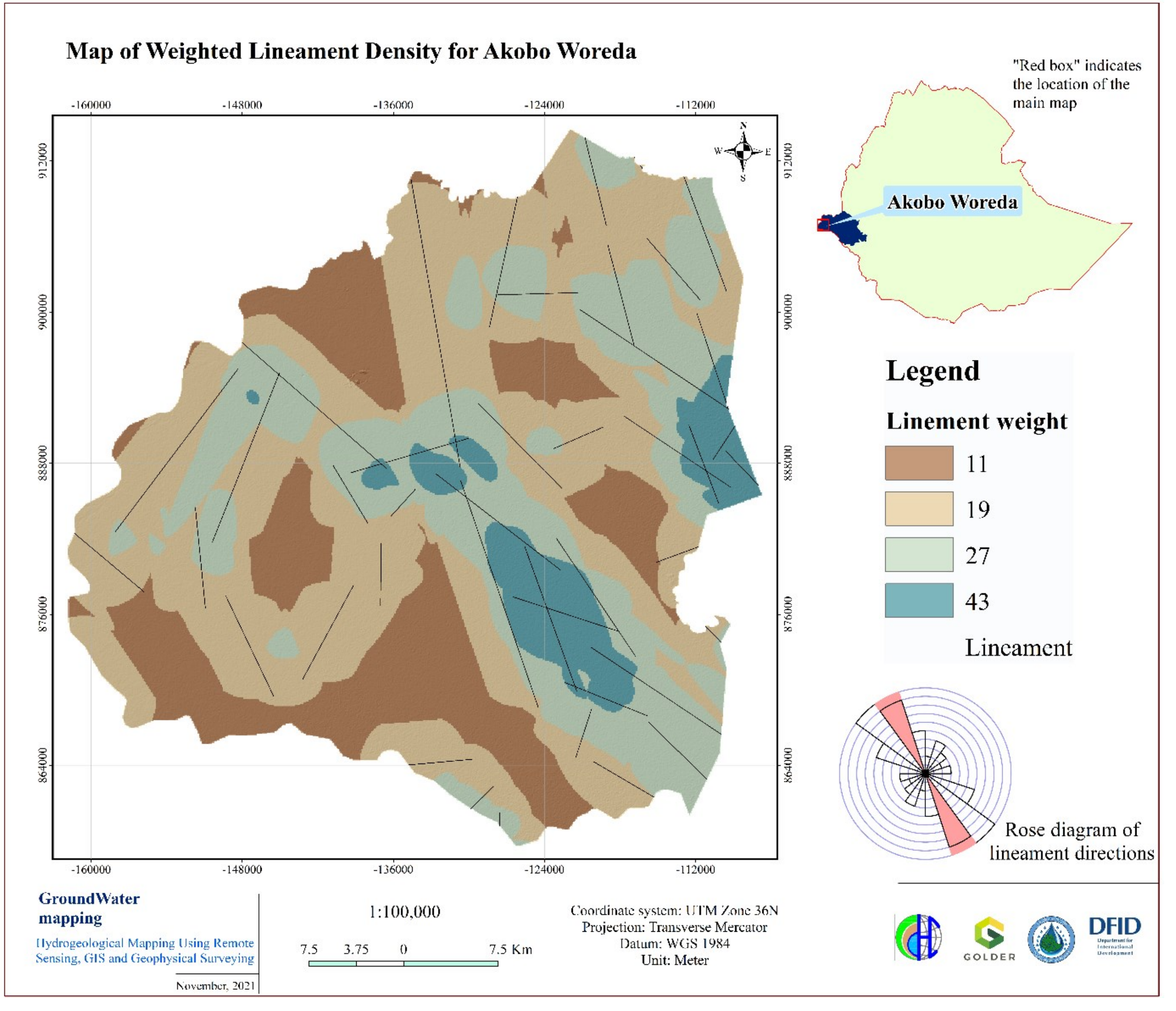

Figure 5.60: Map of weighted lineament density for Akobo Woreda

III. Topographic Wetness Index (TWI)

In this study area, the TWI value ranges between 6.3 and 24.17. A closer look at the classification revealed that areas with high TWI value is confined within the river plain with flat slopes whereas large part of the woreda away from river plain has low TWI value suggesting the significance of river plain deposits in accumulating voluminous groundwater. Therefore, an area with higher value of TWI has good prospect for groundwater occurrence and flow, and accordingly high weightage value (0.40) was assigned to this class. Whereas, areas with lowest TWI value are gentle slopes which triggers runoff were considered with low groundwater prospect and given low weightage value (0.12).

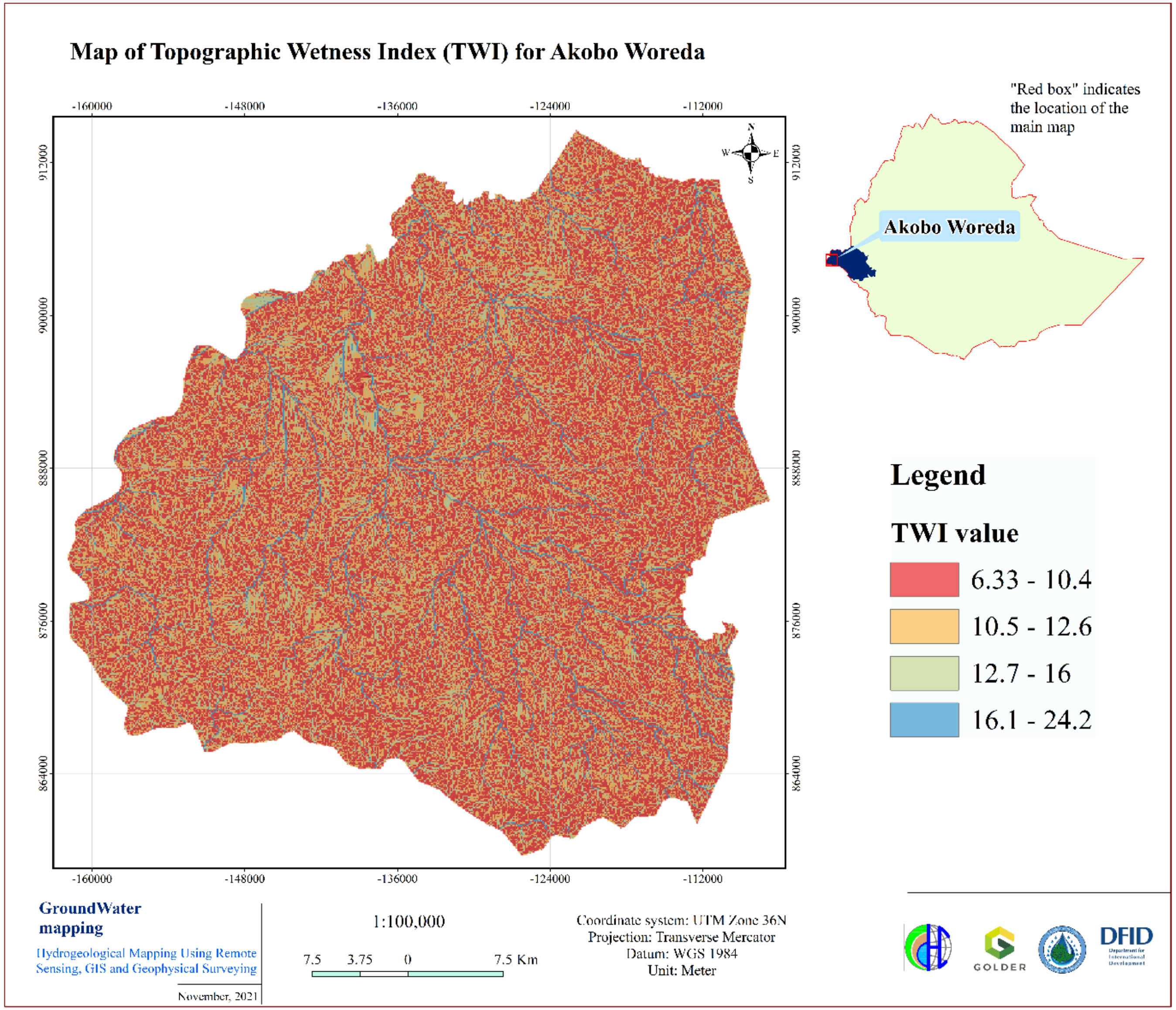

Figure 5.61: Map of topographic wetness index (TWI) for Akobo Woreda

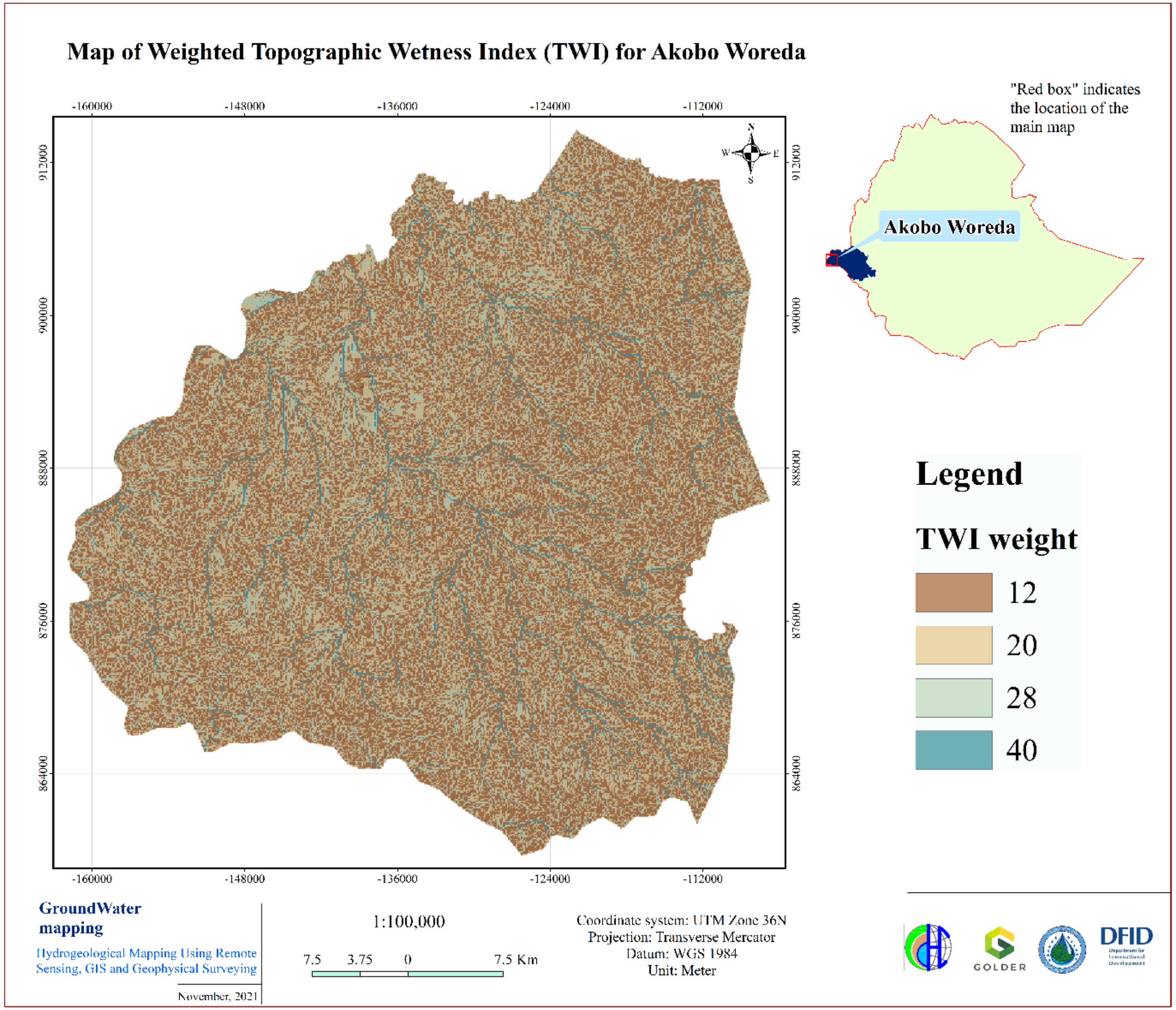

Figure 5.62. Map of weighted topographic wetness index (TWI) for Akobo Woreda

IV. Recharge

The 10 years spatial annual recharge rate distribution in the Akobo woreda ranges from 153 to 249 mm suggesting groundwaters in most part of the woreda area underlain by alluvial sediment receives high amount of recharge while areas covered by elluvial deposit which contains large proportion of clay and silty materials have relatively low recharge amount (Figure 5.63). Accordingly, areas with higher and moderate amount of recharge have weightage factor of 0.40 and 0.28, high and moderate groundwater potential signifying which covers about 181.69 Km2 (9 %) and 474.55 Km2 (23 %), respectively while areas with the lowest amount of recharge have weightage factor of 0.12, suggesting poor groundwater potentiality and represent about 941.16 Km2 (46 %). A closer look at the recharge thematic map revealed that most of the area far-away from Akobo River plain have relatively low to moderate recharge (< 134 mm/y) the central part of the area within Akobo River plain has high recharge (> 134mm/y. Generally, the study area is can be considered as having moderate to high mean annual recharge.

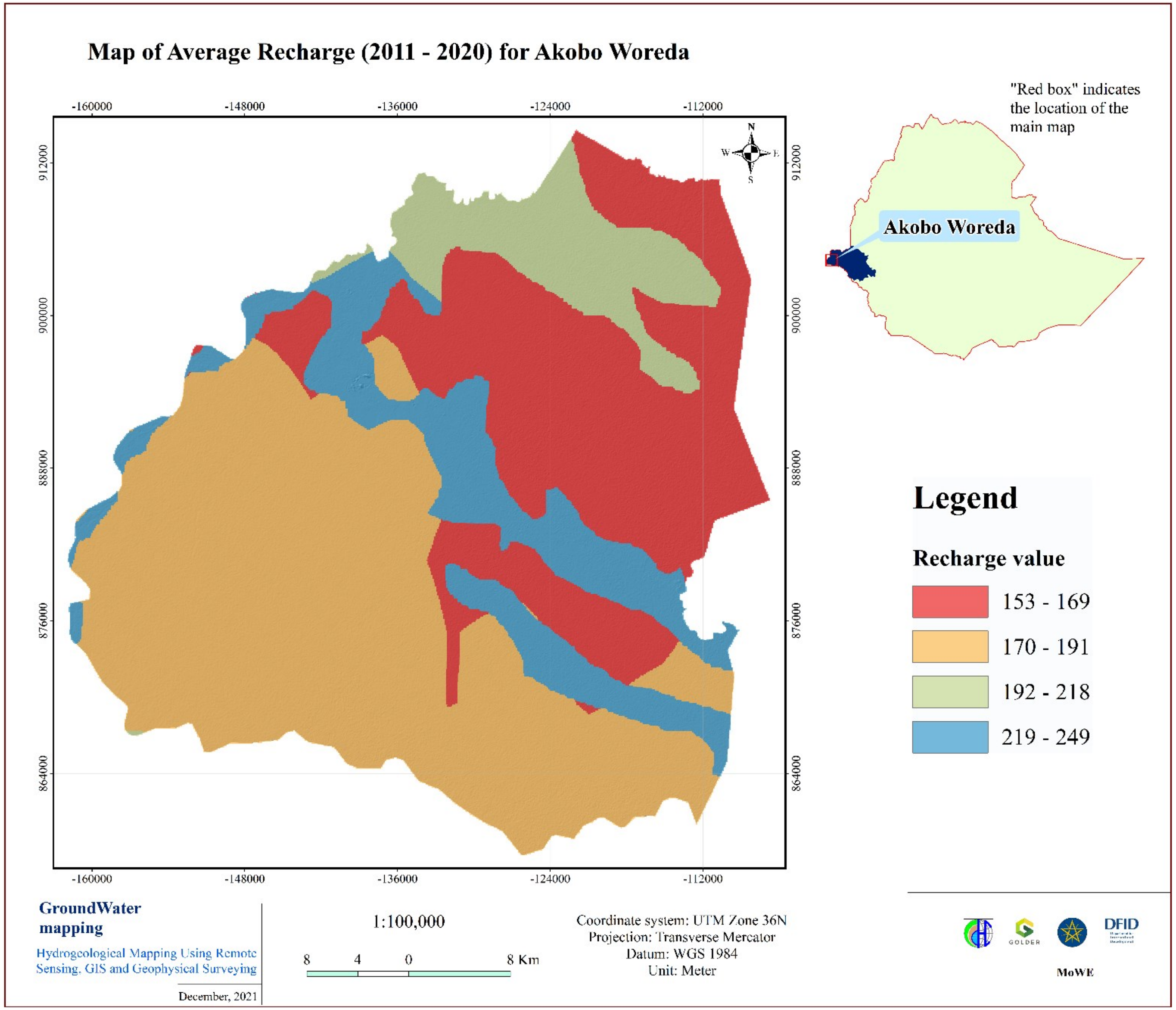

Figure 5.63. Map of yearly (mm/year) recharge for Akobo Woreda

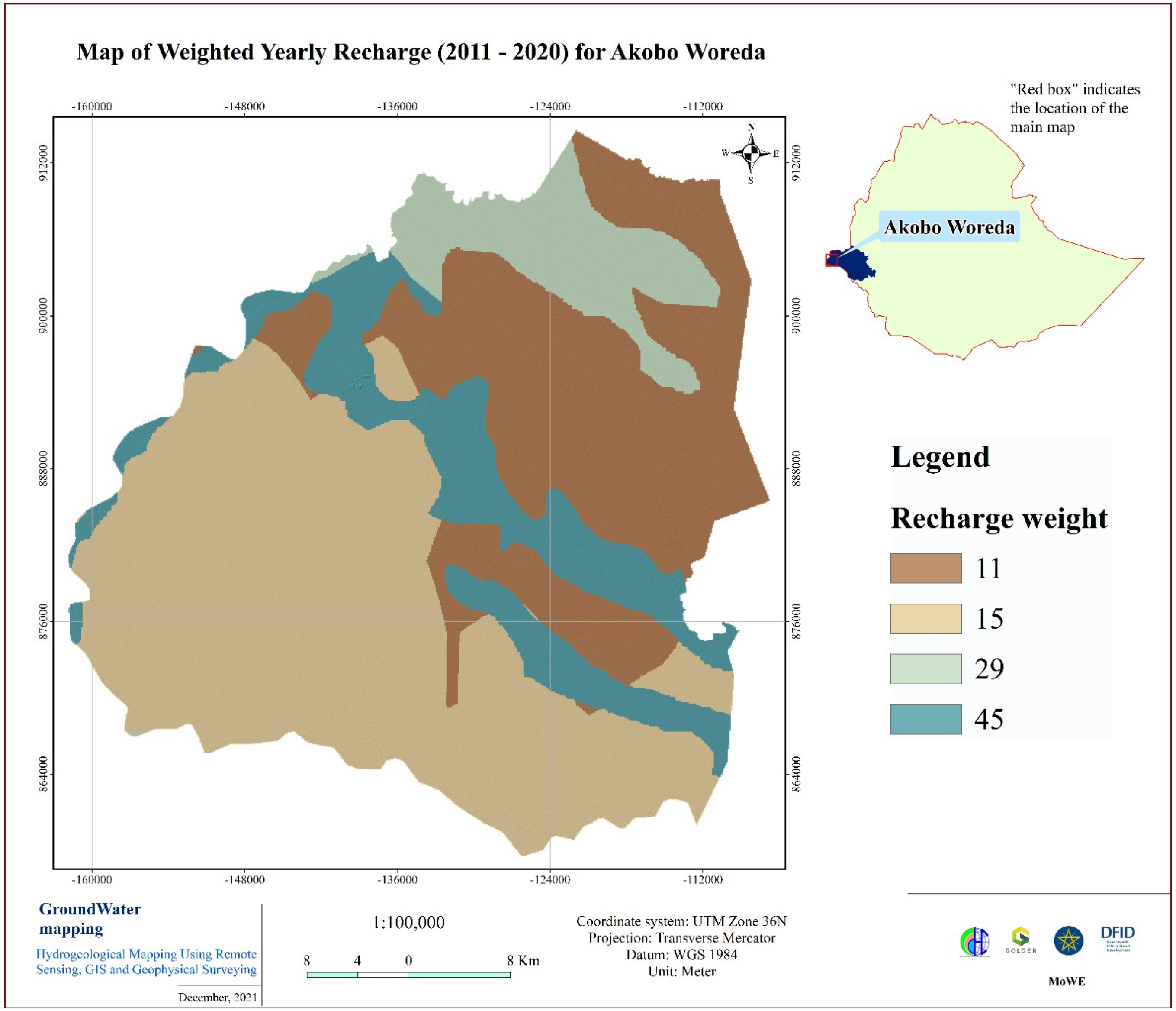

Figure 5.64. Map of weighted yearly (mm/year) recharge for Akobo Woreda

5.8.2. Classification of Groundwater Potential Zones

On the basis of the assignment and normalized weighting of the individual features of the thematic layers, a potential groundwater index map was produced (Figure 5.65). The potential groundwater zones (PGZ) of the Akobo woreda revealed three distinct zones. The wider areas in south, central north and north part of the woreda is classified as low groundwater potential zone with groundwater yield 0.5-2 l/s, whereas area in northwest, southeast and west periphery of the woreda is classified as moderate with yield less than 3l/s in and the central and central southeast part of the woreda is high groundwater potential zone with yield 5-16.8 l/s.

The potential map, as presented in Figure 5.65, gives a quick assessment of the occurrence of groundwater resources in the study area. The groundwater potential map revealed that high groundwater potential zone is directly related to areas with high lineament density within alluvial sediments within Akobo river plain indicating groundwater receives high recharge from Akobo River during spillover flow. Region demarcated as low groundwater potential zone is elluvial soils which could be due to low recharge by clay or silty materials of this sediment which hinders local vertical recharge.

In general, a closer assessment of the groundwater potential map revealed that the distribution high groundwater potential zone is closely related to recharge and lithology whereas topographic wetness index has relatively low impact on occurrence and distribution of groundwater in the woreda as the topographic is almost uniform over the entire woreda area. Summary of the groundwater potential zones identified in the Akobo woreda is presented in the table below (Table 5.23).

Table 5-23 Classification of groundwater potential zones and coverage areas alongside the respective yield categories in Akobo Woreda

GWP Zones	Area (Km2)	Area (%)	Major Aquifer Units	Borehole Yield Classification (l/s)
				Q (Range)
Very High	649.33	30	Quaternary flood plain and Alluvium sediments (Qa)	10-16.8
High	1577.8	70	Elluvium soil (Qe)	5 - 10

5.8.3. Validation with Borehole Yield Data

In order to validate the classification of the groundwater potential zones as revealed by the GIS based groundwater potential map, data on existing wells (yield) were collated around the study woreda area. Because of existing borehole data scarcity, for the validation, borehole yield data clother to the woreda boundary was used. The borehole data were superimposed on the groundwater potential map and numbers of wells with different yield ranges for different groundwater potential zones were evaluated. Generally, the yields of the boreholes in the study area vary from 10 to 16 lit/sec in very high potential zones and varying from 5 lit/sec to 10 lit/sec in high potential zones as compared with 3 lit/sec to 5 lit/sec in the moderate and from 1 to 3 lit/sec in the low potential zones (Figure 5.65). As shown in the figure, the occurrence of number of wells with yield of in the range 5- 10 lit/sec (high yield) and of > 10lit/sec (very high yield) cut across mainly the recent quaternary flood plain and Alluvial deposits. However, the less frequency of wells within Elluvial soil in the low yield category signifies the generally low potential of these rocks as highlighted by the GIS-based potential map.

The validation clearly highlights the efficiency of the integrated RS and GIS methods employed in this study as useful modern approach for proper groundwater resource evaluation and sustainable groundwater development. Nonetheless, the groundwater potential zonation presented here can be applied only for regional studies for the purpose of groundwater development, providing quick prospective guides for groundwater exploration and exploitation in such basement and sedimentary settings, while individual site selection for groundwater development should take into consideration other site-specific conventional ground-truthing methods.

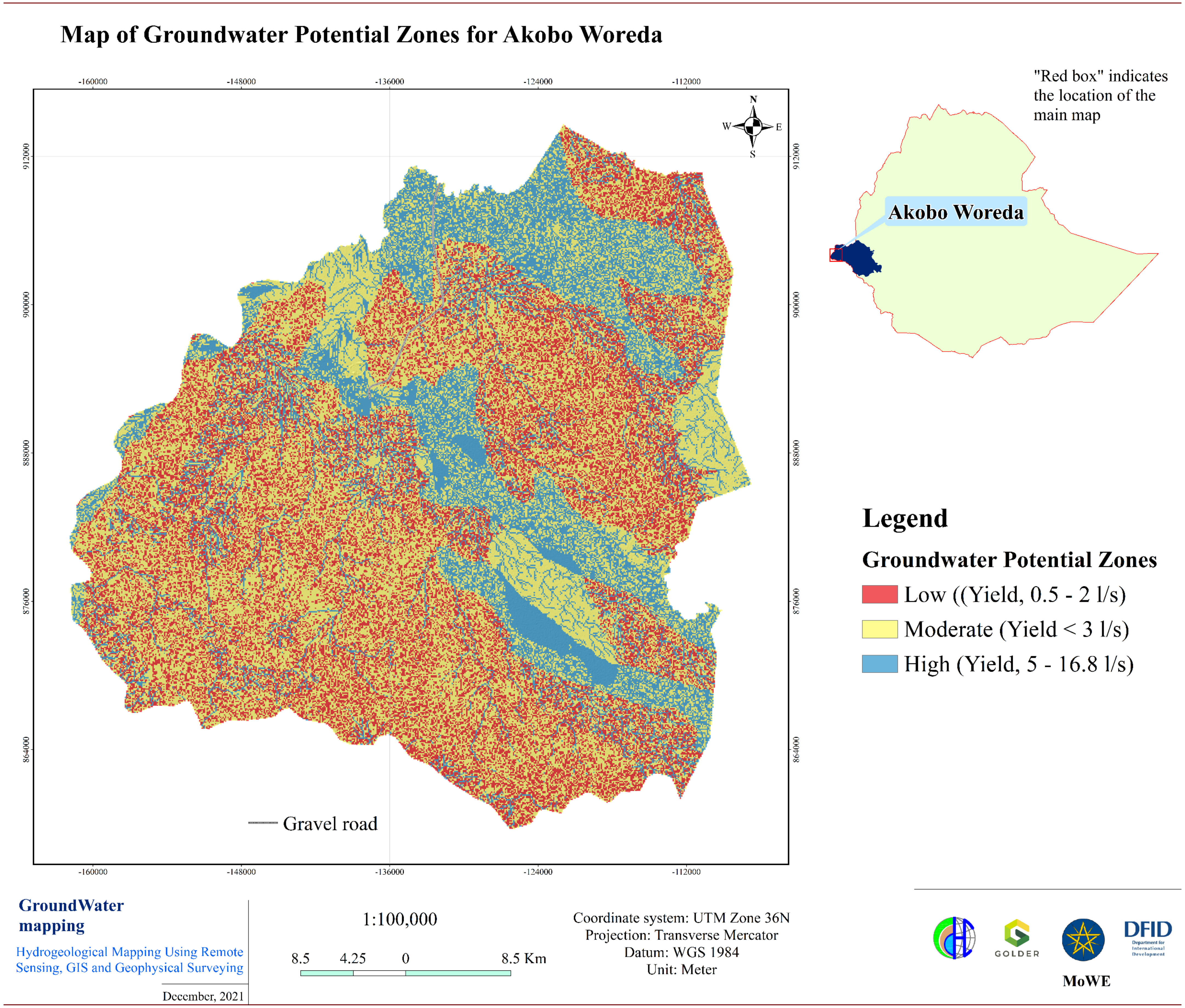

Figure 5.65: Map of groundwater potential zones showing three zones identified by the GIS overlay analysis in Akobo Woreda

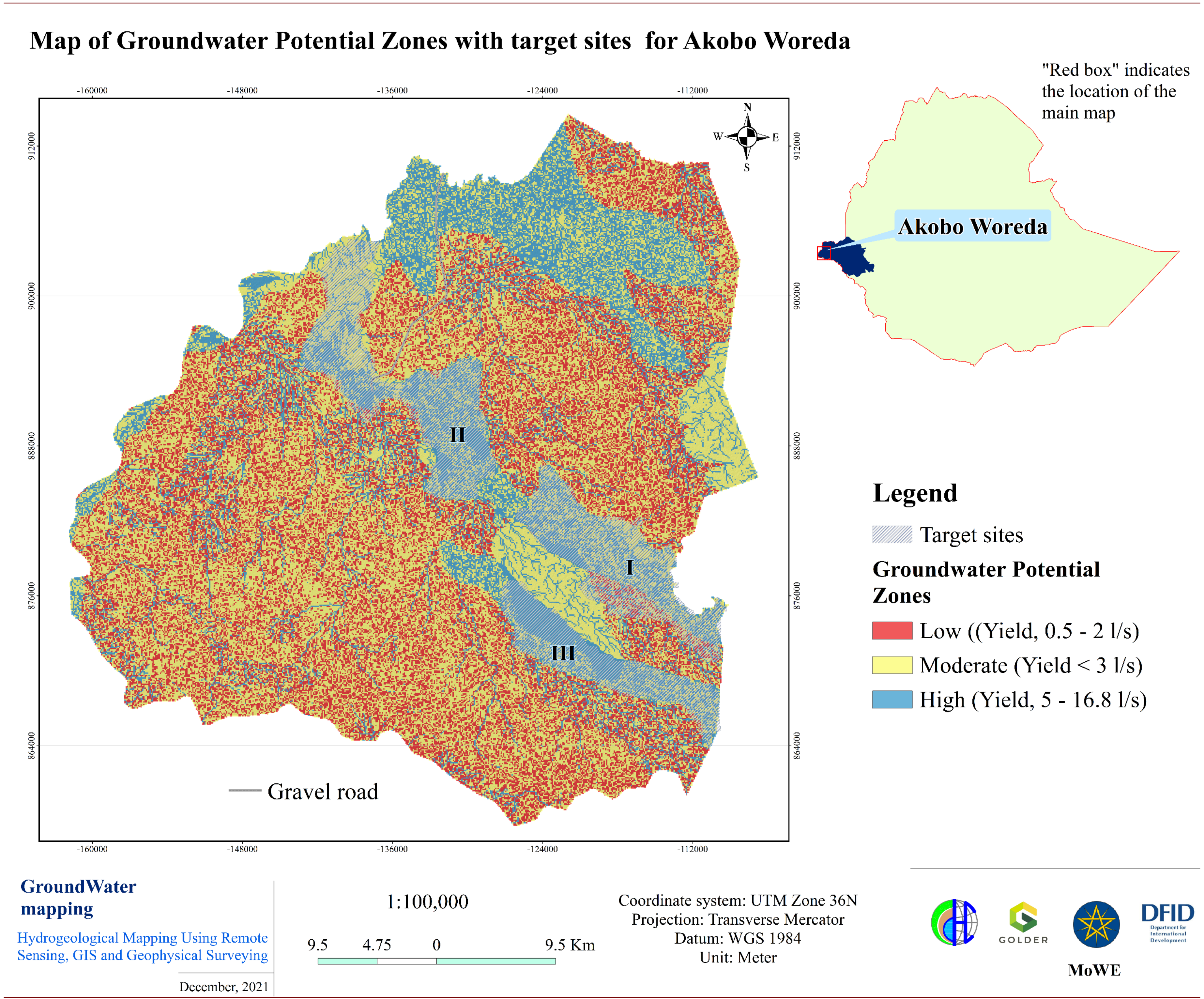

Figure 5.66: Map of groundwater potential zones with selected target sites in Akobo Woreda

5.8.4. Propsed Target Sites

Three target sites are identified and proposed within the woreda based on the identified groundwater potential zones, the productivity of the hydrostratigraphic units with their expected optimum borehole yield, proximity to beneficiaries and population density. With further discussion and consultation with stakeholders, two priority sites will be selected for further hydrogeological and geophysical investigations in phase III. The following are the four proposed sites:

Target Site-I:

This target site is located within the narrow area in central southeast part of the woreda. It is situated in the identified very high potential zones with expected optimum yield above 10 l/s. This target site is mainly underlain by quaternary recent deposits of alluvial and lacustrine sediments.

Target Site-II:

This target site is located at central northern part of the woreda. It is situated mainly in the identified high potential zones with expected optimum borehole discharge of about 5 l/s. This target site is mainly underlain by quaternary older deposits of alluvial sediments associated lineaments.

Target Site-III:

This target site is located in few areas in southeast of the woreda. It is situated mainly in the identified moderate potential zones with expected optimum borehole discharge of about >3 l/s. This target site is also covered by alluvial sediment associated with moderate lineaments density.

5.8.5. Conceptual hydrogeological model of Akobo Woreda

Hydrogeological conceptual models are collections of hypotheses based on geological structural and geomorphological evidence and existing wells lithologic logs to describe and understand the groundwater occurrence, localization, and movement beneath the ground surface. The purpose of the hydrogeological model across inferred groundwater flow direction is to reflect the prototype of regional groundwater flow system into the two priority sites selected for further study in phase III. In the conceptual model, groundwater head represents the regional groundwater table along with major geological section which marks most important aquifers and physical boundaries.

The conceptual hydrogeological models for this woreda to be constructed along/across groundwater flow path will be produced after stake holder consultation workshop to select priority target sites for further hydrogeological characterization. This conceptual hydrogeological model summarizes what is known about the hydrogeological system and thereby provides a framework for hydrogeological system of the target woreda at broad scale including the following.

- ✓ Major groundwater flow zone (inflow, groundwater flow paths, inferred depth, and outflow).
- ✓ Groundwater condition of target woreda area such as delineate inferred groundwater table from existing data (spring, river and boreholes).

5.9. Jor Woreda

The four thematic layers which were integrated for groundwater potential mapping in Jor Woreda are summarized in Table 5.24 below. The notes on the description of each thematic layers including classification of potential zones, validation with borehole and scheme datasets, population projection, water demand and selected target sites presented in the sub-sections.

Table 5-24. Assigned and normalized weights for the individual features of the four thematic layers for groundwater potential zoning in Jor Woreda

Theme	Class	Groundwater Prospect	Weight assigned	Normalized weight	Rank	Area (Km2)	Area (%)
Geology/ Lithology, 'GG'	Quaternary flood plain and alluvial fan deposits	Very good	4	0.6	0.40	2276.51	68
	Eluvial soil	Good	3	0.4		1038.58	32
Lineament Density,' LD' (Km/Km2)	0 - 0.15	Very poor	1	0.12	0.39	715.21	21.40
	0.15- 0.31	Poor	2	0.2		1282.49	38.37
	0.31– 0.47	Moderate	3	0.25		1076.29	32.20
	0.47– 0.63	good	4	0.43		268.27	8.03
Topographic Wetness Index, 'TWI'	7.20-10.30	poor	1	0.12	0.15	1846.77	55.3
	10.30 – 12.58	Moderate	2	0.2		959.17	28.7
	12.58 – 16.09	Good	3	0.28		425.15	12.7
	16.09 – 24.78	Very good	4	0.40		111.25	3.3
Recharge, 'GR' (mm/y)	150 – 185	poor	1	0.11	0.06	718.03	21.7
	186 – 217	Moderate	2	0.15		916.45	27.6
	218 – 238	Good	3	0.29		1022.08	30.8
	239 – 296	Very good	4	0.45		658.65	19.9

5.9.1. Integration of Thematic Layers for Groundwater Potential Zoning

The details of geology/lithology, recharge, lineament density and topographic wetness index together with their spatial distribution in Jor woreda are presented below:

I. Geology/lithology

In general, most parts of Jor woreda are covered largely by eluvial deposits and few Quaternary flood plain alluvial sediments and Tertiary volcanics. The eluvial sediments cover wider areas in central part whereas the alluvial deposit and volcanic units are being mostly found in south corridor and northwest margin.

These two lithological units have been considered in classification with weighted assigned to each of them based on their significances to groundwater. As there is no hydrogeological data (borehole, springs) that can quantitatively support the ranking in assigning the weightage to lithological factors, the ranking and weightage has been based on experts' judgment. In this way, the Quaternary alluvial deposits and Tertiary volcanics which cover the south and few areas in northwest areas is given high rank whereas the eluvial deposits covering large areas and have silty-clay composition is assigned low rank in assigning weightages to these lithologic units. Grouped lithologic units and their weightage is shown in Figure 5.67 and 5.68, respectively.

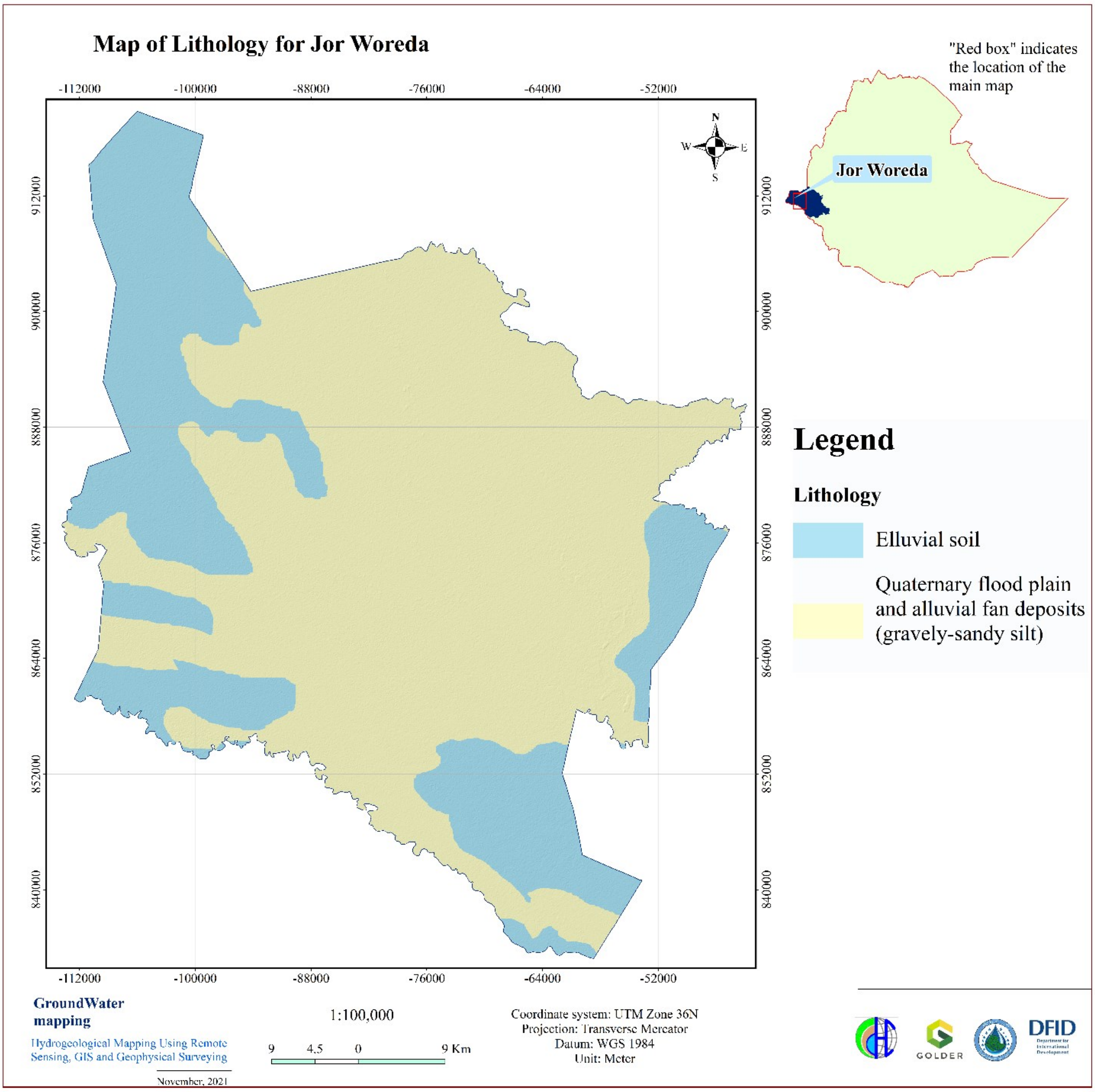

Figure 5.67: Map of lithology class Jor Woreda

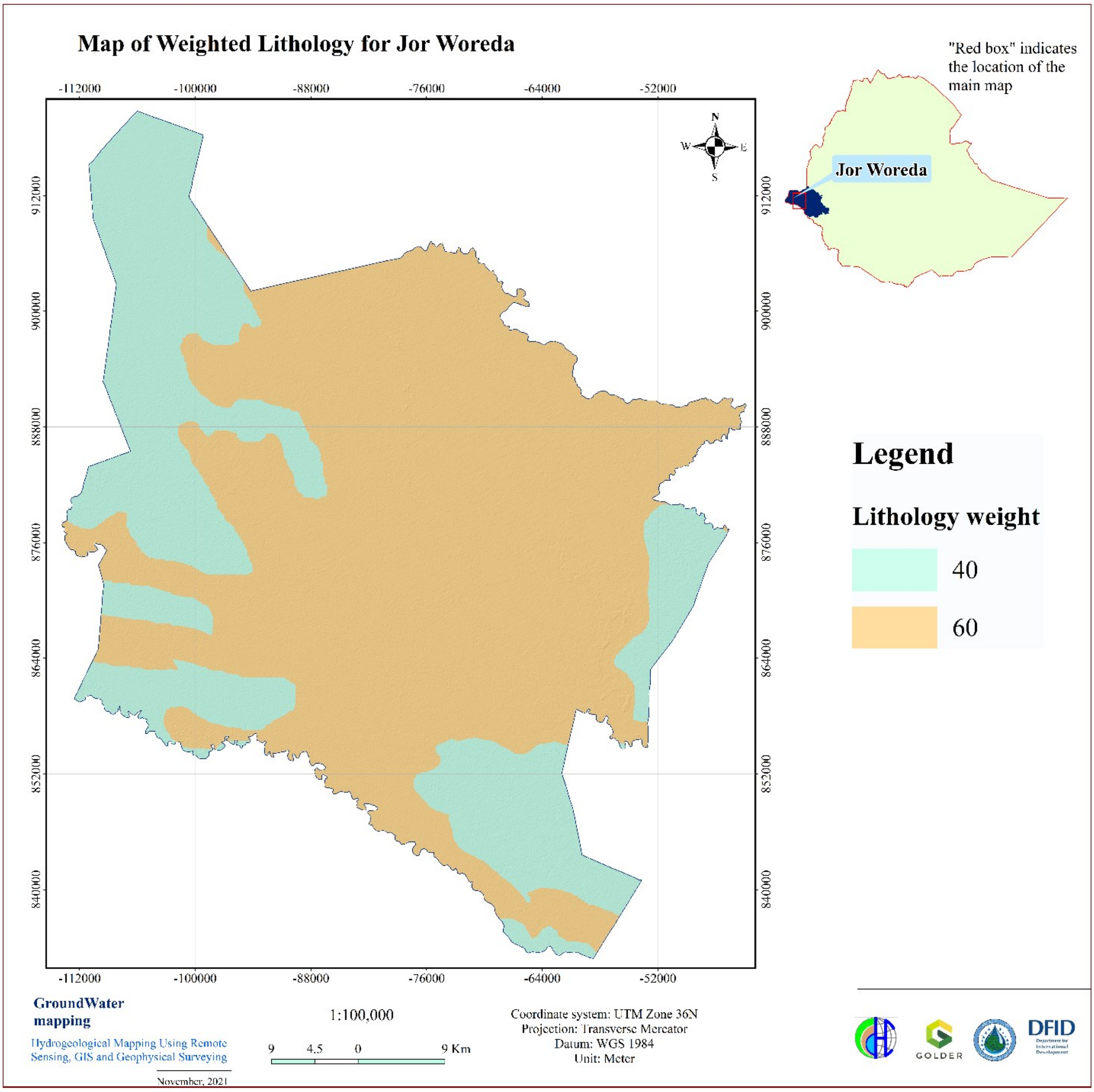

Figure 5.68: Map of weighted lithology class Jor Woreda

II. Lineaments and lineament density

Lineaments are manifestation of linear features that can be identified directly on the rock units or from remote sensing data. Lineaments and their intersections play a significant role in the occurrence and movement of groundwater. The presence of lineaments may act as a conduit for groundwater movement which results in increased secondary porosity and, therefore, can serve as groundwater potential zone (Rao, 2006; Prasad et al., 2008). Accordingly, detailed lineament of the study area was extracted from a mosaicked Sentinel-2 selected from the year 2020 to 2021 series combined with geomorphology of the area and mapped using ArcGIS 10.8 software, and subsequently lineament density map was computed in using GIS algorithm and expressed in terms of length of the lineament per unit area (km/Km2).

Some bedding-like structures are developed in central part of the area, which are a primary structure noted in elluvial deposits. These structures are produced based on the horizontal depositions of the layer by sedimentation compactions of transgressed materials (GSE, 2018).

The lineament density varies from less than 0.11 km/Km2 to 0.64 km/Km2 with the central north, central east, south and central west has relatively high lineament density (Figure 5.69 and 5.70). Though the lineaments are widespread across the study area, however, the distribution of lineaments suggests geologic control with areas covered by Quaternary sediment central area have higher lineament density above 0.35 km/Km2) which is good for groundwater development. Consequently, higher weightage of 0.43 was assigned to area with high density of lineaments, while a low weightage of 0.12 was assigned to areas with low lineament density (Figure 5.70).

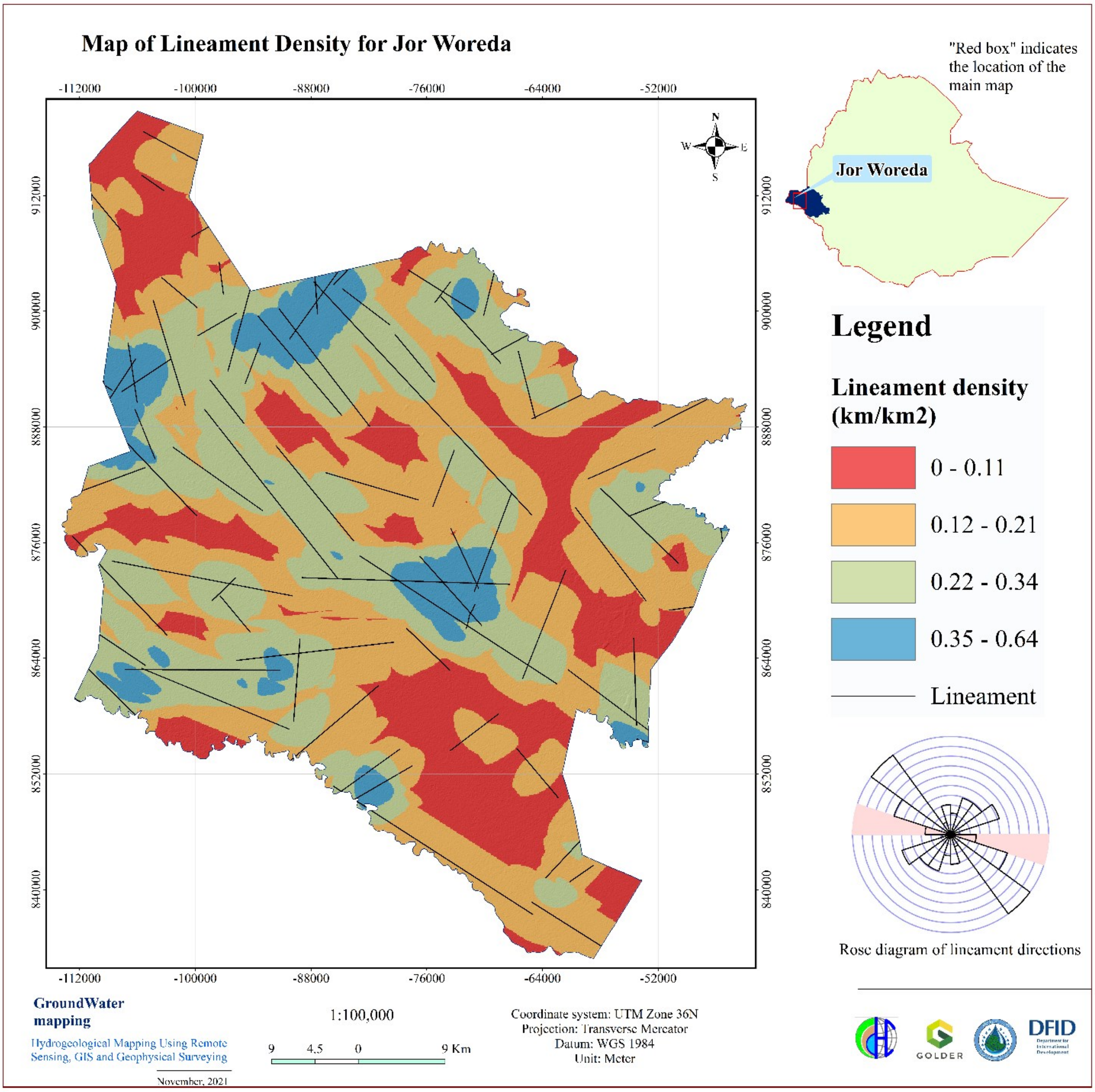

Figure 5.69: Map of lineament density Jor Woreda

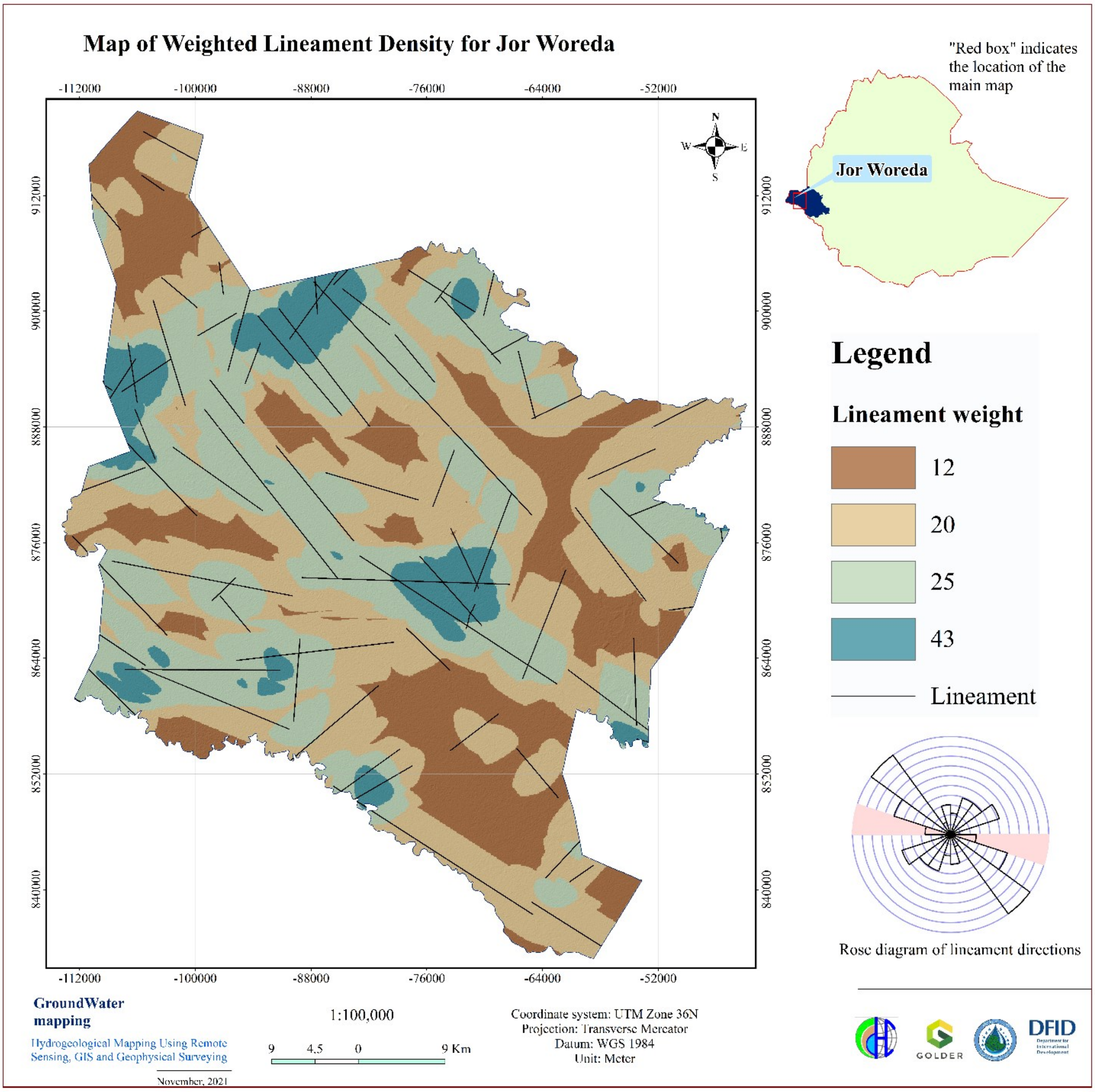

Figure 5.70: Map of weighted lineament density Jor Woreda

III. Topographic Wetness Index (TWI)

In this study area, the TWI value ranges between 7.21 and 24.8 (Figure 5.71). A closer look at the classification revealed that areas with high TWI value is confined within the river plain with flat slopes whereas large part of the woreda away from river plain has low TWI value suggesting the significance of river plain deposits in accumulating voluminous groundwater (Figure 5.72). Therefore, an area with higher value of TWI has good prospect for groundwater occurrence and flow, and accordingly high weightage value (0.40) was assigned to this class. Whereas areas with lowest TWI value are gentle slopes which triggers runoff were considered with low groundwater prospect and given low weightage value (0.12).

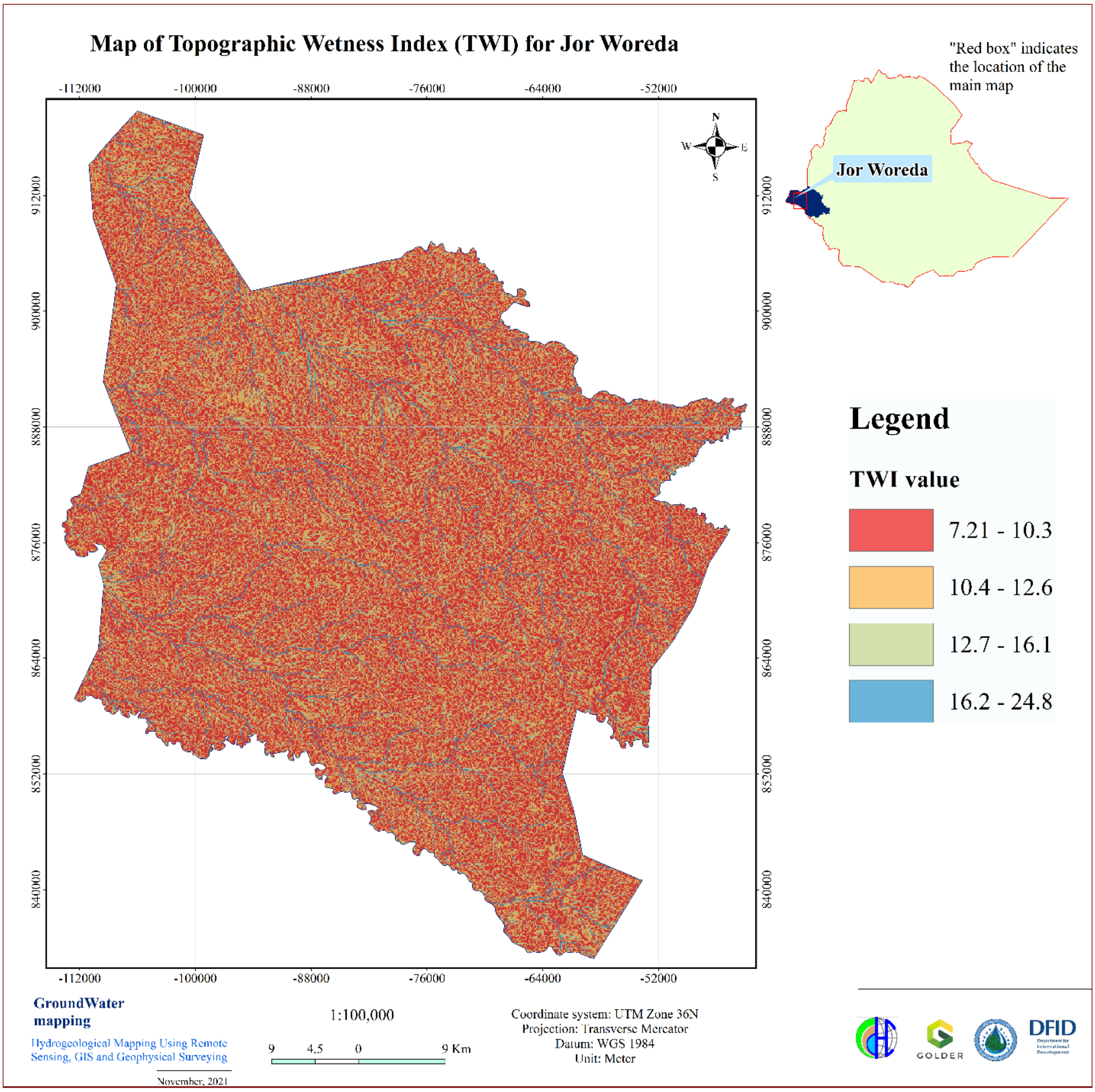

Figure 5.71: Map of topographic wetness index (TWI) for Jor Woreda

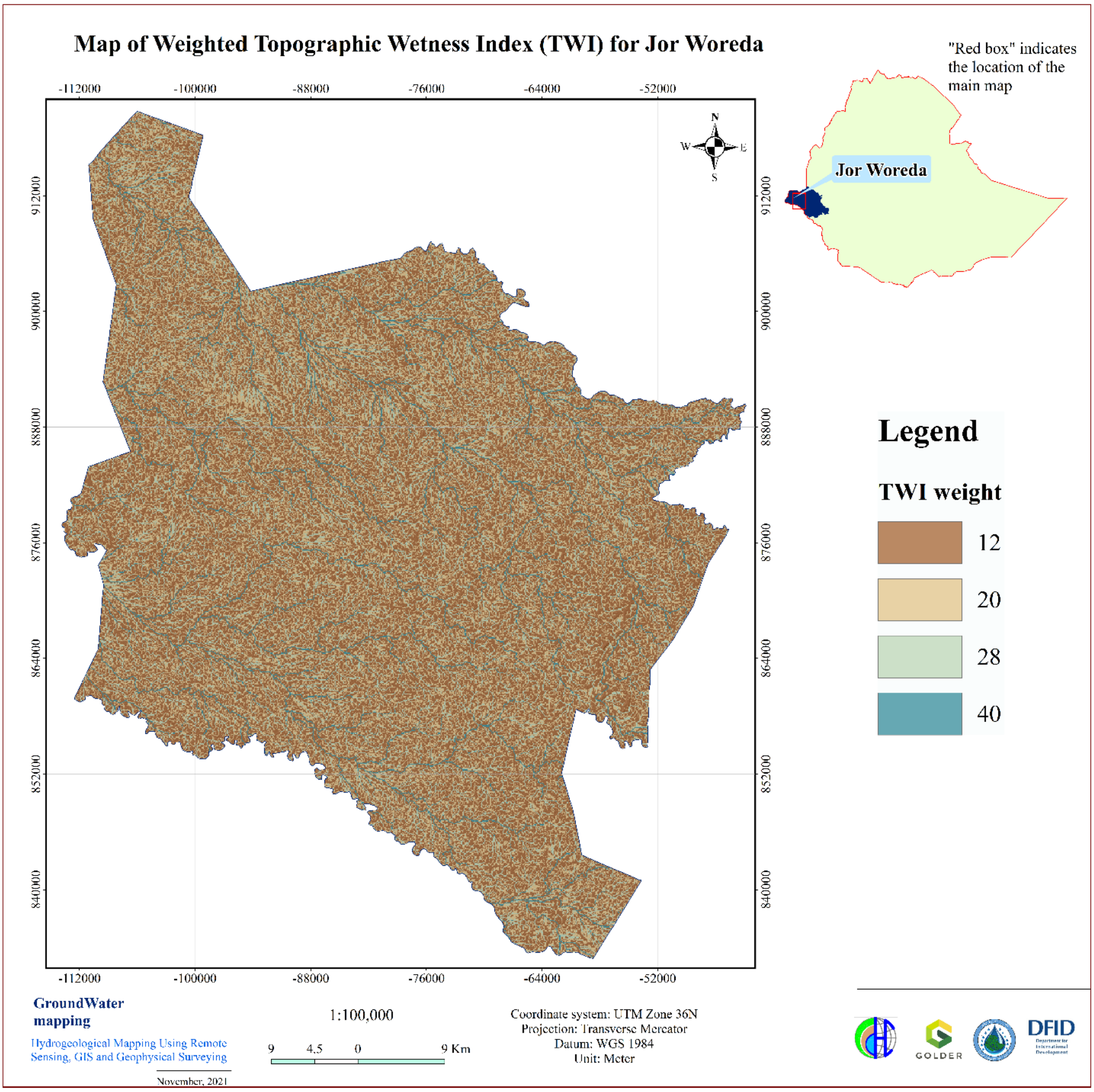

Figure 5.72: Map of weighted topographic wetness index (TWI) for Jor Woreda

IV. Recharge

The 10 years average recharge rate distribution in the Jor woreda ranges from 150 to 296 mm suggesting groundwaters receives high amount of recharge (Figure 5.73). In this overlay analysis, areas with higher and moderate amount of recharge have weightage factor of 0.45 and 0.29, high and moderate groundwater potential signifying which covers about 658 Km2 (19.9 %) and 1022.08 Km2 (38.8 %), respectively while areas with the lowest amount of recharge have weightage factor of 0.11, suggesting poor groundwater potentiality and represent about 718 Km2 (21.7 %). A closer look at the recharge thematic map revealed that recharge is linked with lithology whereby the alluvial deposits and tertiary volcanics in south and west have relatively high recharge compared to the eluvial sediments which covers the wider areas in central part (Figure 5.73).

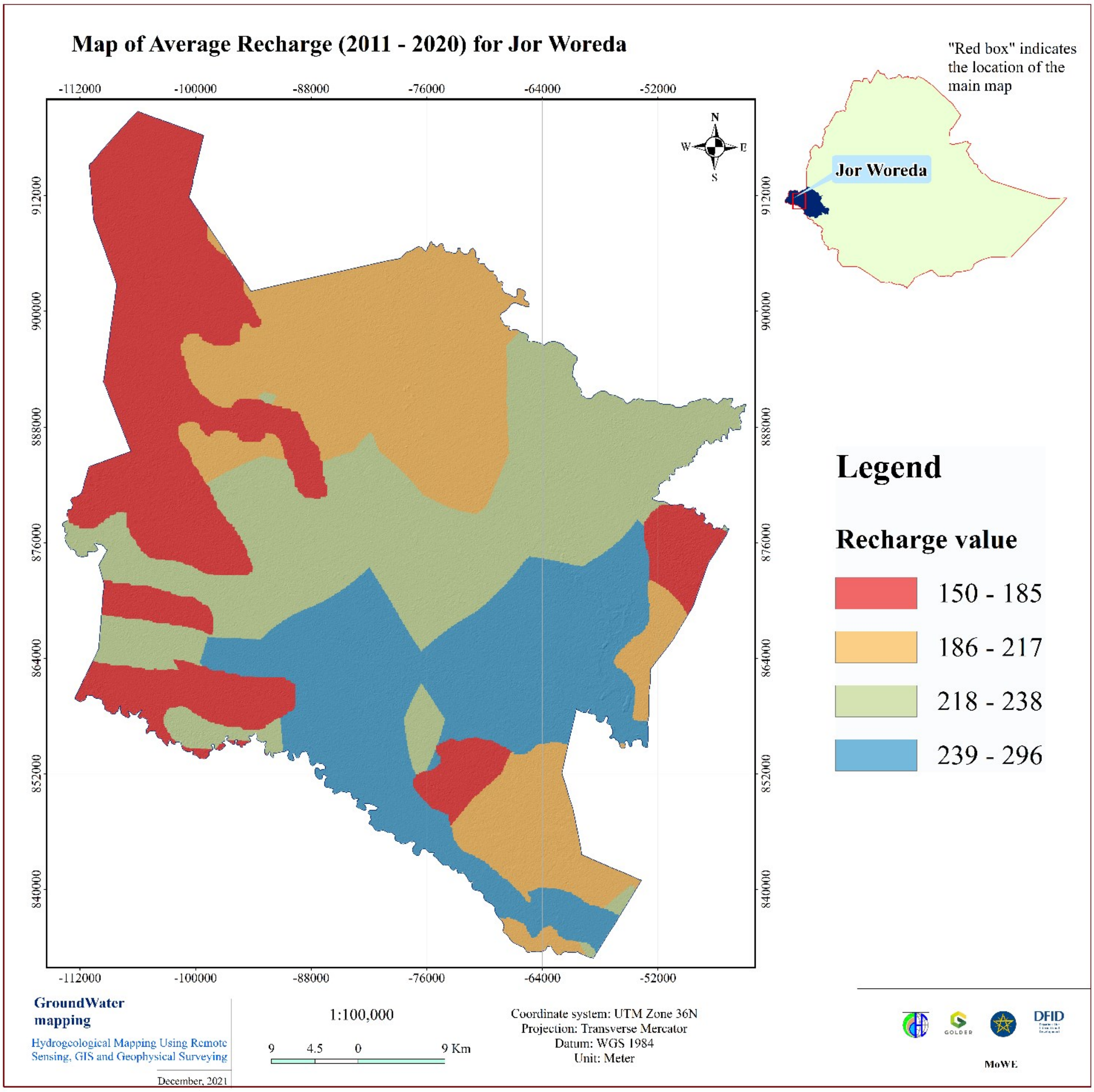

Figure 5.73:- Map of average recharge (2011 – 2020) for Jor Woreda

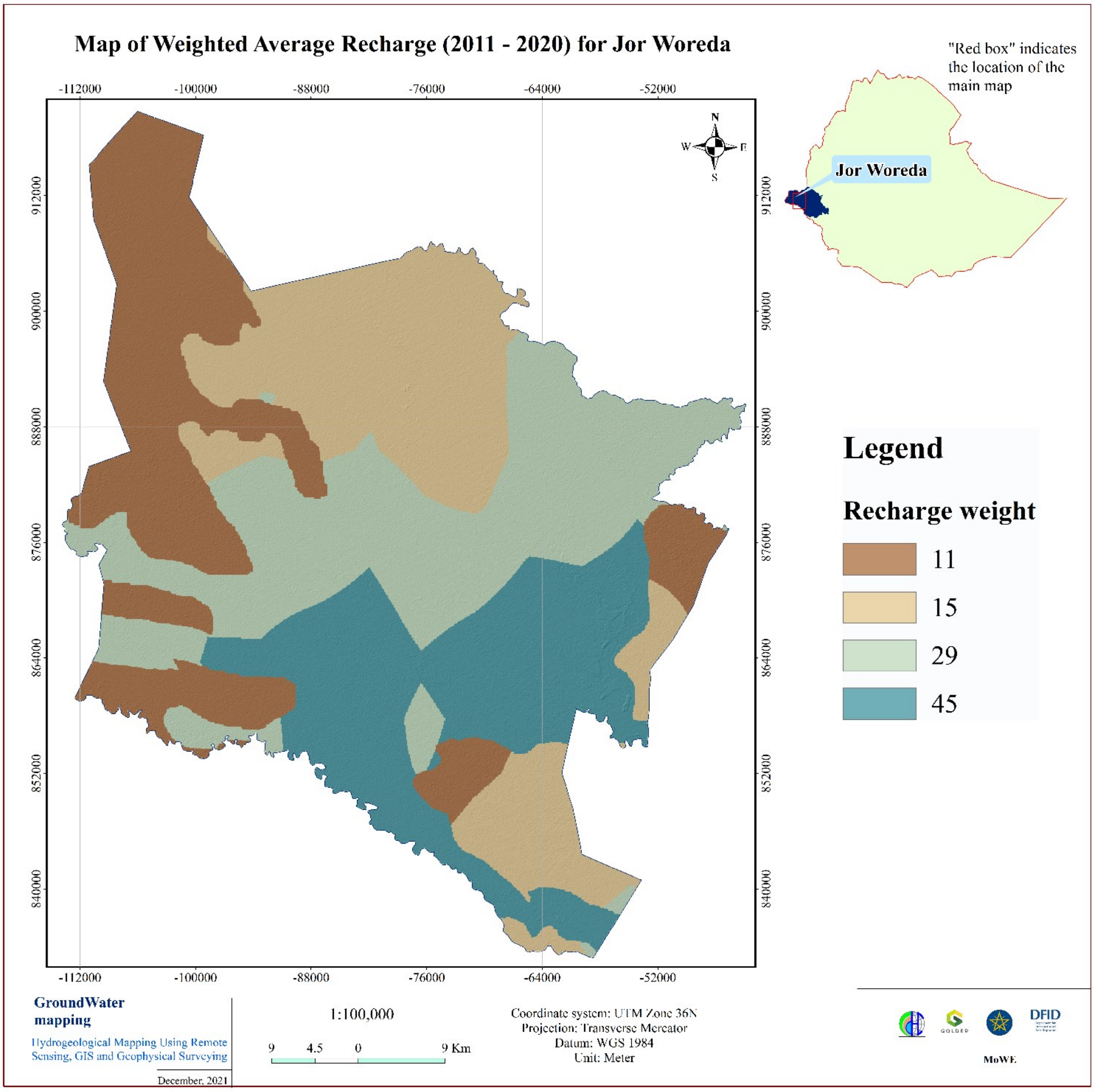

Figure 5.74:- Weighted map of average recharge (2011 – 2020) for Jor Woreda

5.9.2. Classification of Groundwater Potential Zones

Based on the assignment and normalized weighting of the individual features of the thematic layers, a potential groundwater index map was produced (Figure 5.75). The potential groundwater zones (PGZ) northeast and central of the woreda representing about 32 % of total area is classified as low groundwater potential zone with groundwater yield less 3 l/s, and north, northcentral, northwest and few areas in south central and east is classified as high to very high groundwater potential with yield 5-10 l/s (Figure 5.75) The potential map, as presented in Figure 5.75, gives a quick assessment of the occurrence of groundwater resources in the study area. The groundwater potential map revealed that high groundwater potential zone is directly related to areas covered by alluvial sediments associated with high lineament density. Region demarcated as low groundwater potential zone is elluvial soils which could be due to low recharge by clay or silty materials of this sediment which hinders local vertical recharge.

In general, a closer assessment of the groundwater potential map revealed that the distribution high groundwater potential zone is closely related to recharge and lithology whereas topographic wetness index has relatively low impact on occurrence and distribution of groundwater in the woreda as the woreda has low elevation contrast (404-444m asl.) Summary of the groundwater potential zones identified in the Jor woreda is presented in the table below (Table 5.25).

Table 5-25:-Classification of groundwater potential zones and coverage areas alongside the respective yield categories in Jor Woreda

GWP Zones	Area (Km2)	Area (%)	Major Aquifer Units	Borehole Yield Classification (l/s)
Very High	2276.51	68	Quaternary flood plain and alluvial sediments	>10
High	1038.58	32	Eluvial sediments	5-10
Moderate				3-5
Low				<3

5.9.3. Validation with Borehole Yield Data

There are no boreholes (drilled wells and springs) data in the woreda that can be used as validation. However, for boreholes closer to the surrounding woreda was used and the Akobo-Alwero River which floods the adjacent alluvial plain during summer season and contribute voluminous of recharge via this sediment can be considered as ground-truth in validating the certainty or reliability of groundwater potential map produced by this overlay method. The alluvial aquifer of river extends in the northern and southern parts of the study area, the aquifer is interconnected with the river water and the water table is shallower from the borehole data collected in cluster outside the woreda.

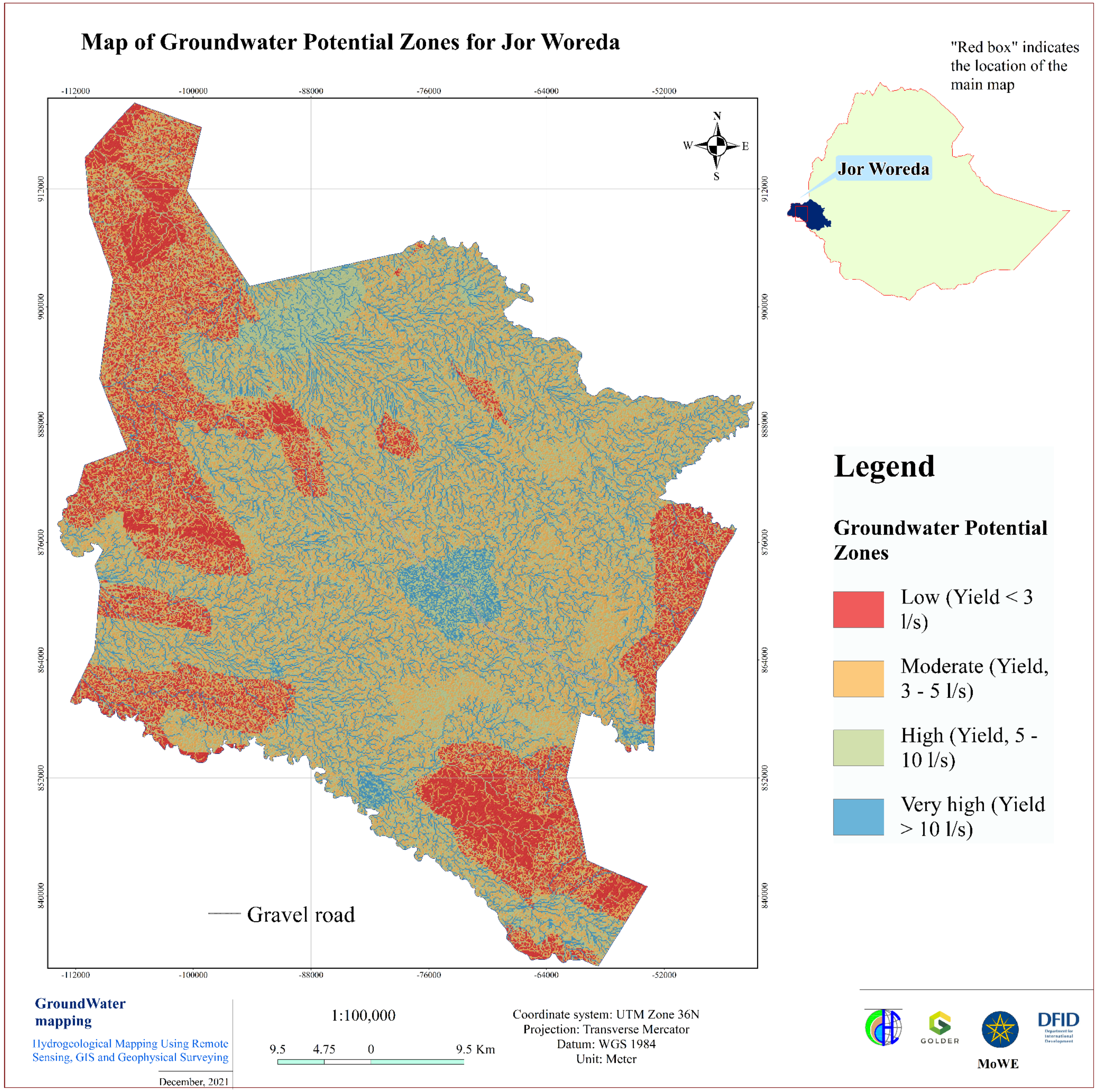

Figure 5.75: Map of groundwater potential zones showing four zones identified by the GIS overlay analysis in Jor Woreda

5.9.4. Population projection and water demand

5.9.4.1. Population

It is essential that the water supply system is designed to meet the requirements of the population expected to be living in the community at the end of design period by taking into account the design period and annual growth rate. Hence in order to avoid or minimize the aforementioned population related risks, efforts are made to review & justify the credibility of the available population data and growth rate figures.

Population projection is made making use of the geometric growth rate method by using the base population figure estimated by the central statistical Authority. The CSA has set average growth rates for urban and rural areas of the country varying at different times during the design period as shown in the table below. Accordingly, these values are adopted in forecasting future population of the town.

Table 5-26 CSA Rural Population Growth Rates

Rural Population Projection Growth Rate of Regions: 2008-2037						
YEAR / Growth Rate % (Rural)	2008-2012	2013-2017	2018-2022	2023-2027	2028-2032	2033-2037
Oromia Region	2.74	2.54	2.29	2.03	1.8	1.56
SNNP Region	2.49	2.37	2.31	2.03	1.82	1.57
Somali Region	2.75	2.63	2.35	2.05	1.89	1.83
Gambela Region	3.52	3.1	3.13	2.76	2.46	2.31

Source: CSA Population Projection for Ethiopia 2007-2037, Addis Ababa July 2013

Geometric method forecasting formula

$$P=Po\,(1 + r)^{n}$$

Where P – projected population
Po – current population
n – Number of years for projection
r – Population growth rate

The population of Jor Woreda has been projected forward until 2036 using the projected scale of Gambella Regional State. The minimum and maximum population in the Woreda is 767 and 3,236 respectively. The total population of the Jor Woreda in 2036 is going to be 20,302. Figure 5.76 presents the projected population for each kebele in the Woreda.

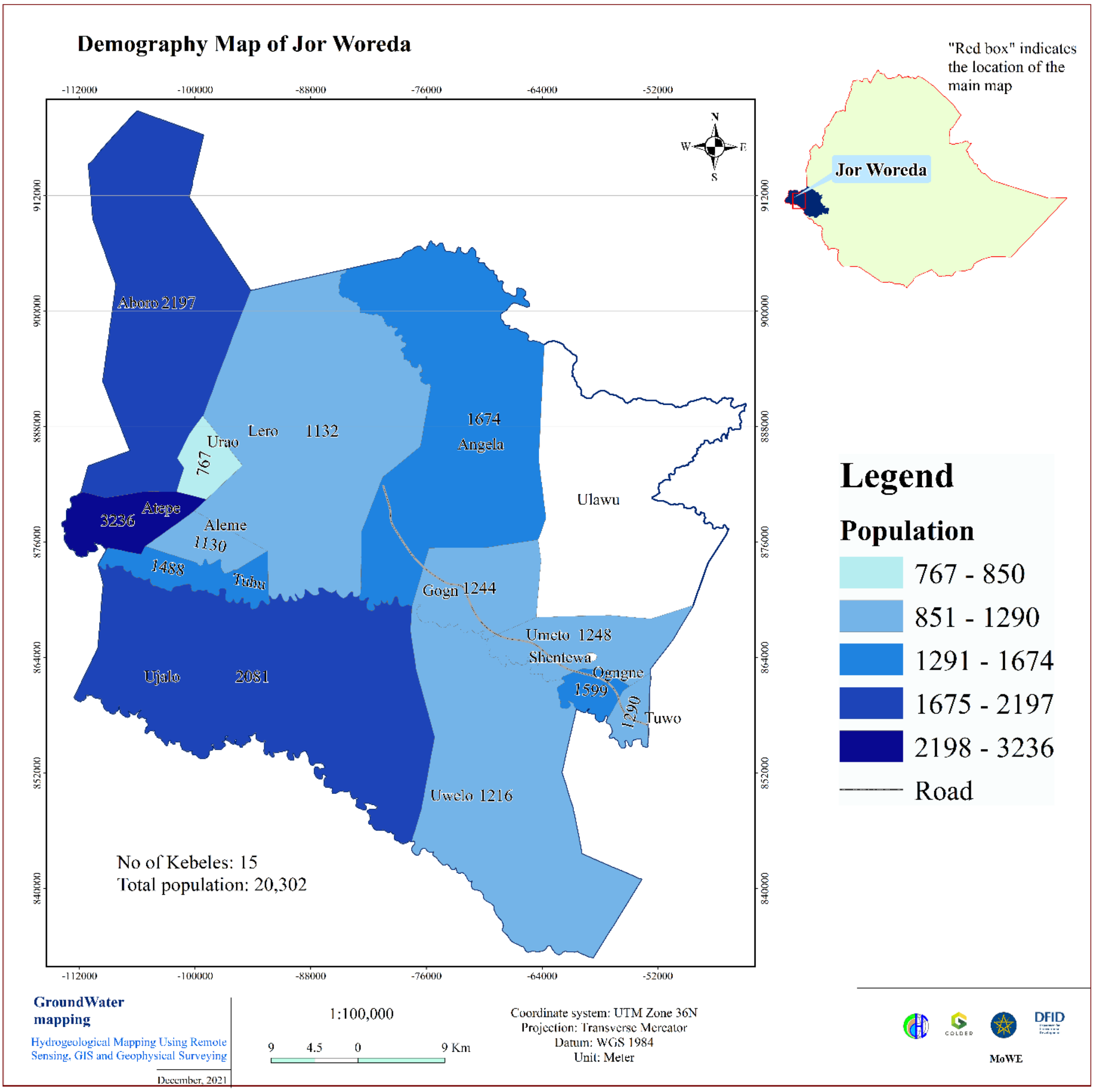

Figure 5.76: Map of projected population (2036) for Jor Woreda.

5.9.4.2. Water Demand Projection

Projected Water Demand

Estimating water demands mainly depends on the size of the population to be served, their standard of living and activities. To make the demand projection reliable and suitable for rural areas it is better to classify in details as domestic and non-domestic demands.

Domestic Water Demand

Domestic water demand is the amount of water needed for drinking, food preparation, washing, cleaning, bathing and other miscellaneous domestic purposes. The amount of water used for domestic purposes greatly depends on the lifestyle, living standard, and climate, mode of service and affordability of the users.

Domestic water demand service can be categorized according to the level of service to be provided and amount of per capita water required satisfying the demand served by the level of service. Modes of services used for our projection are classified into four categories, namely: -

- Traditional Source users (TSU)
- Public tap users (PTU)
- Yard connections and Neighbourhood (shared) connections (YCO) & (YCS)
- House tap connections (HTU)

In projecting the domestic water demand, the following procedures were followed:

- Determining population percentage distribution by mode of service and its future projection
- Establishment of per capita water demand by purpose for each mode of service;
- Projected consumption by mode of service;
- Adjustment for climate;
- Adjustment due to socio-economic conditions.

After considering the necessary mode of services, per-capita demand and applying the adjustment factors the domestic demand for the corresponding year and population has been calculated.

Non-Domestic Water Demand

Non-domestic water demand was also determined systematically. We have classified it into three major categories based on our projection:

- Institutional water demands (Public and governmental);
- Commercial water demand;
- Livestock water demand

N.B: - The use of a reliable base population figure is very important for optimizing the water sources but adopting 2007 CSA data as a base population has real impact on the projection so to compensate some unforeseen situation like migration and unplanned rural town growth. To compensate for such

- To estimate the demand of public institutions and commercial services we have adopted 15% - 20% of the domestic demand for our consumption.
- The demand for livestock watering adopted in the projection is 10% -15% of the domestic demand.

Total Average daily day demand

The average daily day demand is taken to be the sum of domestic demands and non-domestic demand. The water demand in a day varies with time according to the consumer's life style. It is the total sum of adjusted domestic, public and livestock demand.

Maximum Day Demand

The maximum day demand is the highest demand of any one 24-hour period over any specific year. It represents the change in demand with season. This demand is used to design source capacity. The deviation of consumption from the average day demand is taken care of as per the maximum daily coefficient figures. Usually a value from1.1 to 1.3 is adopted as maximum day factor. A constant value of 1.3 is adopted as maximum day factor for all of the villages.

Figure 5.77 shows the distribution of water demand in each Kebeles of the Woreda. The minimum and maximum water demand for Kebeles is 89 M^3/day and 291 M^3/day respectively. The overall water demand for the projected population in the Jor Woreda is 1,824 M^3/day.

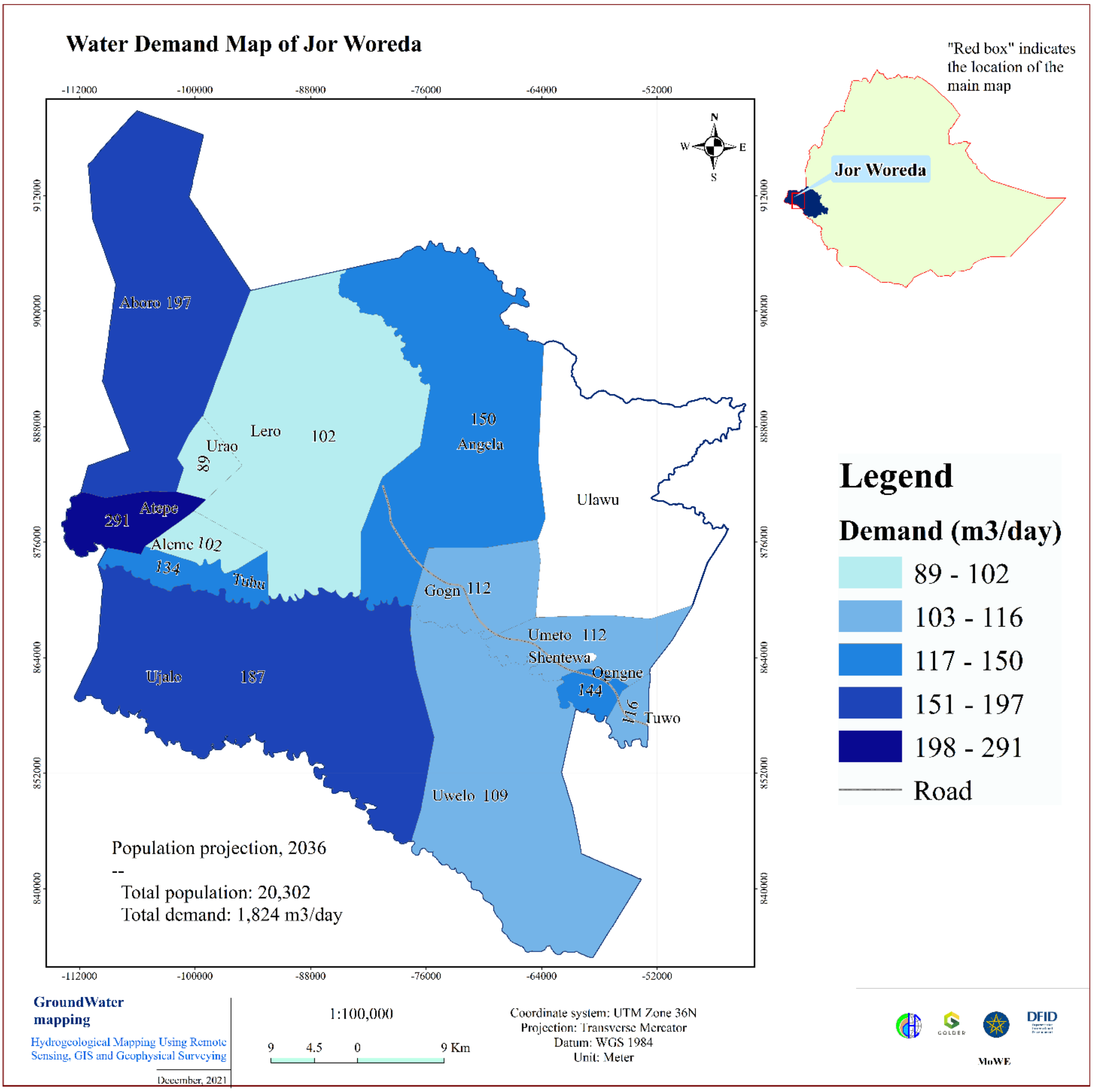

Figure 5.77: Map of water demand (M^3/day) for Amaro Woreda.

5.9.5. Proposed Target Sites

Proposed target sites are identified, prioritized, and selected within the woreda based on the identified groundwater potential zones, the productivity of the hydro-stratigraphic units with their expected optimum borehole yield, proximity to beneficiaries, population density and discussion made with the woreda's stakeholders so that to understand and identify kebeles with sever water shortage in particular. Accordingly, two priority target sites were selected and delineated within the Jor woreda for detail studies to be carried out to verify further and locate appropriate borehole drilling sites.

Target Site-I:

This target site is in the southern part of the woreda in, Tuwo, ongogne, Gog, Ulawu, Tuhu, Ujalo, Awelo and Atebe are include within this potential zones. It is situated in the identified very high potential zones with expected optimum borehole discharge of about >10 l/s. This target site is mainly overlain by quaternary recent deposits of alluvial and eluvial soils.

Target Site-II:

This target site is located at eastern part of the woreda. It is situated mainly in the identified high potential zones with expected optimum borehole discharge of about 5 to 10 l/s. the area is closer to Alwero perineal river.

Target Site-III:

This target site is located t northwestern part of the woreda. It is situated mainly in the identified moderate potential zones with expected optimum borehole discharge of about (3-5 l/s).

Target Site-IV:

This target site is located at northwestern in Wanke kebele. It is situated mainly in the identified low potential zones with expected optimum borehole discharge <3 l/s. This target site is mainly underlain by volcanic/ basement granitic rocks.

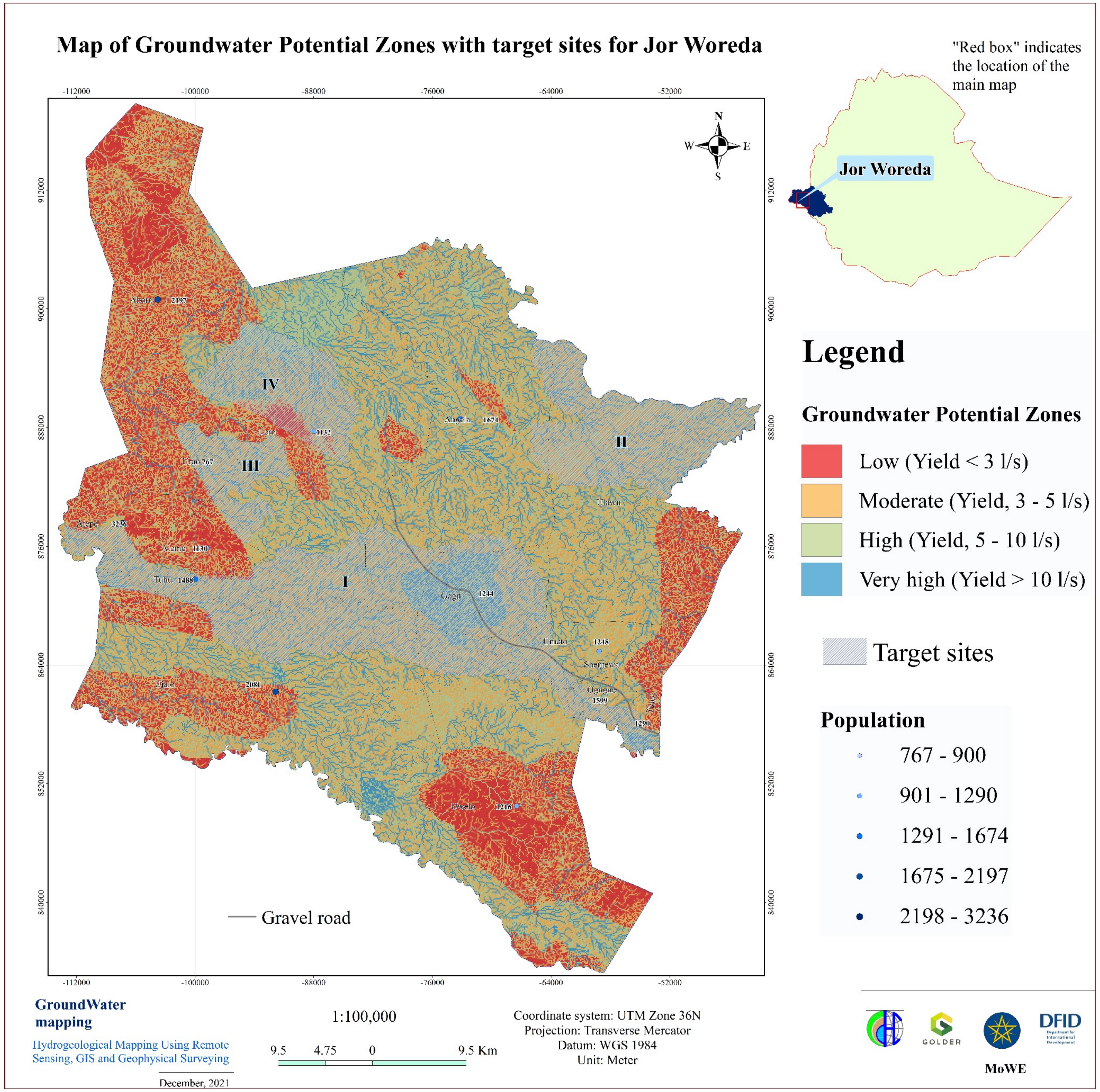

Figure 5.78: Map of groundwater potential zones with selected target sites in Jor Woreda

5.9.6. Conceptual hydrogeological model of Jor Woreda

Hydrogeological conceptual models are collections of hypotheses based on geological structural and geomorphological evidence and existing wells lithologic logs to describe and understand the groundwater occurrence, localization, and movement beneath the ground surface. The purpose of the hydrogeological model across inferred groundwater flow direction is to reflect the prototype of regional groundwater flow system into the two priority sites selected for further study in phase III. In the conceptual model, groundwater head represents the regional groundwater table along with major geological section which marks most important aquifers and physical boundaries. Itang woreda is characterized with lowlands formed mainly from post tectonic intrusive granite outside the woreda boundary. Quaternary sediments overlying the Volcanic and crystalline basement rocks are important for groundwater storage in the area.

This region has a compartmentalized groundwater flow system constrained by geology, geological structures and topography. Groundwater gets recharge mainly from local rain that falls on central and a northeast surrounding highland with expected lateral inflow from northwest adjacent highlands. Groundwater flow direction is generally towards northwest and central lowlands through alluvial plain and weathered crystalline basement rocks. Development of the hydrogeological conceptual model of the target Woreda area has been prepared based on the converging evidence of secondary data including digital elevation model (DEM), geological and hydrogeological maps and structures, lithological well logs

The conceptual hydrogeological models for this woreda to be constructed along/across groundwater flow path will be produced after stake holder consultation workshop to select priority target sites for further hydrogeological characterization. This conceptual hydrogeological model summarizes what is known about the hydrogeological system and thereby provides a framework for hydrogeological system of the target woreda at broad scale including the following.

- ✓ Major groundwater flow zone (inflow, groundwater flow paths, inferred depth, and outflow).
- ✓ Groundwater condition of target woreda area such as delineate inferred groundwater table from existing data (spring, river, and boreholes).

5.10. Itang Woreda

The four thematic layers which were integrated for groundwater potential mapping in Itang Woreda are summarized in Table 5.27 below. The notes on the description of each thematic layers including classification of potential zones, validation with borehole and scheme datasets, population projection, water demand and selected target sites presented in the sub-sections.

Table 5-27. Assigned and normalized weights for the individual features of the four thematic layers for groundwater potential zoning in Jor Woreda

Theme	Class	Groundwater Prospect	Weight assigned	Normalized weight	Rank	Area (Km2)	Area (%)
Geology/ Lithology, 'GG'	Quaternary flood plain and alluvial fan deposits	Very good	4	0.6	0.40	649.3	30
	Eluvial soil	Good	3	0.4		1577.8	70
Lineament Density,' LD' (Km/Km2)	0 - 0.18	Very poor	1	0.11	0.39	580.86	26.5
	0.18- 0.33	Poor	2	0.19		638.95	29.2
	0.33– 0.48	Moderate	3	0.27		593.5	27.1
	0.48– 0.82	good	4	0.43		377.25	17.2
Topographic Wetness Index, 'TWI'	5.05-9.66	poor	1	0.12	0.15	1167.47	53
	9.66 – 11.86	Moderate	2	0.2		649.91	30
	11.86 – 15.44	Good	3	0.28		286.87	13
	15.44 – 23.71	Very good	4	0.40		86.28	0.4
Recharge, 'GR' (mm/y)	150 – 173	poor	1	0.11	0.06	1013.55	46.6
	174 – 195	Moderate	2	0.15		785.66	36.1
	196 – 225	Good	3	0.29		202.67	9.3
	226 – 260	Very good	4	0.40		173.91	8.0

5.10.1. Integration of Thematic Layers for Groundwater Potential Zoning

The details of geology/lithology, recharge, lineament density and topographic wetness index together with their spatial distribution in Itang woreda are presented below:

I. Geology/lithology

In general, most parts of Itang woreda are covered largely by eluvial deposits and Quaternary flood plain alluvial sediments and Tertiary volcanics. The eluvial sediments covers wider areas in central part whereas the alluvial deposit and volcanic units are mostly found in south corridor and northwest margin. These two lithological units have been considered in classification with weighted assigned to each of them based on their significances to groundwater. As there is no hydrogeological data (borehole, springs) that can quantitatively support the ranking in assigning the weightage to lithological factors, the ranking and weightage has been based on experts' judgment. In this way, the Quaternary alluvial deposits and Tertiary volcanics which cover the south and few areas in northwest areas is given high rank whereas the eluvial deposits covering large areas and have silty-clay composition is assigned low rank in assigning weightages to these lithologic units. Grouped lithologic units and their weightage is shown in Figure 5.79 and 5.80, respectively.

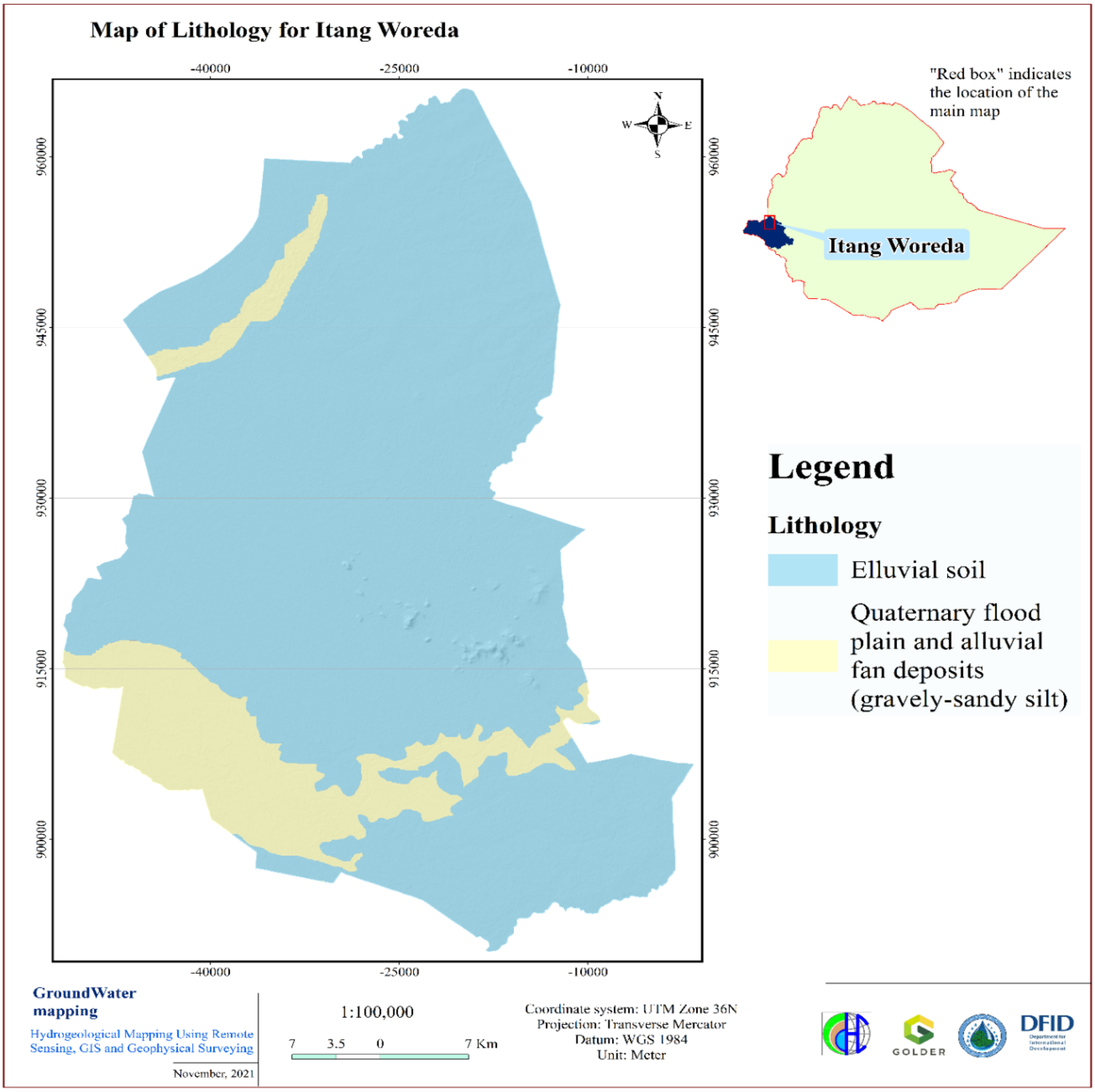

Figure 5.79: Map of lithology class for Itang Woreda

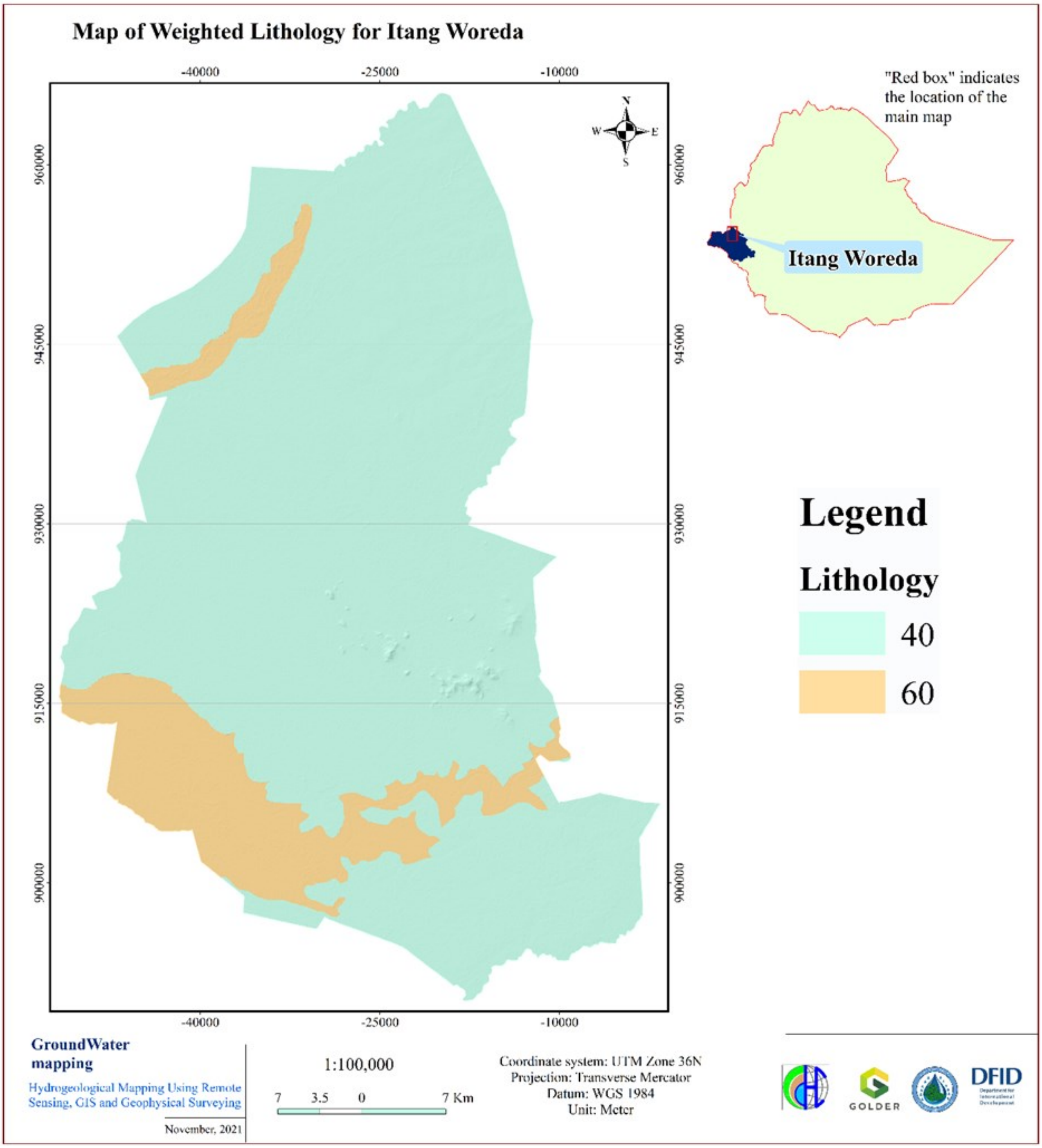

Figure 5.80: Map of weighted lithology class for Itang Woreda

II. Lineaments and lineament density

Lineaments are manifestation of linear features that can be identified directly on the rock units or from remote sensing data. Lineaments and their intersections play a significant role in the occurrence and movement of groundwater. The presence of lineaments may act as a conduit for groundwater movement which results in increased secondary porosity and, therefore, can serve as groundwater potential zone (Rao, 2006; Prasad et al., 2008). Accordingly, detailed lineaments of the study area were extracted from a mosaicked Cloud Free Images Sentinel-2 selected from the year 2020 to 2021 series combined with geomorphology of the area and mapped using ArcGIS 10.8 software, and subsequently lineament density map was computed in using GIS algorithm and expressed in terms of length of the lineament per unit area (km/Km2).

Some bedding-like structures are developed in central part of the area, which are a primary structure noted in elluvial deposits. These structures are produced based on the horizontal depositions of the layer by sedimentation compactions of transgressed materials (GSE, 2018).

The lineament density varies from less than 0.18 km/Km2 to 0.82 km/Km2 with the central north, central east, south and central west has relatively high lineament density (Figure 5.81 and 5.82). Though the lineaments are widespread across the study area, however, the distribution of lineaments suggests geologic control with areas covered by Quaternary sediment central area have higher lineament density above 0.33 km/Km2) which is good for groundwater development. Consequently, higher weightage of 0.43 was assigned to area with high density of lineaments, while a low weightage of 0.11 was assigned to areas with low lineament density (Figure 5.82).

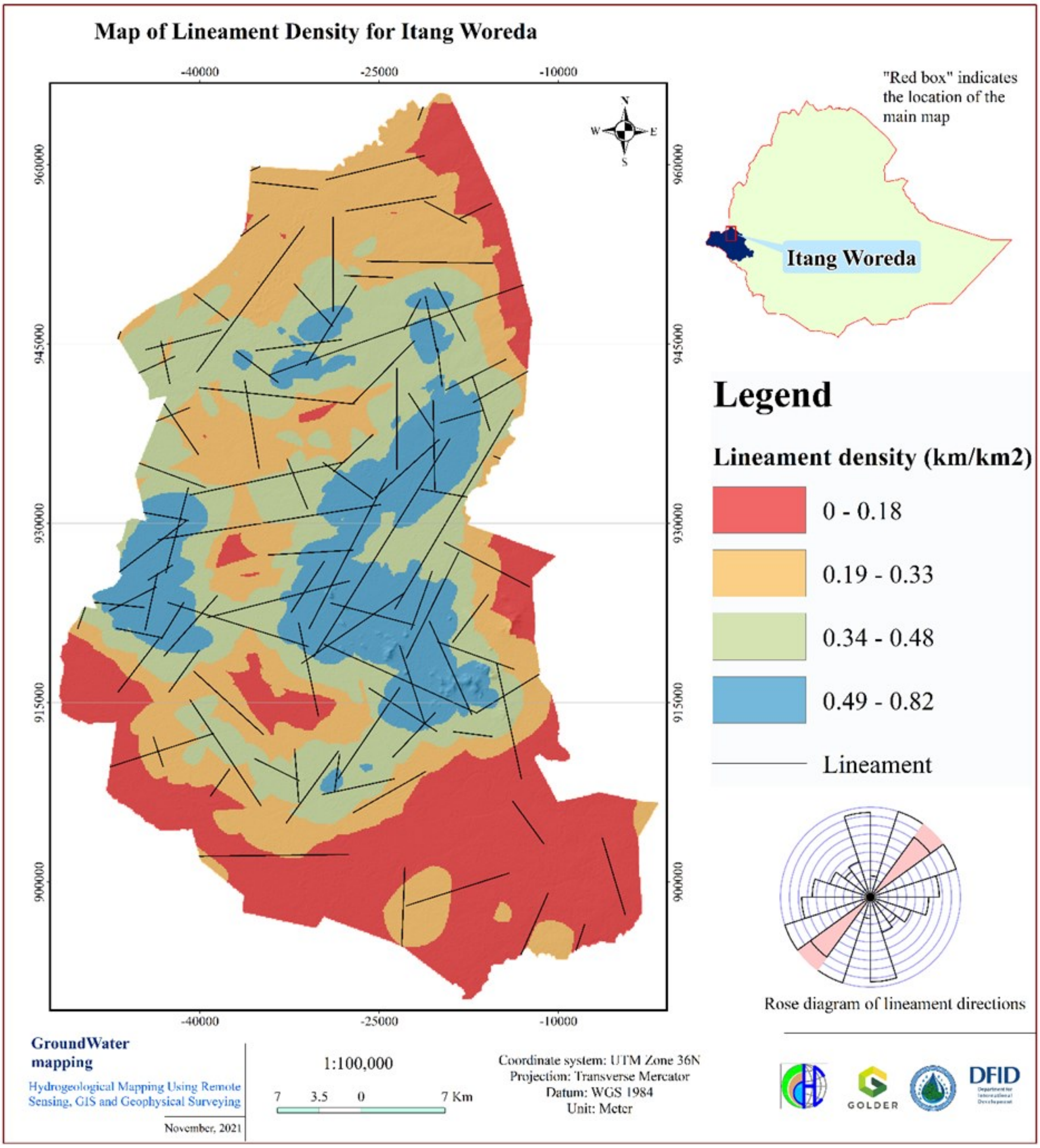

Figure 5.81: Map of lineament density for Itang Woreda

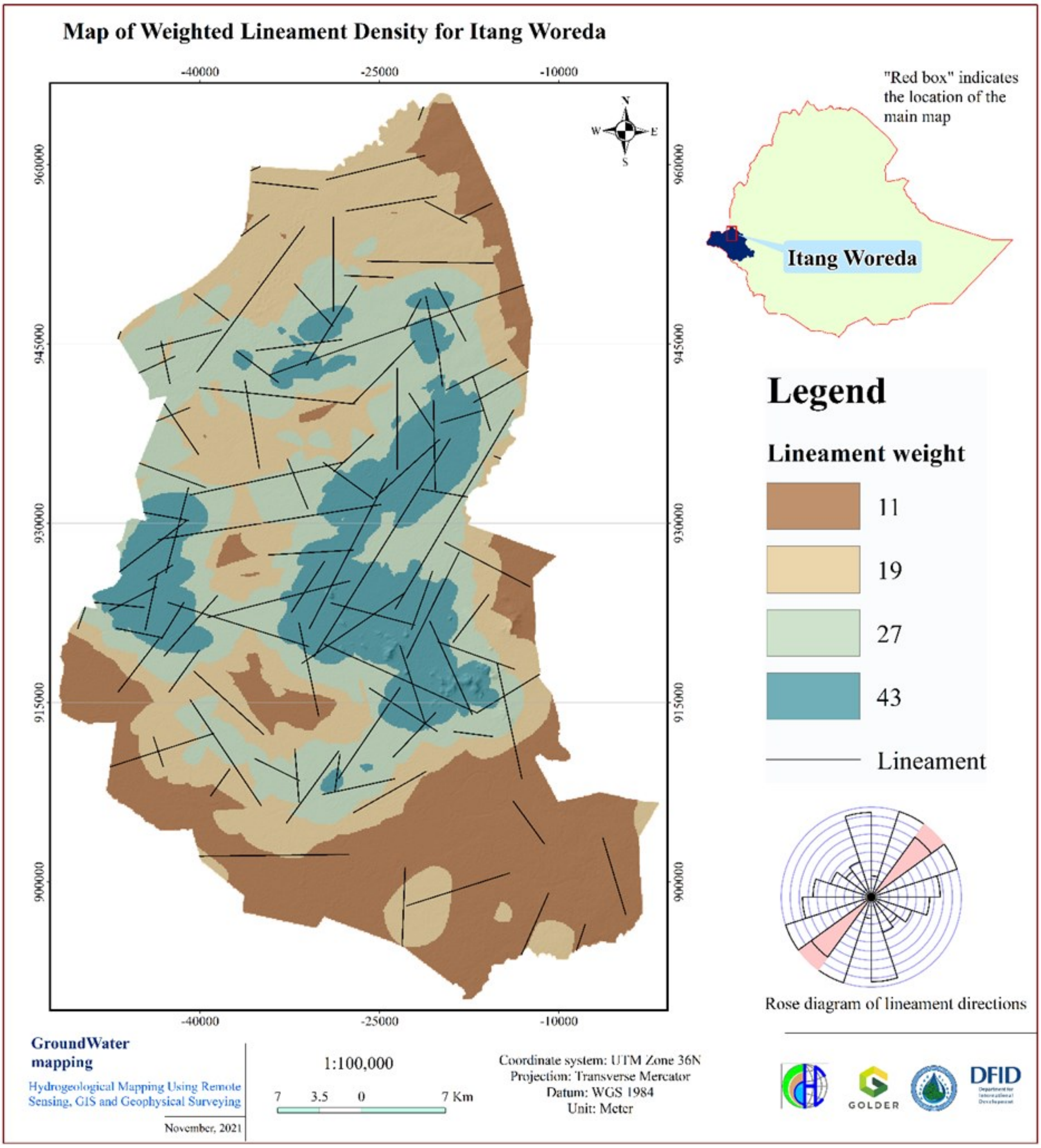

Figure 5.82: Map of weighted lineament density for Itang Woreda

III. Topographic Wetness Index (TWI)

In this study area, the TWI value ranges between 5.05 and 23.17 (Figure 5.83). A closer look at the classification revealed that areas with high TWI value is confined within the river plain with flat slopes whereas large part of the woreda away from river plain has low TWI value suggesting the significance of river plain deposits in accumulating voluminous groundwater (Figure 5.83). Therefore, an area with higher value of TWI has good prospect for groundwater occurrence and flow, and accordingly high weightage value (0.40) was assigned to this class. Whereas, areas with lowest TWI value are gentle slopes which triggers runoff were considered with low groundwater prospect and given low weightage value (0.12).

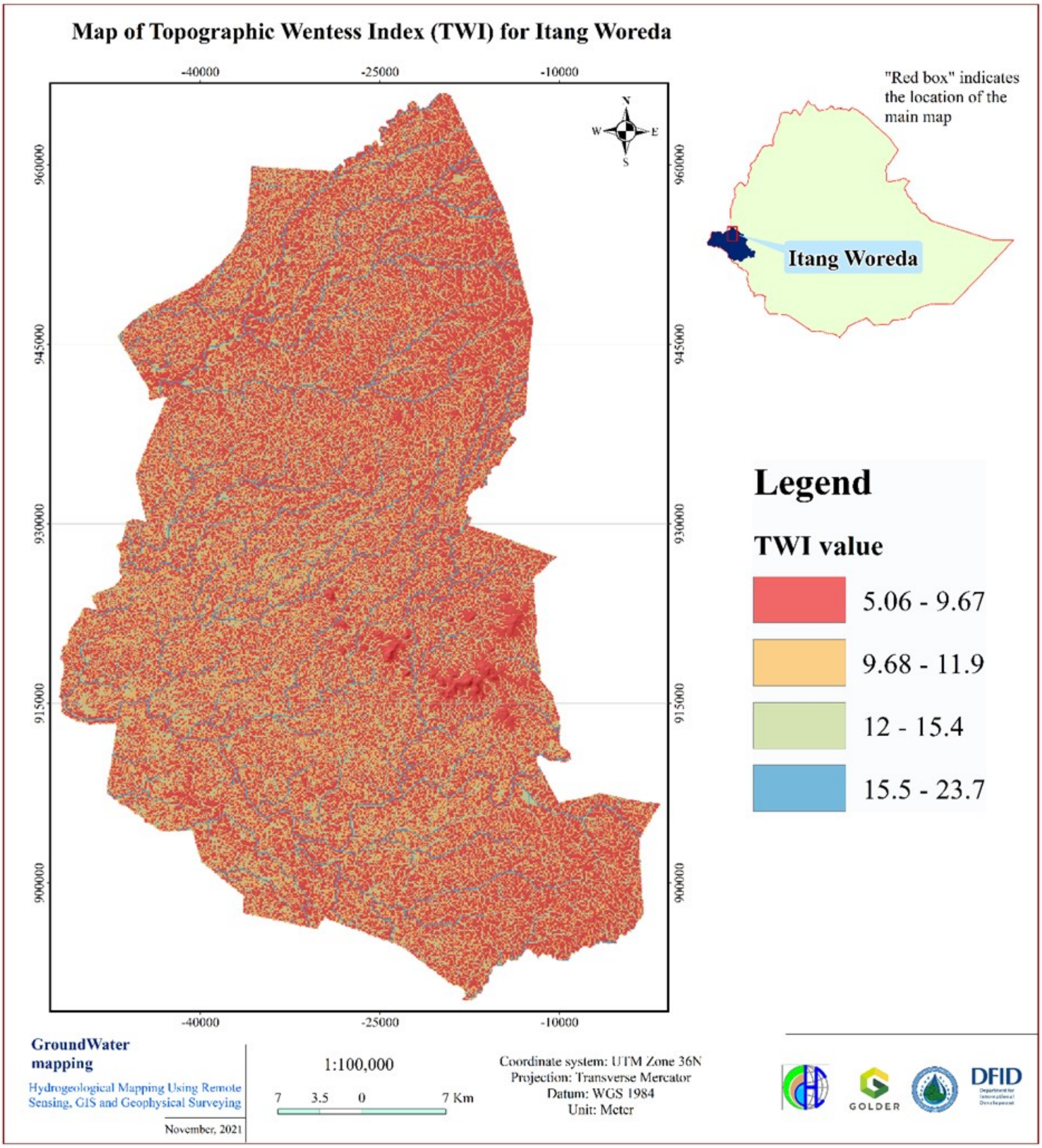

Figure 5.83: Map of topographic wetness index (TWI) for Itang Woreda

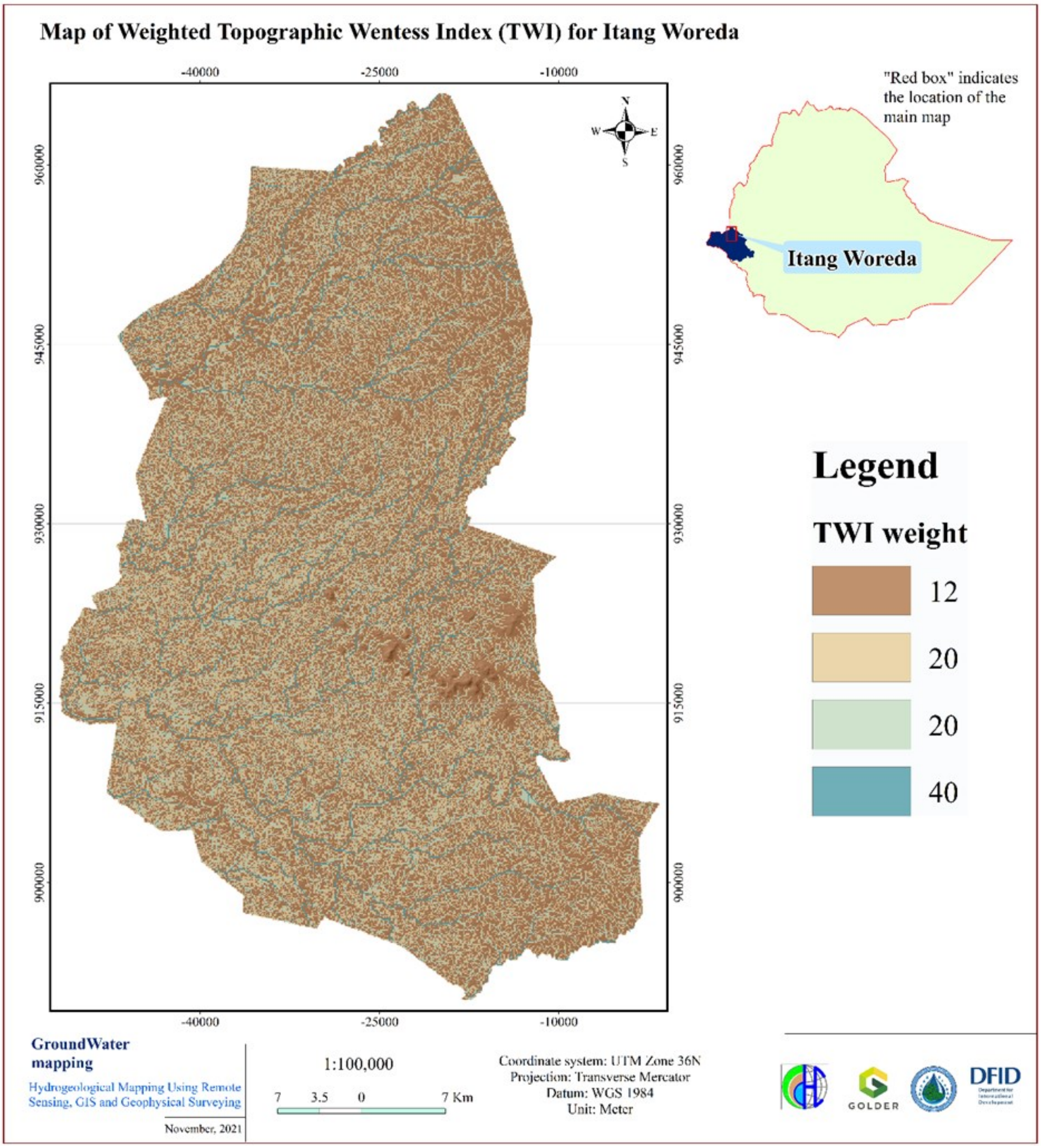

Figure 5.84: Map of weighted topographic wetness index (TWI) for Itang Woreda

IV. Recharge

The spatial 10 years average recharge rate distribution in the Itang woreda ranges from 150 to 260 mm suggesting groundwaters receives high amount of recharge (Figure 5.85). In this overlay analysis, areas with higher and moderate amount of recharge have weightage factor of 0.45 and 0.29, high and moderate groundwater potential signifying which covers about 173.91 Km2 (8 %) and 785.66 Km2 (36 %), respectively while areas with the lowest amount of recharge have weightage factor of 0.11, suggesting poor groundwater potentiality and represent about 1013.55 Km2 (46 %). A closer look at the recharge thematic map revealed that recharge is linked with lithology whereby the alluvial deposits and tertiary volcanics in south and west have relatively high recharge compared to the eluvial sediments which covers the wider areas in central part (Figure 5.85).

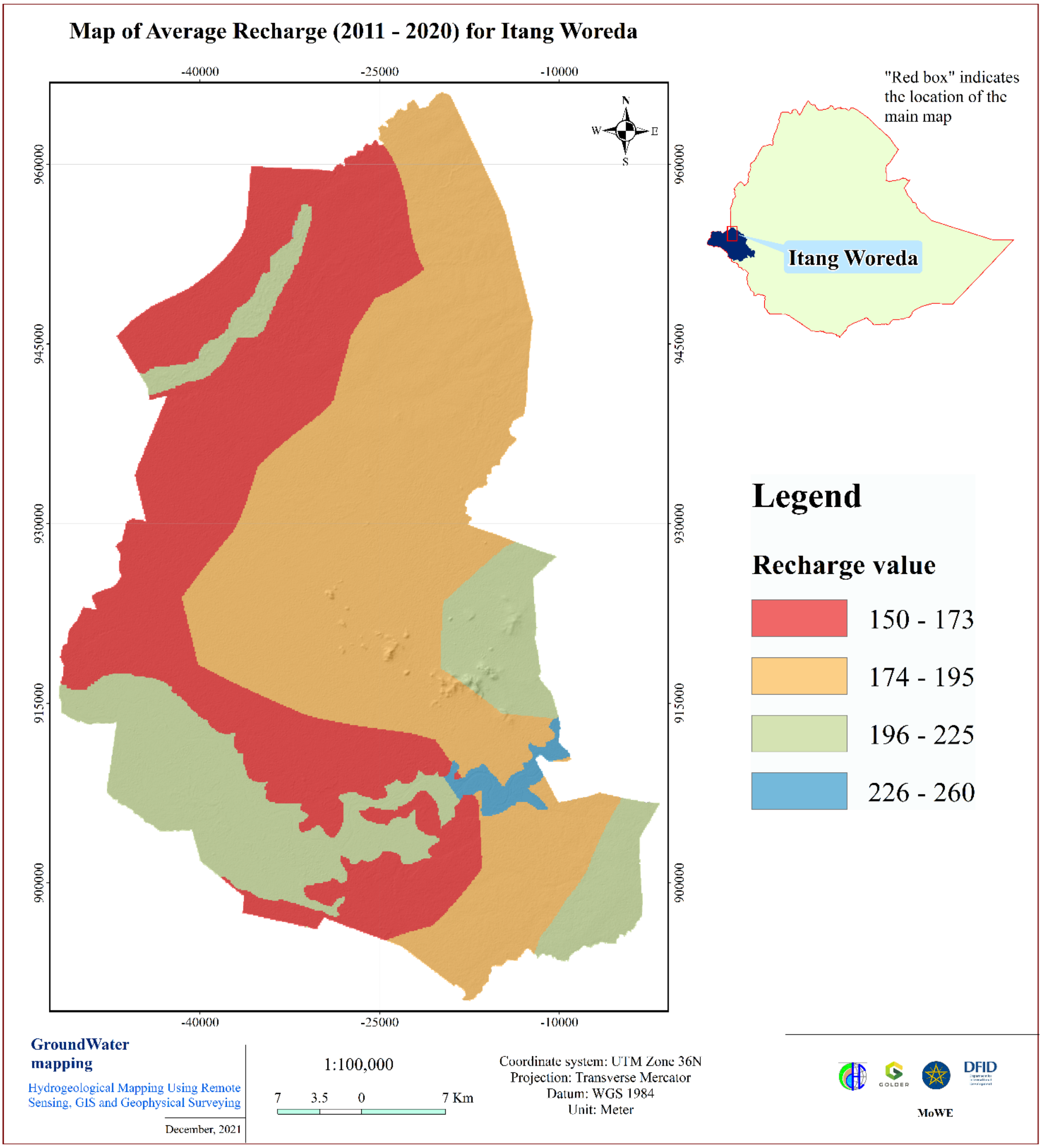

Figure 5.85. Map of average recharge (2011 – 2020) for Itang Woreda

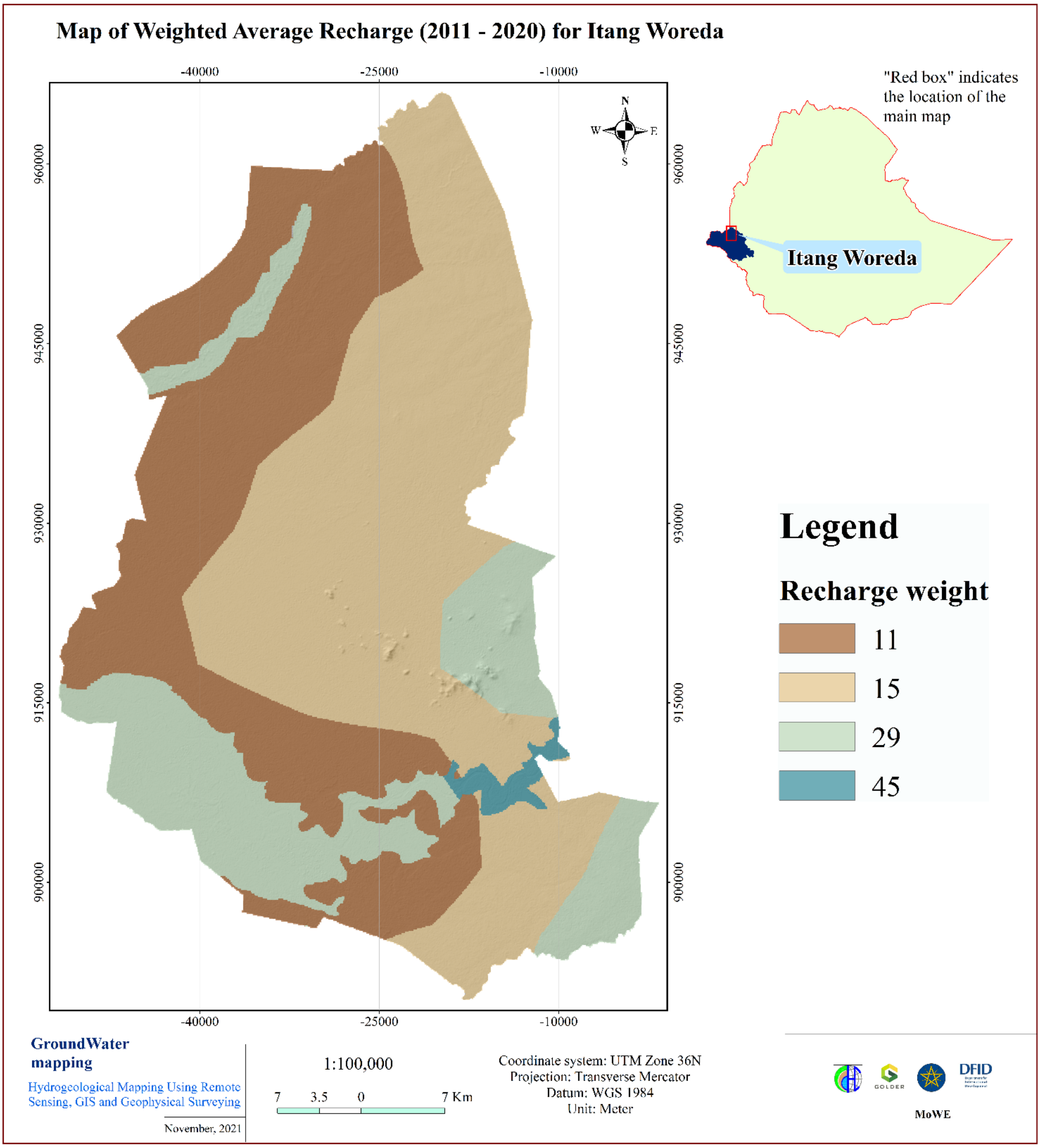

Figure 5.86. Weighted map of average recharge (2011 – 2020) for Itang Woreda

5.10.2. Classification of Groundwater Potential Zones

Based on the assignment and normalized weighting of the individual features of the thematic layers, a potential groundwater index map was produced (Figure 5.87). The potential groundwater zones (PGZ) of the Itang woreda revealed four distinct zones. The wider areas in south, central north and northeast part of the woreda is classified as low groundwater potential zone with groundwater yield less 2 l/s, and south , central south and southwest, and few areas in central and northwest is identified as moderate groundwater potential with yield 3-5 l/s, whereas very few area in south and north west is classified as high groundwater potential while the south central southwest and northwest covered by Quaternary sediment and tertiary volcanic is classified very high groundwater potential with yield 10l/s (Figure 5.87) The potential map, as presented in Figure 5.87, gives a quick assessment of the occurrence of groundwater resources in the study area. The groundwater potential map revealed that high groundwater potential zone is directly related to areas covered by alluvial sediments and Tertiary volcanics associated with high lineament density. Region demarcated as low groundwater potential zone is elluvial soils which could be due to low recharge by clay or silty materials of this sediment which hinders local vertical recharge.

In general, a closer assessment of the groundwater potential map revealed that the distribution high groundwater potential zone is closely related to recharge and lithology whereas topographic wetness index has relatively low impact on occurrence and distribution of groundwater in the woreda as the woreda has low elevation contrast (450-700m asl.) Summary of the groundwater potential zones identified in the Itang woreda is presented in the table below (Table 5.28).

Table 5-28 Classification of groundwater potential zones and coverage areas alongside the respective yield categories in Itang Woreda

GWP Zones	Area (Km2)	Area (%)	Major Aquifer Units	Borehole Yield Classification (l/s)
Very High	649.3	70.84	Quaternary flood plain and alluvila sedimets	>10
Moderate	1577.84	29.15	Elluvial sediments	5-10
Low				3-5
Very Low				<3

5.10.3. Validation with Borehole Yield Data

There are boreholes data in the woreda that can be used as validation. The Akobo-Alwero River which floods the adjacent alluvial plain during summer season also contribute voluminous of recharge via this sediment can be considered as ground-truth in validating the certainty or reliability of groundwater potential map produced by these overlay methods. The Tertiary volcanics, mainly basalt is often fractures associated with geological structures. This volcanic region is categorized as high groundwater potential as these units hydrogeologically known for its high permeability. This can be further validating the reliability of groundwater potential map produced by this overlay technique/method.

5.10.4. Population projection and water demand

5.10.4.1. Population

It is essential that the water supply system is designed to meet the requirements of the population expected to be living in the community at the end of design period by taking into account the design period and annual growth rate. Hence in order to avoid or minimize the aforementioned population related risks, efforts are made to review & justify the credibility of the available population data and growth rate figures.

Population projection is made making use of the geometric growth rate method by using the base population figure estimated by the central statistical Authority. The CSA has set average growth rates for urban and rural areas of the country varying at different times during the design period as shown in the table below. Accordingly, these values are adopted in forecasting future population of the town.

Rural Population Projection Growth Rate of Regions: 2008-2037						
YEAR / Growth Rate % (Rural)	2008-2012	2013-2017	2018-2022	2023-2027	2028-2032	2033-2037
Oromia Region	2.74	2.54	2.29	2.03	1.8	1.56
SNNP Region	2.49	2.37	2.31	2.03	1.82	1.57
Somali Region	2.75	2.63	2.35	2.05	1.89	1.83
Gambela Region	3.52	3.1	3.13	2.76	2.46	2.31

Source: CSA Population Projection for Ethiopia 2007-2037, Addis Ababa July 2013

Geometric method forecasting formula

$$P = Po\,(1 + r)^{n}$$

Where P – projected population
Po – current population
n – Number of years for projection
r – Population growth rate

The population of Itang Woreda has been projected forward until 2036 using the projected scale of Gambella Regional State. The minimum and maximum population in the Woreda is 273 and 9,136 respectively. The total population of the Itang Woreda in 2036 is going to be 69,110. Figure 5.87 presents the projected population for each kebele in the Woreda.

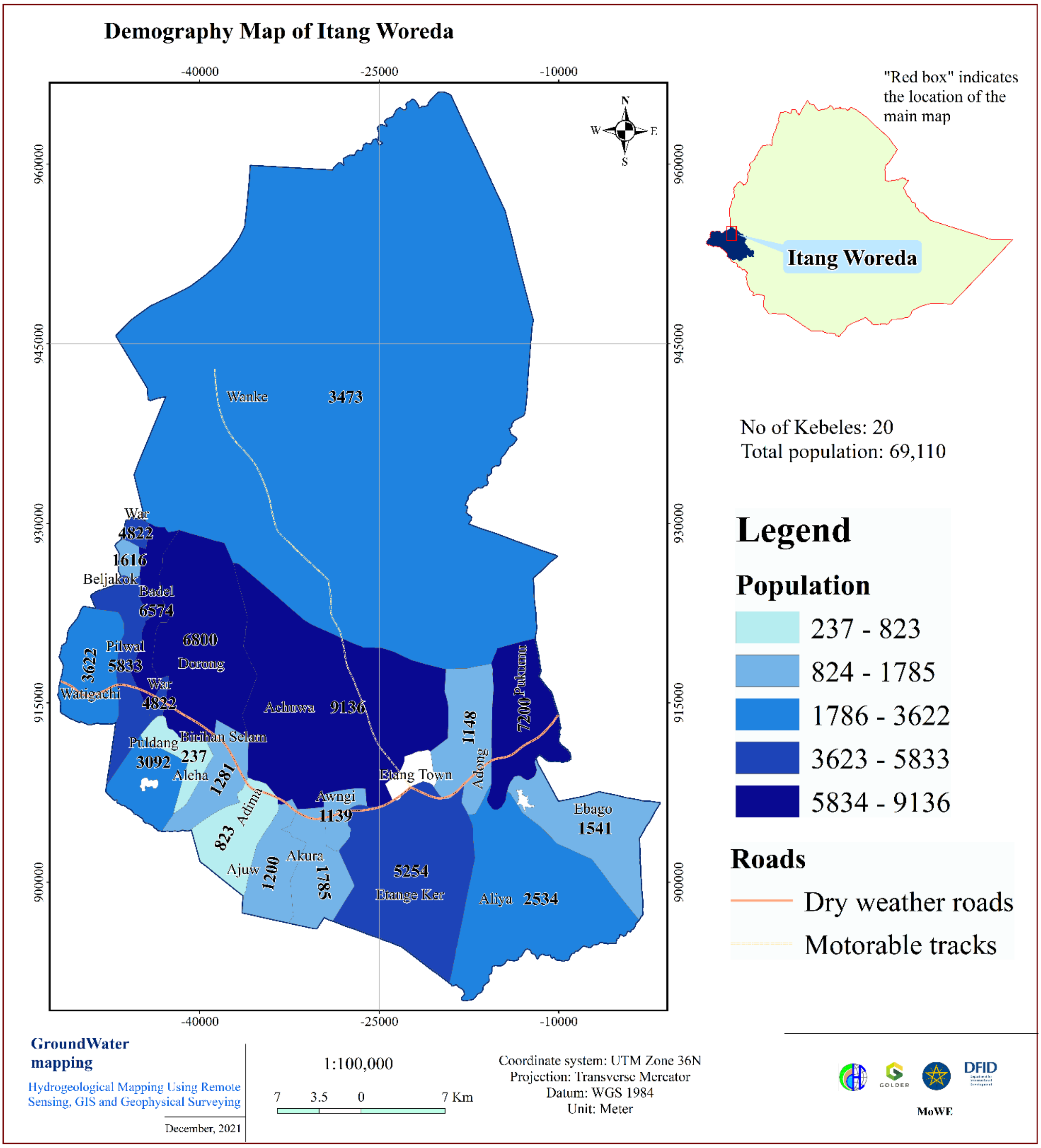

Figure 5.87: Map of projected population (2036) for Itang Woreda.

5.10.4.2. Water Demand Projection

Projected Water Demand

Estimating water demands mainly depends on the size of the population to be served, their standard of living and activities. To make the demand projection reliable and suitable for rural areas it is better to classify in details as domestic and non-domestic demands.

Domestic Water Demand

Domestic water demand is the amount of water needed for drinking, food preparation, washing, cleaning, bathing and other miscellaneous domestic purposes. The amount of water used for domestic purposes greatly depends on the lifestyle, living standard, and climate, mode of service and affordability of the users.

Domestic water demand service can be categorized according to the level of service to be provided and amount of per capita water required satisfying the demand served by the level of service. Modes of services used for our projection are classified into four categories, namely: -

- Traditional Source users (TSU)
- Public tap users (PTU)
- Yard connections and Neighbourhood (shared) connections (YCO) & (YCS)
- House tap connections (HTU)

In projecting the domestic water demand, the following procedures were followed:

- Determining population percentage distribution by mode of service and its future projection
- Establishment of per capita water demand by purpose for each mode of service;
- Projected consumption by mode of service;
- Adjustment for climate;
- Adjustment due to socio-economic conditions.

After considering the necessary mode of services, per-capita demand and applying the adjustment factors the domestic demand for the corresponding year and population has been calculated.

Non-Domestic Water Demand

Non-domestic water demand was also determined systematically. We have classified it into three major categories based on our projection:

- Institutional water demands (Public and governmental);
- Commercial water demand;
- Livestock water demand

N.B: - The use of a reliable base population figure is very important for optimizing the water sources but adopting 2007 CSA data as a base population has real impact on the projection so to compensate some unforeseen situation like migration and unplanned rural town growth. To compensate for such

- To estimate the demand of public institutions and commercial services we have adopted 15% - 20% of the domestic demand for our consumption.
- The demand for livestock watering adopted in the projection is 10% -15% of the domestic demand.

Total Average daily day demand

The average daily day demand is taken to be the sum of domestic demands and non-domestic demand. The water demand in a day varies with time according to the consumer's life style. It is the total sum of adjusted domestic, public and livestock demand.

Maximum Day Demand

The maximum day demand is the highest demand of any one 24 hour period over any specific year. It represents the change in demand with season. This demand is used to design source capacity. The deviation of consumption from the average day demand is taken care of as per the maximum daily coefficient figures. Usually a value from1.1 to 1.3 is adopted as maximum day factor. A constant value of 1.3 is adopted as maximum day factor for all of the villages.

Figure 5.88 shows the distribution of water demand in each Kebeles of the Woreda. The minimum and maximum water demand for Kebeles is 21 M^3/day and 821 M^3/day respectively. The overall water demand for the projected population in the Itang Woreda is 23,194 M^3/day.

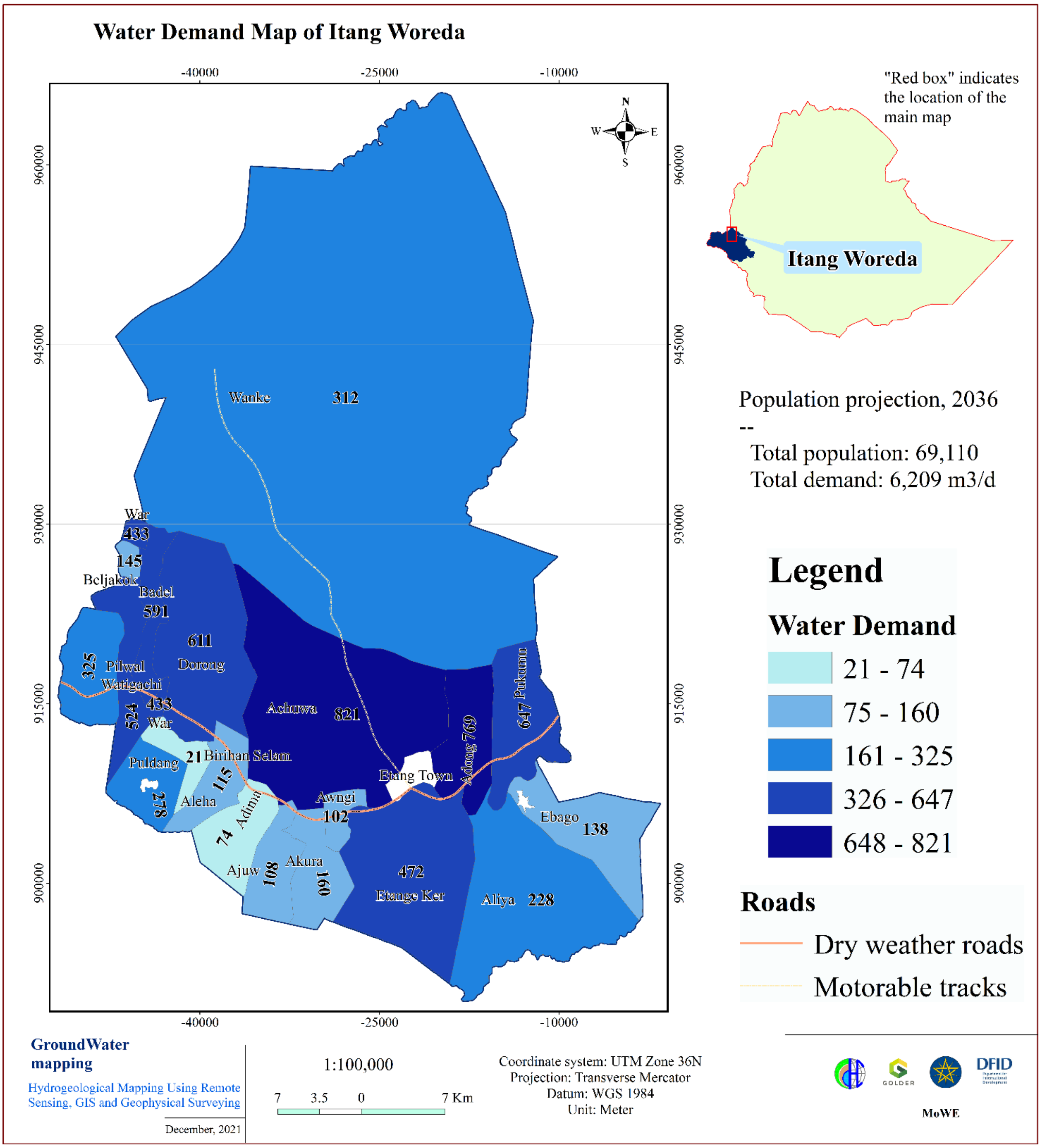

Figure 5.88: Map of water demand (M^3/day) for Itang Woreda.

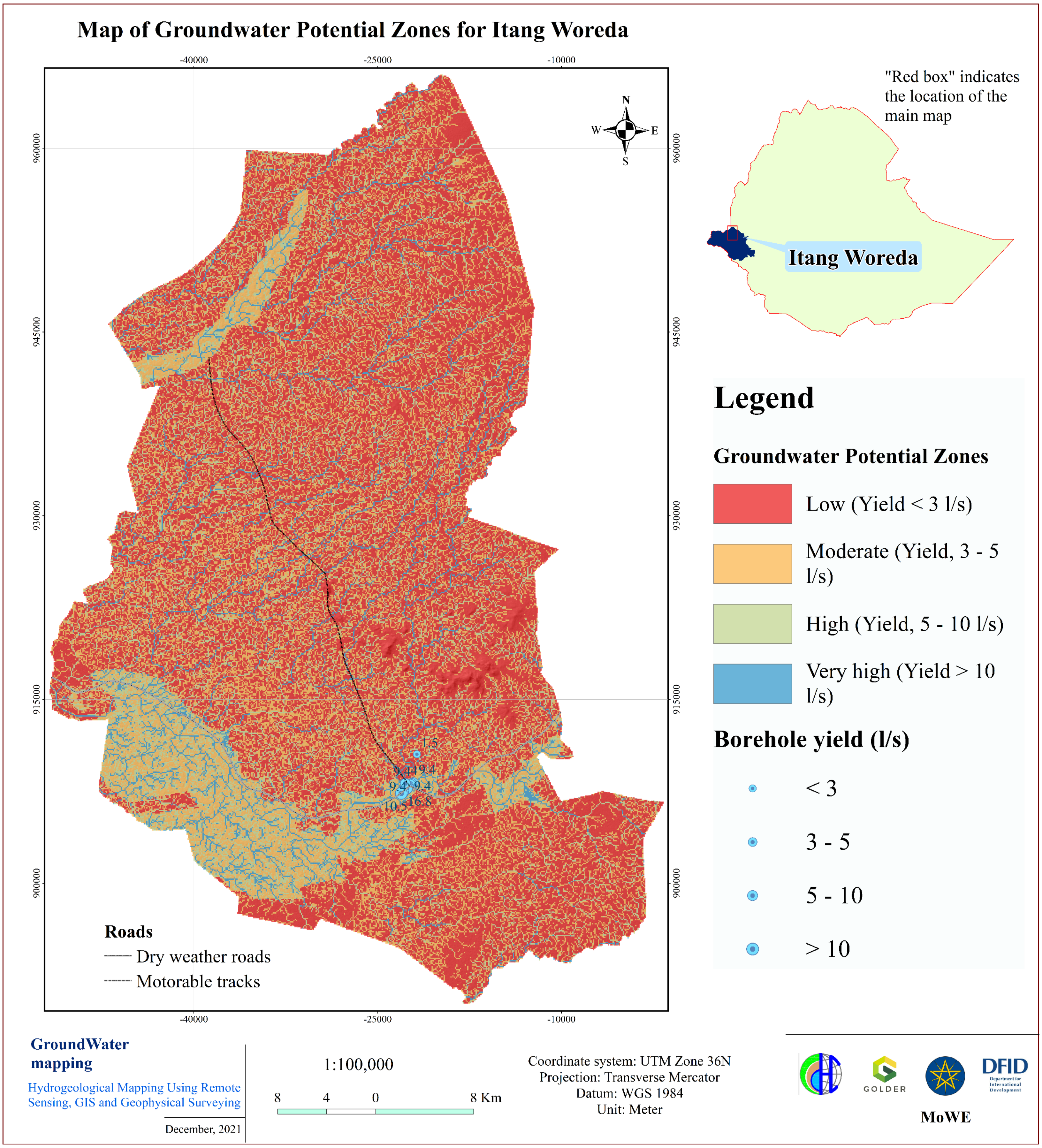

Figure 5.89: Map of groundwater potential zones showing four zones identified by the GIS overlay analysis in Itang Woreda

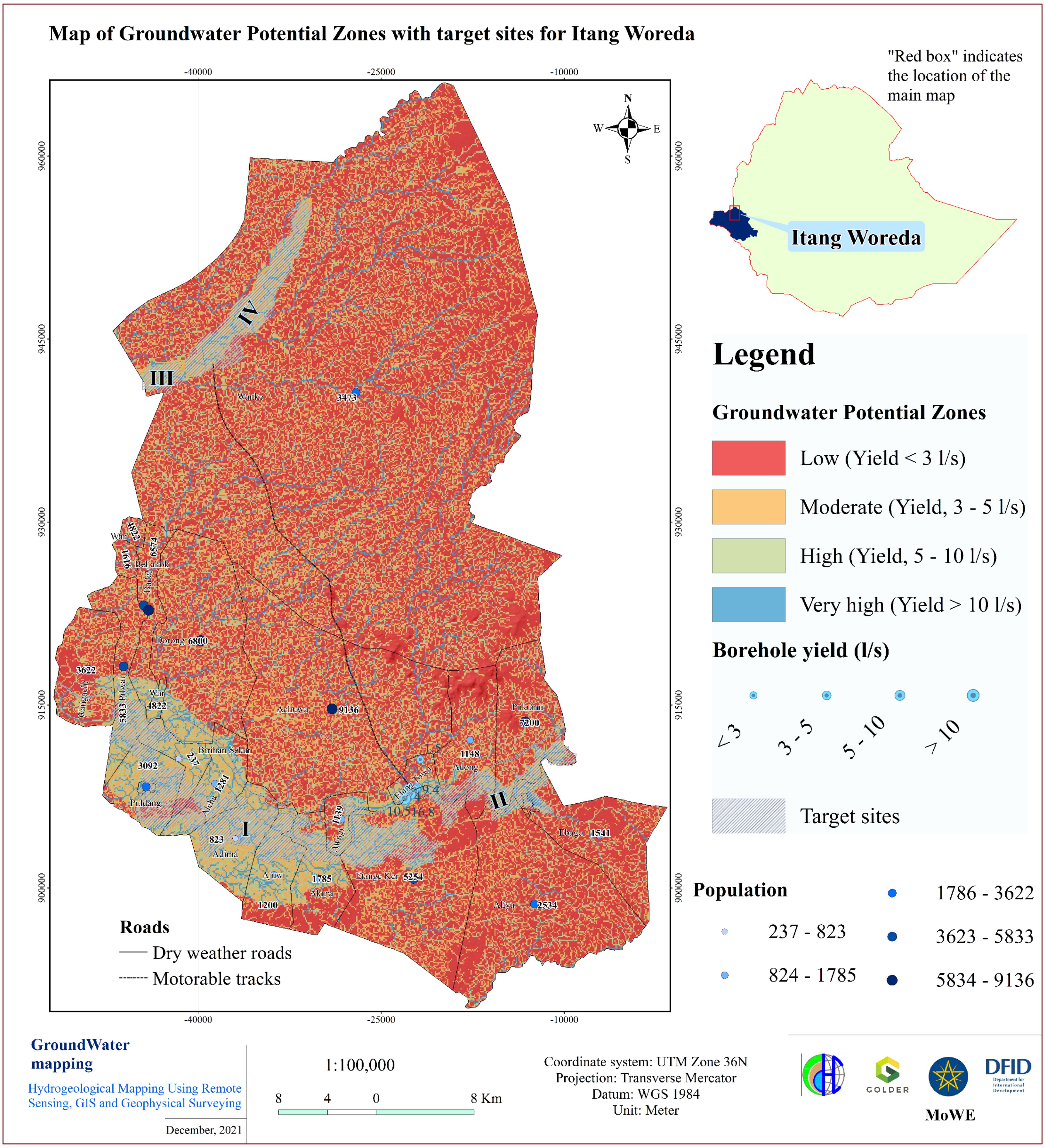

Figure 5.90: Map of groundwater potential zones with selected target sites in Itang Woreda

5.10.5. Proposed Target Sites

Proposed target sites are identified, prioritized, and selected within the woreda based on the identified groundwater potential zones, the productivity of the hydro-stratigraphic units with their expected optimum borehole yield, proximity to beneficiaries, population density and discussion made with the woreda's stakeholders so that to understand and identify kebeles with sever water shortage in particular. Accordingly, four priority target sites were selected and delineated within the Itang woreda for detail studies to be carried out to verify further and locate appropriate borehole drilling sites.

Target Site-I:

This target site is in the southern part of the woreda in Itang ker, Akura, Ajaw, Adima, Aleh, Puldong, Birehane Selam, War, Pilwal and watiganchi kebeles are include within this potential zones. It is situated in the identified very high potential zones with expected optimum borehole discharge of about >10 l/s. This target site is mainly overlain by quaternary recent deposits of alluvial and eluvial soils.

Target Site-II:

This target site is located at southern part of the woreda. It is situated mainly in the identified high potential zones with expected optimum borehole discharge of about 5 to 10 l/s. This target site is mainly underlain by tertiary basalt or granite.

Target Site-III:

This target site is located around Wanke town northwestern part of the woreda. It is situated mainly in the identified moderate potential zones with expected optimum borehole discharge of about (3-5 l/s).

Target Site-IV:

This target site is located at northwestern in Wanke kebele. It is situated mainly in the identified very low potential zones with expected optimum borehole discharge of about <3 l/s. This target site is mainly underlain by Metamorphic / basement granitic rocks.

5.10.6. Conceptual hydrogeological model of Itang Woreda

Hydrogeological conceptual models are collections of hypotheses based on geological structural and geomorphological evidence and existing wells lithologic logs to describe and understand the groundwater occurrence, localization, and movement beneath the ground surface. The purpose of the hydrogeological model across inferred groundwater flow direction is to reflect the prototype of regional groundwater flow system into the two priority sites selected for further study in phase III. In the conceptual model, groundwater head represents the regional groundwater table along with major geological section which marks most important aquifers and physical boundaries. Itang woreda is characterized with lowlands formed mainly from post tectonic intrusive granite outside the woreda boundary. Quaternary sediments overlying the Volcanic and crystalline basement rocks are important for groundwater storage in the area.

This region has a compartimentalized groundwater flow system constrained by geology, geological structres and topography. Groundwater gets recharge mainly from local rain that falls on central and a northeast surrounding highland with expected lateral inflow from northwest adjacent highlands. Groundwater flow direction is generally towards northwest and central lowlands through alluvial plain and weathered crystalline basement rocks. Development of the hydrogeological conceptual model of the target Woreda area has been prepared based on the converging evidence of secondary data including digital elevation model (DEM), geological and hydrogeological maps and structures, lithological well logs

The conceptual hydrogeological models for this woreda to be constructed along/across groundwater flow path will be produced after stake holder consultation workshop to select priority target sites for further hydrogeological characterization. This conceptual hydrogeological model summarizes what is known about the hydrogeological system and thereby provides a framework for hydrogeological system of the target woreda at broad scale including the following.

- ✓ Major groundwater flow zone (inflow, groundwater flow paths, inferred depth, and outflow).
- ✓ Groundwater condition of target woreda area such as delineate inferred groundwater table from existing data (spring, river, and boreholes).

5.11. Shashemene Woreda

The four thematic layers which were integrated for groundwater potential mapping in Shashemene Woreda are summarized in Table 5.29 below. The notes on the description of each thematic layers including classification of potential zones, validation with borehole and scheme datasets, population projection, water demand and selected target sites presented in the sub-sections.

Table 5-29:-Assigned and normalized weights for the individual features of the four thematic layers for groundwater potential zoning in Shashemene Woreda

Theme	Class	Groundwater Prospect	Weight assigned	Normalized weight	Rank	Area (Km2)	Area (%)
Geology/ Lithology, 'GG'	Lacustrine sediment	Very good	4	0.3	0.40	56.82	7.25
	Nazret Group and Dino formation	Good	3	0.25		638.58	81.58
	Central volcanics	Moderate	2	0.25		86.77	11.08
	Basalts of the rift floor	Poor	1	0.2		0.56	0.07
Lineament Density,' LD' (Km/Km2)	0 - 0.09	Very poor	1	0.12	0.39	243.37	36.3
	0.09- 0.23	Poor	2	0.20		316.92	35.1
	0.23– 0.39	Moderate	3	0.28		150.92	18.3
	0.39– 0.71	good	4	0.40		71.39	10.2
Topographic Wetness Index, 'TWI'	4.52-8.11	poor	1	0.11	0.15	243.37	31.1
	8.11 – 9.79	Moderate	2	0.2		316.92	40.5
	9.79 – 12.08	Good	3	0.29		150.92	19.3
	12.08 –18.80	Very good	4	0.40		71.39	9.12

Theme	Class	Groundwater Prospect	Weight assigned	Normalized weight	Rank	Area (Km2)	Area (%)
Recharge, 'GR' (mm/y)	0-46.21	poor	1	0.11	0.06	435.48	56
	46.21– 70.46	Moderate	2	0.15		163.07	21
	70.46– 97.73	Good	3	0.29		86.59	11
	97.73 – 193.20	Very good	4	0.45		95.23	12

5.11.1. Integration of Thematic Layers for Groundwater Potential Zoning

The details of geology, rainfall, lineament density, geomorphology, land slope, soil type, land use/land cover, groundwater depth and drainage density together with their spatial distribution in Shashamanne woreda are presented below:

I. Geology/lithology

The geology of Shashamanne Woreda is Quaternary tuff, ignimbrite and pryoclasts.

Ignimbrite and Pyroclast deposits (Qdi)

The lithologic units is covers the wide area in central, north and northeast of the woreda (Fig 5.91.). It is derived from volcanic ejects.

The Nazert group and Dino formation (NQS)

This unit covers the southaest part of the woreda. This rock unit is found southeastern of the project with relatively higher area coverage in the Woreda. It contains different types of lithological units such as Ignimbrites, rhyolites, Basalts, and tuffs.

Dino Formation (Qdi)

Dino formation covers vast of the area on the woreda with variable thickness and it comprises a number of flows of compacted fiamme ignimbrites in place intercalated with aphyric basalt and unwelded pyroclastics.

Basalts of the Rift floor (Qwpb)

This rock unit found on the margin of western part of the woreda and has small areal coverage. The alkali basalts consist of magnesian olivine, augitic clinopyroxene, labradorite and opaque phenocrysts, while in the groundmass these minerals are sometimes accompanied by alkali feldspar. Very close mineral logically are transitional alkali basalts, but they completely lack alkali feldspar, and clinopyroxne occurs mainly in the groundmass (GSE 2012). The basalts are clearly controlled by extensional fractures and generally display fresh surfaces. Chains of scoraceous cones follow the lines of fractures.

Central volcanic complex (Qwa, Qwo and Qwpu)

Most of the central volcanoes of the Wonji group are disposed along the axial zone of the rift, the Wonji fault belt. They are either huge conical mountains or calderas formed in the place of older volcanoes. The main volcanic centers from north to south within the rift include Aluto, Shala and Corbetti (GSE 2012). These units are Rhyolite with trachyte lava flow (Qwa), Obsidian and pitch stone (Qwo) and pumice with unwelded tuff (Qwpu). These units found North western, southern and western area within the woreda.

Lacustrine sediment (Ql)

In the rift Quaternary sediments and mostly lacustrine origin are intercalated with Pliocene to Pleistocene ignimbrites both in the rift floor and rift shoulders. The older sediments are lacustrine diatomites, tuffaceous clays and silts inter-bedded with basal ignimbrites of the Nazret Group. The lacustrine sediments are intercalated with redeposit volcanic ash and tuffs (GSE, 2012). The thickness of this unit is variable in the area. This unit is also found in southern region on the project area

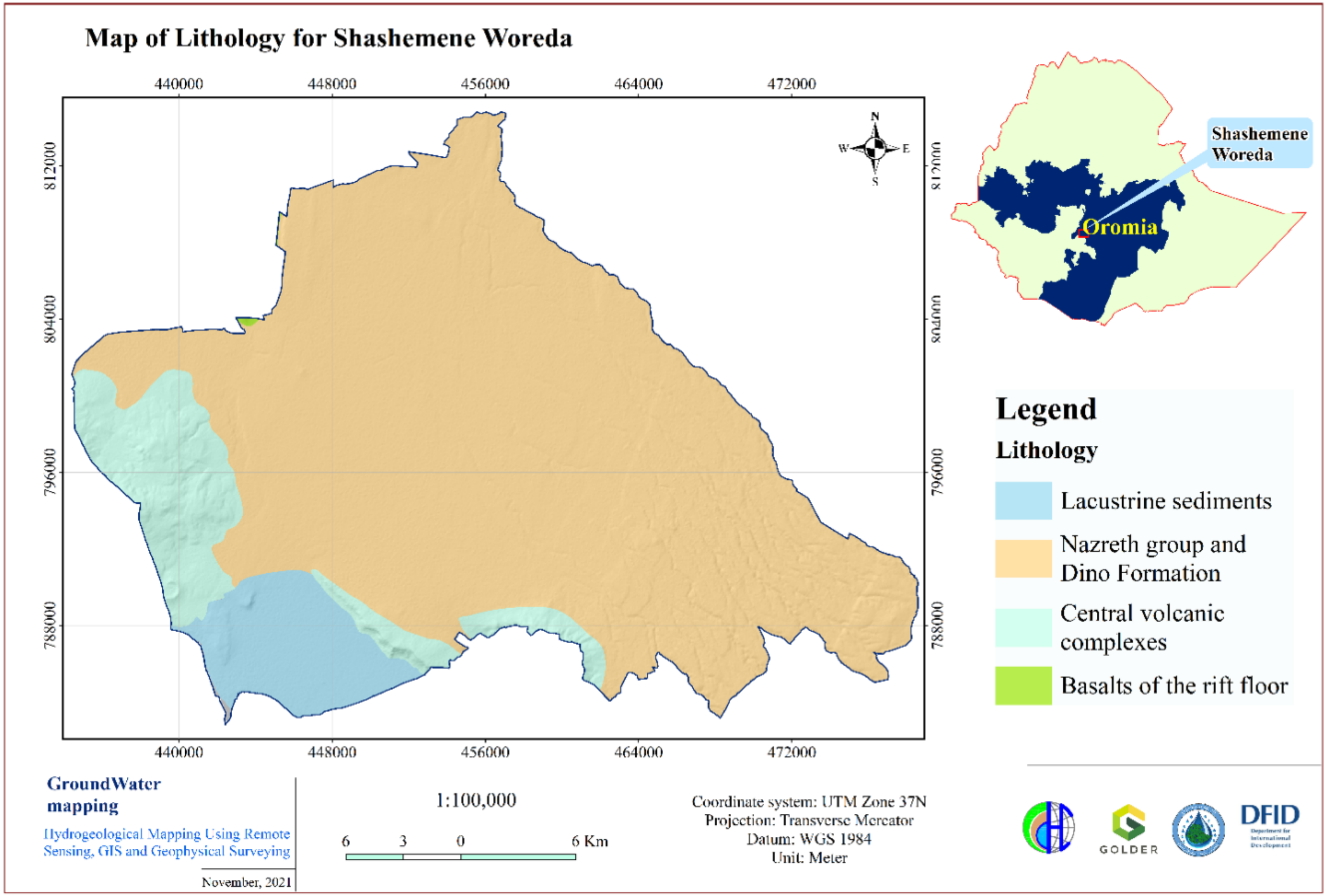

Figure 5.91: Map of lithology class for Shashemene Woreda

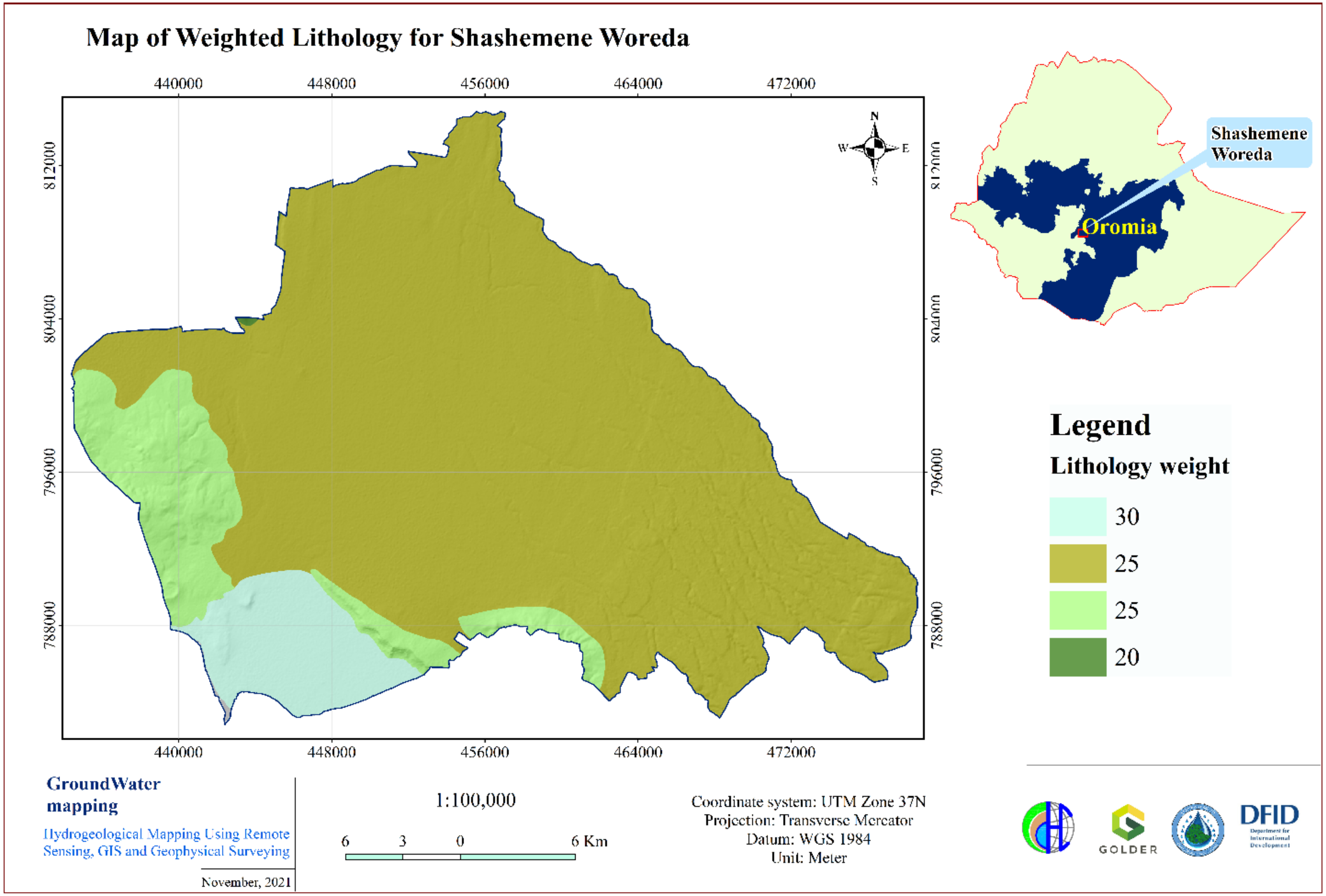

Figure 5.92: Map of weighted lithology class for Shashemene Woreda

II. Lineaments and lineament density

Lineaments are manifestation of linear features that can be identified directly on the rock units or from remote sensing data. Lineaments and their intersections play a significant role in the occurrence and movement of groundwater. The presence of lineaments may act as a conduit for groundwater movement which results in increased secondary porosity and, therefore, can serve as groundwater potential zone (Rao, 2006; Prasad et al., 2008). Accordingly, detailed lineament of the study area was extracted from a mosaicked Cloud Free Images Sentinel-2 selected from the year 2020 to 2021 series combined with geomorphology of the area and mapped using ArcGIS 10.8 software, and subsequently lineament density map was computed in using GIS algorithm and expressed in terms of length of the lineament per unit area (km/Km2).

Some bedding-like structures are developed in the recent alluvial deposits, which are a primary structure noted in alluvial formation layers. These structures are produced based on the horizontal depositions of the layer by sedimentation compactions of transgressed materials (GSE, 2018).

The lineament density varies from less than 0.08km/Km2 to 0.71 km/Km2 with north, east and northeast have relati vely high lineament density (Figure 5.93). Though the lineaments are widespread across the study area, however, the distribution of lineaments suggests geologic control with areas covered by pyroclastics deposits, ignimbrite and tuff have higher lineament density of 0.23 – 0.71km/Km2) which is good for groundwater development. Consequently, higher weightage of 0.40 was assigned to area with high density of lineaments, while a low weightage of 0.12 was assigned to areas with low lineament density (Figure 5.94).

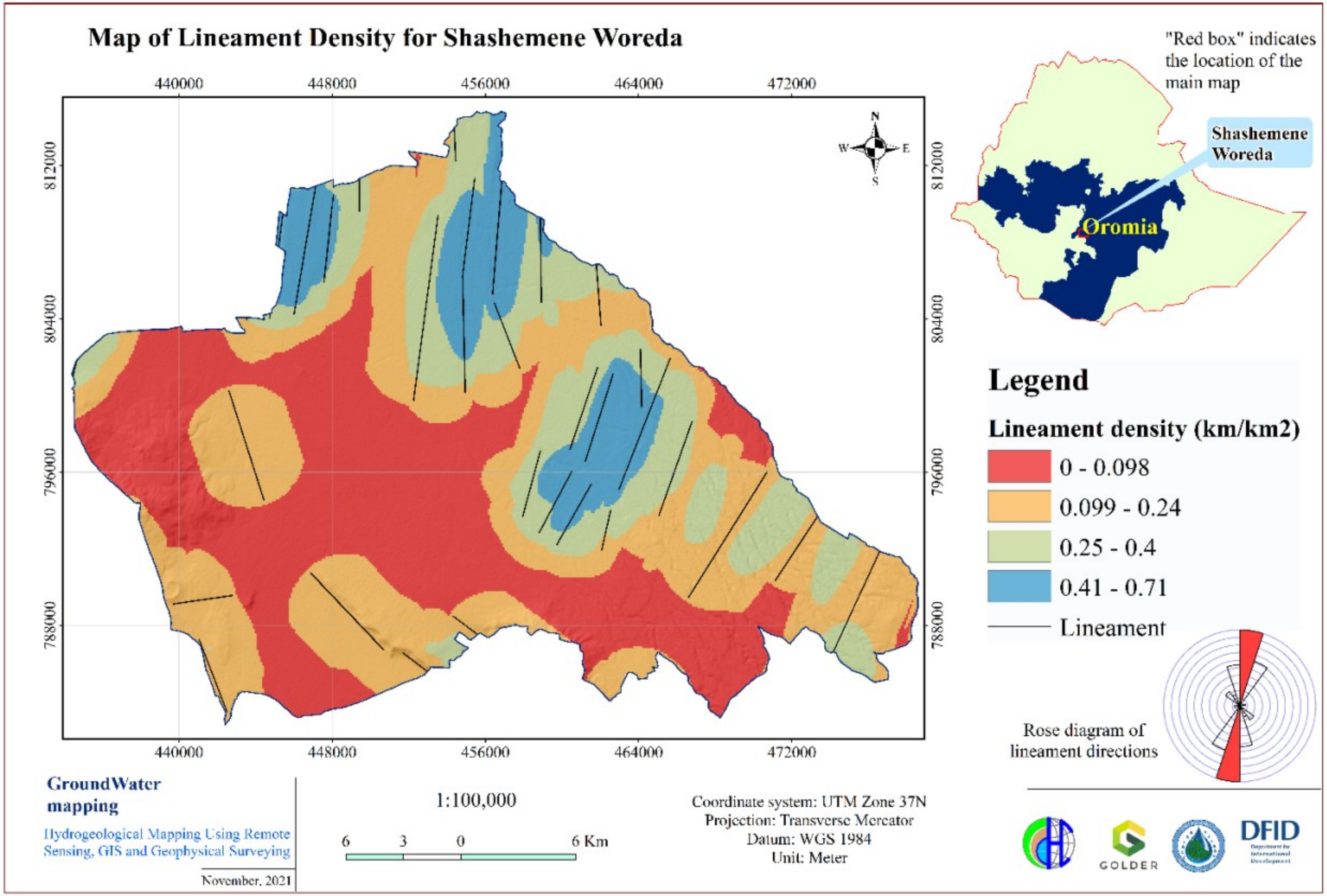

Figure 5.93: Map of lineament density for Shashemene Woreda

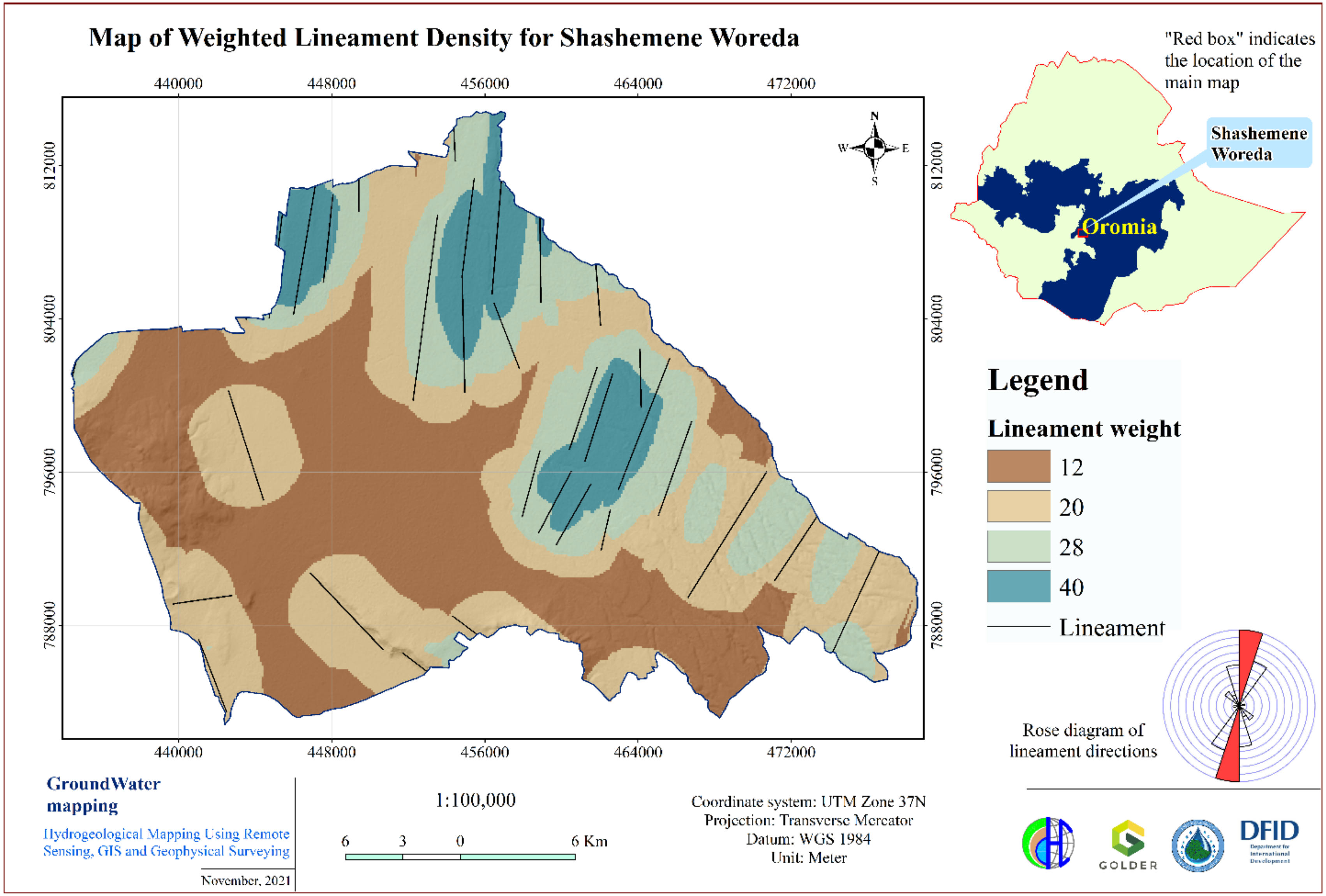

Figure 5.94: Map of weighted lineament density for Shashemene Woreda

III. Topographic Wetness Index (TWI)

In this study area, the TWI value ranges between 4.52 and 18.17. A closer look at the classification revealed that areas with high TWI value is confined within the central rift valley (flat slopes) whereas large part of the woreda away from this zone has low TWI value suggesting the significance of low slope area in accumulating voluminous groundwater (Fig 5.95). Therefore, an area with higher value of TWI has good prospect for groundwater occurrence and flow, and accordingly high weightage value (0.4) was assigned to this class. Whereas areas with lowest TWI value are gentle slopes which triggers runoff were considered with low groundwater prospect and given low weightage value (0.11).

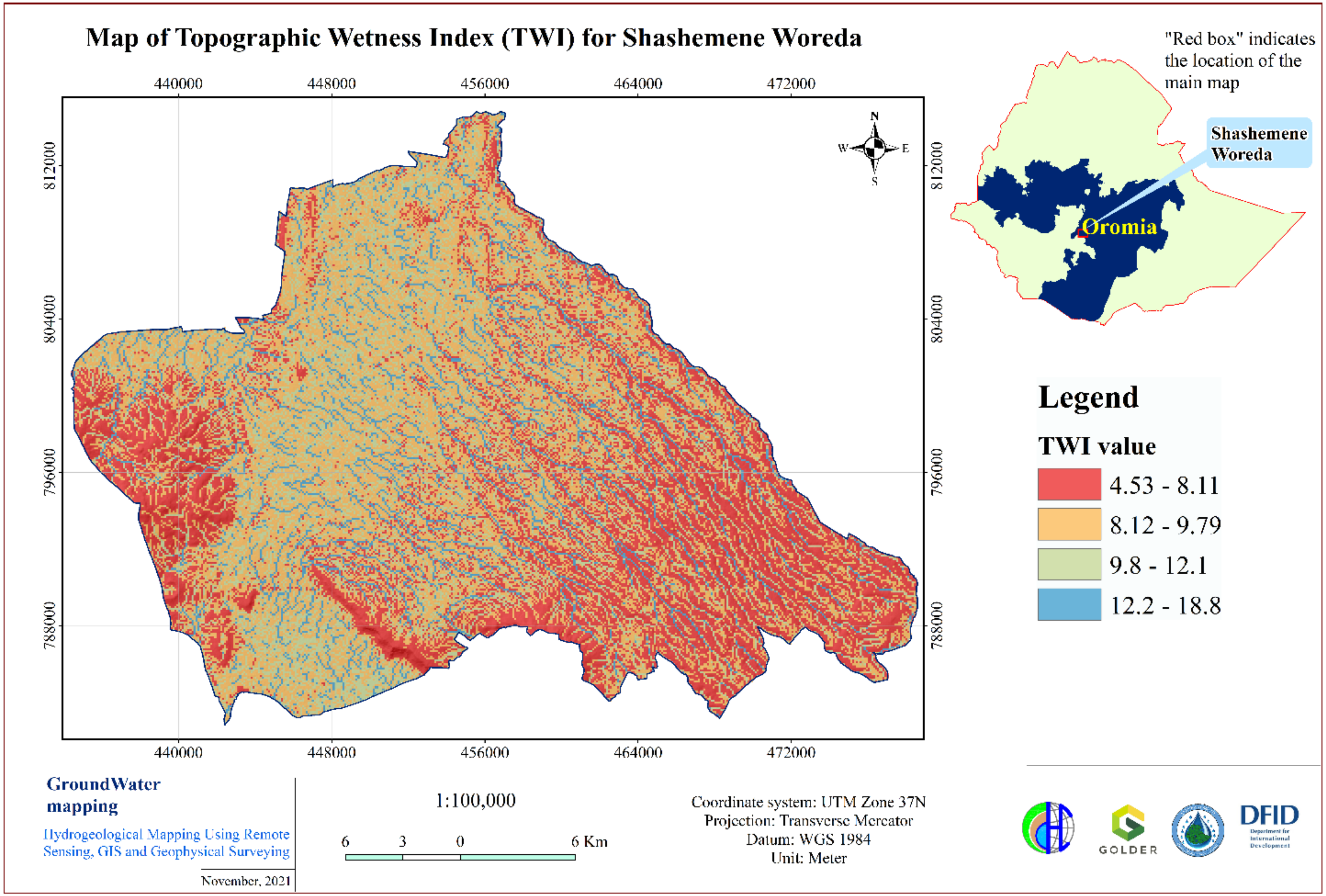

Figure 5.95: Map of topographic wetness index (TWI) for Shashemene Woreda

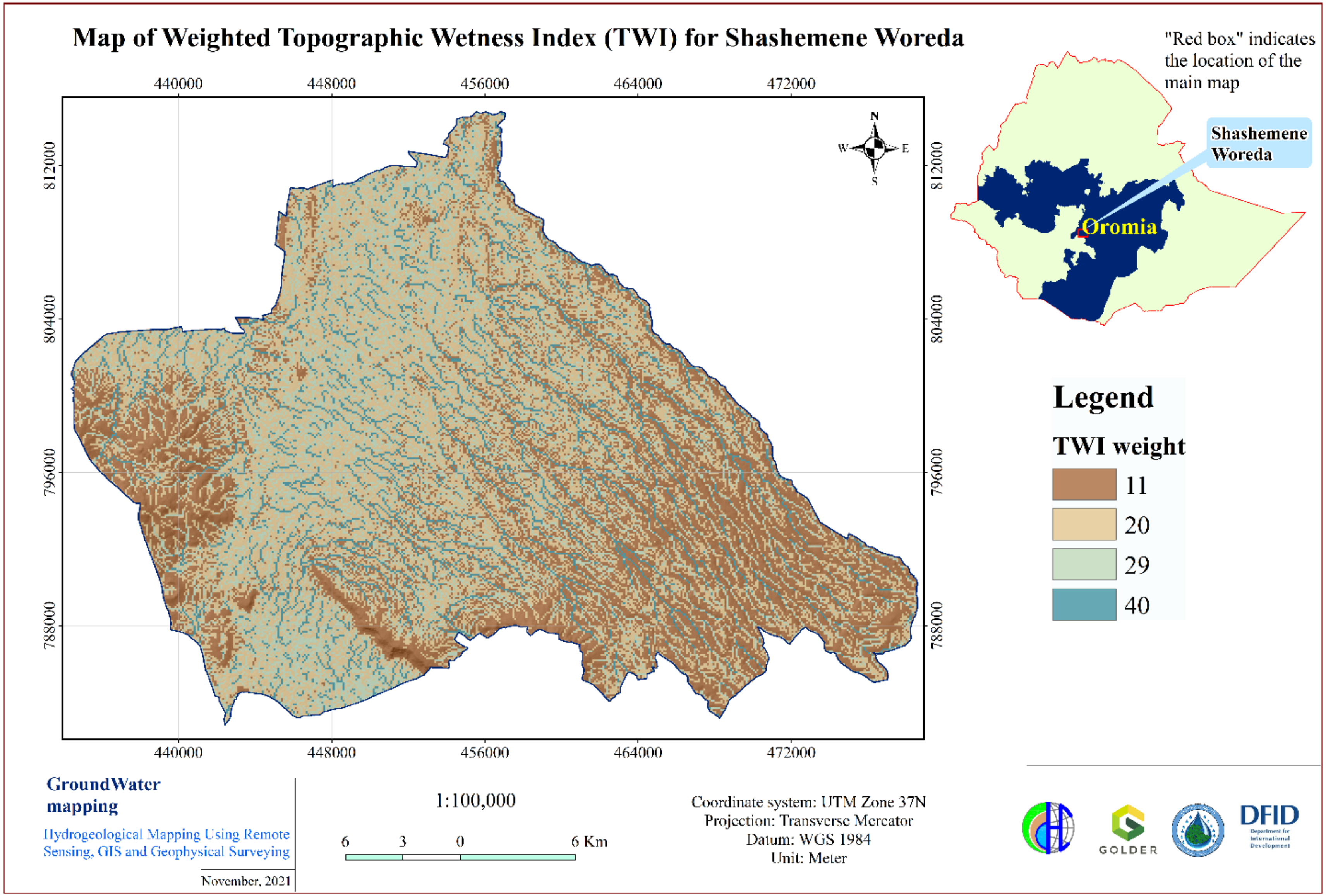

Figure 5.96: Map of weighted topographic wetness index (TWI) for Shashemene Woreda

IV. Recharge

The 10 years spatial average recharge rate distribution in the Itang woreda ranges from 99.2 to 192 mm suggesting groundwaters receives high amount of recharge in southeast part of the woreda area underlain by volcanic rocks associated with high lineament density have relatively high recharge amount (Figure 5.97). The central and north and northwest which is covered by pyroclas deposits have low recharge whereas few areas in east and southwest have moderate recharge. Accordingly, areas with moderate and low amount of recharge have weightage factor of 0.15 and 0.11, respectively. A closer look at the recharge thematic map revealed that most of the area wthin zone of main rift valley center have relatively low to moderate recharge (< 23.53 mm) whereas areas exterior to this zone has high recharge (> 50mm). The lowest annual recharge is 23.53 mm, zero or no values on the map represent the lake Hawasa with small area coverage on the southern of the woreda boundary.

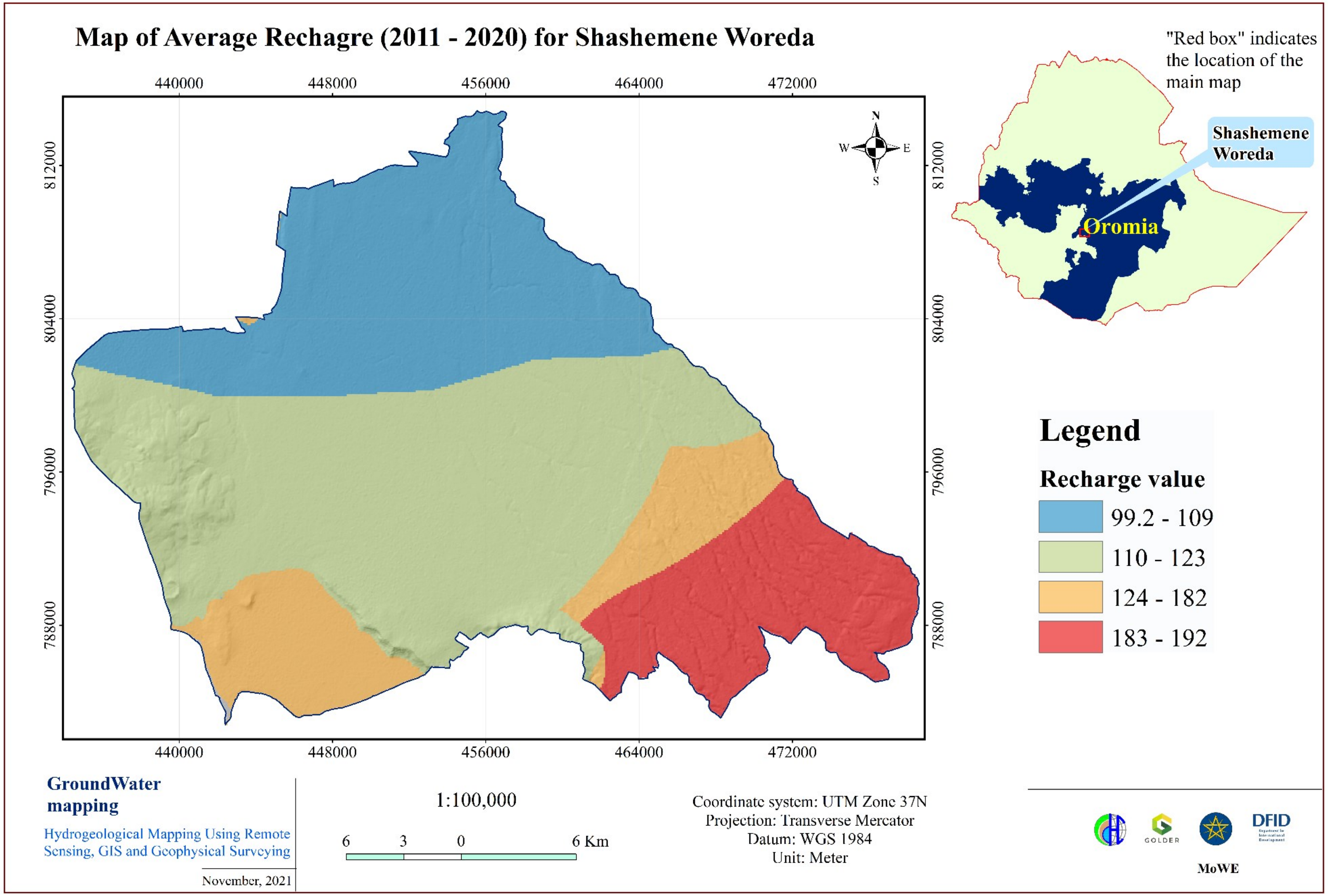

Figure 5.97: Map of average recharge (2011 – 2020) for Shashemene

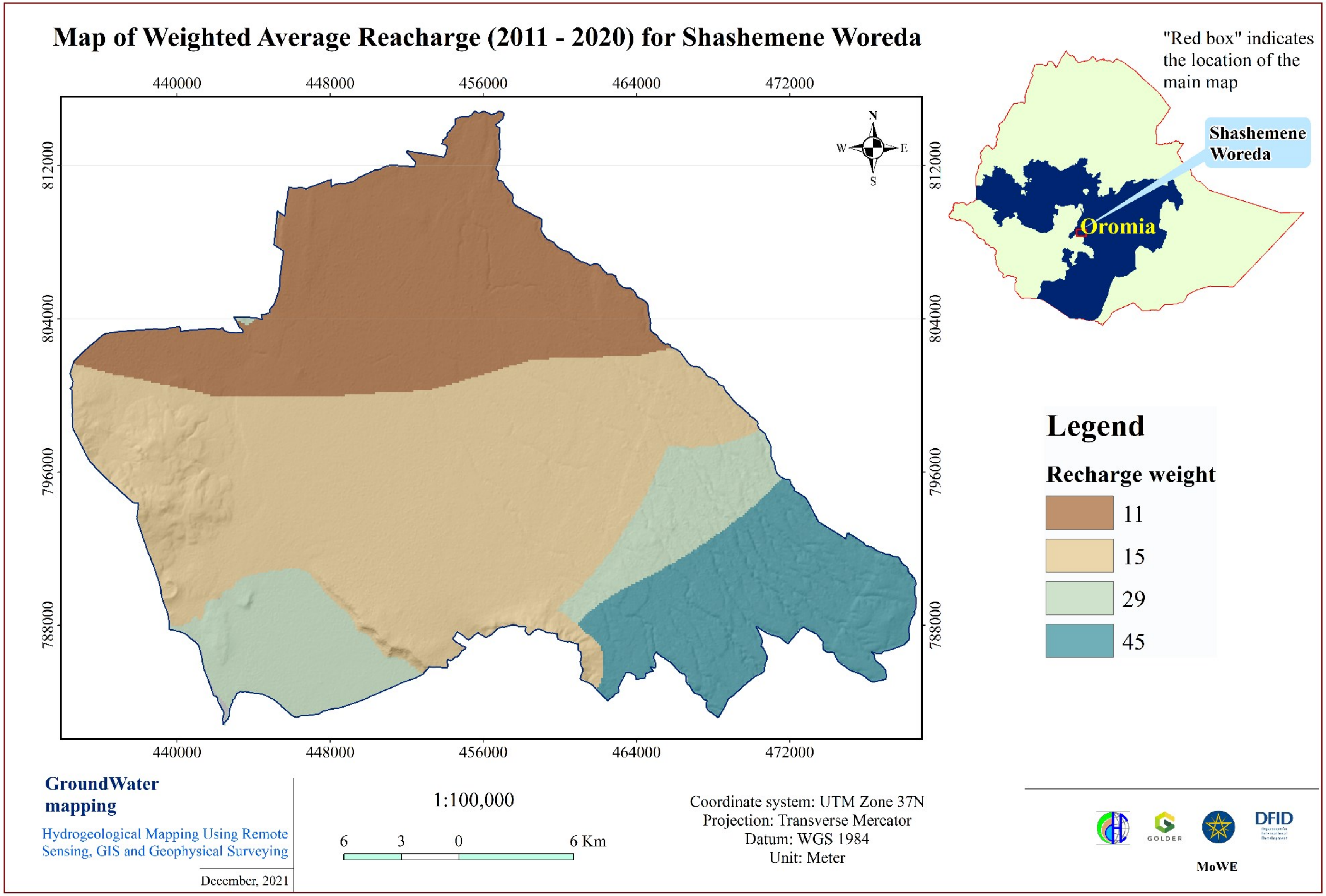

Figure 5.98: Weighted map of average recharge (2011 – 2020) for Shashemene Woreda

5.11.2. Classification of Groundwater Potential Zones

Based on the assignment and normalized weighting of the individual features of the thematic layers, a potential groundwater index map was produced (Figure 5.99). The potential groundwater zones (PGZ) of the Shashamanne woreda revealed four distinct zones. The wider areas in central, north and northwest part of the woreda is classified as low groundwater potential zone with groundwater yield < 5 l/s, whereas area the southwest and few areas in east of the woreda is classified as moderate with yield less than 5-10l/s whereas the southeast part and the marginal south of the woreda classified as high to very groundwater potential zone with yield > 10l/s l/s.

The potential map, as presented in Figure 5.99, gives a quick assessment of the occurrence of groundwater resources in the study area. The groundwater potential map revealed that high groundwater potential zone is directly related to areas with high lineament density within volcanic rocks. Region demarcated as low groundwater potential zone is pyroclastic deposts which could be due to low recharge by clay or silty materials which develop within this sediment and barrier local vertical recharge.

In general, a closer assessment of the groundwater potential map revealed that the distribution high groundwater potential zone is closely related to recharge, lithology and lineament density whereas topographic wetness index has relatively low impact on occurrence and distribution of groundwater. Summary of the groundwater potential zones identified in the Shashamanne woreda is presented in the table below (Table 5.30).

Table 5-30:- Classification of groundwater potential zones and coverage areas alongside the respective yield and transmissivity categories in Shashemene Woreda

GWP Zones	Area (Km2)	Area (%)	Major Aquifer Units	Borehole Yield Classification (l/s)		Transmissivity Classification (m^2/d)	
				Q (Range)	Mean 'Q'	T (Range)	Mean 'T'
Very High	14.21	15.5	Nazerth group and Dino formation undiffirentiated (NQS)	> 30l/s	35	40.6 – 96.6	68.6
High	29.53	32.9	Ignimbrite and Pyroclast (Qdi)	10-20 l/s	15	17.5-32.7	25.1
Moderate	26.87	28.95	Ignimbrite, Pyroclast and tuff (Qdi)	5-10 l/s	7	13.4-17.5	15.45
Low	10.1	11.24	Pumice, unwelded tuff and pitch stone (QWPU, QWO)	< 5 l/s	3	< 8	5

5.11.3. Validation with Borehole Yield Data

In order to validate the classification of the groundwater potential zones as revealed by the GIS based groundwater potential map, data on existing wells (yield) were collated for over 50 boreholes in and around the study woreda area and from this data the boreholes that have yield data and the depth of the boreholes range from 250m to 400m was used for the validation.

The borehole data were superimposed on the groundwater potential map and numbers of wells with different yield ranges for different groundwater potential zones were evaluated. Generally, the yields of the boreholes in the study area is over 30 lit/sec in very high potential zones and varying from 10 lit/sec to 20 lit/sec in high potential zones as compared with 10 lit/sec to 5 lit/sec (in the moderate and less than 5 lit/sec in the low potential zones (Figure 5.99). As shown in the figure 5.99, the occurrence of number of wells with yield of in the range 10- 20 lit/sec (high yield) and of > 30 lit/sec (very high yield) cut across mainly the Ignimbrite and pyroclasts. However, the less frequency of wells within tuff and pumice area in the low yield category signifies the generally low potential of these rocks as highlighted by the GIS-based potential map. This is consistent with the low, moderate, high and very high groundwater potential classification of the GIS map for these rocks' unit.

The validation clearly highlights the efficiency of the integrated RS and GIS methods employed in this study as useful modern approach for proper groundwater resource evaluation and sustainable groundwater development. Nonetheless, the groundwater potential zonation presented here can be applied only for regional studies for the purpose of groundwater development, providing quick prospective guides for groundwater exploration and exploitation in such basement and sedimentary settings, while individual site selection for groundwater development should take into consideration other site-specific conventional ground-truthing methods.

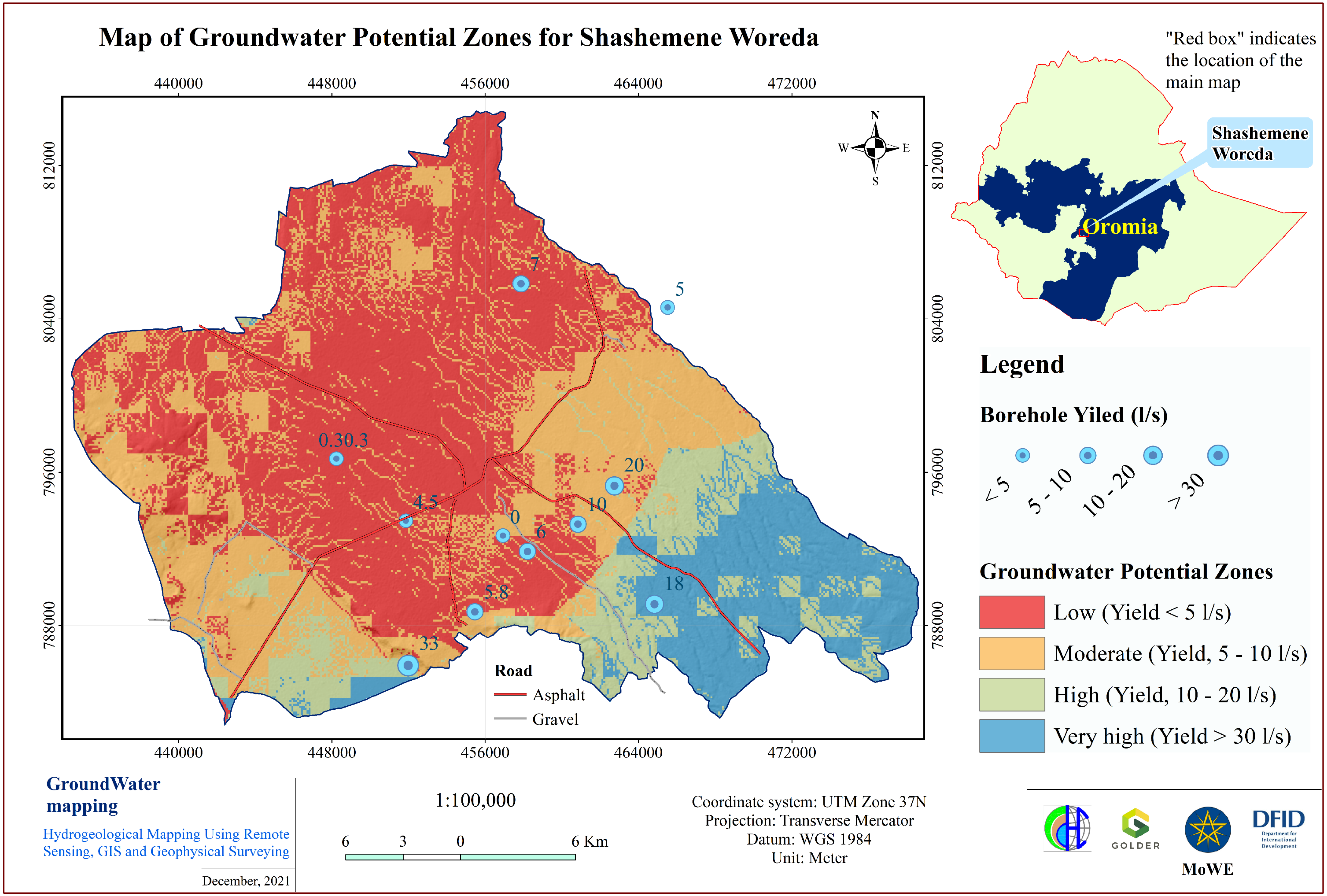

Figure 5.99: Map of groundwater potential zones showing four zones identified by the GIS overlay analysis in Shashemene Woreda

5.11.4. Population projection and water demand

5.11.4.1. Population

It is essential that the water supply system is designed to meet the requirements of the population expected to be living in the community at the end of design period by taking into account the design period and annual growth rate. Hence in order to avoid or minimize the aforementioned population related risks, efforts are made to review & justify the credibility of the available population data and growth rate figures.

Population projection is made making use of the geometric growth rate method by using the base population figure estimated by the central statistical Authority. The CSA has set average growth rates for urban and rural areas of the country varying at different times during the design period as shown in the table below. Accordingly these values are adopted in forecasting future population of the town.

Table 5-31 CSA Rural Population Growth Rates

Rural Population Projection Growth Rate of Regions: 2008-2037						
YEAR / Growth Rate % (Rural)	2008-2012	2013-2017	2018-2022	2023-2027	2028-2032	2033-2037
Oromia Region	2.74	2.54	2.29	2.03	1.8	1.56
SNNP Region	2.49	2.37	2.31	2.03	1.82	1.57
Somali Region	2.75	2.63	2.35	2.05	1.89	1.83
Gambela Region	3.52	3.1	3.13	2.76	2.46	2.31

Source: CSA Population Projection for Ethiopia 2007-2037, Addis Ababa July 2013

Geometric method forecasting formula

$$P = Po\,(1 + r)^{n}$$

Where P – projected population
Po – current population
n – Number of years for projection
r – Population growth rate

The population of Shashamane Woreda has been projected forward until 2036 using the projected scale of Southern Nation Nationalities and Peoples Regional State. The minimum and maximum population in the Woreda is 64 and 22,285 respectively. The total population of the Shashamane Woreda in 2036 is going to be 443,479. Figure 5.100 presents the projected population for each kebele in the Woreda.

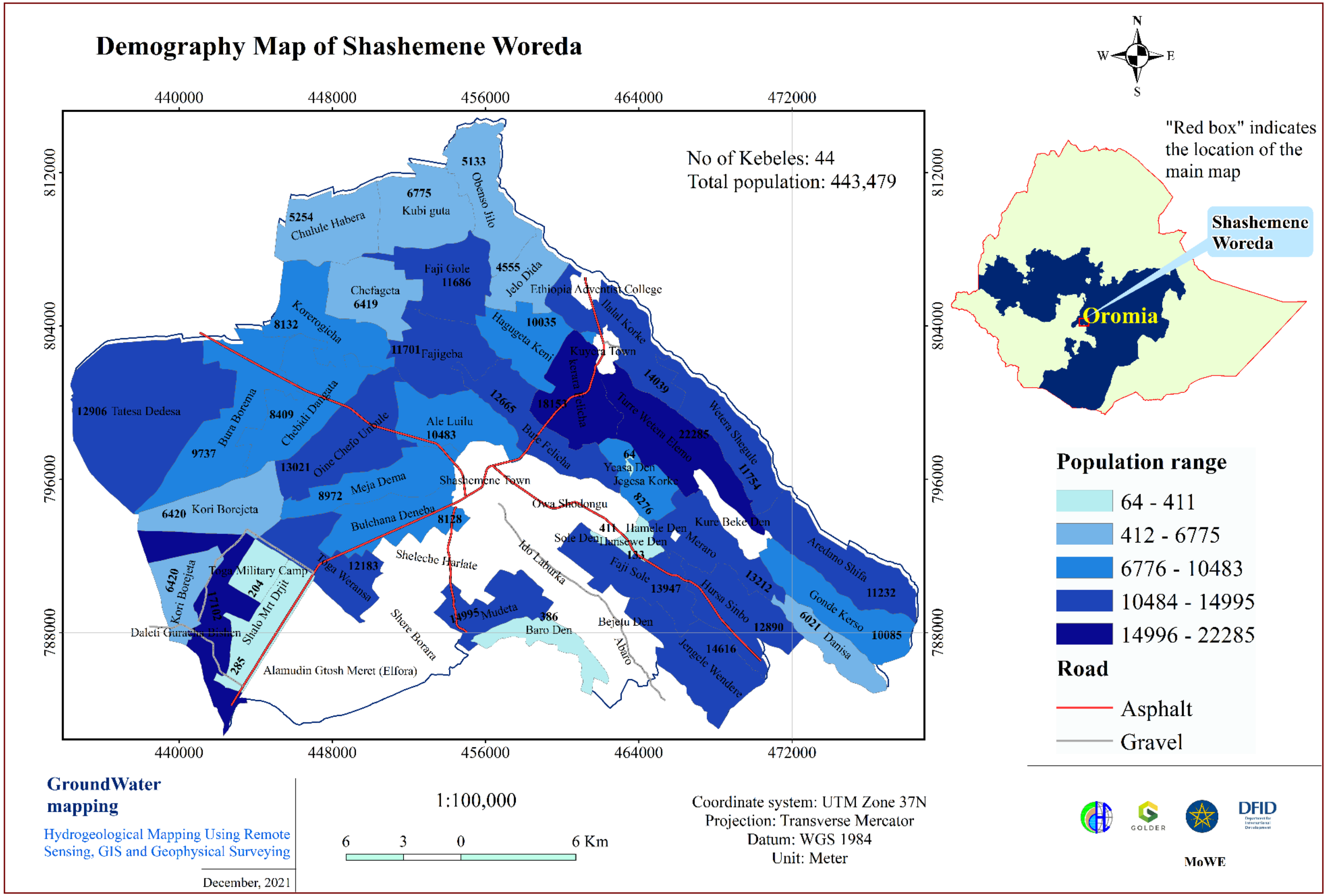

Figure 5.100 Map of projected population (2036) for Shashemene Woreda.

3.1.1.1 Water Demand Projection

Projected Water Demand

Estimating water demands mainly depends on the size of the population to be served, their standard of living and activities. To make the demand projection reliable and suitable for rural areas it is better to classify in details as domestic and non-domestic demands.

Domestic Water Demand

Domestic water demand is the amount of water needed for drinking, food preparation, washing, cleaning, bathing and other miscellaneous domestic purposes. The amount of water used for domestic purposes greatly depends on the lifestyle, living standard, and climate, mode of service and affordability of the users.

Domestic water demand service can be categorized according to the level of service to be provided and amount of per capita water required satisfying the demand served by the level of service. Modes of services used for our projection are classified into four categories, namely: -

- Traditional Source users (TSU)
- Public tap users (PTU)
- Yard connections and Neighbourhood (shared) connections (YCO) & (YCS)
- House tap connections (HTU)

In projecting the domestic water demand the following procedures were followed:

- Determining population percentage distribution by mode of service and its future projection
- Establishment of per capita water demand by purpose for each mode of service;
- Projected consumption by mode of service;
- Adjustment for climate;
- Adjustment due to socio-economic conditions.

After considering the necessary mode of services, per-capita demand and applying the adjustment factors the domestic demand for the corresponding year and population has been calculated.

Non-Domestic Water Demand

Non-domestic water demand was also determined systematically. We have classified it into three major categories based on our projection:

- Institutional water demands (Public and governmental);
- Commercial water demand;
- Livestock water demand

N.B:- The use of a reliable base population figure is very important for optimizing the water sources but adopting 2007 CSA data as a base population has real impact on the projection so to compensate some unforeseen situation like migration and unplanned rural town growth. To compensate for such

- To estimate the demand of public institutions and commercial services we have adopted 15% - 20% of the domestic demand for our consumption.
- The demand for livestock watering adopted in the projection is 10% -15% of the domestic demand.

Total Average daily day demand

The average daily day demand is taken to be the sum of domestic demands and non-domestic demand. The water demand in a day varies with time according to the consumer's life style. It is the total sum of adjusted domestic, public and livestock demand.

Maximum Day Demand

The maximum day demand is the highest demand of any one 24 hour period over any specific year. It represents the change in demand with season. This demand is used to design source capacity. The deviation of consumption from the average day demand is taken care of as per the maximum daily coefficient figures. Usually a value from1.1 to 1.3 is adopted as maximum day factor. A constant value of 1.3 is adopted as maximum day factor for all of the villages.

Figure 5.101 shows the distribution of water demand in each Kebeles of the Woreda. The minimum and maximum water demand for Kebeles is 6 M^3/day and 942 M^3/day respectively. The overall water demand for the projected population in the Shashamane Woreda is 39,847 M^3/day.

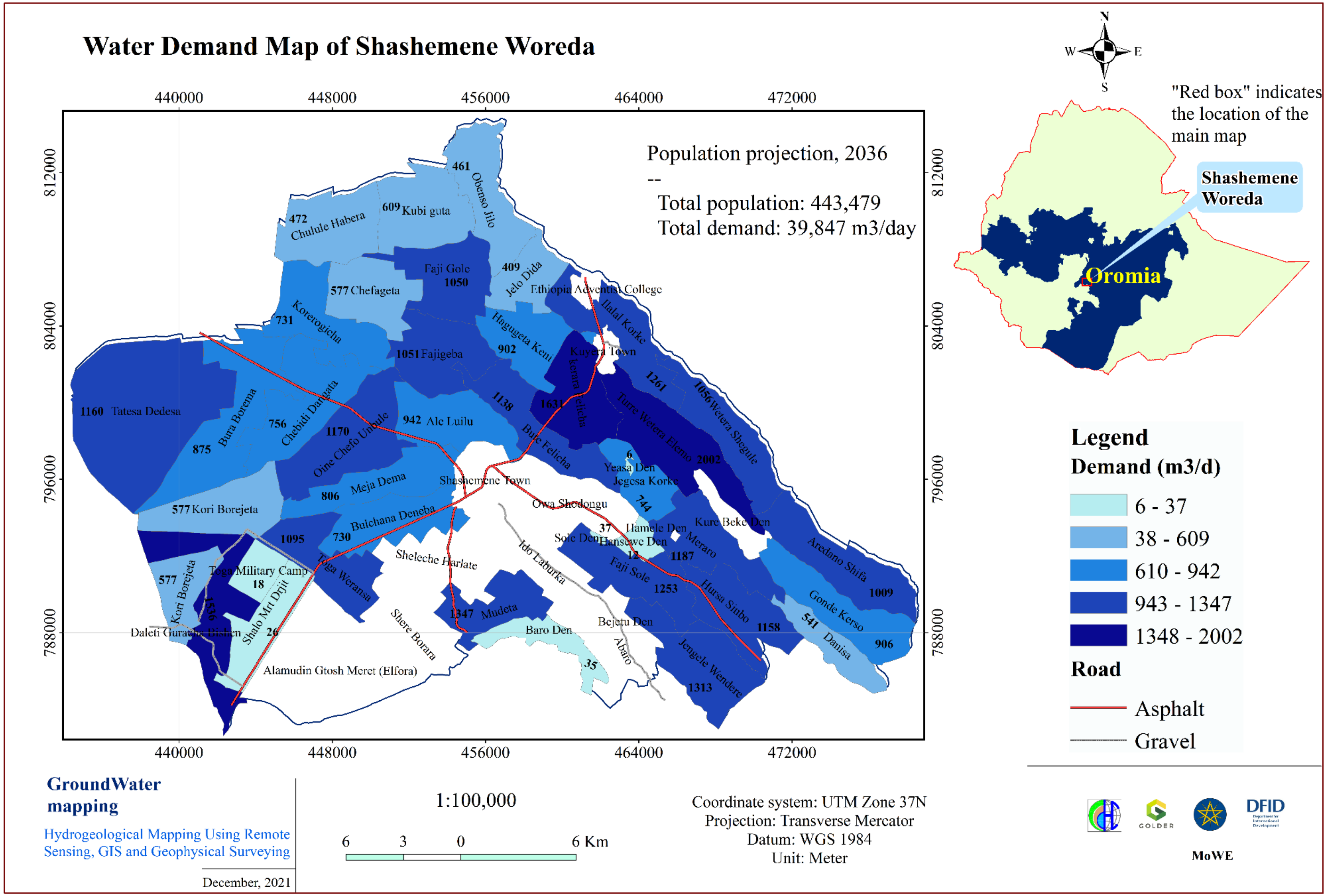

Figure 5.101: Map of water demand (M^3/day) for Shashemene Woreda.

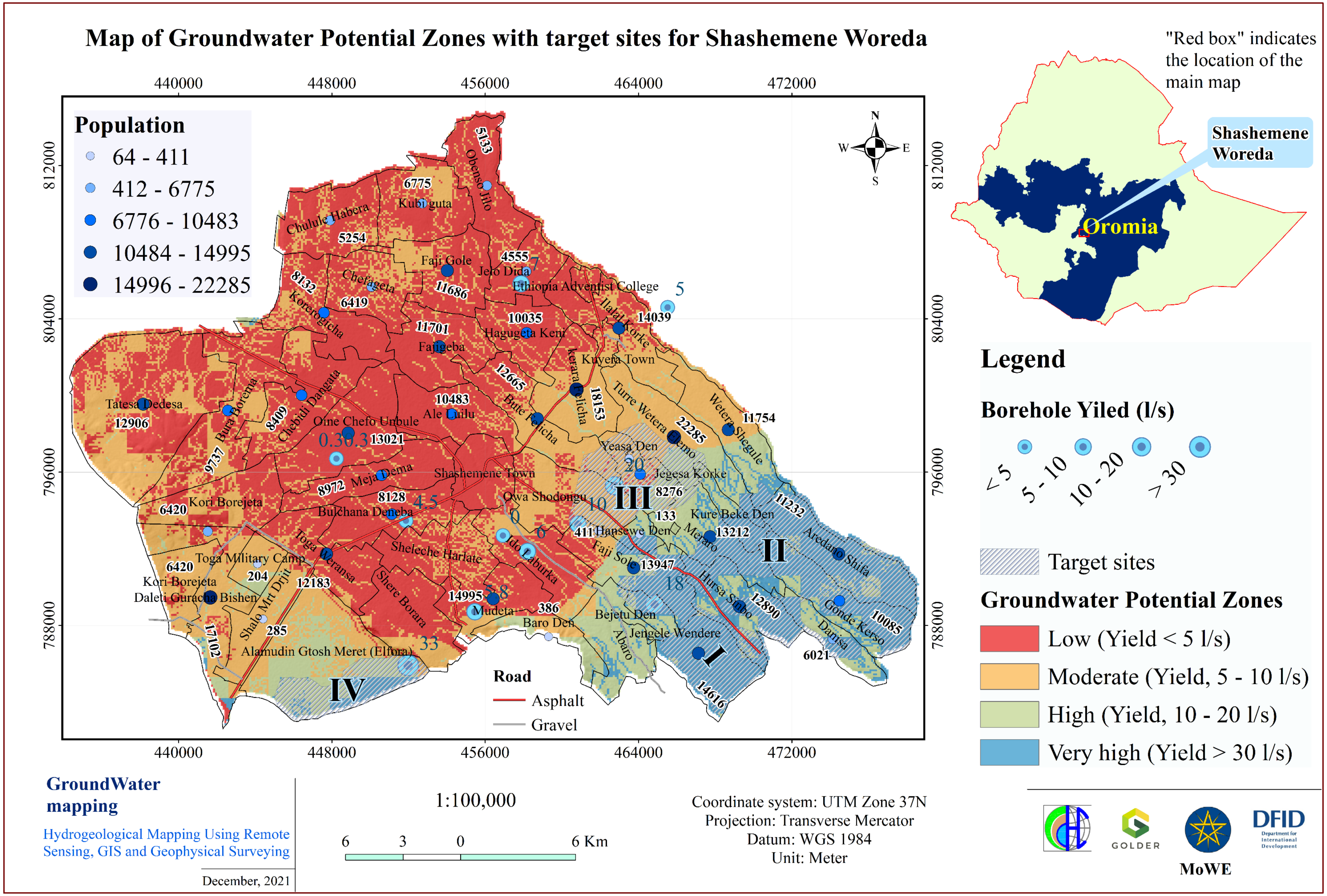

Figure 5.102: Map of groundwater potential zones with selected target sites in Shashemene Woreda

5.11.5. Proposed Target Sites

Four target sites are identified and proposed within the woreda based on the identified groundwater potential zones, the productivity of the hydrostratigraphic units with their expected optimum borehole yield, proximity to beneficiaries and population density. With further discussion and consultation with stakeholders, two priority sites will be selected for further hydrogeological and geophysical investigations in phase III. The following are the four proposed sites:

Target Site-I:

This target site is located in the southern part of the woreda in Faji Sole, Jengele wender, and Bejitu Den kebeles. It is situated in the identified Very high potential zones with expected optimum borehole discharge of greater than 20 l/s. This target site is mainly underlain by quaternary recent deposits of alluvial and lacustrine sediments and also volcanic rocks (Pumice, basalt, trachyte, and ignimbrite).

Target Site-II:

This target site is located at southeastern part of the woreda, around Hursa Simbo, Gonde Kerso, Aredano Shifa and Kure Beke kebele area. It is situated mainly in the identified high groundwater potential zone.

Target Site-III:

This target site is located at central eastern part of the woreda, Eastern of Melka Oda area. It is situated mainly in the identified Moderate groundwater potential. This target site is mainly underlain by weathered ignimbrite, basalt, trachyte pyroclast and unconsolidated sediments.

Target Site-IV:

This target site is located in the southernn part of the woreda, towards eastern of Shallo area. It is situated in the identified very high potential zones with expected optimum borehole discharge of greater than 30 l/s. This target site is mainly underlain by quaternary recent deposits of alluvial and lacustrine sediments and also volcanic rocks (Pumice, basalt, trachyte, and ignimbrite). Although, thist site has high groundwater potential in the, the fluoride concentaration needs further detail investigation in next phaseIII work.

5.11.6. Conceptual hydrogeological model of Shashamanne Woreda

Hydrogeological conceptual models are collections of hypotheses based on geological structural and geomorphological evidences and existing wells lithologic logs to describe and understand the groundwater occurrence, localization and movement beneath the ground surface. The purpose of the hydrogeological model across inferred groundwater flow direction is to reflect the prototype of regional groundwater flow system into the two priority sites selected for further study in phase III. In the conceptual model, groundwater head represents the regional groundwater table along with Shashamanne geological section which marks most important aquifers and physical boundaries.

The conceptual hydrogeological models for this woreda to be constructed along/across groundwater flow path will be produced after stake holder consultation work shop to select priority target sites for further hydrogeological characterization. This conceptual hydrogeological model summarizes what is known about the hydrogeological system and thereby provides a framework for hydrogeological system of the target woreda at broad scale including the following.

- ✓ Shashamanne groundwater flow zone (inflow, groundwater flow paths, inferred depth, and outflow).
- ✓ Groundwater condition of target woreda area such as delineate inferred groundwater table from existing data (spring, river and boreholes).

5.12. Liben Woreda

The four thematic layers which were integrated for groundwater potential mapping in Liben Woreda are summarized in Table 5.32 below. The notes on the description of each thematic layers including classification of potential zones, validation with borehole and scheme datasets, population projection, water demand and selected target sites presented in the sub-sections.

Table 5-32 Assigned and normalized weights for the individual features of the four thematic layers for groundwater potential zoning

Theme	Class	Groundwater Prospect	Weight assigned	Normalized weight	Rank	Area (Km2)	Area (%)
Geology/ Lithology, 'GG'	Tertiary volcanics and quaternary deposits of recent alluvium	Very good	4	0.50	0.43	601.78	29
	Mesozoic sedimentary rocks and quaternary alluvium deposits	Good	3	0.33		1,554.87	1
	Basement rocks	poor	1	0.17		5,240.84	70
Lineament Density,' LD' (Km/Km2)	0 - 0.23	poor	1	0.10	0.28	1,539.65	21
	0.24 - 0.47	Moderate	2	0.20		2,192.82	30
	0.48 – 0.70	Good	3	0.30		2,466.17	33
	0.71 – 0.93	Very good	4	0.40		1,227.64	16
Topographic Wetness Index, 'TWI'	4.19 – 7.34	poor	1	0.10	0.21	2,534.4	34
	7.35 – 9.1	Moderate	2	0.20		3,251.96	43
	9.11 – 11.8	Good	3	0.30		1,156.5	16
	11.9 – 19.1	Very good	4	0.40		483.55	7
Recharge, 'GR' (mm/y)	23.2 – 28.5	poor	1	0.10	0.08	6715.46	90
	28.6 – 48	Moderate	2	0.20		109.65	1.5
	48.1 – 97	Good	3	0.30		252.99	3.5
	97.1 - 190	Very good	4	0.40		348.79	4.5

5.12.1. Integration of Thematic Layers for Groundwater Potential Zoning

The details of geology, rainfall, lineament density, geomorphology, land slope, soil type, land use/land cover, groundwater depth and drainage density together with their spatial distribution in Liben woreda are presented below:

I. Geology/lithology

In general, most parts of the Liben woreda are underlain by basement complexes of intrusive granitic and gneissic rocks. Tertiary volcanics and quaternary alluvial deposits are mostly found in central and southern areas. Whereas most sedimentary formations of limestone and sandstone rocks outcropped at the central and eastern parts of the woreda.

However, the lithological units found in the woreda are further classified into three major groups based on their significances to groundwater occurrence and productivity using borehole data on yield and transmissivity analysis in particular.

- Tertiary volcanics and quaternary alluvial deposits (high productive with Qav. = 5.4 l/s)
- Mesozoic sedimentary rocks and quaternary alluvium deposits (moderate productive with Qav = 4.6 l/s)
- Basement rocks of granitic and gneissic rocks overlain by thin eluvium soils at places (low productive with Qav = 1.25 l/s)

The crystalline basement rocks are the main lithologic framework of the Liben woreda which together covered a total area of about 5,240.8 Km2 or 70 % of the woreda area, Tertiary volcanics and quaternary alluvial deposits covered about 601.78 Km2 (1 %), and Mesozoic sedimentary rocks and quaternary alluvium deposits covered about 1,554.7 Km2 or 29 % of the woreda area (Figure 5.103).

Usually, massive unfractured lithologic units in sedimentary and basement complex settings have little influence on groundwater availability except in cases with secondary porosity through the development of karstification and weathered overburden, and fractured bedrock units, which form potential groundwater zones. Hence, on the basis of the presence and nature of the weathered regolith units, karstification and fracture systems, appropriate weights are assigned to the different lithological units in the study area. The weightage in terms of increasing groundwater potentiality is in the order of poor productivity of basement rocks (0.17), moderate productivity of Tertiary volcanics and quaternary alluvial deposits (0.33) and high productivity of Mesozoic sedimentary rocks and quaternary alluvium deposits (0.50).

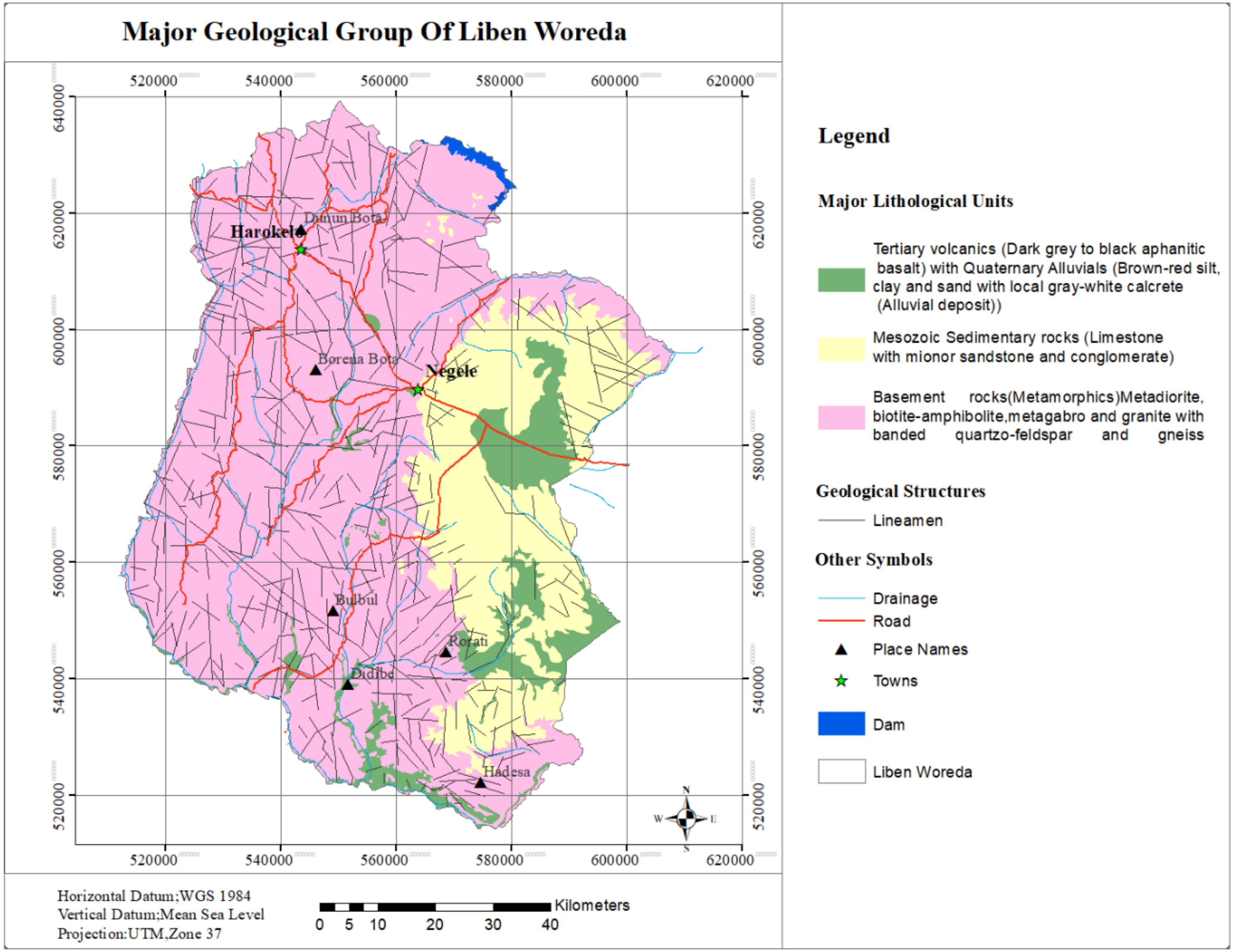

Figure 5.103: Map of lithology class for Liben Woreda

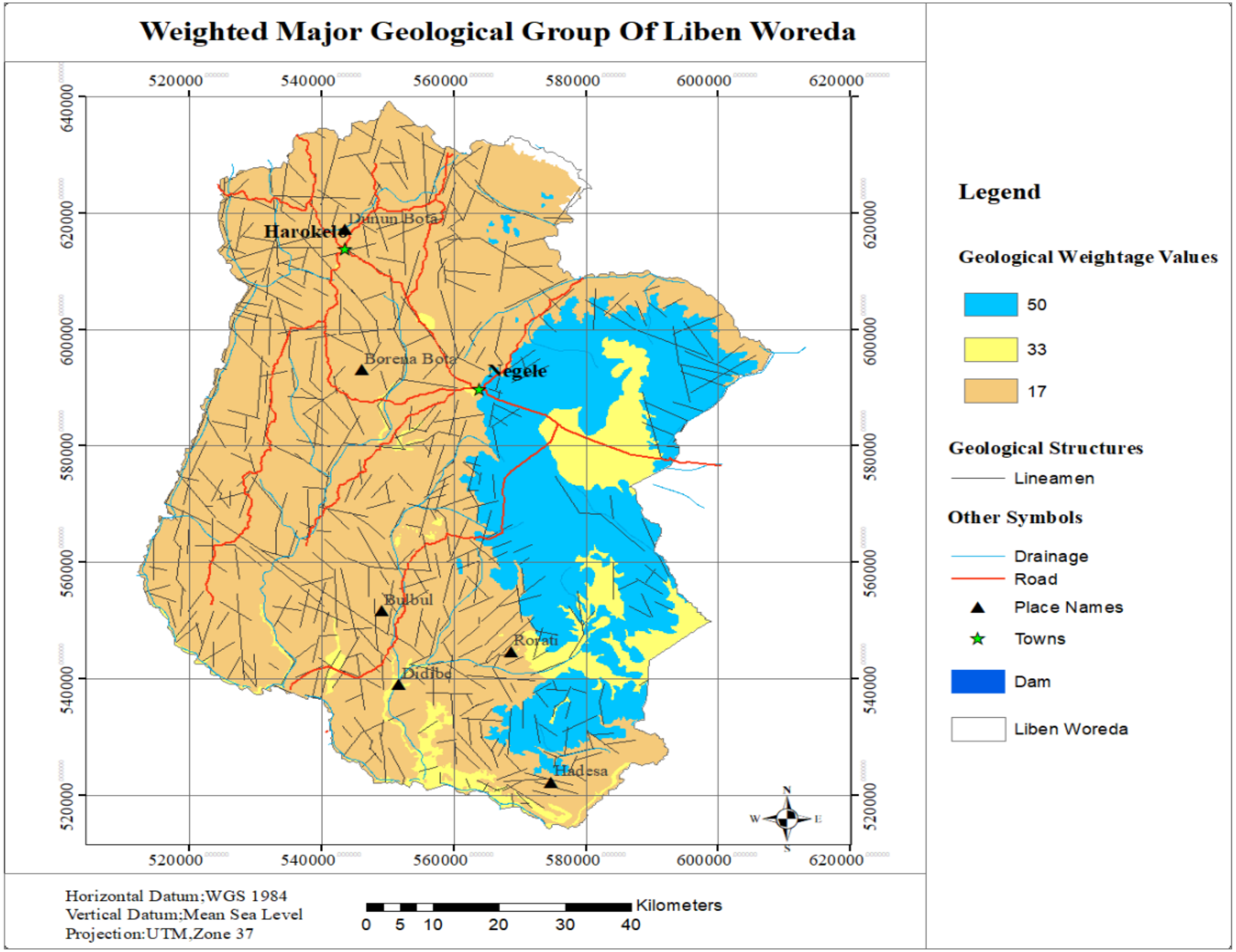

Figure 5.104: Map of weighted lithology class for Liben Woreda

II. Lineaments and lineament density

The study area is highly affected by lineaments and/or fractures consequent to a number of tectonic activities in the past. Two prominent directions identified are N–S and NW-SE trending lineaments. Usually, lineament density map is a measure of quantitative length of linear feature per unit area which can indirectly reveal the groundwater potentials as the presence of lineaments usually denotes a permeable zone. For most of the study area, the lineament density varies from less than 0.3 km/Km2 to 2.0 km/Km2 (Figure 5.105). Though the lineaments are widespread across the study area, however, the distribution of lineaments suggests geologic control with areas underlain by crystalline basement complex associated with Basement rocks having relatively higher lineament density of 1.1-2.0 km/Km2) compared with areas underlain by quaternary alluvium deposits with lower lineament densities of (< 0.3 km/Km2).

Thus, areas with higher lineament density are regarded as good for groundwater development. Consequently, higher weightage of 0.4 was assigned to area with high density of lineaments, while a low weightage of 0.1 was assigned to areas with low lineament density (Figure 5.106).

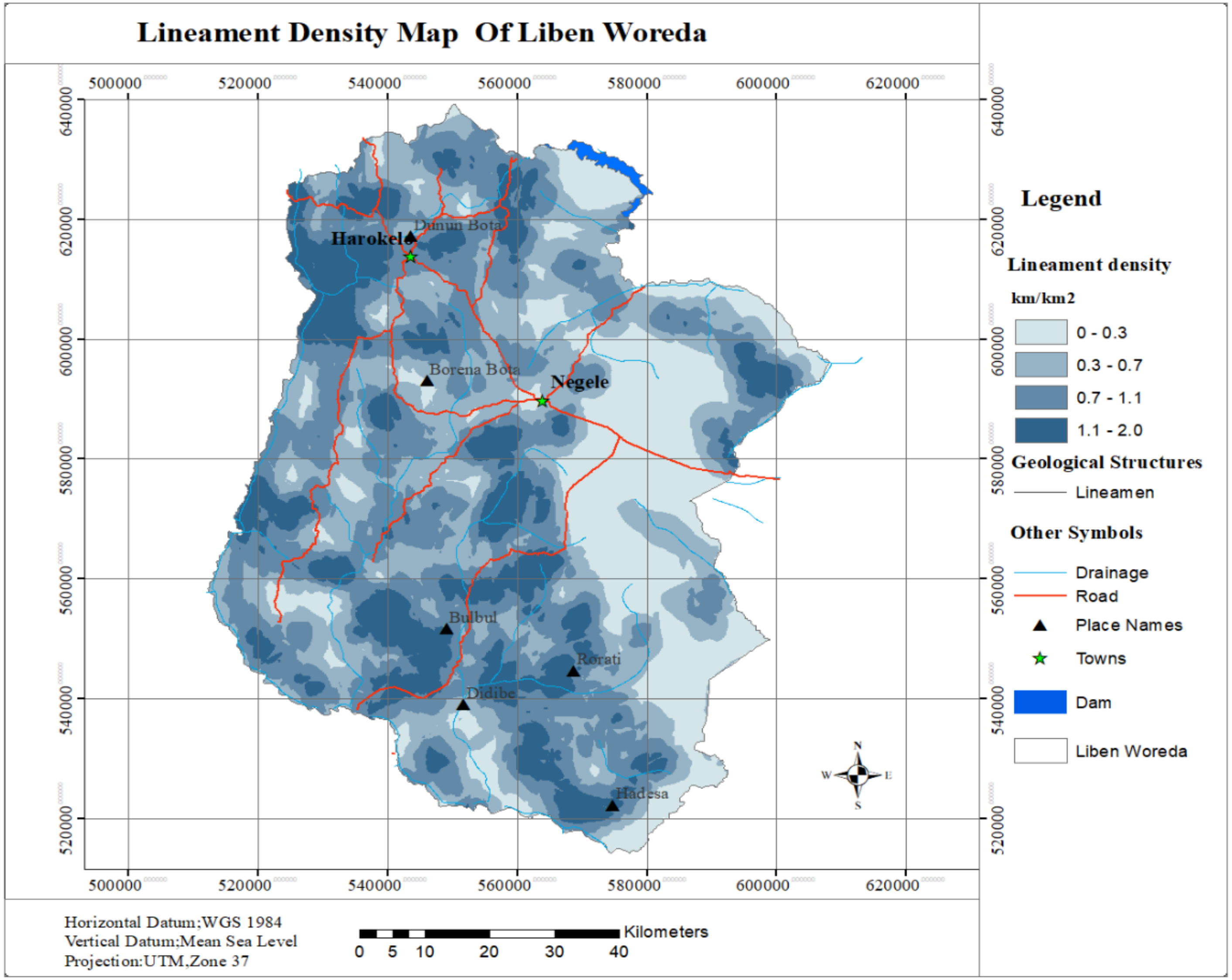

Figure 5.105: Map of lineament density for Liben Woreda

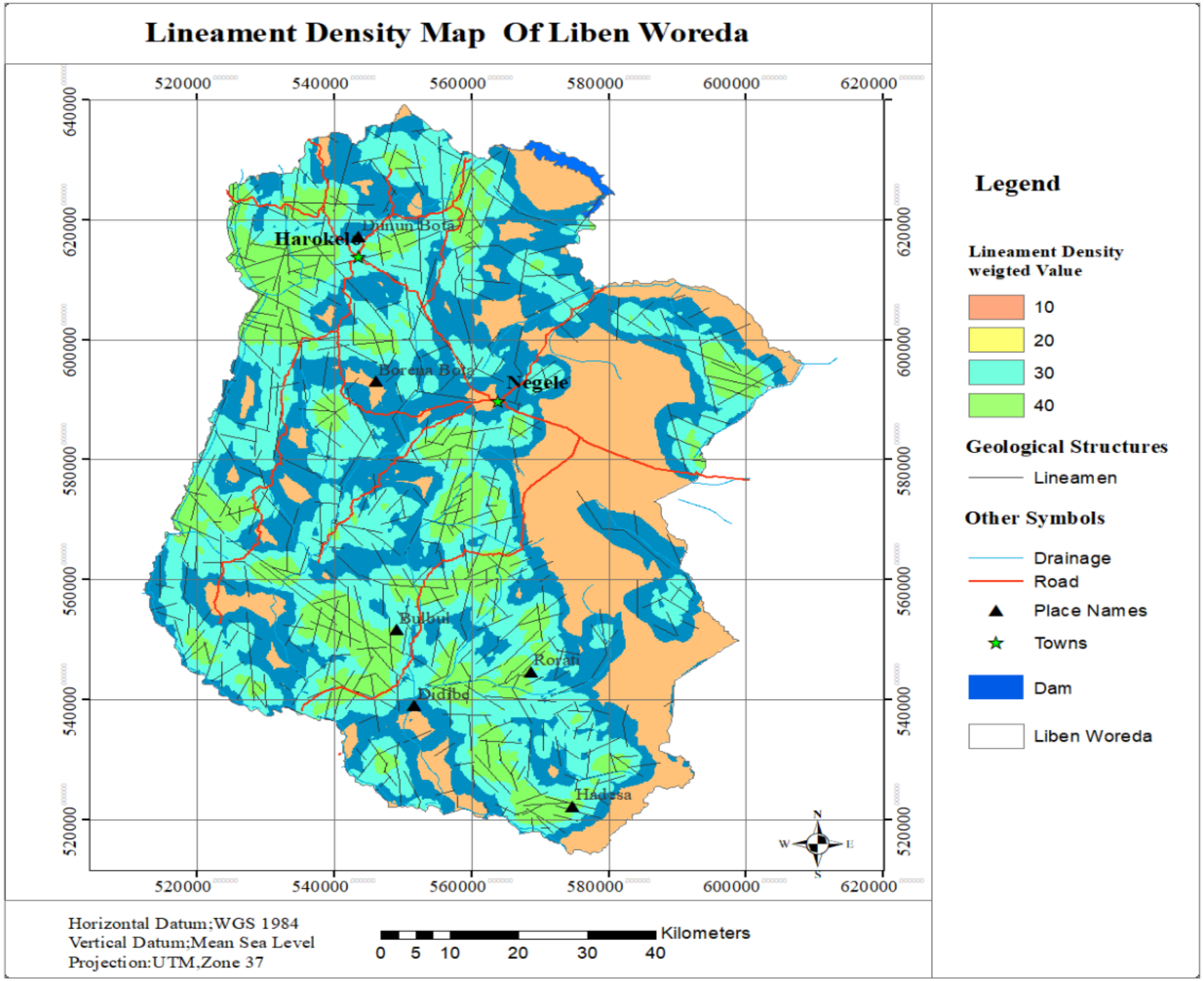

Figure 5.106: Map of weighted lineament density for Liben Woreda

III. Topographic Wetness Index (TWI)

In this study area, the TWI value ranges between 4.6 and 19.5. A closer look at the classification revealed that most the high elevated areas and drainage systems with steep slopes have relatively lower TWI value while the low-lying areas and drainage systems with gentle and flat slopes area in eastern and southern regions in particular have relatively higher wetness index value where runoff waters from highlands flow and accumulates mostly. Therefore, an area with higher value of TWI has good prospect for groundwater occurrence and flow, and accordingly high weightage value (0.4) was assigned to this class. Whereas, areas with lowest TWI value are steep slopes which triggers runoff were considered with low groundwater prospect and given low weightage value (0.1).

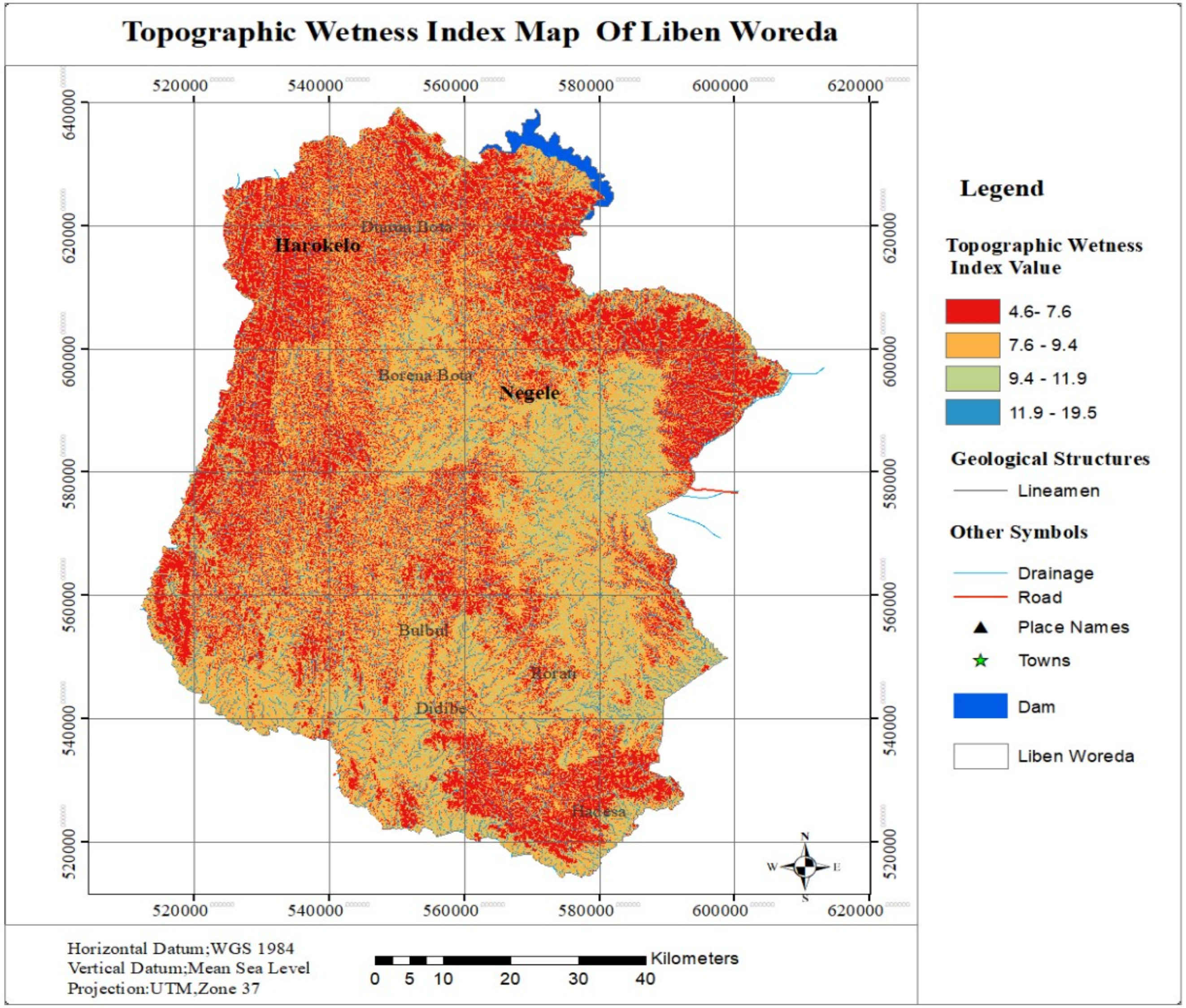

Figure 5.107: Map of topographic wetness index (TWI) for Liben Woreda

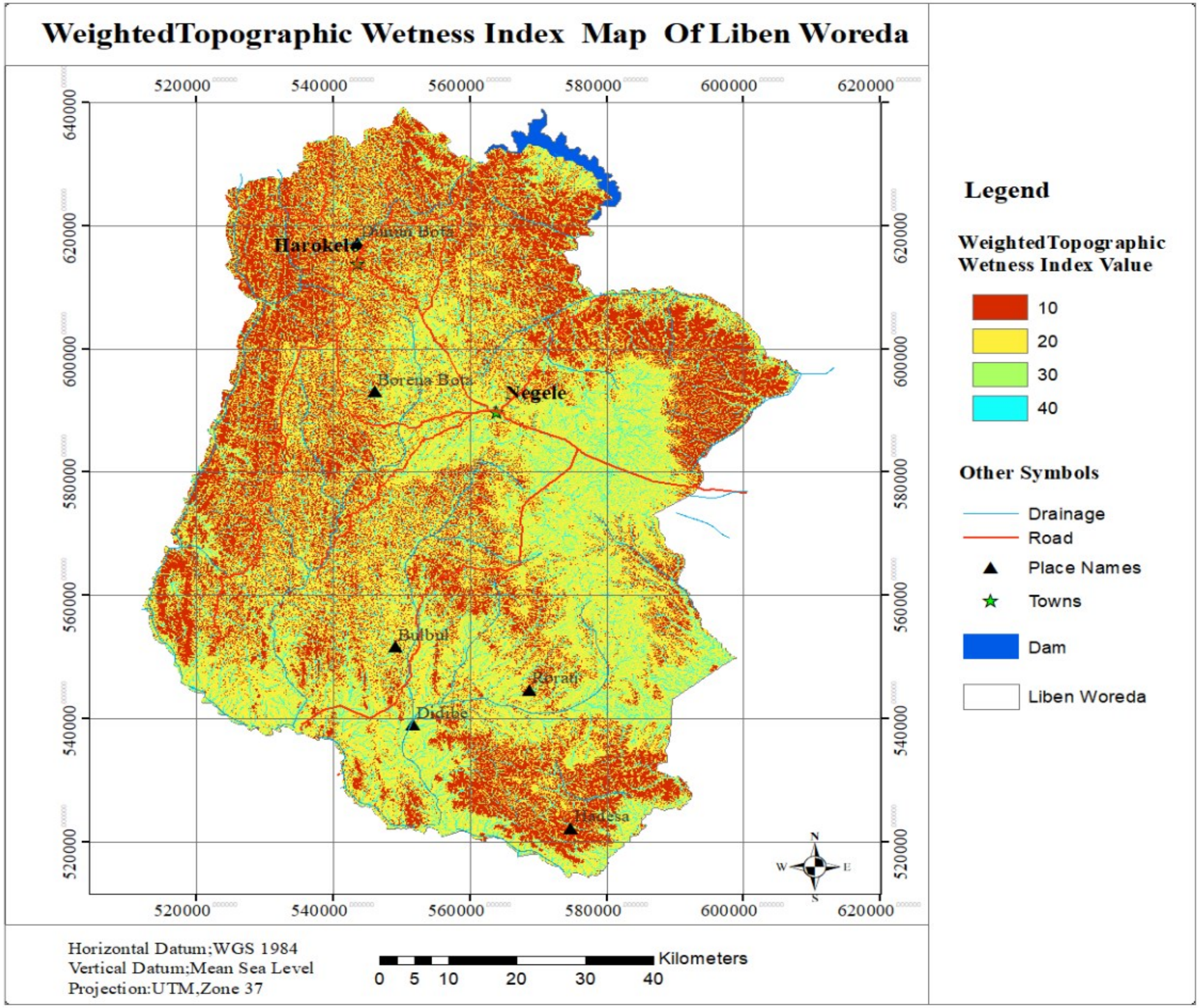

Figure 5.108: Map of weighted topographic wetness index (TWI) for Liben Woreda

IV. Recharge

The 10 years spatial annual recharge rate distribution in the Liben woreda ranges from 0 to 179.6 mm suggesting groundwaters in most part of the woreda area underlain by basement complex receive low amount of recharge while areas underlain by sedimentary rocks and quaternary sediments have relatively higher recharge amount (Figure 5.109). Accordingly, areas with higher and moderate amount of recharge have weightage factor of 0.4 and 0.3, respectively signifying High and moderate groundwater potential which covers about 348.79 Km2 (4.5 %) and 252.99 Km2 (3.5 %), respectively while areas with the lowest amount of recharge have weightage factor of 0.1, suggesting poor groundwater potentiality and represent about 6,715.46 Km2 (90 %). A closer look at the recharge thematic map revealed that most of the central and eastern low-lying parts of the woreda have relatively lower recharge (< 30 mm/y). Generally, the study area is characterized with very low to low mean annual recharge amount, whereas only limited areas at western and northern parts have moderate to high mean annual recharge amount (47.8-179.6 mm).

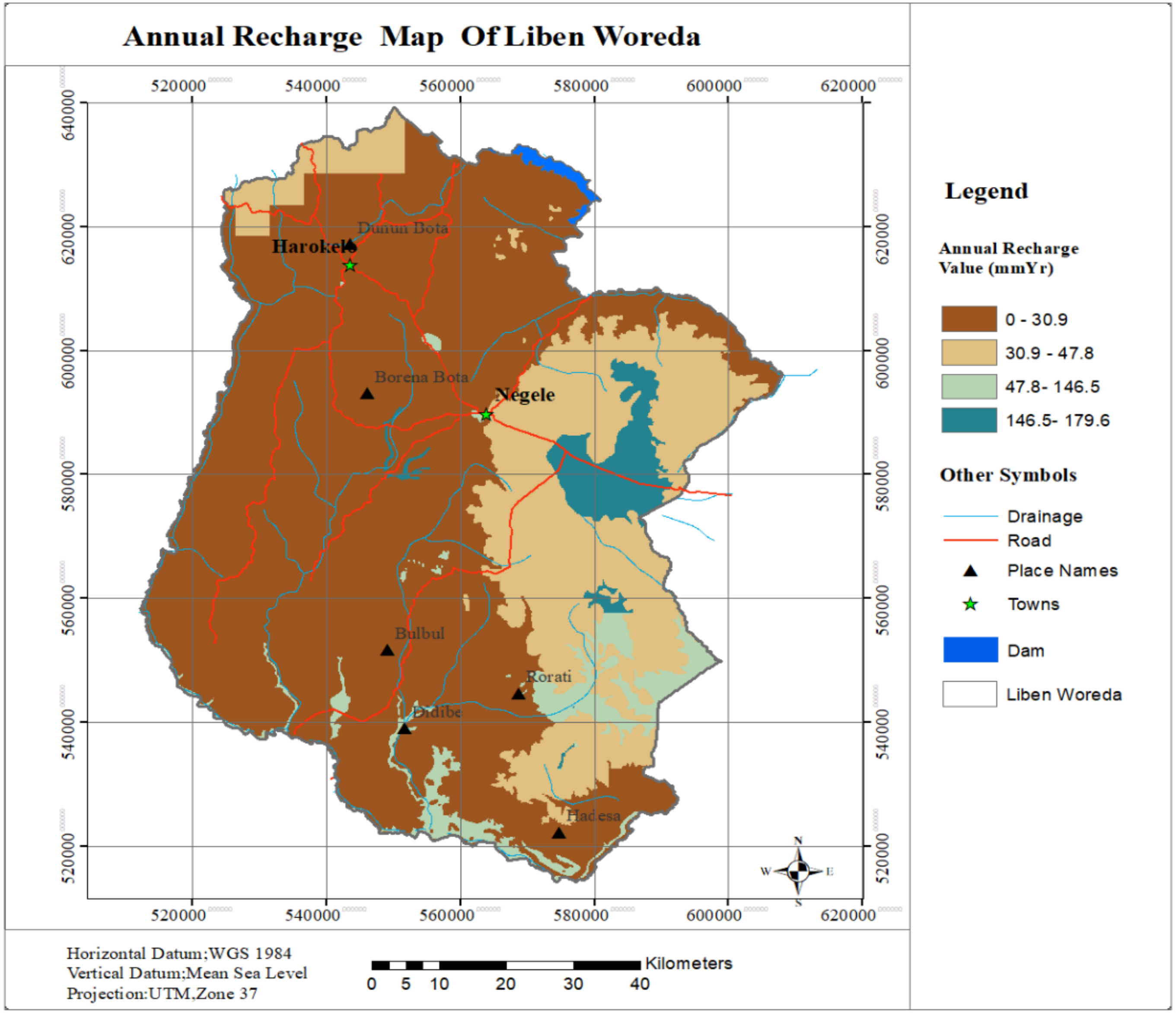

Figure 5.109: Map of yearly (mm/year) recharge for Liben Woreda

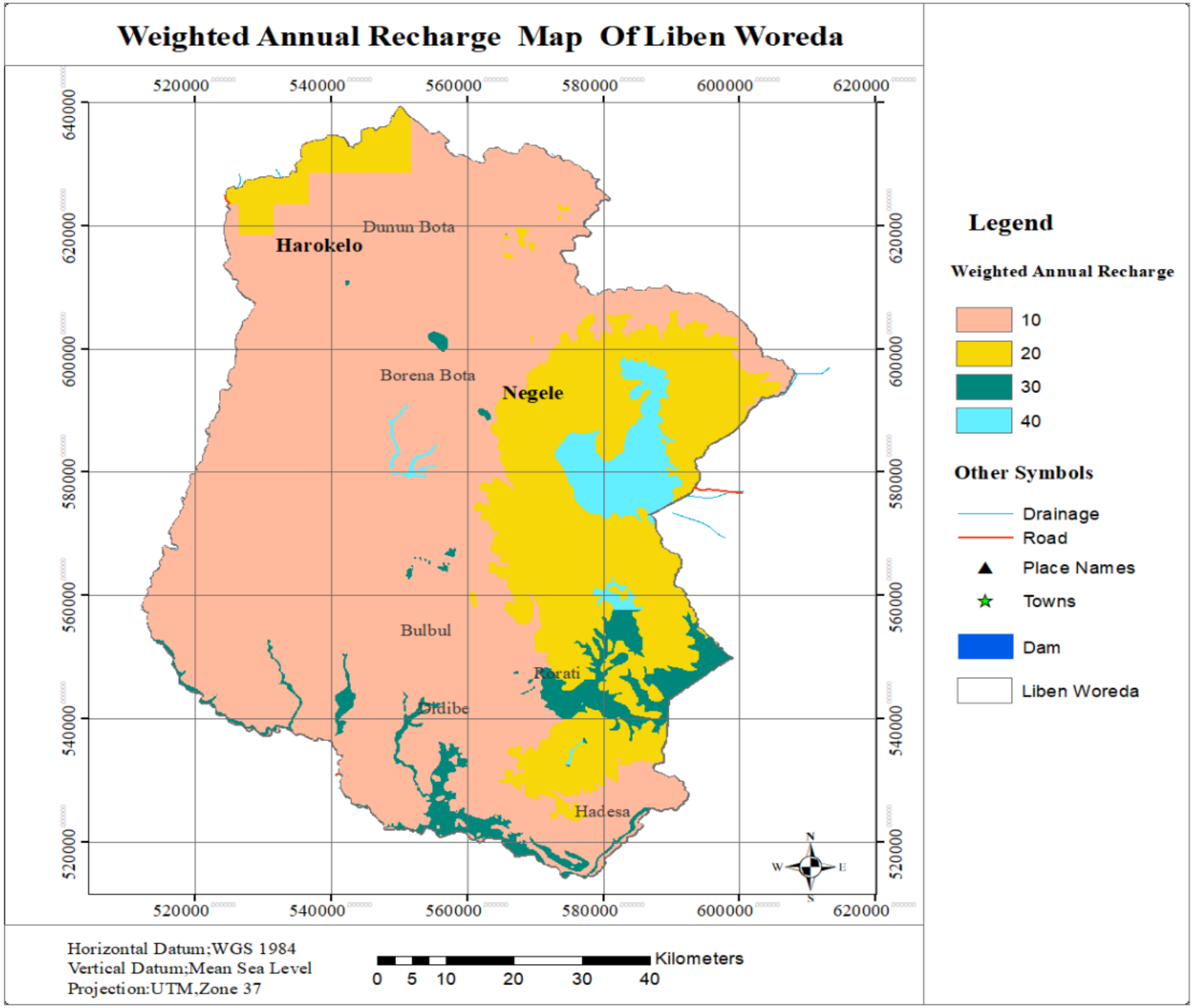

Figure 5.110: Map of weighted yearly (mm/year) recharge for Liben Woreda

5.12.2. Classification of Groundwater Potential Zones

The hydrogeological system of Liben woreda is comprised of three main lithological units as Tertiary volcanics and quaternary deposits, Mesozoic Limestone Formation and Basement Rocks. At regional scale, Quaternary deposits form extensive and high productive aquifers. Within the domain of Liben woreda also theses, Quaternary deposits form aquifers with high groundwater potential.

At regional scale, the Mesozoic Limestone Formation and lower sandstone form extensive and moderately productive aquifers having high hydraulic conductivity. However, at local scale, within the domain of Liben woreda, due to the geomorphic setup, the Mesozoic Limestone Formation and the underlying units form moderate potential aquifer as revealed from existing borehole information.

Only the upper weathered and slightly fractured part of the crystalline basement rocks along lineamnets and faults have potential to store groundwater at shallow depth. Weathered and slightly fractured Crystaline basement rocks with overlying Quaternary deposit form major potential aquifer within the domain of Liben Woreda along lineament and fault lines and associated plains. Hydrogeological data from water point inventory, hydro-chemical data and geophysical investigation outcome of the next phase will help to improve the understanding of hydrogeological frame work of the area.

On the basis of the assignment and normalized weighting of the individual features of the thematic layers, a potential groundwater index map was produced (Figure 5.111). The potential groundwater zones (PGZ) of the Liben woreda revealed four distinct zones, namely Vert low, low, moderate, and high zones whose distribution and extents are 5,136.02 Km2 (70 %), 1,689.08 Km2 (23 %), 347.35 Km2 (4 %) and 254.44 Km2 (3%), respectively as presented in Table 5.24.

The potential map, as presented in Figure 5.111, gives a quick assessment of the occurrence of groundwater resources in the study area. The groundwater potential map revealed that most elevated areas around the peripheries and western parts of the Liben Woreda generally have very low potentials with area coverage of about 70 %, while limited areas at central eastern regions generally exhibits high to moderate potentials representing about 3% and 4 % of the study area, respectively. The generally high to moderate groundwater potentiality of the study area as reflected by 7 % coverage is a confirmation of generally moderate to high productive aquifers of Mesozoic sedimentary rocks, tertiary volcanics in association with quaternary alluvial deposits, whereas low groundwater potential areas have an indication of limited aquifers capabilities of basement complex terrain.

Furthermore, a closer assessment of the groundwater potential map revealed that the distribution is more or less a reflection of the geology and lineament density in addition to the topographic wetness index control. In addition, areas underlain by recent quaternary deposits especially in the central eastern and southern sections of the study area which are characterized by relatively plain land with flat slope and higher recharge amount due to the presence of dense lineaments and apparently deep fracturing and weathering have high and moderate groundwater potential on the one hand. On the other hand, areas underlain by crystalline basement complexes in the majority of the woreda areas are characterized by small ridges and steep slopes, lower recharge and lineament densities, exhibit low groundwater potential while areas underlain by sedimentary rocks associated with sediments have medium potential. Moreover, high drainage densities and predominance of crystalline rock outcrops can be attributed to the observed low groundwater potentials at the most western and peripheries of the study area. However, predominance of recent sediments and sedimentary rock outcrops, low drainage density, high recharge and low slope which can enhance infiltration of water into the groundwater system can be attributed to the observed high groundwater potential exhibited at northern and northwestern portions of the study area. Summary of the groundwater potential zones identified in the Liben woreda is presented in the table below (Table 5.33).

Table 5-33. Classification of groundwater potential zones and coverage areas alongside the respective yield categories in Liben Woreda

GWP Zones	Area (Km2)	Area (%)	Major Aquifer Units	Borehole Yield Classification (l/s)
High	254.44	3.0	Tertiary volcanics and Quaternary alluvial Sediments (Qal2 & Qls)	>7
Moderate	347.35	4.0	Sedimentary Rocks and Quaternary alluvial (Qal1)	3-7
Low	1,689.08	23.0	Sedimentary Rocks (Jh1 & Ja)	1-3
Very Low	5,136.02	70	Basement rocks (Pgt1, Pgt2, Pugn, Pgtgn, Pqfs)	<1

5.12.3. Validation with Borehole Yield Data

In order to validate the classification of the groundwater potential zones as revealed by the GIS based groundwater potential map, data on existing wells (yield) were collated for boreholes in and around the study woreda area.

The borehole data were superimposed on the groundwater potential map and numbers of wells with different yield ranges for different groundwater potential zones were evaluated. Generally, the yields of the boreholes in the study area vary from >7 lit/sec in high potential zones and varying from 3 lit/sec to 7 lit/sec in moderate potential zones as compared with 1 lit/sec to 3 lit/sec in the low and <1 lit/sec in the very low potential zones (Figure 5.111). As shown in the figure, the occurrence of number of wells with yield in the range > 7 lit/sec (high yield) cut across mainly the Tertiary volcanics and quaternary deposits and sedimentary rocks. However, the less frequency of wells within basement rocks in the low yield category signifies the generally very low potential of these rocks as highlighted by the GIS-based potential map. In addition, the moderate-yield (3-7 lit/sec) and low-yield (1 - 3 lit/sec) categories are associated also with wells in the Mesozoic sedimentary rocks and quaternary alluvial deposits along river channel. This is also consistent with the very low, low, moderate and high groundwater potential classification of the GIS map for these rocks' unit.

The validation clearly highlights the efficiency of the integrated RS and GIS methods employed in this study as a useful modern approach for proper groundwater resource evaluation and sustainable groundwater development. Nonetheless, the groundwater potential zonation presented here can be applied only for regional studies for the purpose of groundwater development, providing aquick prospective guides for groundwater exploration and exploitation in such basement and sedimentary settings, while individual site selection for groundwater development should take into consideration other site-specific conventional ground-truthing methods.

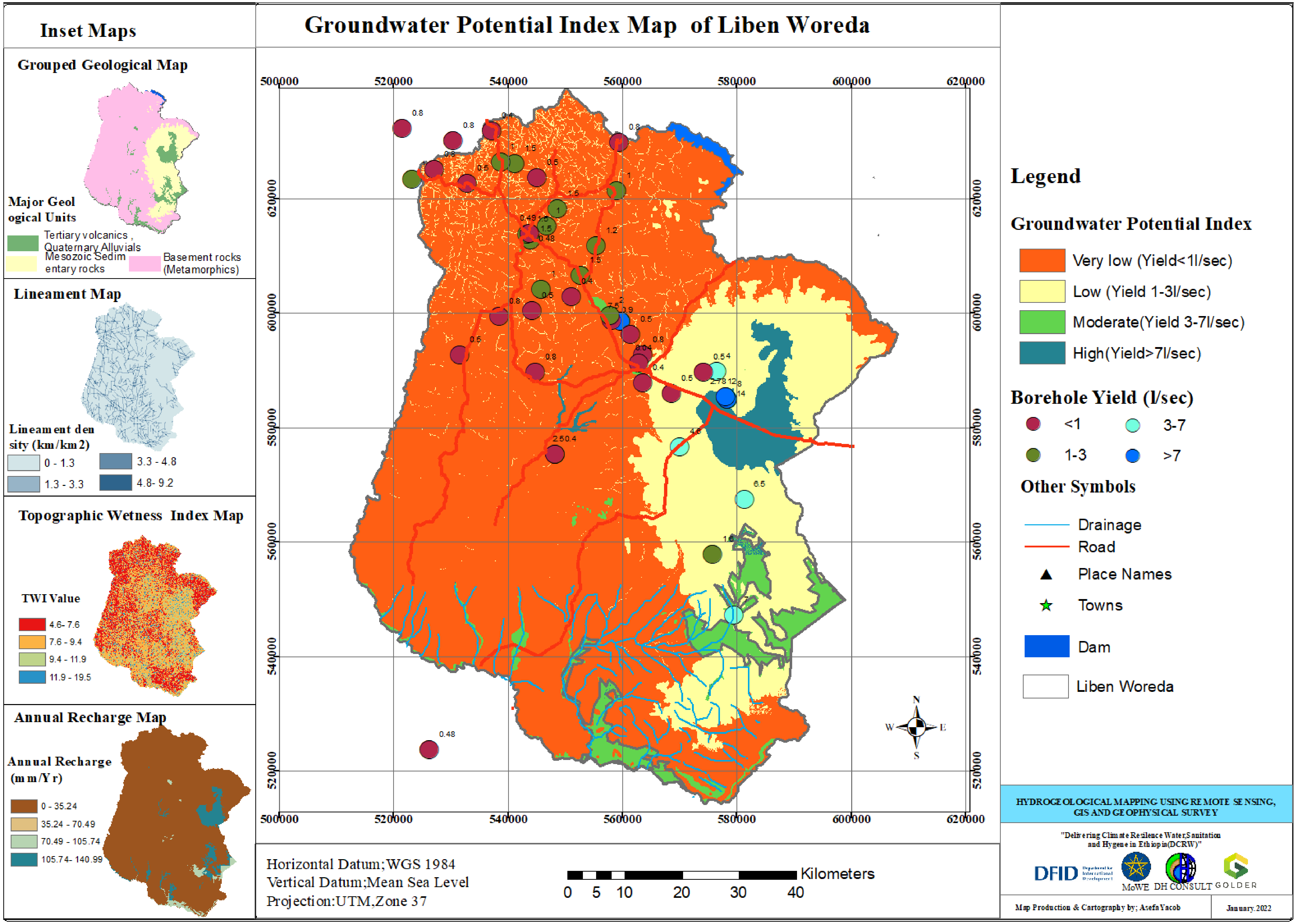

Figure 5.111: Map of groundwater potential zones showing four zones identified by the GIS overlay analysis in Liben Woreda

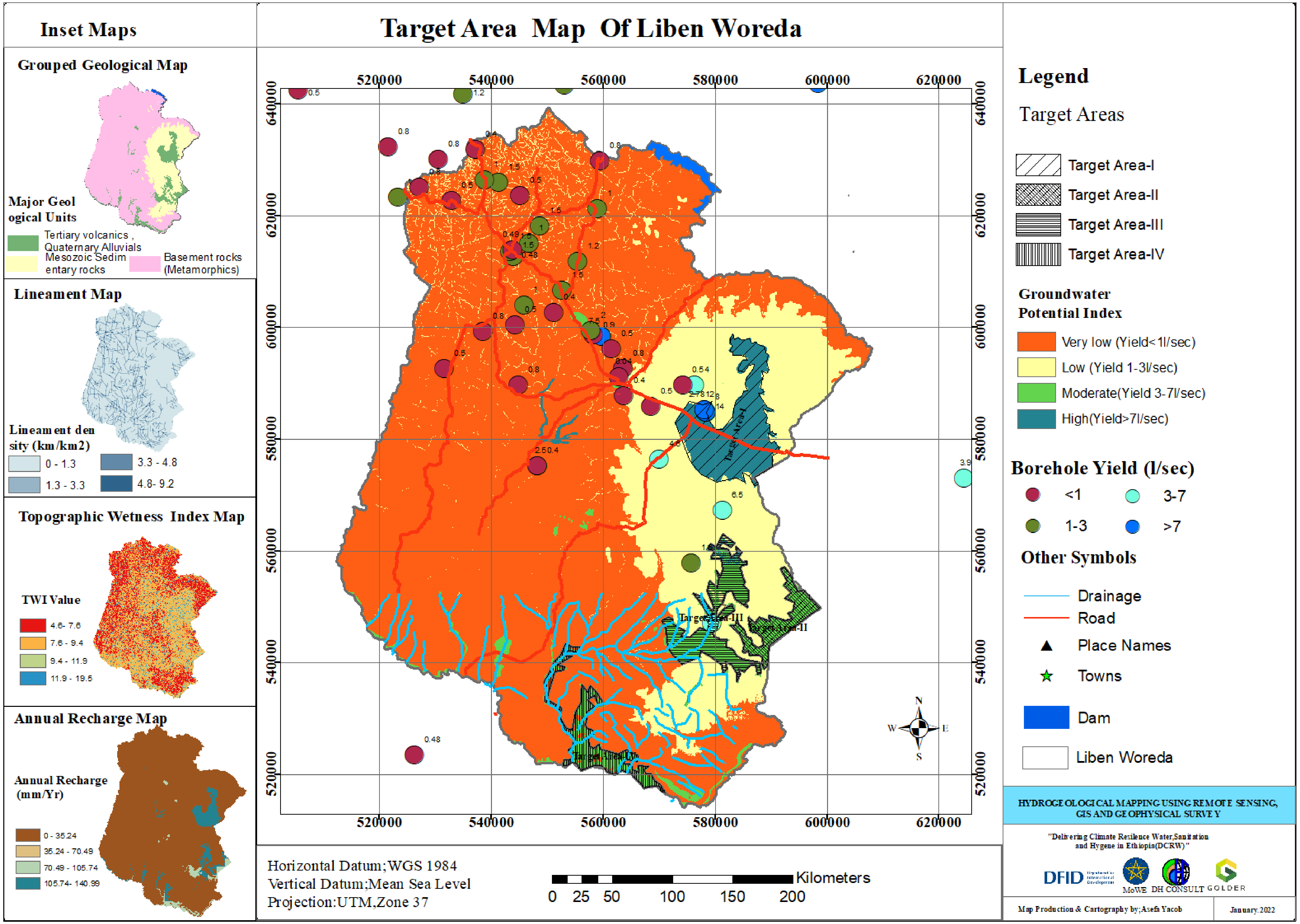

Figure 5.112: Map of groundwater potential zones with selected target sites in Liben Woreda

5.12.4. Propsed Target Sites

Four target sites are identified and proposed within the woreda based on the identified groundwater potential zones, the productivity of the hydrostratigraphic units with their expected optimum borehole yield, proximity to beneficiaries and population density. With further discussion and consultation with stakeholders, two priority sites will be selected for further hydrogeological and geophysical investigations in phase III. The following are the four proposed sites:

Target Site-I:

This target site is located in the eastern part of the woreda. It is situated in the identified high potential zones with expected optimum borehole discharge of about >7 l/s. This target site is mainly underlain by quaternary recent deposits of alluvial and Tertiary volcanics.

Target Site-II:

This target site is located in the eastern part of the woreda. It is situated in the identified high potential zones with expected optimum borehole discharge of about >7 l/s. This target site is mainly underlain by quaternary recent deposits of alluvial and Tertiary volcanics.

Target Site-III:

This target site is located in the eastern part of the woreda. It is situated in the identified high potential zones with expected optimum borehole discharge of about >7 l/s. This target site is mainly underlain by quaternary recent deposits of alluvial and Tertiary volcanics.

Target Site-IV:

This target site is located in the eastern part of the woreda. It is situated in the identified high potential zones with expected optimum borehole discharge of about >7 l/s. This target site is mainly underlain by quaternary recent deposits of alluvial and Tertiary volcanics.

Proposed target sites are identified, prioritized and selected within the woreda based on the identified groundwater potential zones, the productivity of the hydrostratigraphic units with their expected optimum borehole yield, proximity to beneficieries, population density and discussion made with the woreda's stakeholders so that to understand and identify kebeles with sever water shortage in particular. Accordingly, four priority target sites were selected and delineated within the Liben woreda for detail studies to be carried out in order to verify further and locate appropriate borehole drilling sites.

5.12.5. Conceptual hydrogeological model of Liben Woreda

Hydrogeological conceptual models are collections of hypotheses based on geological structural and geomorphological evidences and existing wells lithologic logs to describe and understand the groundwater occurrence, localization and movement beneath the ground surface. The purpose of the hydrogeological model across inferred groundwater flow direction is to reflect the prototype of regional groundwater flow system into the two priority sites selected for further study in phase III. In the conceptual model, groundwater head represents the regional groundwater table along with major geological section which marks most important aquifers and physical boundaries. Liben woreda is characterized both with high and lowlands formed mainly from post tectonic intrusive granite with exposures of thin layers of Mesozoic limestone and sandstone in some areas affected by geological strucures. Quaternary sediments overlying the sedimentary and crystalline basement rocks are important for groundwater storage in the area.

This region has a compartimentalized groundwater flow system constrained by geology, geological structres and topography. Groundwater gets recharge mainly from local rain that falls on central and a northeast surrounding highland with expected lateral inflow from northwest adjacent highlands. Groundwater flow direction is generally towards southwest and central lowlands through alluvial plain and weathered crystalline basement rocks. Development of the hydrogeological conceptual model of the target Woreda area shall be prepared based on the converging evidence of secondary data including digital elevation model (DEM), geological and hydrogeological maps and structures, lithological well logs

The conceptual hydrogeological models for this woreda to be constructed along/across groundwater flow path will be produced after stake holder consultation work shop to select priority target sites for further hydrogeological characterization. This conceptual hydrogeological model summarizes what is known about the hydrogeological system and thereby provides a framework for hydrogeological system of the target woreda at broad scale including the following.

- ✓ Major groundwater flow zone (inflow, groundwater flow paths, inferred depth, and outflow).
- ✓ Groundwater condition of target woreda area such as delineate inferred groundwater table from existing data (spring, river and boreholes).

CHAPTER 6 : CONCLUSIONS AND RECOMMENDATION

6.1. Conclusion

Multidisciplinary integrated approach has been employed to characterize the areas for groundwater occurrence, localization and flow dynamics. Four thematic layers (Geology/lithology, Lineaments/ lineament density, Topographic Wetness index and groundwater recharge) were produced to be integrated into groundwater potential zones. Integration and overlay analysis of thematic layers by assigning weights depending on their hydrogeological significance helps to identify four to five groundwater potential zones:

- Very high groundwater potential zones,
- High groundwater potential zones,
- Moderate groundwater potential zones,
- Low groundwater potential zones and
- Very low groundwater potential zones.

From the general overview of mapping the groundwater potential zones geological units, structures, geomorphology play significant role in groundwater occurrence, localization and flow characteristics. The target sites selected based on the overlay analysis have groundwater at different depths depending on the litho-stratgraphic set-up of the sub-surface.

Three to four target sites were selected for further discussion with stake holders at woreda level to prioritize two for further study in phase III. Conceptual hydrogeological model lines orientation for the two target sites will be determined ones the target sites are determined. Conceptual models will be produced at woreda and target site scale.

6.2. Recommendations

Based on the groundwater potential zones mapping result the following recommendations are given:

- Four priority target sites are proposed given consideration to better groundwater potential and proximity to the target community. In consultation with stakeholders, two sites will be selected out of the proposed sites for further hydrogeological study in phase III. Conceptual hydrogeological model summarizes what is known about the hydrogeological system and thereby provides a framework for hydrogeological system of the area, hence the conceptual models will be constructed along/across groundwater flow path ones the stake holder consultation work shop conducted and priority sites identified,
- Detail field based hydrogeological study that include water point inventory and hydrogeological mapping is recommended including water quality assessment,
- The overlay analysis methods employed in this study are recommended as a preliminary approach to identify the most suitable priority sites or areas for further geophysical and hydrogeological studies.

- Geophysical investigation using Vertical Electrical Sounding approach is recommended to be conducted at two identified target sites where the lateral electrode spread depends on the nature of the aquifer material identified in this phase and AB/2 will be determined based on the actual data obtained during the survey.

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ANNEX-POTENTIAL MAPS OF 12 WOREDAS (A0 & A1 Sizes)

Appendix-II. Population and Water Demand

Table 1 - Population projection and water demand for Bule Hora Woreda

Kebeles	Population 1999	Population 2012	Population 2021	Population 2036	Water Demand (M^3/day)
Gadu Jebesera	5,171	7,264	7,264	9,693	871
Hera Lipitu	7,387	10,376	10,376	13,847	1244
Dego Bulicha	6,822	9,583	9,583	12,788	1149
Sakichs	8,563	12,028	12,028	16,052	1442
Har Tume Lema	6,288	8,833	8,833	11,787	1059
Rusa Hanika	7,119	10,000	10,000	13,345	1199
Meta Lema	9,321	13,093	13,093	17,473	1570
Mereteure Kuma	10,537	14,801	14,801	19,752	1775
Chere Gulelcha	3,755	5,275	5,275	7,039	632
Dnibela Hara	4,798	6,740	6,740	8,994	808
Gelena Metera	5,700	8,007	8,007	10,685	960
Sororo Melika Jowa	3,066	4,307	4,307	5,747	516
Mediba	3,169	4,451	4,451	5,941	534
Soymba Suro	2,869	4,030	4,030	5,378	483
Motokuma Hara	5,369	7,542	7,542	10,065	904
Bule Kenga	3,359	4,718	4,718	6,297	566
Burika Ebela	4,067	5,713	5,713	7,624	685
Dibisa Ogo	6,199	8,708	8,708	11,620	1044
Sarij Ela Bedessa	9,194	12,915	12,915	17,235	1548
Kilonso Mokoniso	8,106	11,386	11,386	15,195	1365
Kilonso RESA	10,316	14,491	14,491	19,338	1737
Galesa Burika	8,904	12,507	12,507	16,691	1500
Galesa Negesso	8,982	12,617	12,617	16,837	1513
Sorle Wachu	11,263	15,821	15,821	21,113	1897
Kelencha Muruti	9,779	13,736	13,736	18,331	1647
Kelebeletu Say	8,917	12,526	12,526	16,716	1502
Miringo Korobo	7,663	10,764	10,764	14,365	1291
Beruidaye Chebiti	10,866	15,263	15,263	20,369	1830
Kuya	6,553	9,205	9,205	12,284	1104
Buda Meganda	5,171	7,264	7,264	9,693	871
Ropi	7,522	10,566	10,566	14,101	1267
Dekisa Chebeti	10,866	15,263	15,263	20,369	1830
Yemengiste Den	1,583	2,224	2,224	2,967	267
Total	**229,244**	**322,016**	**322,016**	**429,735**	**38,610**

Table 2 - Population projection and water demand for Mirab Abaya Woreda

Kebeles	Population 1999	Population 2012	Population 2021	Population 2036	Water Demand (M^3/day)
Qorga Geramo	1,186	1,902	1,634	2,178	196
Qola Mulatu	3,179	5,099	4,379	5,837	524
Wanke Wagefo	4,547	7,293	6,264	8,349	750
Qola Barana	2,180	3,496	3,003	4,003	360
Zela Barena	2,735	4,387	3,768	5,022	451
Weye Barena	3,238	5,193	4,460	5,946	534
Dega Shengola	1,772	2,842	2,441	3,254	292
Yayeqea	2,627	4,213	3,619	4,824	433
Doshe	1,130	1,812	1,557	2,075	186
Moreda	2,160	3,464	2,975	3,966	356
Zala Gutesha	6,739	10,808	9,283	12,374	1,112
Layo Terga	2,627	4,213	3,619	4,824	433
Fetla Dronge	847	1,358	1,167	1,555	140
Alge	2,864	4,593	3,945	5,259	472
Dalbo	2,963	4,752	4,082	5,441	489
Menena	1,797	2,882	2,475	3,300	296
Mole	5,407	8,672	7,448	9,928	892
Ankober	6,067	9,731	8,358	11,140	1,001
Dega Done	3,533	5,666	4,867	6,487	583
Uomolante	6,746	10,820	9,293	12,387	1,113
Fura	1,698	2,723	2,339	3,118	280
Faragosa	1,371	2,199	1,889	2,517	226
Uogayo	1,720	2,759	2,369	3,158	284
Birbir-Town	5,834	32,832	8,037	10,712	962
Total	**74,967**	**143,712**	**103,270**	**137,654**	**12,367**

Table 3 - Population projection and water demand for Konso Woreda

Kebeles	Population 1999	Population 2012	Population 2021	Population 2036	Water Demand (M^3/day)
Fuchucha	1304	1,599	1,796	2,394	215
Beayide	5400	6,622	7,439	9,915	891
Tish Male	4637	5,687	6,388	8,514	765
Gelebo	5701	6,992	7,853	10,468	940
Arfayide	3578	4,388	4,929	6,570	590
Lehayite	4316	5,293	5,945	7,925	712
Sorobo	5189	6,364	7,148	9,528	856
Dera	3530	4,329	4,863	6,482	582
Jarso	11617	14,247	16,003	21,331	1,916
Naliya Segen	3780	4,636	5,207	6,941	624
Buso	3247	3,982	4,473	5,962	536
Mechelo	2699	3,310	3,718	4,956	445
Gocha	2640	3,238	3,637	4,848	436
Aba Roba	8266	10,137	11,387	15,178	1,364
Melegana Dugaya	2,227	3,757	3,068	4,089	367
Segen Gent	2,943	4,965	4,054	5,404	485
Garche	1,272	2,146	1,752	2,336	210
Ayilota Doketu	5,292	8,928	7,290	9,717	873
Addis Gebre	2,248	3,793	3,097	4,128	371
Becho	1,790	3,020	2,466	3,287	295
Birbirsa	5,947	10,034	8,192	10,920	981
Lulitu	6,233	10,516	8,586	11,445	1,028
Kemele	7220	11,329	9,946	13,257	1,191
Doha	8865	13,910	12,212	16,278	1,462
Fasha	6789	10,653	9,352	12,466	1,120
Gaho	8707	13,662	11,994	15,988	1,436
Mecheqe	2952	4,632	4,066	5,420	487
Gera	3015	4,731	4,153	5,536	497
Sew Game	3563	5,591	4,908	6,542	588
Gesergiyo	3470	5,445	4,780	6,372	572
Debeno	5401	8,475	7,440	9,917	891
Gargama	3088	2590	4,254	5,670	509
Turuba	1583	1328	2,181	2,907	261
Welango	2380	1996	3,279	4,370	393
Guma	4258	3571	5,866	7,819	702
Kerkerte	4163	3492	5,735	7,644	687
Iyana	2203	1848	3,035	4,045	363
Gewada	5967	5005	8,220	10,957	984
Kunyara	4781	4010	6,586	8,779	789
Borqara	6213	5211	8,559	11,408	1,025
Madoriyana Gizaba	9467	7940	13,041	17,383	1,562
Masoya	2542	2132	3,502	4,668	419
Gelgelena Qolmale	10516	8820	14,486	19,309	1,735

Tebelana Quchele	6679	5602	9,201	12,264	1,102
Kashile	4789	4017	6,597	8,794	790
Karat-Town	5788	8820	7,973	10,628	955

Table 4 - Population projection and water demand for Kochere Woreda

Kebeles	Population 1999	Population 2012	Population 2021	Population 2036	Water Demand (M^3/Day)
Kedida Giwa	3,568	4,837	4,915	6552	589
Haniku	3,171	4,299	4,368	5823	523
Baya	7,765	10,527	10,697	14258	1,281
Beloya	4,487	6,083	6,181	8239	740
Anonecha	5,500	7,457	7,576	10099	907
Shashemene	6,458	8,755	8,896	11858	1,065
Debo	5,699	7,726	7,851	10464	940
Buniki Busa	3,824	5,184	5,268	7022	631
Gololicha	3,795	5,145	5,228	6968	626
Boji	4,727	6,409	6,512	8680	780
Hama	6,477	8,781	8,922	11893	1,068
Kore	4,790	6,494	6,598	8795	790
Buno	4,458	6,044	6,141	8186	735
Sibaga	1,923	2,607	2,649	3531	317
Reko	5,270	7,145	7,260	9677	869
Shifo	10,109	13,705	13,926	18562	1,668
Jelido	5,192	7,039	7,152	9534	856
Anichebi	4,787	6,490	6,594	8790	790
Halo Aritume	8,817	11,954	12,146	16190	1,454
Chelelektu-Town	6,912	28,576	9,522	12692	1,140
Fiseha Genet-Town	3,694	6,795	5,089	6783	609
Total	**111,423**	**172,054**	**153,489**	**204,594**	**18,381**

Table 5 - Population projection and water demand for Kemba Woreda

Kebeles	Population 1999	Population 2012	Population 2021	Population 2036	Water Demand (M^3/day)
Garisa Hanika	7,240	9,054	9,973	13,294	1,183
Hanika Pasa	1,867	2,335	2,572	3,428	305
Maze	3,091	3,866	4,258	5,676	505
Dinigamo	3,806	4,760	5,243	6,989	622
Garisa Aniko	3,705	4,633	5,104	6,803	605
Bola Aniko	5,715	7,147	7,873	10,494	934
Hareniga Shele	3,233	4,043	4,454	5,936	528
Soriba	6,347	7,937	8,743	11,654	1,037
Bola Hanika	6,567	8,213	9,046	12,058	1,073
Otolo	3,374	4,219	4,648	6,195	551
Domobe Sale	1,715	2,145	2,362	3,149	280
Domobe Deliba	3,767	4,711	5,189	6,917	616
Balita Toyilo	4,647	5,811	6,401	8,533	759
Balita Kale	1,731	2,165	2,385	3,178	283
Balita Soke	2,570	3,214	3,540	4,719	420
Balita Tolata	3,165	3,958	4,360	5,812	517
Balita Koto	1,943	2,430	2,677	3,568	317
Balita Giyalo	2,306	2,884	3,177	4,234	377
Balita Yele	3,203	4,006	4,412	5,881	523
Balita Beke	4,357	5,449	6,002	8,000	712
Balita Telo	3,156	3,947	4,348	5,795	516
Boko Shele	4,873	6,094	6,713	8,948	796
Laea Geta Fudele	9,651	12,069	13,295	17,721	1,577
Domobe Sero	2,505	3,133	3,451	4,600	409
Shamela	4,451	5,566	6,131	8,173	727
Mero Shele	1,941	2,427	2,674	3,564	317
Mero	3,485	4,358	4,801	6,399	569
Osa Merichu	9,293	11,622	12,801	17,064	1,519
Total	**113,704**	**142,195**	**156,631**	**208,783**	**18,580**

Table 7 - Population projection and water demand for Burji Woreda

Kebeles	Population 1999	Population 2012	Population 2021	Population 2036	Water Demand (M^3/day)
Tinisha Keyate	1,650	2363	2,273	3,030	272
Gobeze	1,200	1718	1,653	2,203	198
Bereki	3,192	4571	4,397	5,861	527
Beneya	3,468	4966	4,777	6,368	572
Haleme	3,099	4437	4,269	5,690	511
Nedele	4,507	6454	6,209	8,276	743
Harale	1,224	1753	1,686	2,248	202
Walaya	2,446	3502	3,369	4,491	404
Gera	2,066	2958	2,846	3,794	341
Ladishe	2,713	3885	3,737	4,982	448
Raliyabila	2,006	2872	2,763	3,683	331
Raliyagoche	2,758	3949	3,799	5,064	455
Yebeno	2,245	3215	3,093	4,122	370
Denibecho	2,867	4105	3,949	5,264	473
Gude	1,261	1806	1,737	2,315	208
Otomolo	1,783	2553	2,456	3,274	294
Hara Weniji	528	756	727	970	87
Tisho	1,159	1660	1,597	2,128	191
Mure	1,825	2613	2,514	3,351	301
Dalia	1,231	1763	1,696	2,260	203
Lemo	1,997	2859	2,751	3,667	329
Sego	814	1166	1,121	1,495	134
Gemoyo	1,505	2155	2,073	2,763	248
Kilicho	1,779	2547	2,451	3,267	293
Mehamed Wele Irsha Limat	5	7	7	9	1
Ahimed Mehamed Irsha Limat	79	113	109	145	13
Total	**49,407**	**70,746**	**68,060**	**90,721**	**8,150**

Table 8 - Population projection and water demand for Amaro Woreda

Kebeles	1999	2012	2021	2036	Demand (m3/day)
Tafete	4,979	7692	6,859	9,142	821
Derbamenena	7,417	11458	10,217	13,619	1,224
Gumure	5,067	7828	6,980	9,304	836
Shro	4,267	6592	5,878	7,835	704
Dorbede	3,184	4919	4,386	5,846	525
Kerda	3,928	6068	5,411	7,213	648
Zokesa	3,494	5398	4,813	6,416	576
Dalaae	3,898	6022	5,370	7,157	643
Yero	4,876	7533	6,717	8,953	804
Gena	5,339	8248	7,355	9,803	881
Haylo	4,018	6207	5,535	7,378	663
Aela	2,548	3936	3,510	4,679	420
Gamule	5,889	9098	8,112	10,813	971
Kele	6,275	9694	8,644	11,522	1,035
Jelo	1,066	1647	1,468	1,957	176
Kobo	4,371	6753	6,021	8,026	721
Mareta	2,721	4204	3,748	4,996	449
Ayukure	5,770	8914	7,948	10,595	952
Aysume	2,544	3930	3,504	4,671	420
Segen	4,288	6624	5,907	7,874	707
Alfecho	907	1401	1,249	1,665	150
Abulo	795	1228	1,095	1,460	131
Zergete	6,374	9847	8,780	11,704	1,051
Danobulto	7,003	10819	9,647	12,859	1,155
Golbe	4,920	7601	6,777	9,034	812
Korebiko	8,241	12731	11,352	15,132	1,359
Medayne	5,572	8608	7,676	10,231	919
Werkele	2,829	4370	3,897	5,195	467
Kerma	5,382	8314	7,414	9,882	888
Suluko	2,595	4009	3,575	4,765	428
Dayketa	3,863	5968	5,321	7,093	637
Shafale	3,474	5367	4,786	6,379	573
Buniti	2,704	4177	3,725	4,965	446
Total	**140,598**	**140,598**	**193,679**	**258,165**	**23,194**

Table 9- Population projection and water demand for Jor Woreda

Kebeles	Population 1999	Population 2012	Population 2021	Population 2036	Water Demand (M^3/day)
Aboro	945	1,593	1,471	2,197	197
Lero	487	821	758	1,132	102
Angela	720	1,214	1,121	1,674	150
Gogn	535	902	833	1,244	112
Umeto	537	905	836	1,248	112
Tuwo	555	936	864	1,290	116
Ogngne	688	1,160	1,071	1,599	144
Uwelo	523	882	814	1,216	109
Ujalo	895	1,509	1,393	2,081	187
Tuhu	640	1,079	996	1,488	134
Aleme	486	819	757	1,130	102
Atepe	1,392	2,347	2,167	3,236	291
Urao	330	556	514	767	69
Total	**8,733**	**14,724**	**13,595**	**20,302**	**1,824**

Table 10 - Population projection and water demand for Itang Woreda

Kebeles	Population 1999	Population 2012	Population 2021	Population 2036	Water Demand (M^3/day)
Watigachi	1,558	2,627	2,425	3,622	325
Piwal	2,509	4,230	3,906	5,833	524
Beljakok	695	1,172	1,082	1,616	145
War	2,074	3,497	3,229	4,822	433
Badel	2,828	4,768	4,403	6,574	591
Wanke	1,494	2,519	2,326	3,473	312
Dorong	2,925	4,932	4,554	6,800	611
Birhane Selam	102	172	159	237	21
Puldang	1,330	2,242	2,070	3,092	278
Aleha	551	929	858	1,281	115
Adima	354	597	551	823	74
Ajuw	516	870	803	1,200	108
Akura	768	1,295	1,196	1,785	160
Awbgi	490	826	763	1,139	102
Etangere Ker	2,260	3,810	3,518	5,254	472
Achuwa	3,930	6,626	6,118	9,136	821
Adong	494	833	769	1,148	103
Pukuma	3,097	5,222	4,821	7,200	647
Aliya	1,090	1,838	1,697	2,534	228
Ebago	663	1,118	1,032	1,541	138
Total	**29,728**	**50,121**	**46,279**	**69,110**	**6,209**

Table 11 - Population projection and water demand for Jor Woreda

Kebeles	Population 1999	Population 2012	Population 2021	Population 2036	Water Demand (M^3/day)
Chulule Obora	2,803	3,896	3769	5254	472
Kubi Guta	3,614	5,023	4859	6775	609
Obenso Jilo	2,738	3,806	3681	5133	461
Jelo Dida	2,430	3,378	3267	4555	409
Faji Golo	6,234	8,665	8382	11686	1050
Chefe Guta	3,424	4,759	4604	6419	577
Korerogiicha	4,338	6,030	5832	8132	731
Fajigiba	6,242	8,676	8392	11701	1051
Hagugeta Keni	5,353	7,441	7197	10035	902
Ilalal Korke	7,489	10,410	10069	14039	1261
Wetera Shegule	6,270	8,715	8430	11754	1056
Turre Wetera Elemo	11,888	16,524	15983	22285	2002
Kerara Felicha	9,684	13,461	13020	18153	1631
Bute Felicha	6,756	9,391	9083	12665	1138
Ale Luile	5,592	7,773	7518	10483	942
Oine Chefo Unbure	6,946	9,655	9339	13021	1170
Chebidi Dangata	4,486	6,236	6031	8409	756
Bura Borema	5,194	7,220	6983	9737	875
Tatesa Dedesa	6,885	9,570	9257	12906	1160
Kori Boredjeta	3,425	4,761	4605	6420	577
Daleti Bishen Guracha	9,123	12,681	12266	17102	1536
Toga Weransa	6,499	9,034	8738	12183	1095
Meja Dema	4,786	6,653	6435	8972	806
Bulchansa Deneba	4,336	6,027	5830	8128	730
Alecha Harembo	8,204	11,404	11030	15379	1382
Shere Horema	8,587	11,936	11545	16097	1446
Mudeta	7,999	11,119	10755	14995	1347
Adola Burqua	10,574	14,698	14217	19822	1781
Awash Dangu	7,439	10,340	10002	13945	1253
Jegesa Korke	4,415	6,137	5936	8276	744
Meraro	7,048	9,797	9476	13212	1187
Fuji Sole	7,440	10,342	10003	13947	1253
Araro	8,287	11,519	11142	15535	1396
Jengele Wendere	7,797	10,838	10483	14616	1313
Hursa Sinbo	6,876	9,558	9245	12890	1158
Danisa	3,212	4,465	4319	6021	541
Gonde Kereso	5,380	7,478	7233	10085	906
Arendano Shifa	5,992	8,329	8056	11232	1009
Toga Military Camp	109	152	147	204	18
Yeasa Den	34	47	46	64	6
Hansewe Den	71	99	95	133	12
Sole Den	219	304	294	411	37
Baro Den	206	286	277	386	35

Shalo Mrt Drjin	152	211	204	285	26
Total	**236,576**	**328,841**	**318,077**	**443,479**	**39,847**

Appendix-III. Boreholes and scheme data

Table 1 - Borehole and scheme data used in SNNP and Bule Hora synoptic area mapping

Woreda	Locality of wells (Kebele)	Site name	X-co	Y-co	Z	Scheme types	Depth (m)	SWL (m)	Yield (L/Sec.)	Date of inventory
Aida	<Null>	<Null>	261787	687852	1362	<Null>	4	<Null>	<Null>	2008
Aida	<Null>	<Null>	261863	687977	1487	<Null>	7.5	<Null>	<Null>	2008
Aida	<Null>	<Null>	261755	687903	1408	<Null>	9	<Null>	<Null>	2008
Aida	<Null>	<Null>	260986	688326	1393	<Null>	10	<Null>	<Null>	2008
Aida	<Null>	<Null>	261890	688600	1350	<Null>	14	<Null>	<Null>	2008
Aida	<Null>	<Null>	261246	689012	1413	<Null>	16	<Null>	<Null>	2008
Aida	<Null>	<Null>	261787	687920	1420	<Null>	16	<Null>	<Null>	2008
Aida	<Null>	<Null>	261780	687830	1350	<Null>	19.5	<Null>	<Null>	2008
Aida	<Null>	<Null>	261872	688605	1345	<Null>	28	<Null>	3	2008
Aida	<Null>	<Null>	261483	688415	1360	<Null>	31.5	<Null>	5	2008
Aida	<Null>	<Null>	261865	688610	1338	<Null>	31.5	<Null>	<Null>	2008
Aida	<Null>	<Null>	261290	688543	1360	<Null>	34.5	<Null>	<Null>	2008
Aida	<Null>	<Null>	261013	688445	1382	<Null>	37.5	<Null>	2	2008
Aida	<Null>	<Null>	261769	687998	1346	<Null>	40.5	<Null>	4	2008
Aida	<Null>	<Null>	261355	688710	1393	<Null>	46.5	<Null>	2	2008
Aida	<Null>	<Null>	261246	688203	1372	<Null>	52	<Null>	1.5	2008
Aida	<Null>	<Null>	261872	689415	1344	<Null>	52.5	<Null>	<Null>	2008
Aida	<Null>	<Null>	261866	689422	1339	<Null>	55	<Null>	2	2008
Amaro	Abulo	Doysa	345197	628906	1278	SHW	<Null>	<Null>	0.46	25/12/07
Amaro	Alfecho	Doysa	346054	620211	1252	DW	<Null>	<Null>	5.6	25/12/07
Amaro	Aykure	Gufa	371853	638066	2657	SP-SPT	<Null>	<Null>	0.31	25/12/07
Amaro	Aykure	Kilale	371538	638064	2660	SP-SPT	<Null>	<Null>	0.35	25/12/07
Amaro	Buniti	Chefersa	341451	621895	1473	DW	<Null>	<Null>	4.63	25/12/07
Amaro	Dalea	Dano	367124	646861	2263	SP-SPT	<Null>	<Null>	0.25	25/12/07

Amaro	Dawa	Dawa	375346	644234	1788	SP-D	<Null>	<Null>	0.5	25/12/07
Amaro	Derba	Duliche	371690	654685	1938	SP-D	<Null>	<Null>	0.48	25/12/07
Amaro	Derba	Sankale/Codo	370435	655025	1799	SP-D	<Null>	<Null>	1.5	25/12/07
Amaro	Dorbade	Berbere-1	387559	648625	1285	SHW	<Null>	<Null>	0.35	25/12/07
Amaro	Dorbade	Fachute-1	386036	651298	1285	SHW	<Null>	<Null>	1	25/12/07
Amaro	Dorbade	Malikaodoku-2	386721	650581	1283	SHW	<Null>	<Null>	1	25/12/07
Amaro	Etate	Fize	369157	640760	2620	SP-D	<Null>	<Null>	0.52	25/12/07
Amaro	Gamule	Wercho	376268	646887	2029	SP-D	<Null>	<Null>	0.26	25/12/07
Amaro	Gena	Ketema-1	364500	644655	2510	SP-SPT	<Null>	<Null>	0.3	25/12/07
Amaro	Golbe	Dale	377081	637417	2009	SP-D	<Null>	<Null>	0.37	25/12/07
Amaro	Gumure	Masha	373378	655870	2178	SP-D	<Null>	<Null>	0.32	25/12/07
Amaro	Jalo	Oyma-1	387767	642823	1297	SHW	<Null>	<Null>	0.5	25/12/07
Amaro	Jalo	Oyma-2	387348	642322	1301	SHW	<Null>	<Null>	0.3	25/12/07
Amaro	Jalo	Walo-1	387062	642757	1307	SHW	<Null>	<Null>	0.5	25/12/07
Amaro	Jalo	Walo-1	386631	643149	1308	SHW	<Null>	<Null>	1	25/12/07
Amaro	Jijola	Kanole	374520	627600	1884	SP-D	<Null>	<Null>	0.45	25/12/07
Amaro	Kele G/Mahiber	Baro	382940	643292	1370	SHW	<Null>	<Null>	1	25/12/07
Amaro	Kele G/Mahiber	Fucha-1	382692	645422	1375	SHW	<Null>	<Null>	1	25/12/07
Amaro	Kereda	Mesha	375011	653070	2454	SP-D	<Null>	<Null>	2.6	25/12/07
Amaro	Ketamatatno	Tadho	378830	630405	1557	SHW	<Null>	<Null>	<Null>	25/12/07
Amaro	Kobo	Gamalo	382990	642648	1372	SHW	<Null>	<Null>	1	25/12/07
Amaro	Kobo	Lokoindo	379324	641974	1583	SP-D	<Null>	<Null>	0.3	25/12/07
Amaro	Kobo	Lokoindo	379339	642009	1583	SP-D	<Null>	<Null>	0.4	25/12/07
Amaro	Mareta	Godoba	375059	643331	2718	SP-SPT	<Null>	<Null>	0.3	25/12/07
Amaro	Mareta	Mayra	374199	642469	2393	SP-SPT	<Null>	<Null>	0.2	25/12/07
Amaro	Miyondo	Miyondo	376460	637681	2102	SP-D	<Null>	<Null>	0.28	25/12/07
Amaro	Segen	Worso/Tsale	364002	638445	2279	SP-D	<Null>	<Null>	0.32	25/12/07
Amaro	Shafule	Dale	374963	633680	1900	Shw	<Null>	<Null>	0.43	25/12/07
Amaro	Shoea-1	Shoea-1	378400	629773	1546	SHW	<Null>	<Null>	0.3	25/12/07

Amaro	Suluko	Shinakanka	373465	626306	2092	SP-D	<Null>	<Null>	0.89	25/12/07
Amaro	Tadhel 2	Tadhel 2	381492	629995	1401	SHW	<Null>	<Null>	0.28	25/12/07
Amaro	Tadhel 3	Tadhel 3	380520	630176	1425	SHW	<Null>	<Null>	0.25	25/12/07
Amaro	Tifate	Duliche	370176	651227	2190	SP-D	<Null>	<Null>	1	25/12/07
Amaro	Tifate	Sore	369674	651342	1993	SP-D	<Null>	<Null>	1	25/12/07
Amaro	Yero	Tsorle	361083	647782	1915	SP-D	<Null>	<Null>	0.2	25/12/07
Amaro	Zokesa	Chegucha	387131	640919	1860	SP-D	<Null>	<Null>	0.9	25/12/07
Arba Minch	<Null>	<Null>	340707	670049	<Null>	<Null>	61	<Null>	5.5	2004
Arba Minch	<Null>	<Null>	340615	669775	<Null>	<Null>	55	<Null>	<Null>	2002
Arba Minch	<Null>	<Null>	340699	669886	<Null>	<Null>	70	<Null>	4.7	2002
Arba Minch	<Null>	<Null>	340615	669775	<Null>	<Null>	70	<Null>	4.75	2002
Arba Minch Zuria	AAP-BH16	<Null>	343836	668033	1204	<Null>	100	<Null>	<Null>	<Null>
Arba Minch Zuria	ABS-BH	<Null>	342062	667757	1215	<Null>	<Null>	<Null>	<Null>	<Null>
Arba Minch Zuria	ACF-BH14	<Null>	345046	666302	1201	<Null>	51	<Null>	<Null>	<Null>
Arba Minch Zuria	ACF-BH15	<Null>	345057	666349	1192	<Null>	74	7	3	1,989
Arba Minch Zuria	AMU-BH19	<Null>	340880	670794	1244	<Null>	<Null>	<Null>	<Null>	<Null>
Arba Minch Zuria	AMU-BH4	<Null>	340942	671002	1225	<Null>	73	24	3	1,985
Arba Minch Zuria	AMU-BH5	<Null>	341050	671208	1229	<Null>	92	19	3	1,988
Arba Minch Zuria	AMU-BH6	<Null>	340798	670209	1230	<Null>	100	19	4	1,988
Arba Minch Zuria	AMU-BH7	<Null>	340693	670331	1220	<Null>	91	24	4	1,989
Arba Minch Zuria	AMU-BH8	<Null>	340777	670174	1227	<Null>	69	18	8	2,001
Arba Minch Zuria	AMU-BH9	<Null>	340618	339974	1235	<Null>	75	27	10	2,001
Arba Minch Zuria	ATF-BH10	<Null>	341044	668541	1209	<Null>	70	19	4	1,988
Arba Minch Zuria	ATF-BH11	<Null>	340880	668346	1225	<Null>	61	18	4	1,989
Arba Minch Zuria	ATF-BH12	<Null>	341252	668346	1222	<Null>	61	22	2	1,989
Arba Minch Zuria	ATF-BH13	<Null>	341010	668070	1225	<Null>	70	19	4	1,983
Arba Minch Zuria	ATT-BH17	<Null>	341398	667344	1229	<Null>	48	<Null>	3	<Null>
Arba Minch-Shelle	<Null>	<Null>	327307	650947	1164	<Null>	107	<Null>	10	2011
Bule Hora	Ageremariam No. 1	<Null>	415864	622824	1930	<Null>	76	39	1.67	<Null>

Bule Hora	Ageremariam No. 2	<Null>	415401	622057	1910	<Null>	0		0	<Null>
Bule Hora	Ageremariam No. 3	<Null>	415710	622517	0	<Null>	56	38.2	4	<Null>
Bule Hora	Bulchanii Du/Bulchani BH	<Null>	421636	638533	2237	<Null>	0	Unknown	0	<Null>
Bule Hora	Bule No. 1	<Null>	413709	621598	1800	<Null>	38.3	4.5	1.38	<Null>
Bule Hora	Dida Heera Hira Liphatu	<Null>	420011	643924	2355	<Null>	0	Unknown	0	<Null>
Bule Hora	Eela Harruu Sakkicha BH	<Null>	429327	635228	2028	<Null>	0	Unknown	0	<Null>
Bule Hora	Eela Lakee Mirgo BH	<Null>	423531	617166	1863	<Null>	0	Unknown	0	<Null>
Bule Hora	Fincha's (Jiges)	<Null>	423360	586767	1498	<Null>	22	3.5	0	<Null>
Bule Hora	Finchawa No. 1	<Null>	421212	592572	1560	<Null>	70.5	16.8	2.25	<Null>
Bule Hora	Jabasiree Gadojabasire	<Null>	416436	645060	2245	<Null>	0	Unknown	0	<Null>
Bule Hora	Kilenso No.	<Null>	422459	606511	1979	<Null>	100.5	15.92	0.87	<Null>
Bule Hora	Killensa	<Null>	426583	625490	1969	<Null>	94	11.33	1.35	<Null>
Bule Hora	Killensa	<Null>	426583	625490	1969	<Null>	94	11.33	1.35	<Null>
Bule Hora	So/Hancaru Dh/Magada	<Null>	426216	608647	1691	<Null>	0	Unknown	0	<Null>
Bule Hora	Udee Ogo Dambi	<Null>	419136	622739	1748	<Null>	0	Unknown	0	<Null>
Burji	Arbicho	School Sefer	375221	602870	1776	SHW	<Null>	<Null>	0.57	29/12/07
Burji	Ayija	Ayija	375045	605573	1793	SHW	<Null>	<Null>	0.55	29/12/07
Burji	Batula	Ayija	375266	605792	1795	SHW	<Null>	<Null>	0.57	29/12/07
Burji	Charayile	Turu	374730	619300	1871	SP-D	<Null>	<Null>	0.95	29/12/07
Burji	Dalee	Mehal Dalee	373755	620980	2002	SP-D	<Null>	<Null>	0.5	29/12/07
Burji	Edget	Kotcha	348803	618068	1683	DW	<Null>	<Null>	1.8	29/12/07
Burji	Gambela	Godinga Lag	366866	59948	1789	DW	<Null>	<Null>	1.85	29/12/07
Burji	Gandile	Gandile	371324	600167	1695	SHW	<Null>	<Null>	0.01	29/12/07
Burji	Gerada	Chare	380167	616229	1545	SHW	<Null>	<Null>	0.54	29/12/12
Burji	Goremale	Chafe	370333	609190	1616	SHW	<Null>	<Null>	0.35	29/12/07
Burji	Kombolicha	Rasa	374260	599233	1836	SP-D	<Null>	<Null>	0.1	29/12/07
Burji	Koro	Koro	368502	610155	2314	SP-SPT	<Null>	<Null>	0.038	29/12/07
Burji	Kuro	Ano	379604	611856	1584	SHW	<Null>	<Null>	0.54	29/12/07
Burji	Lula	Chafe	379416	608899	1619	SHW	<Null>	<Null>	0.37	29/12/07

Burji	Mehal Ketena	Mantaye Bata	376977	621828	1631	SHW	<Null>	<Null>	0.74	29/12/07
Burji	Mehal Ketena	Metucheyisala	376905	621559	1655	SHW	<Null>	<Null>	0.15	29/12/07
Burji	Orkobe	Moshole	379277	607743	1642	SHW	<Null>	<Null>	0.35	16-Jun-11
Burji	Segen	Segen Area Peoples Zone	354867	594814	880	SHW	<Null>	<Null>	0.2	29/12/07
Burji	Soyoma	Kosa	375335	602984	1585	SHW	<Null>	<Null>	0.57	29/12/07
Burji	Suburo	Hayila	367960	609238	2309	SPT-SPT	<Null>	<Null>	0.4	29/12/07
Burji	Wetega	Balesa	378273	615535	1668	SP-D	<Null>	<Null>	0.5	29/12/11
Kochere	Chelelekti	<Null>	406110	664270	1700	151	16	32	<Null>	<Null>
Debre Tsehay	<Null>	<Null>	265632	669492	<Null>	<Null>	49	<Null>	<Null>	2004
Dire	Rer Baha	<Null>	438051	625490	0	<Null>	101	30.05	1.32	<Null>
Dugda Dawa	Abura	<Null>	394666	607855	1758	<Null>	0	Unknown	0	<Null>
Dugda Dawa	Barbare W/Medanobh2	<Null>	422404	600759	1670	<Null>	0	Unknown	0	<Null>
Dugda Dawa	Dakka Hema H/Kinsho	<Null>	405213	604886	1767	<Null>	88	19.41	2.54	<Null>
Dugda Dawa	Finca'a 02	<Null>	419750	595777	1597	<Null>	60	3.43	4.54	<Null>
Dugda Dawa	Godolle B/Qudhi	<Null>	395042	595300	1684	<Null>	0	Unknown	0	<Null>
Dugda Dawa	Hadha'a H/Korma	<Null>	395393	602177	1768	<Null>	0	Unknown	0	<Null>
Dugda Dawa	Hagansa W/Medanobh1	<Null>	422686	597756	1669	<Null>	0	Unknown	0	<Null>
Dugda Dawa	Mokonisa Magada	<Null>	414355	610855	1792	<Null>	0	Unknown	0	<Null>
Dugda Dawa	Tullu	<Null>	433002	579022	1419	<Null>	0	Unknown	0	<Null>
Galana	Birmajji 2ffaa Jirime BH3	<Null>	406027	660872	1700	<Null>	0	Unknown	0.2	<Null>
Galana	Birmajjii Jirime BH2	<Null>	405994	661174	1697	<Null>	0	Unknown	0.2	<Null>
Galana	Dildila Waachuu BH	<Null>	404894	662610	1691	<Null>	0	Unknown	0.2	<Null>
Galana	M/Barumsa Jirime BH1	<Null>	405768	662167	1694	<Null>	0	Unknown	0.2	<Null>
Galana	Malka Dhakiti T/Badiya BH	<Null>	406702	654403	1692	<Null>	0	Unknown	1.2	<Null>
Galana	Muume 2ffaa Jirime BH5	<Null>	406017	658197	1688	<Null>	0	Unknown	1.2	<Null>
Galana	Muummee Jirime BH4	<Null>	405596	659250	1681	<Null>	0	Unknown	0.2	<Null>
Kemba	<Null>	<Null>	285734	660908	983	<Null>	97.5	<Null>	<Null>	2007
Kemba	SHAKARO WELL No 1	<Null>	285734	660908	983	97.5	….	Abandoned	<Null>	<Null>
Kemba	SHAKARO WELL No 2	<Null>	283963	660224	955	94	50	2.5	<Null>	<Null>

Kemba	Abeta	Asheta	302657	666511	2410	SP-SPOT	<Null>	<Null>	0.5	<Null>
Kemba	Amaro	Dubeta	302395	677526	1938	SP-D	<Null>	<Null>	0.817	<Null>
Kemba	Arsa	Boko Arsa	303940	666916	2420	HDW	<Null>	<Null>	0.87	<Null>
Kemba	Boko	Giyaso	303840	668142	2411	SP-SPOT	<Null>	<Null>	0.4	<Null>
Kemba	Boko	Mana	303460	667988	2733	SP-SPOT	<Null>	<Null>	0.2	<Null>
Kemba	Bola Garda	Achu	293623	660330	1489	SP-D	<Null>	<Null>	0.51	<Null>
Kemba	Chora	Chora	303985	667871	2715	SP-SPOT	<Null>	<Null>	0.9	<Null>
Kemba	Darara	Shodo	300072	678776	1998	SP-SPT	<Null>	<Null>	0.51	<Null>
Kemba	Fudalle	Mada	295663	666369	1777	SP-SPT	<Null>	<Null>	0.37	<Null>
Kemba	Garda	Bokola	291655	659427	1251	SP-D	<Null>	<Null>	0.67	<Null>
Kemba	Garma	Mish Kare	301661	679550	1868	SP-SPT	<Null>	<Null>	0.43	<Null>
Kemba	Geta	Laysha	298123	666702	2038	SP-D	<Null>	<Null>	0.7	<Null>
Kemba	Gudumale	Tsila	296057	668254	1703	SP-D	<Null>	<Null>	6	<Null>
Kemba	Korrza	Weyda	302046	676245	1811	SP-D	<Null>	<Null>	0.53	<Null>
Kemba	Meche	Meche	304673	667555	2684	SP-SPOT	<Null>	<Null>	0.89	<Null>
Kemba	Misha	<Null>	295811	676899	<Null>	SP-D	<Null>	<Null>	0.4	<Null>
Kemba	Okaso	Boko Okaso	304157	667238	2593	SP-SPOT	<Null>	<Null>	0.7	<Null>
Kemba	Okoso	Okoso	304740	666924	2521	HDW	<Null>	<Null>	0.4	<Null>
Kemba	Shakaro	Zonssie	283925	660229	954	SHW	<Null>	<Null>	1.2	<Null>
Kemba	Arsa	Boko Arsa	301940	660001	2426	SP-SPOT	<Null>	<Null>	0.9	<Null>
Kemba	Balta Bake	Buno	309255	669177	2851	SP-D	<Null>	<Null>	0.468	<Null>
Kemba	Balta Bake	Dano	308501	668331	2784	SP-SPOT	<Null>	<Null>	0.9	<Null>
Kemba	Balta Bake	Ocholo	309733	669311	2661	SP-SPOT	<Null>	<Null>	1	<Null>
Kemba	Balta Bake	Wempha	309746	669917	2972	SP-D	<Null>	<Null>	4	<Null>
Kemba	Balta Tolatya	Kicho	310344	671266	2645	SP-D	<Null>	<Null>	0.15	<Null>
Kemba	Balta Tolatya	Tolata Wolo	309671	673881	3040	SP-D	<Null>	<Null>	0.8	<Null>
Kemba	Dolcha	Dolcha	300660	667281	2595	SP-D	<Null>	<Null>	3.38	<Null>
Kemba	Haylo	Haylo	303955	669154	2858	SP-D	<Null>	<Null>	0.58	<Null>
Kemba	Mash Gope	<Null>	295773	675942	<Null>	SP-D	<Null>	<Null>	0.71	<Null>

Kemba	Shawuza	<Null>	297360	676028	<Null>	SP-D	<Null>	<Null>	0.63	<Null>
Kemba	Zoba	Share	297666	675816	1761	SP-SPT	<Null>	<Null>	0.52	<Null>
Kercha	Chemeri Bachano N. 1	<Null>	421867	625887	1922	<Null>	155	53.75	3.83	<Null>
Kercha	Gerba No. 1	<Null>	411857	639871	0	<Null>	88.52	29	2.85	<Null>
Kochere	<Null>	<Null>	411678	666464	2046	<Null>	18	<Null>	<Null>	2009
Kochere	<Null>	<Null>	411721	665950	1990	<Null>	31.5	<Null>	2	2009
Kochere	<Null>	<Null>	402181	670473	2043	<Null>	37	<Null>	3	2009
Kochere	<Null>	<Null>	407660	664450	1824	<Null>	37.5	<Null>	2	2009
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Kochere	<Null>	<Null>	402033	671991	2050	<Null>	40.5	<Null>	<Null>	2009
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Kochere	<Null>	<Null>	412672	663759	2129	<Null>	52.5	<Null>	5	2009
Kochere	<Null>	<Null>	407659	664450	1810	<Null>	61.5	<Null>	2	2009
Kochere	<Null>	<Null>	404945	667244	1742	<Null>	77	<Null>	2	2009
Kochere	<Null>	<Null>	406275	664100	1690	<Null>	31.5	<Null>	3	2001
Kochere	Chichu Well	<Null>	424450	724213	1557	178	1.5	25	<Null>	<Null>
Kochere	Fiseha Genet Well	<Null>	412137	671448	2225	160	69.3	6.7	<Null>	<Null>
Kocherie	<Null>	<Null>	422912	702672	1570	<Null>	28.5	<Null>	3	2009
Kocherie	<Null>	<Null>	417650	698467	1750	<Null>	45	<Null>	2	2009
Kocherie	<Null>	<Null>	410459	673425	2125	<Null>	46.5	<Null>	2	2009
Kocherie	<Null>	<Null>	422937	702591	1550	<Null>	53	<Null>	2	2009
Kocherie	<Null>	<Null>	415535	695342	2113	<Null>	55.5	<Null>	2	2009
Kocherie	<Null>	<Null>	427090	702635	2011	<Null>	58.5	<Null>	<Null>	2009
Kocherie	<Null>	<Null>	426901	702612	2090	<Null>	64.5	<Null>	<Null>	2009
Kocherie	<Null>	<Null>	408243	671197	2030	<Null>	76.5	<Null>	2	2009
Kocherie	<Null>	<Null>	415424	695224	2000	<Null>	76.5	<Null>	<Null>	2009
Kocherie	<Null>	<Null>	410288	670440	2110	<Null>	85.5	<Null>	2	2009
Kocherie	Anchabi Shallow	<Null>	407570	664490	1850	40.5	25	2	<Null>	<Null>
Kocherie	Baya Shaloow Well	<Null>	404945	667244	1742	77	73	2	<Null>	<Null>

Kocherie	Bojji Shallow Well	<Null>	411678	666464	2046	49.5	34	3	<Null>	<Null>
Kocherie	Buno Shallow Well	<Null>	406275	664100	1690	31.5	13	3	<Null>	<Null>
Kocherie	Reko Shallow Well	<Null>	412672	663759	2129	52.5	32	5	<Null>	<Null>
Kocherie	Shifo Shallow Well	<Null>	411721	665950	1990	31.5	16	2	<Null>	<Null>
Kocherie	Sigiga Shallow Well	<Null>	407659	664450	1810	<Null>	<Null>	<Null>	<Null>	<Null>
Kocherie	Sisota Shallow Well	<Null>	407660	664450	1824	37.5	29	2	<Null>	<Null>
Konso	Amarayta	Ealalita	336376	606885	1338	SP-SPT	<Null>	<Null>	0.232	27/12/07
Konso	Anegabet	Abgabet	307895	591444	1423	SHW	<Null>	<Null>	0.3	27/12/07
Konso	Areyle	Lomita	315195	582657	1791	SP-SPT	<Null>	<Null>	0.25	27/12/07
Konso	Asko	Abite	310806	605202	1568	SHW	<Null>	<Null>	0.42	27/12/07
Konso	Atikile	Lahaito	329019	589539	1273	SHW	<Null>	<Null>	0.26	27/12/07
Konso	Bareysa	Bareysa	330899	596760	1203	SHW	<Null>	<Null>	1.5	27/12/07
Konso	Borkila	Kadafa	316727	582855	1770	DW	<Null>	<Null>	2	27/12/07
Konso	Burkuta	Dibibo	323814	589564	1565	DW	<Null>	<Null>	2	27/12/07
Konso	Buso	Machate	321510	582866	1720	SP-SPT	<Null>	<Null>	0.35	27/12/07
Konso	Chamot	Chamot	308144	590936	1415	DW	<Null>	<Null>	0.82	27/12/07
Konso	Doukatu	Madimada	312984	588698	1491	SHW	<Null>	<Null>	0.38	27/12/07
Konso	Erfa	Batala	320223	587537	1655	SHW	<Null>	<Null>	0.3	27/12/07
Konso	Faro	Tohaba	326106	583223	1384	DW	<Null>	<Null>	3	27/12/07
Konso	Fuchucha	Fuchucha	328864	609481	4	HDW	<Null>	<Null>	3	27/12/07
Konso	Gersale	Gersale	328296	591912	1323	DW	<Null>	<Null>	2	27/12/07
Konso	Gocha	Sobe	336208	611156	1432	SHW	<Null>	<Null>	0.4	27/12/07
Konso	Guro	Orobaya	314130	583447	1786	SP-SPT	<Null>	<Null>	0.2	27/12/07
Konso	Halako	Debsa	335962	611921	1427	SHW	<Null>	<Null>	0.4	27/12/07
Konso	Halako	Debsa	335813	611800	1425	DW	<Null>	<Null>	2.5	27/12/07
Konso	Hawaito	Kalao	347850	588383	892	SHW	<Null>	<Null>	0.42	27/12/07
Konso	Holitaha	Sawatekuta	353039	597868	892	SHW	<Null>	<Null>	0.229	27/12/07
Konso	Kamina	Papaka	322124	590277	1560	SP-SPT	<Null>	<Null>	0.12	27/12/07
Konso	Kamota	Bahile	319727	587657	1628	SP-SPT	<Null>	<Null>	0.35	27/12/07

Konso	Kayle	Arkuba	315649	587954	1662	SP-SPT	<Null>	<Null>	0.14	27/12/07
Konso	Kelime	Kelime	329132	588880	1259	SHW	<Null>	<Null>	0.36	27/12/07
Konso	Koste	Yelasote	343630	590338	917	SHW	<Null>	<Null>	0.21	27/12/07
Konso	Kubale	Baleta	320134	587333	1842	SHW	<Null>	<Null>	0.35	27/12/07
Konso	Kube	Basawa	330697	589660	1204	DW	<Null>	<Null>	3	27/12/07
Konso	Kurtanga	Buibura	317610	583474	1782	DW	<Null>	<Null>	3	27/12/07
Konso	Kuyele	Tagule	329132	587739	1205	SHW	<Null>	<Null>	0.18	27/12/07
Konso	Mabeke	Kuma	314502	598923	1559	DW	<Null>	<Null>	2.2	27/12/07
Konso	Markuta	Hankale	305821	582986	1396	SHW	<Null>	<Null>	0.35	27/12/07
Konso	Mcheke	Oriba	321119	585830	1717	DW	<Null>	<Null>	2.2	27/12/07
Konso	Oibale	Makawule	314022	588349	1600	SP-SPT	<Null>	<Null>	0.1	27/12/07
Konso	Oribahe	Aribo	319510	578690	1582	SP-SPT	<Null>	<Null>	0.28	27/12/07
Konso	Sakantote	Ketema	337395	618490	1599	SHW	<Null>	<Null>	0.44	27/12/07
Konso	Sawule	Akartokama	306811	584364	1427	DW	<Null>	<Null>	2.1	27/12/07
Konso	Sewgeme	Wakayte	320558	582301	1755	SP-SPT	<Null>	<Null>	0.15	27/12/07
Konso	Taba	Krkara-1	320187	593879	1453	SHW	<Null>	<Null>	0.28	27/12/07
Konso	Taba	Krkara-1	320074	593941	1449	DW	<Null>	<Null>	4	27/12/07
Konso	Tabate	Oranto	312486	602050	1498	SHW	<Null>	<Null>	0.43	27/12/07
Konso	Tano	Tebel	315769	602693	1707	SP-D	<Null>	<Null>	2	27/12/07
Konso	Tarakoma	Koshe	331410	585753	1119	SHW	<Null>	<Null>	0.31	27/12/07
Konso	Taratawi	Taratawi	315859	582706	1724	SP-SPT	<Null>	<Null>	0.1	27/12/07
Konso	Torkale	Kumita	332551	593469	1316	DW	<Null>	<Null>	5	27/12/07
Konso	Hilte Well	<Null>	305456	387624	1365	<Null>	<Null>	7.67	<Null>	<Null>
Konso	Kondere	<Null>	334880	586973	<Null>	<Null>	<Null>	Abandoned	<Null>	<Null>
Melekoza	<Null>	<Null>	239210	707337	<Null>	<Null>	146	<Null>	7.3	2003
Mirab Abaya	<Null>	<Null>	346528	699185	<Null>	<Null>	110	<Null>	7.33	2004
Mirab Abeya	Birbir Well	<Null>	346528	699185	2600	110	15.3	7	<Null>	<Null>
Mirab Abeya	Waif Well	<Null>	361300	714473	1213	100	18	10	<Null>	<Null>
Moyale	Ulagagofa	<Null>	432908	625490	1189	<Null>	75	13.9	3.7	<Null>

Urga	Wachu Well 11	<Null>	453075	673549	2197	250	28	11.5	<Null>	<Null>
Yabelo	Kilkilee Well1	<Null>	422380	583415	1491	<Null>	0	Unknown	0	<Null>
Yabelo	Kilkle Camp Well2	<Null>	420691	584399	1498	<Null>	0	Unknown	0	<Null>
Yabelo	Oda No. 1	<Null>	428743	583813	1560	<Null>	12	5	0.93	<Null>
Yabelo	Oda No. 2	<Null>	428743	583813	1560	<Null>	17.8	3.1	0.7	<Null>
Yabelo	Oda No. 3	<Null>	428743	583813	1560	<Null>	38.8		0	<Null>
Yabelo	Surupa WELL NO 2	<Null>	428583	577826	1545	<Null>	47	2	0	<Null>

Table 2 - Borehole and scheme data used in Gambella synoptic area mapping

Woreda	Locality of wells (Kebele)	X-cor.	Y-cor.	Z	Depth (m)	Yield (L/Sec.)	SWL	T (M^2/day)
Jikawo	Makwar	582547	920217	458	60	1	3	0
Jikawo	Lewel/Rake	591284	916485	408	45	1	3.5	0
Jikawo	Katchtiang	583860	919305	417	50	1.5	3	0
Jikawo	Katchtiang/Kenia	584055	919719	420	50	2	3	0
Jikawo	Katchtiang/Chedier	584386	920062	407	45	2	3.5	0
Jikawo	Katchtiang/Dure	583481	919975	407	45	1.5	3	0
Jikawo	Katchtiang	583805	919619	412	45	2	3	0
Jikawo	Nibneb	583306	920205	415	50	1	0	0
Jikawo	Lekchor	577983	920175	408	50	0.5	3.5	0
Jikawo	Merya/Dobrar	572719	925684	412	60	4	3.5	0
Jikawo	Chogn/Dobrar	572117	925744	415	60	4	3.5	0
Makwey	Nenegnang/Belyet	574721	917371	417	60	0.8	4	0
Makwey	Nenegnang/Bitwany	575392	916890	410	50	0.8	5	0
Makwey	Condey/ new land	562960	922465	405	45	0.8	5	0
Makwey	Tormork/Tur	556798	922204	412	50	1	5	0
Makwey	Tormork/Tur health	555570	922685	400	50	1.5	0	0
Makwey	Adura/Sewat	560172	921698	408	60	2	5	0
Makwey	Kuatguar	563479	925644	411	60	3	4	0
Makwey	Letnarwach/Pandar	566534	928258	403	50	0.1	4	0
Makwey	Bilker	563690	925259	404	59	0.8	5	0
Makwey	Gerguer/Bolock	579214	920326	408	60	3	3	0
Makwey	Gier/Bilguch	571763	911322	412	60	5	10	0
Makwey	Gier/school	571005	911611	407	50	4	8.5	0
Makwey	Bildak	582416	911537	410	55	1	3.5	0
Makwey	Bildak/school	582647	912075	412	50	5	3.5	0
Lare	Ngor/Kurmechar	607483	920253	411.8	55	3	17	0
Lare	Bilim Kun/Pagak	607472	920260	432.7	50	3	23	0
Lare	Pal Bol/Kor Day	608073	927455	424	60	1	27	0
Lare	Ngor/Ketema Zuria	605427	922101	420	50	6	13	0
Lare	Teluth/Tetbol Lew	604063	919384	414	55	6	12	0
Lare	Korgen/Ketema	606163	920998	413	55	5	15	0
Lare	Etey/shcool	612744	906123	430	50	4	0	0
Jikawo	Ketir/Chignag	587362	927632	413	50	5	5	0
Jikawo	Ketir/Baydal	588879	928411	410	50	5	5	0
Jikawo	Ketir/Tongdol	595724	924671	409	60	5	8	0
Jikawo	Chedyer/Rake	591625	916378	410	45	4	0	0
Jikawo	Luwal/Rake	592234	916045	409	42	4	0	0
Jikawo	Dobar	572474	925932	402	47	5	0	0
Makwey	Letnarwach	566473	928540	409	46	6	0	0
Makwey	Manding	571770	926882	409	48	4	0	0
Makwey	Bolok	578998	920330	410	46	3	0	0
Makwey	Kokes	572872	916816	407	48	4	0	0
Wanthoa	Mon/Chemker	532406	919704	405	47	5	0	0

Wanthoa	Mon/Chentegn	534149	919831	409	47	5	0	0
Wanthoa	Torogol/Gade 1	549917	922802	410	50	2	0	0
Wanthoa	Torogol/Gade 2	549713	922929	403	50	4	0	0
Wanthoa	Wunthow	547392	925820	413	50	5	0	0
Gambela Zuriya		654552	921987	466	78	6.5	0	0
		638424	845791	0	110	12	27	0
		638308	845486	408	172	10	23	0
Etang	Ashewa village	639392	905350	431	59.8	9.4	5.8	231
Etang	Ashewa village	639277	905277	432	55	9.4	4.8	49
Etang	Ashewa village	639159	905208	427	50	9.4	4.4	127
Etang	Ashewa village	639008	905072	427	49.5	9.4	4.2	60
Etang	Ashewa village	638901	904971	426	48.5	12.2	4.5	189
Etang	Ashewa village	638845	904878	429	50	12.2	4.1	171
Etang	Ashewa village	638749	905271	421.5	60	4	7.15	121
Etang	Ashewa village	638520.3	904564	414	60	10.5	6.8	208
Etang	Ashewa village	638423	904464.6	411	60	16.8	6.1	282
Etang	Ashewa village	639647	907663	425	138	1.5	24	0

Table 3 - Borehole and scheme data used in Shashemene synoptic area mapping

Locality of wells	X-cor.	Y-cor.	Z	Depth (m)	SWL (m)	Z water level	TDD (m)	T (M^2/day)	Yield (L/Sec.)
Danshe	465517	804520	2057	272	135	1922	33.5	8	5
Fagi	457868	805759	1837	227	73	1764	36.9	17.1	7
Shashemene	448234	796629	1802	250	172.38	1629.62	0.4	13	0.3
Shashemene	448234	796629	1802	250	172.38	1629.62	0.4	13	0.3
Shashemena supply	460843	793214	1767	375	68.4	1698.6	0	40.2	10
Shalo	451985	785842	1697	250	0	0	0	0	33
Bekele Adem	458203	791792	2041	316	94.5	0	0	48.2	6
Shashemene	464827	789033	2346	270	26.9	0	0	0	18
Awasho danku	462737	795210	2098	400	89.27	0	0	0	20
Edola Burka	456920	792615	1997	333	203	0	0	0	0
Alacha Arabati	451861	793389	1876	350	202.5	0	0	0	4.5
Gonde Kereso	455465	788638	2488	318	188	0	0	0	5.8